

Audio Toolbox™

Reference



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R2022a



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Audio Toolbox™ Reference Guide

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Revision History

March 2016	Online only	New for Version 1.0 (Release 2016a)
September 2016	Online only	Revised for Version 1.1 (Release 2016b)
March 2017	Online only	Revised for Version 1.2 (Release 2017a)
September 2017	Online only	Revised for Version 1.3 (Release 2017b)
March 2018	Online only	Revised for Version 1.4 (Release 2018a)
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March 2019	Online only	Revised for Version 2.0 (Release 2019a)
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March 2020	Online only	Revised for Version 2.2 (Release 2020a)
September 2020	Online only	Revised for Version 2.3 (Release 2020b)
March 2021	Online only	Revised for Version 3.0 (Release 2021a)
September 2021	Online only	Revised for Version 3.1 (Release 2021b)
March 2022	Online only	Revised for Version 3.2 (Release 2022a)

1	<hr/>	Apps
2	<hr/>	Functions
3	<hr/>	System Objects
4	<hr/>	Classes
5	<hr/>	Blocks

Apps

Audio Labeler

(To be removed) Define and visualize ground-truth labels

Note **Audio Labeler** will be removed in a future release. Use **Signal Labeler** instead. For more information, see “Compatibility Considerations”.

Description

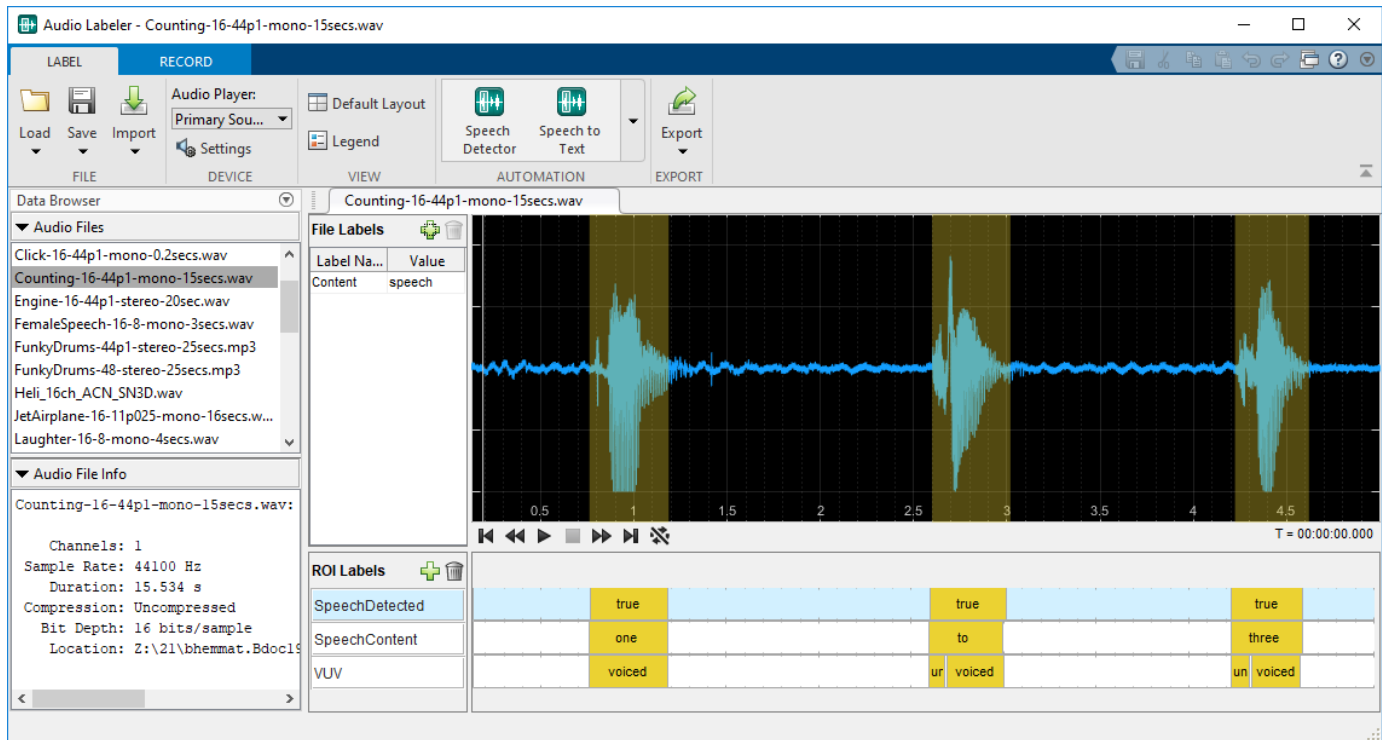
The **Audio Labeler** app enables you to label ground-truth data at both the region level and file level.

Using the app, you can:

- Create label definitions for consistent and fast labeling.
- Visualize the time-domain waveform during playback.
- Interactively specify labels at the file level and region level. You can specify regions by drawing directly on the time-domain waveform.
- Record new audio to add to your dataset.
- Apply automatic labeling of detected speech regions.
- Apply automatic word labeling using third-party speech-to-text transcription services. See “Speech-to-Text Transcription” for more information.

The app exports data as a `labeledSignalSet` object. You can use `labeledSignalSet` to train a network, classifier, or analyze data and report statistics.

- For advanced sublabeling and custom automated labeling functions, see “Import and Play Audio File Data in Signal Labeler”.
- Audio playback and recording are not supported in MATLAB Online.



Open the Audio Labeler App

- MATLAB toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the app icon.
- MATLAB command prompt: Enter `audioLabeler`.

Examples

Create Keyword Spotting Mask Using Audio Labeler

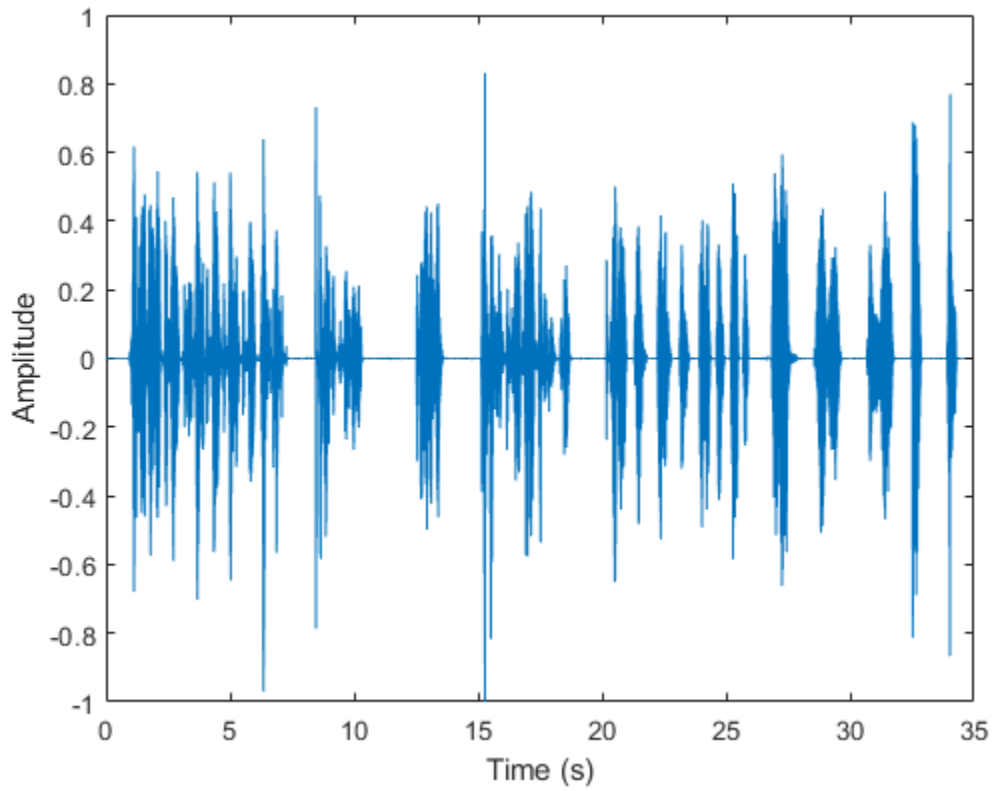
In this example, you create a logical mask for an audio signal where ones correspond to the utterance "yes" and zeros correspond to the absence of the utterance "yes". To create the mask, you use the IBM™ speech-to-text API through the **Audio Labeler** app.

This example requires that you install the “Speech-to-Text Transcription” functionality.

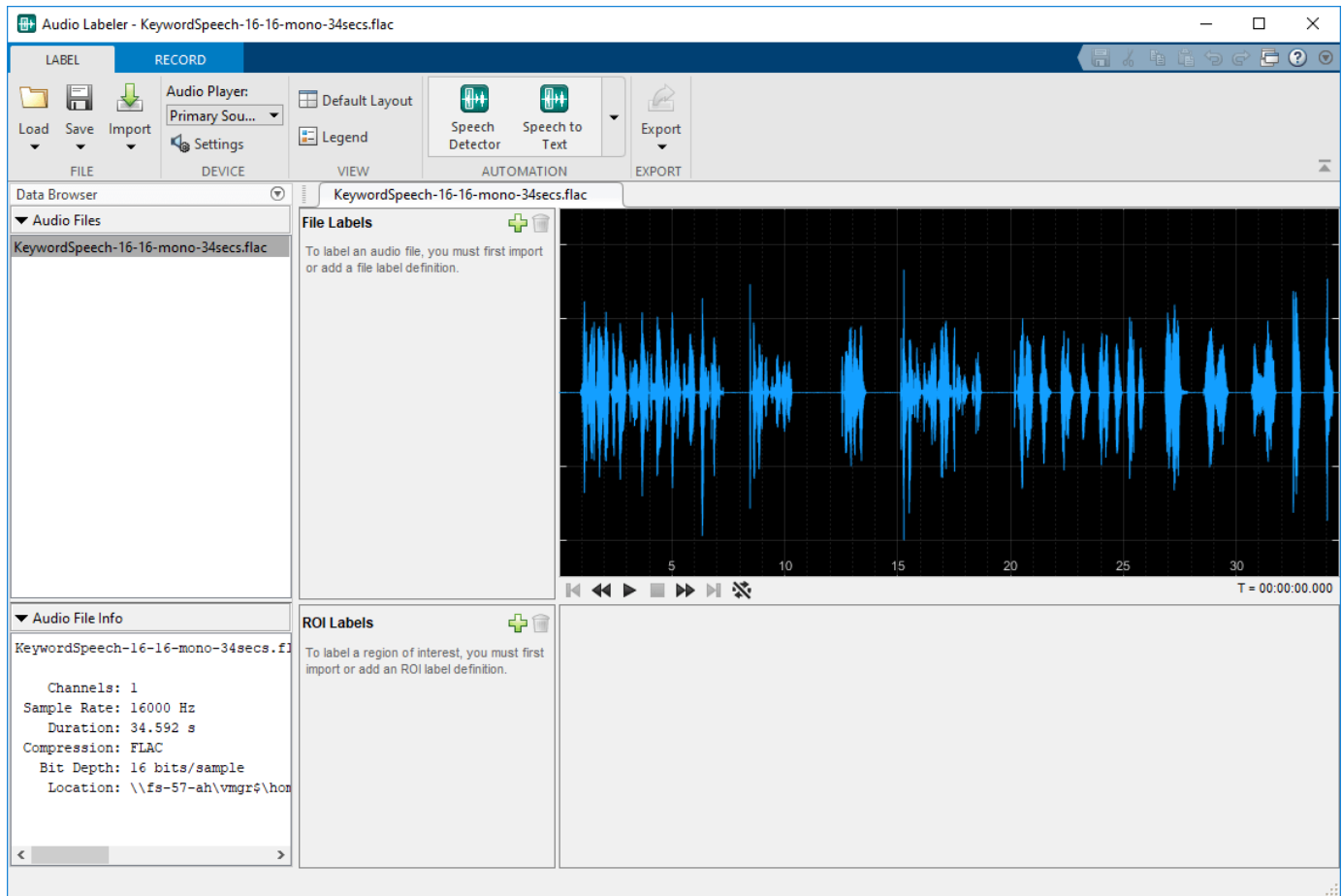
Listen to the audio file that you want to label and then visualize it in the time domain.

```
[audioIn,fs] = audioread("KeywordSpeech-16-16-mono-34secs.flac");
sound(audioIn,fs)

t = (0:numel(audioIn)-1)/fs;
plot(t,audioIn)
xlabel('Time (s)')
ylabel('Amplitude')
```



Open the **Audio Labeler** app and load the `KeywordSpeech-16-16-mono-34secs.flac` file into the **Data Browser**.

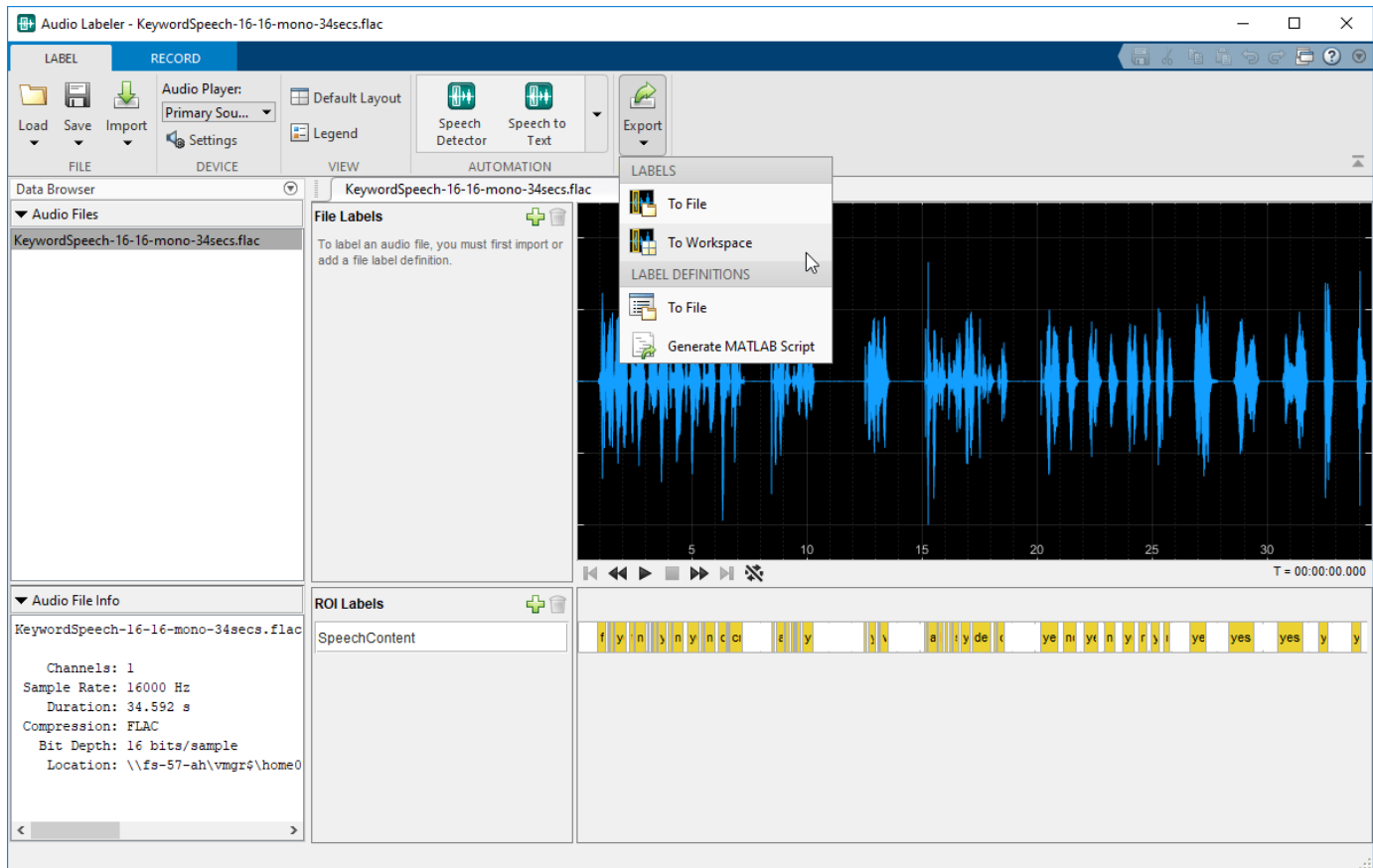


Under **Automation**, click **Speech to Text**. On the **Speech to Text** tab, select your preferred speech-to-text API. This example uses the IBM speech-to-text API. Select **Segment Words** so that the text labels are divided into individual words instead of sentences. Click **Run** to interface with the speech-to-text API and create a new region of interest (ROI) label. The ROI label contains words detected and labeled by IBM's speech-to-text API.

The screenshot displays the 'Audio Labeler' application window. The title bar reads 'Audio Labeler - KeywordSpeech-16-16-mono-34secs.flac'. The interface is organized into several functional areas:

- Top Panel:** Contains tabs for 'LABEL', 'RECORD', and 'SPEECH TO TEXT'. The 'SPEECH TO TEXT' tab is active. Below the tabs is a toolbar with buttons for 'Run', 'Undo Run', 'Close Speech to Text', and 'Close'.
- Data Browser:** Located on the left, it shows a list of audio files, with 'KeywordSpeech-16-16-mono-34secs.flac' selected.
- File Labels:** A central panel with a message: 'To label an audio file, you must first import or add a file label definition.'
- Audio File Info:** A panel at the bottom left providing technical details for the selected file:
 - KeywordSpeech-16-16-mono-34secs.flac
 - Channels: 1
 - Sample Rate: 16000 Hz
 - Duration: 34.592 s
 - Compression: FLAC
 - Bit Depth: 16 bits/sample
 - Location: \\fs-57-ah\vmgrs\home0
- ROI Labels:** A panel at the bottom center with a 'SpeechContent' field containing the text: 'f y n y n y n c c i e y y v a s y d e c ye ni ye n y r y i ye yes yes y y'.
- Waveform Display:** A large area on the right showing a blue waveform of the audio signal against a black background. A timeline at the bottom of the waveform indicates time markers at 5, 10, 15, 20, 25, and 30 seconds. The total time is shown as 'T = 00:00:00.000'.

Close the **Speech to Text** tab and then export the labeled signal set to the workspace.



The labels are exported to the workspace as `labeledSignalSet` object with a time stamp. Set the variable `labeledSet` to the time-stamped `labeledSignalSet` object.

```
labeledSet = myLabeledSet;
```

Inspect the `SpeechContent` label.

```
speechContent = labeledSet.Labels.SpeechContent{1}
```

```
speechContent=52x2 table
    ROIlimits      Value
    _____  _____
    0.87    1.31    "first"
    1.31    1.41    "you"
    1.41    1.63    "said"
    1.63    2.22    "yes"
    2.25    2.52    "then"
    2.52    3.03    "no"
    3.09    3.22    "and"
    3.22    3.32    "you"
    3.32    3.52    "said"
    3.52    3.94    "yes"
    3.94    4.16    "then"
    4.16    4.66    "no"
    4.83    5.39    "yes"
    5.42    5.57    "the"
```

```

5.57    6.07    "no"
6.15    6.56    "driving"
⋮

```

The speech-to-text API returns the limits of the ROI labels in seconds. Use the `SpeechContent` table to create a logical vector.

```

keywordLabels = speechContent(speechContent.Value == "yes",:);
keywordROIlimitsInSamples = round(keywordLabels.ROIlimits*fs);

mask = zeros(size(audioIn),"logical");
for i = 1:size(keywordROIlimitsInSamples)
    mask(keywordROIlimitsInSamples(i,1):keywordROIlimitsInSamples(i,2)) = true;
end

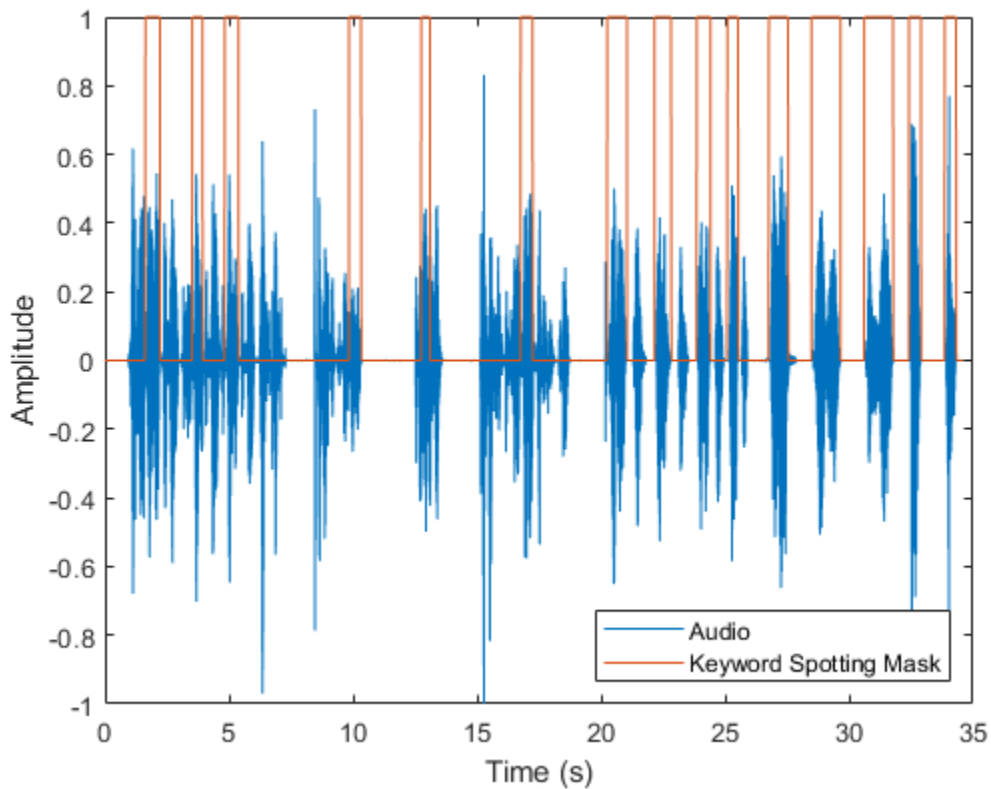
```

Plot the speech signal and the keyword spotting mask.

```

plot(t, audioIn, ...
     t, mask)
xlabel('Time (s)')
ylabel('Amplitude')
legend('Audio', 'Keyword Spotting Mask', 'Location', 'southeast')

```



Programmatic Use

audioLabeler opens the app, enabling you to label ground-truth data about audio.

Compatibility Considerations

Audio Labeler will be removed

Warns starting in R2022a

The **Audio Labeler** app will be removed in a future release. Use **Signal Labeler** instead.

The **Signal Labeler** app:

- Replaces file-level labels with attribute labels to define full-signal characteristics.
- Uses different line colors for channels of an audio file by default.
- Does not expose label tags of label definitions. You cannot interactively see, add, or edit label tags for label definitions.
- Provides two new workflows when running autolabeling algorithms:
 - Label and inspect plotted audio files.
 - Label all audio files or a subset of audio files without inspection.
- Does not automatically create label definitions when running automation algorithms. To automate the detection of speech content, you must first add logical region-of-interest (ROI) label definitions. To perform speech-to-text transcription, you must first add string ROI label definitions.
- Requires automation algorithms be run on one channel at a time. For multichannel audio files, you can choose which channel to use as input.
- Does not provide audio recording.

See Also

Apps

Signal Labeler

Objects

signalLabelDefinition | labeledSignalSet | audioDatastore | audioDeviceReader | audioDeviceWriter

Introduced in R2018b

Impulse Response Measurer

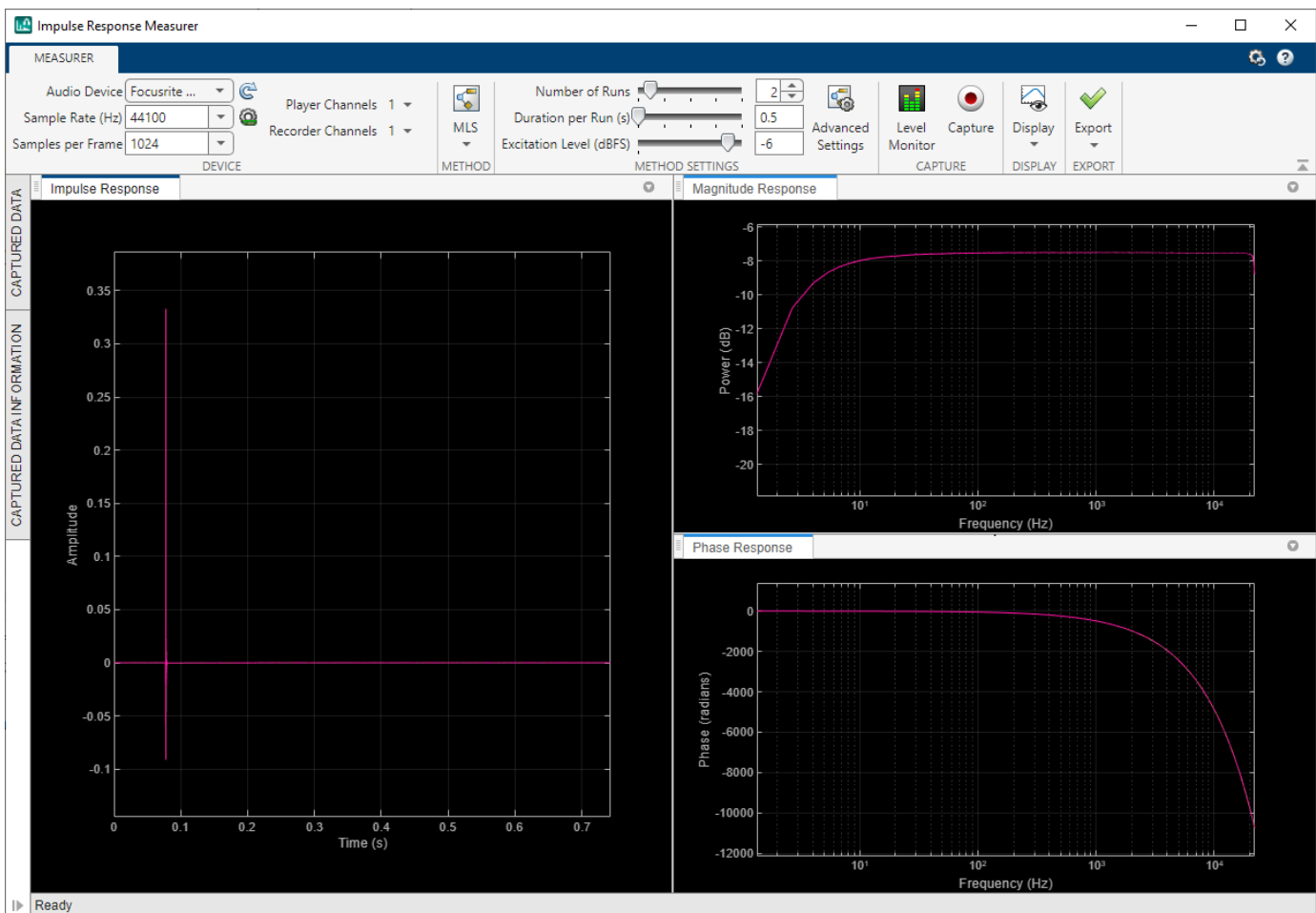
Measure impulse response of audio system

Description

The **Impulse Response Measurer** app enables you to acquire, analyze, and export impulse response and frequency response measurements through a user interface.

Using this app, you can:

- Acquire impulse responses from one or more input channels to create filters and generate models for offline simulations.
- Determine whether audio devices (loudspeakers, for example) meet time and frequency specifications.
- Optimize audio systems, such as automotive-acoustic systems, to match goal specifications.
- Acquire accurate impulse response measurements for use in acoustic reporting.



Open the Impulse Response Measurer App


MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the app icon.

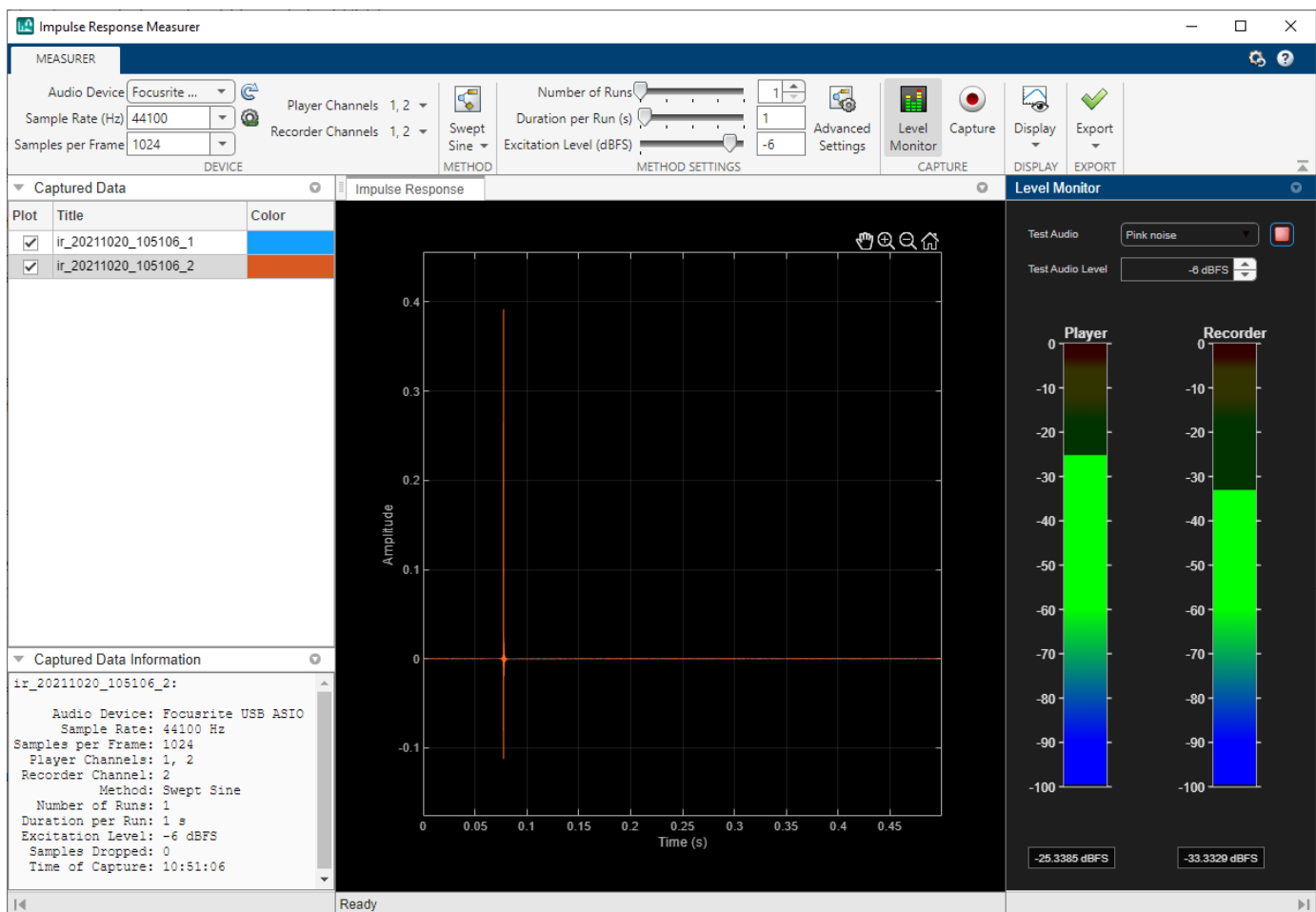
MATLAB Command prompt: Enter `impulseResponseMeasurer`.

Examples

Verify Input/Output Configuration

For large systems with multiple audio devices and multiple input and output channels, tracking how reported devices and channels correspond to physical devices can be difficult. The **Impulse Response Measurer** provides a level monitor so that you can verify your audio I/O configuration.

To open the level monitor, click **Level Monitor**, .



Choose player and recorder channels in the **Device** section of the toolstrip. Choose the test signal and the test audio level in the level monitor. Verify that the level reported by the recorder reacts

appropriately to level changes output by the player. Once you are satisfied that your system is configured correctly, close the level monitor and begin the impulse response capture.

- “Impulse Response Measurer Walkthrough”

Parameters

Method — Select excitation signal as MLS or swept sine wave

MLS (default) | Exponential Swept Sine

Select the excitation signal algorithm used to generate an impulse response measurement:

- **MLS** -- The maximum length sequence (MLS) technique is based on the excitation of the acoustical space by a periodic pseudorandom signal. The impulse response is obtained by circular cross-correlation between the measured output and the test tone. For more details, see [2].
- **Exponential Swept Sine** -- The swept sine measurement technique uses an exponential time-growing frequency sweep as an output signal. The output signal is recorded, and deconvolution is used to recover the impulse response from the swept sine tone. For more details, see [1]. The swept sine technique enables you to modify additional **Advanced Settings** to control the excitation signal. The advanced settings apply per run:
 - **Sweep start frequency**
 - **Sweep stop frequency**
 - **Sweep duration**
 - **End silence duration**

The value of the **End silence duration** is read-only and depends on the **Sweep duration** and **Duration per Run (s)**: End silence duration = Duration per Run – Sweep duration

References

- [1] Farina, Angelo. "Advancements in Impulse Response Measurements by Sine Sweeps." Presented at the *Audio Engineering Society 122nd Convention*, Vienna, Austria, 2007.
- [2] Guy-Bart, Stan, Jean-Jacques Embrachts, and Dominique Archambeau. "Comparison of Different Impulse Response Measurement Techniques." *Journal of Audio Engineering Society*. Vol. 50, Issue 4, 2002, pp. 246-262.
- [3] Armelloni, Enrico, Christian Giottoli, and Angelo Farina. "Implementation of Real-Time Partitioned Convolution on a DSP Board." *Application of Signal Processing to Audio and Acoustics, 2003 IEEE Workshop*, pp. 71-74. IEEE, 2003.

See Also

audioPlayerRecorder | splMeter | reverberator

Topics

“Impulse Response Measurer Walkthrough”

Introduced in R2018a

Audio Test Bench

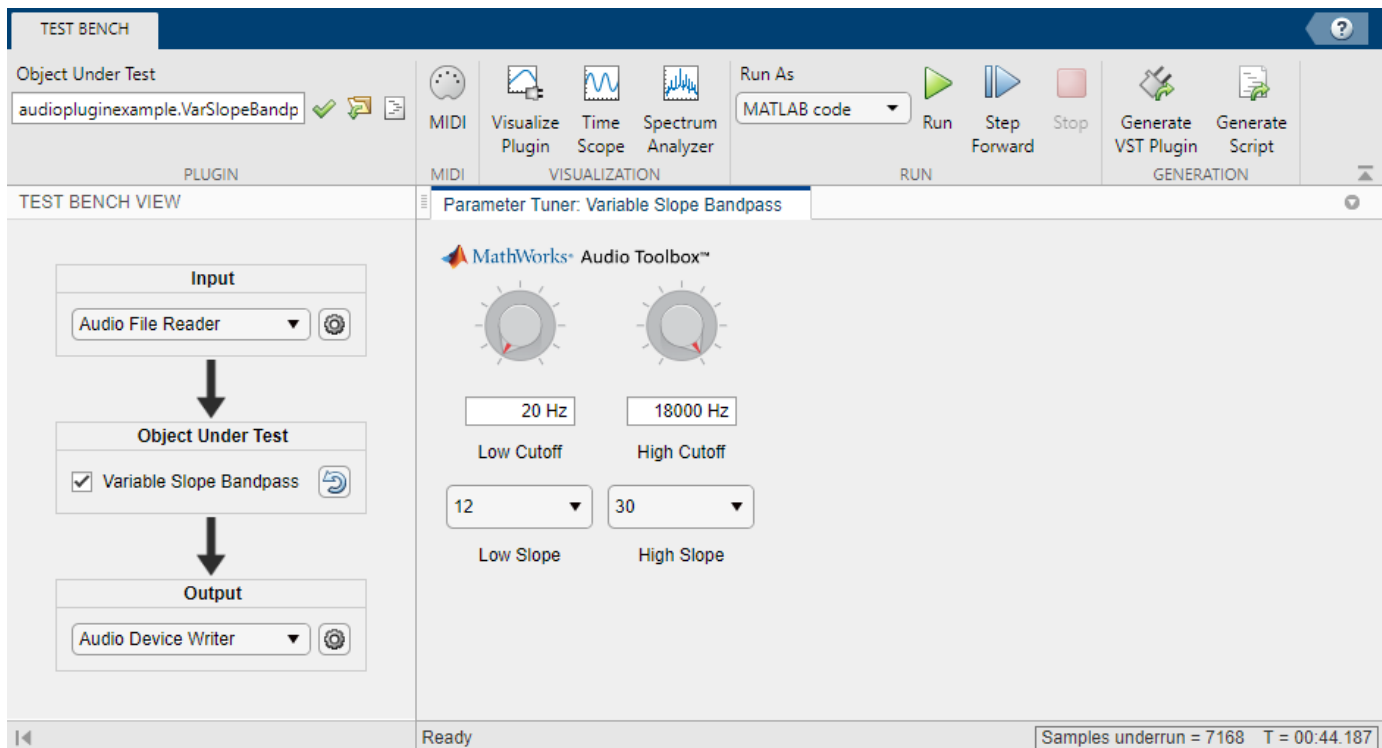
Debug, test, and tune audio plugin

Description

The **Audio Test Bench** provides a graphical interface through which you can develop, debug, test, and tune your audio plugin in real time. You can interact with properties of your audio plugin using associated parameter graphical widgets. See `audioPluginParameter` for more information.

Using the **Audio Test Bench**, you can:

- Debug your audio plugin.
- Simulate your audio plugin as generated in a digital audio workstation (DAW).
- Visualize your processing with time-domain and frequency-domain scopes.
- Interactively synchronize MIDI controls to plugin properties.
- Run validation checks and generate VST plugins.



Open the Audio Test Bench App

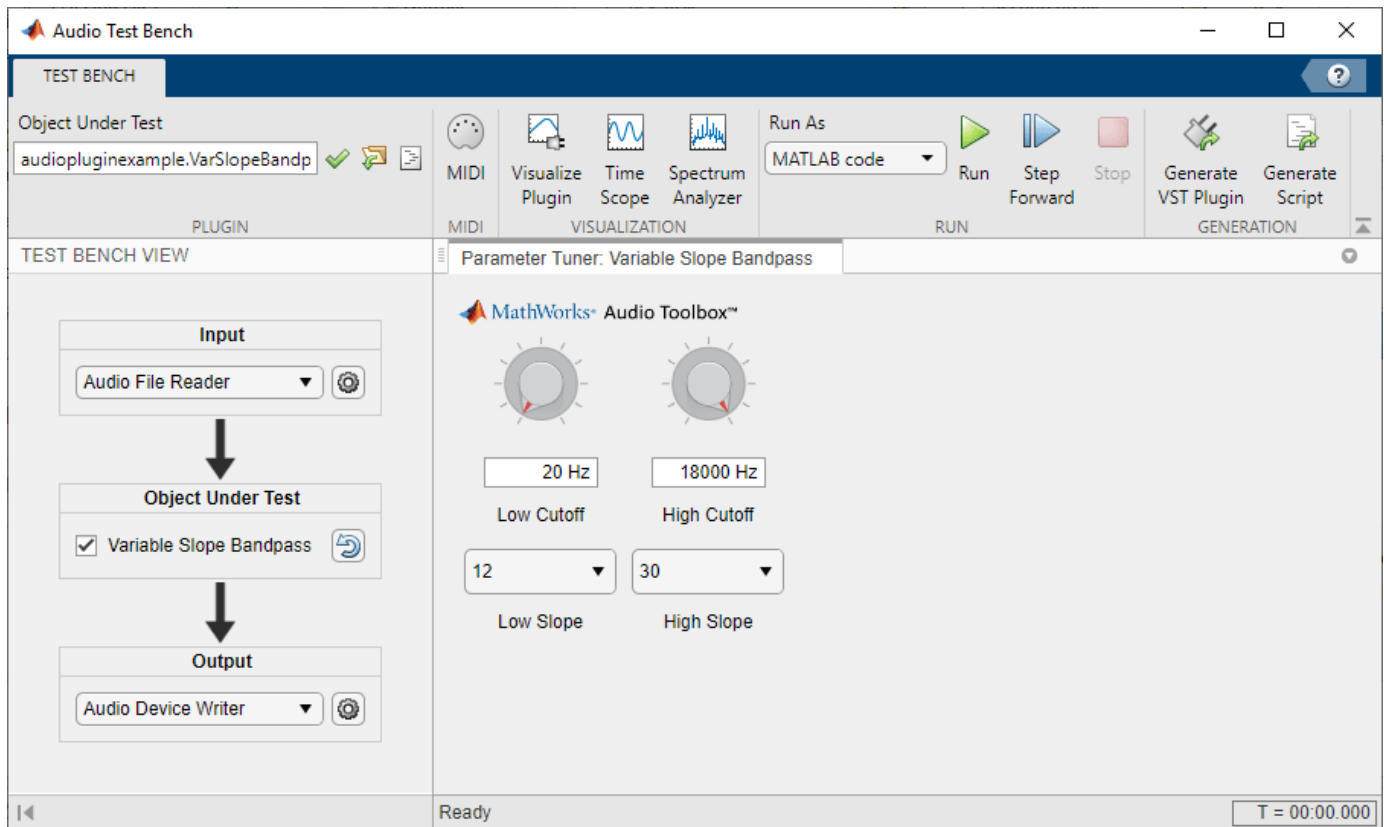
- MATLAB Toolstrip: On the **Apps** tab, under **Signal Processing and Communications**, click the app icon.
- MATLAB command prompt: Enter `audioTestBench`.

Examples

Open Audio Test Bench

Open the **Audio Test Bench** for an audio plugin class.

```
audioTestBench(audiopluginexample.VarSlopeBandpassFilter)
```



- “Audio Test Bench Walkthrough”

Programmatic Use

`audioTestBench(aClass)` opens the **Audio Test Bench** for an instance of `aClass`. Valid classes include:

- An audio plugin class that derives from `audioPlugin`, the base class for audio plugins.
- A compatible Audio Toolbox System object™.

`audioTestBench(aObject)` opens the **Audio Test Bench** for `aObject`. Valid objects include:

- An instance of an audio plugin class, where the class derives from `audioPlugin`, the base class for audio plugins.

- An instance of a compatible Audio Toolbox System object.
- A hosted plugin object, as returned by the `loadAudioPlugin` function.

`audioTestBench(pluginPath)` opens the **Audio Test Bench** for `pluginPath`, where `pluginPath` is the location of an external plugin. Use the full path to specify the audio plugin you want to host. If the plugin is located in the current folder, specify it by its name.

`audioTestBench(' -close ')` closes the **Audio Test Bench**.

Tips

- The **Audio Test Bench** provides persistent input and output settings across sessions.

See Also

Functions

`validateAudioPlugin` | `generateAudioPlugin` | `audioPluginInterface` | `audioPluginParameter`

Classes

`audioPlugin` | `audioPluginSource`

Topics

“Audio Test Bench Walkthrough”

“What Are DAWs, Audio Plugins, and MIDI Controllers?”

“Design an Audio Plugin”

“Audio Plugins in MATLAB”

“Audio Plugin Example Gallery”

Introduced in R2016a

Extract Audio Features

Streamline audio feature extraction in the Live Editor

Description

The **Extract Audio Features** task enables you to configure an optimized feature extraction pipeline by selecting features and parameters graphically. You can reuse the output from **Extract Audio Features** to apply feature extraction to entire data sets. The task automatically generates MATLAB code for your live script.

Using this task, you can:

- Extract features of audio signals common to machine learning and deep learning workflows.
- Create a feature extraction object for use with large data sets.

To learn more about interactive tasks in live scripts, see “Add Interactive Tasks to a Live Script”.

Extract Audio Features

features, extractor = Mel spectrum, zero-crossing rate, and short-time energy extracted from audioIn

▼ Select data

Input audio data Sample rate (Hz)

▼ Specify window properties

Window

Overlap length % FFT length

▼ Select features to extract

Spectral features

Linear spectrum Mel spectrum Bark spectrum ERB spectrum

Cepstral features

MFCC MFCC delta MFCC delta delta
 GTCC GTCC delta GTCC delta delta

Spectral descriptors

Centroid Crest Decrease Entropy
 Flatness Flux Kurtosis Rolloff point
 Skewness Slope Spread

Periodicity features

Pitch Harmonic ratio Zero-crossing rate

Energy features

Short-time energy

▼ Specify feature extractor parameters

Mel spectrum

Spectrum type	<input type="text" value="Power"/>	Frequency range (Hz)	<input type="text" value="[0 11025]"/>
Window normalization	<input type="text" value="On"/>	Num. bands	<input type="text" value="32"/>
Filter bank domain	<input type="text" value="Linear"/>	Filter bank normalization	<input type="text" value="Bandwidth"/>

Zero-crossing rate

Method	<input type="text" value="Difference"/>	Level	<input type="text" value="0"/>
Threshold	<input type="text" value="0"/>	Transition edge	<input type="text" value="Both"/>
Zero positive	<input type="text" value="Off"/>		

▼ Display results

Output summary

Open the Task

- On the **Live Editor** tab, select **Task > Extract Audio Features**.
- In a code block in the script, type a relevant keyword, such as `extract`, `audio`, or `feature`. Select **Extract Audio Features** from the suggested command completions.

Tips

The **Extract Audio Features** task provides a graphical user interface to configure an `audioFeatureExtractor` object. For details on the configuration parameters, see `audioFeatureExtractor`.

See Also

`audioDataAugmenter` | `audioFeatureExtractor` | `audioDatastore`

Introduced in R2020a

Functions

yamnetPreprocess

Preprocess audio for YAMNet classification

Syntax

```
features = yamnetPreprocess(audioIn,fs)
features = yamnetPreprocess(audioIn,fs,'OverlapPercentage',OP)
```

Description

`features = yamnetPreprocess(audioIn,fs)` generates mel spectrograms from `audioIn` that can be fed to the YAMNet pretrained network.

`features = yamnetPreprocess(audioIn,fs,'OverlapPercentage',OP)` specifies the overlap percentage between consecutive audio frames.

For example, `features = yamnetPreprocess(audioIn,fs,'OverlapPercentage',75)` applies a 75% overlap between consecutive frames used to generate the spectrograms.

Examples

Download YAMNet

Download and unzip the Audio Toolbox™ model for YAMNet.

Type `yamnet` at the Command Window. If the Audio Toolbox model for YAMNet is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the YAMNet model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'YAMNetDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/yamnet.zip');
YAMNetLocation = tempdir;
unzip(loc,YAMNetLocation)
addpath(fullfile(YAMNetLocation,'yamnet'))
```

Check that the installation is successful by typing `yamnet` at the Command Window. If the network is installed, then the function returns a `SeriesNetwork` (Deep Learning Toolbox) object.

```
yamnet
ans =
  SeriesNetwork with properties:
    Layers: [86x1 nnet.cnn.layer.Layer]
    InputNames: {'input_1'}
    OutputNames: {'Sound'}
```


Load Pretrained YAMNet

Load a pretrained YAMNet convolutional neural network and examine the layers and classes.

Use `yamnet` to load the pretrained YAMNet network. The output net is a `SeriesNetwork` (Deep Learning Toolbox) object.

```
net = yamnet

net =
  SeriesNetwork with properties:
    Layers: [86x1 nnet.cnn.layer.Layer]
    InputNames: {'input_1'}
    OutputNames: {'Sound'}
```

View the network architecture using the `Layers` property. The network has 86 layers. There are 28 layers with learnable weights: 27 convolutional layers, and 1 fully connected layer.

```
net.Layers
```

```
ans =
  86x1 Layer array with layers:

   1  'input_1'           Image Input           96x64x1 images
   2  'conv2d'           Convolution           32 3x3x1 convolutions with stride
   3  'b'                Batch Normalization  Batch normalization with 32 channels
   4  'activation'       ReLU                  ReLU
   5  'depthwise_conv2d' Grouped Convolution  32 groups of 1 3x3x1 convolutions
   6  'L11'              Batch Normalization  Batch normalization with 32 channels
   7  'activation_1'     ReLU                  ReLU
   8  'conv2d_1'         Convolution           64 1x1x32 convolutions with stride
   9  'L12'              Batch Normalization  Batch normalization with 64 channels
  10  'activation_2'     ReLU                  ReLU
  11  'depthwise_conv2d_1' Grouped Convolution  64 groups of 1 3x3x1 convolutions
  12  'L21'              Batch Normalization  Batch normalization with 64 channels
  13  'activation_3'     ReLU                  ReLU
  14  'conv2d_2'         Convolution           128 1x1x64 convolutions with stride
  15  'L22'              Batch Normalization  Batch normalization with 128 channels
  16  'activation_4'     ReLU                  ReLU
  17  'depthwise_conv2d_2' Grouped Convolution  128 groups of 1 3x3x1 convolutions
  18  'L31'              Batch Normalization  Batch normalization with 128 channels
  19  'activation_5'     ReLU                  ReLU
  20  'conv2d_3'         Convolution           128 1x1x128 convolutions with stride
  21  'L32'              Batch Normalization  Batch normalization with 128 channels
  22  'activation_6'     ReLU                  ReLU
  23  'depthwise_conv2d_3' Grouped Convolution  128 groups of 1 3x3x1 convolutions
  24  'L41'              Batch Normalization  Batch normalization with 128 channels
  25  'activation_7'     ReLU                  ReLU
  26  'conv2d_4'         Convolution           256 1x1x128 convolutions with stride
  27  'L42'              Batch Normalization  Batch normalization with 256 channels
  28  'activation_8'     ReLU                  ReLU
  29  'depthwise_conv2d_4' Grouped Convolution  256 groups of 1 3x3x1 convolutions
  30  'L51'              Batch Normalization  Batch normalization with 256 channels
```

31	'activation_9'	ReLU	ReLU
32	'conv2d_5'	Convolution	256 1x1x256 convolutions with str:
33	'L52'	Batch Normalization	Batch normalization with 256 chan
34	'activation_10'	ReLU	ReLU
35	'depthwise_conv2d_5'	Grouped Convolution	256 groups of 1 3x3x1 convolutions
36	'L61'	Batch Normalization	Batch normalization with 256 chan
37	'activation_11'	ReLU	ReLU
38	'conv2d_6'	Convolution	512 1x1x256 convolutions with str:
39	'L62'	Batch Normalization	Batch normalization with 512 chan
40	'activation_12'	ReLU	ReLU
41	'depthwise_conv2d_6'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
42	'L71'	Batch Normalization	Batch normalization with 512 chan
43	'activation_13'	ReLU	ReLU
44	'conv2d_7'	Convolution	512 1x1x512 convolutions with str:
45	'L72'	Batch Normalization	Batch normalization with 512 chan
46	'activation_14'	ReLU	ReLU
47	'depthwise_conv2d_7'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
48	'L81'	Batch Normalization	Batch normalization with 512 chan
49	'activation_15'	ReLU	ReLU
50	'conv2d_8'	Convolution	512 1x1x512 convolutions with str:
51	'L82'	Batch Normalization	Batch normalization with 512 chan
52	'activation_16'	ReLU	ReLU
53	'depthwise_conv2d_8'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
54	'L91'	Batch Normalization	Batch normalization with 512 chan
55	'activation_17'	ReLU	ReLU
56	'conv2d_9'	Convolution	512 1x1x512 convolutions with str:
57	'L92'	Batch Normalization	Batch normalization with 512 chan
58	'activation_18'	ReLU	ReLU
59	'depthwise_conv2d_9'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
60	'L101'	Batch Normalization	Batch normalization with 512 chan
61	'activation_19'	ReLU	ReLU
62	'conv2d_10'	Convolution	512 1x1x512 convolutions with str:
63	'L102'	Batch Normalization	Batch normalization with 512 chan
64	'activation_20'	ReLU	ReLU
65	'depthwise_conv2d_10'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
66	'L111'	Batch Normalization	Batch normalization with 512 chan
67	'activation_21'	ReLU	ReLU
68	'conv2d_11'	Convolution	512 1x1x512 convolutions with str:
69	'L112'	Batch Normalization	Batch normalization with 512 chan
70	'activation_22'	ReLU	ReLU
71	'depthwise_conv2d_11'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
72	'L121'	Batch Normalization	Batch normalization with 512 chan
73	'activation_23'	ReLU	ReLU
74	'conv2d_12'	Convolution	1024 1x1x512 convolutions with str:
75	'L122'	Batch Normalization	Batch normalization with 1024 cha
76	'activation_24'	ReLU	ReLU
77	'depthwise_conv2d_12'	Grouped Convolution	1024 groups of 1 3x3x1 convolutio
78	'L131'	Batch Normalization	Batch normalization with 1024 cha
79	'activation_25'	ReLU	ReLU
80	'conv2d_13'	Convolution	1024 1x1x1024 convolutions with s
81	'L132'	Batch Normalization	Batch normalization with 1024 cha
82	'activation_26'	ReLU	ReLU
83	'global_average_pooling2d'	Global Average Pooling	Global average pooling
84	'dense'	Fully Connected	521 fully connected layer
85	'softmax'	Softmax	softmax
86	'Sound'	Classification Output	crossentropyex with 'Speech' and !

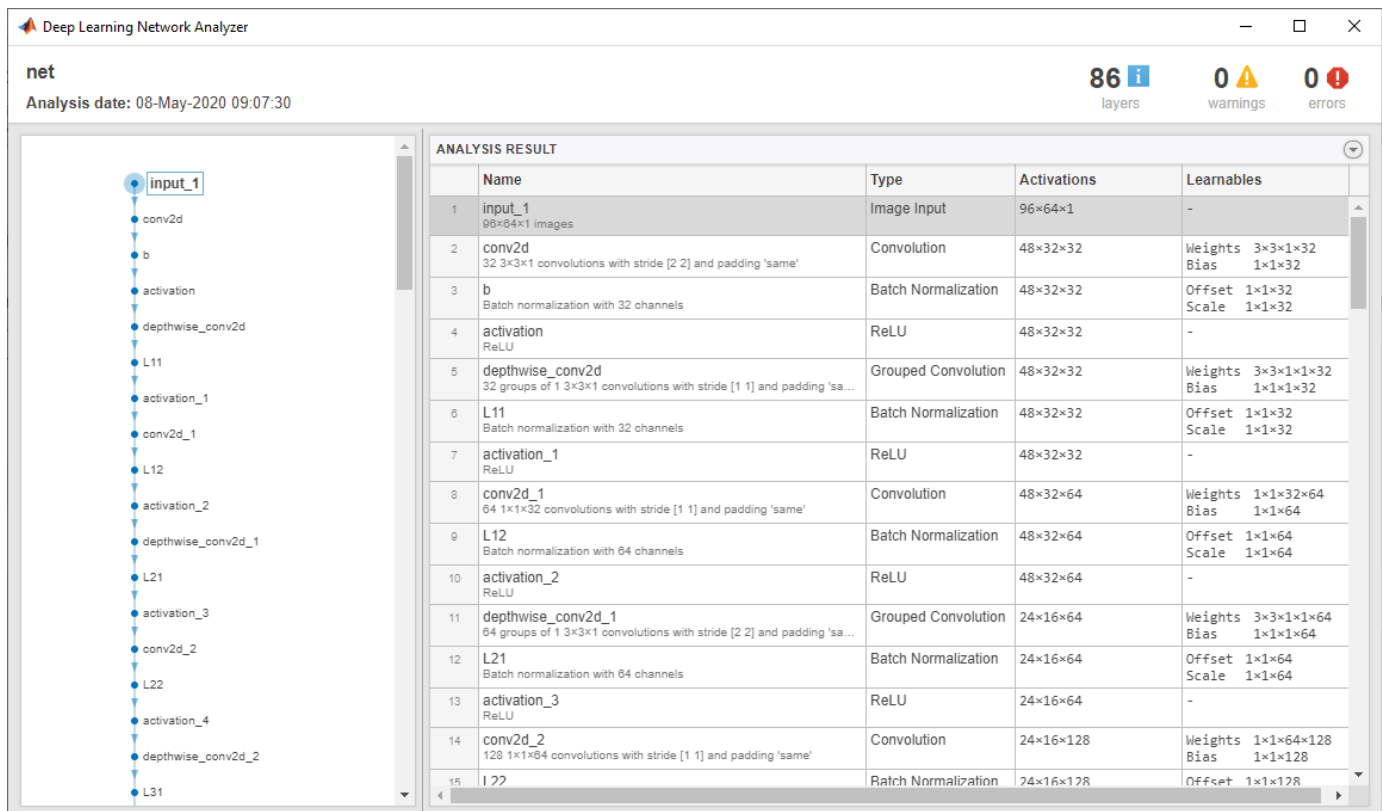
To view the names of the classes learned by the network, you can view the `Classes` property of the classification output layer (the final layer). View the first 10 classes by specifying the first 10 elements.

```
net.Layers(end).Classes(1:10)

ans = 10×1 categorical
    Speech
    Child speech, kid speaking
    Conversation
    Narration, monologue
    Babbling
    Speech synthesizer
    Shout
    Bellow
    Whoop
    Yell
```

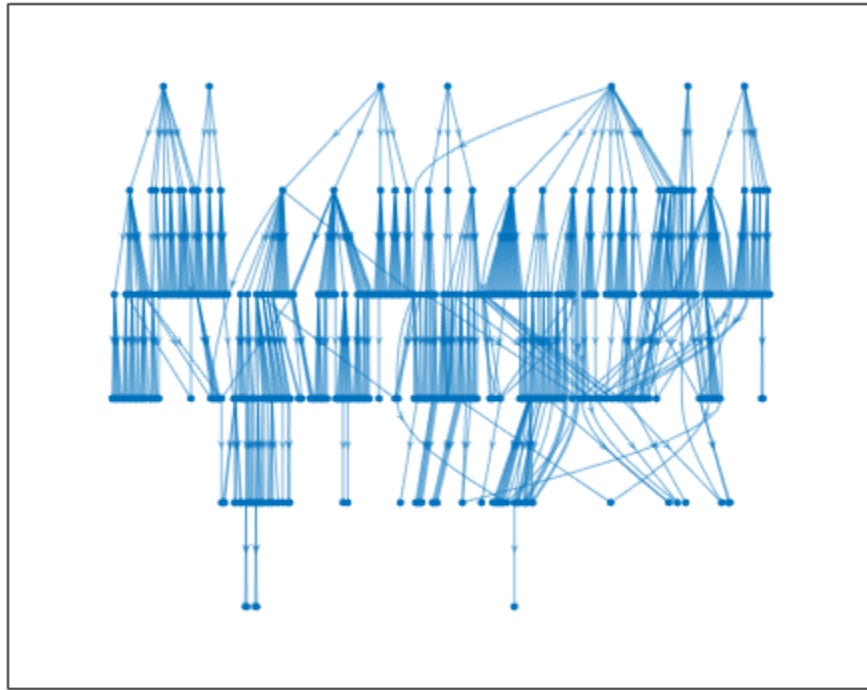
Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

```
analyzeNetwork(net)
```



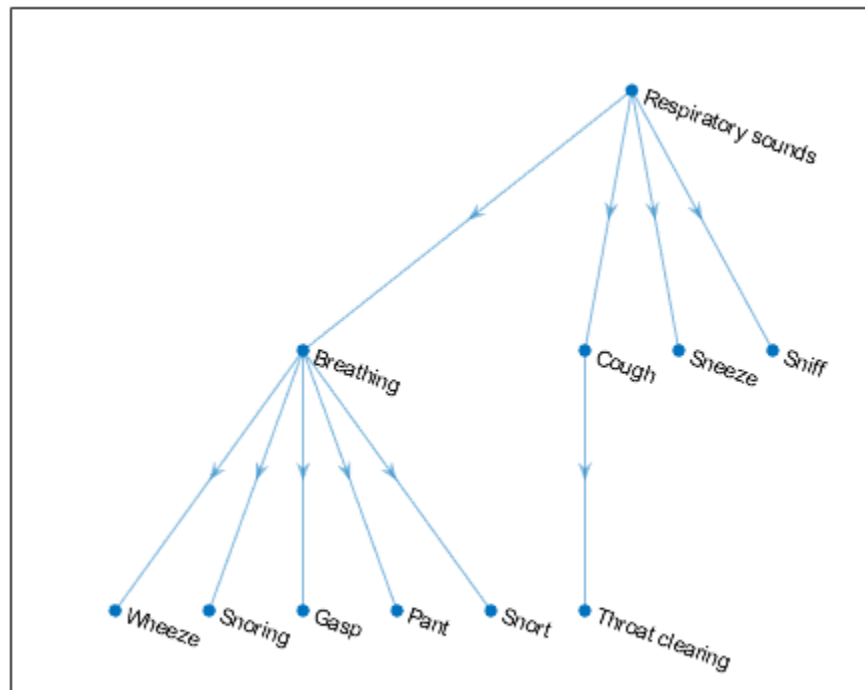
YAMNet was released with a corresponding sound class ontology, which you can explore using the `yamnetGraph` object.

```
ygraph = yamnetGraph;
p = plot(ygraph);
layout(p, 'layered')
```



The ontology graph plots all 521 possible sound classes. Plot a subgraph of the sounds related to respiratory sounds.

```
allRespiratorySounds = dfsearch(ygraph, "Respiratory sounds");  
ygraphSpeech = subgraph(ygraph, allRespiratorySounds);  
plot(ygraphSpeech)
```



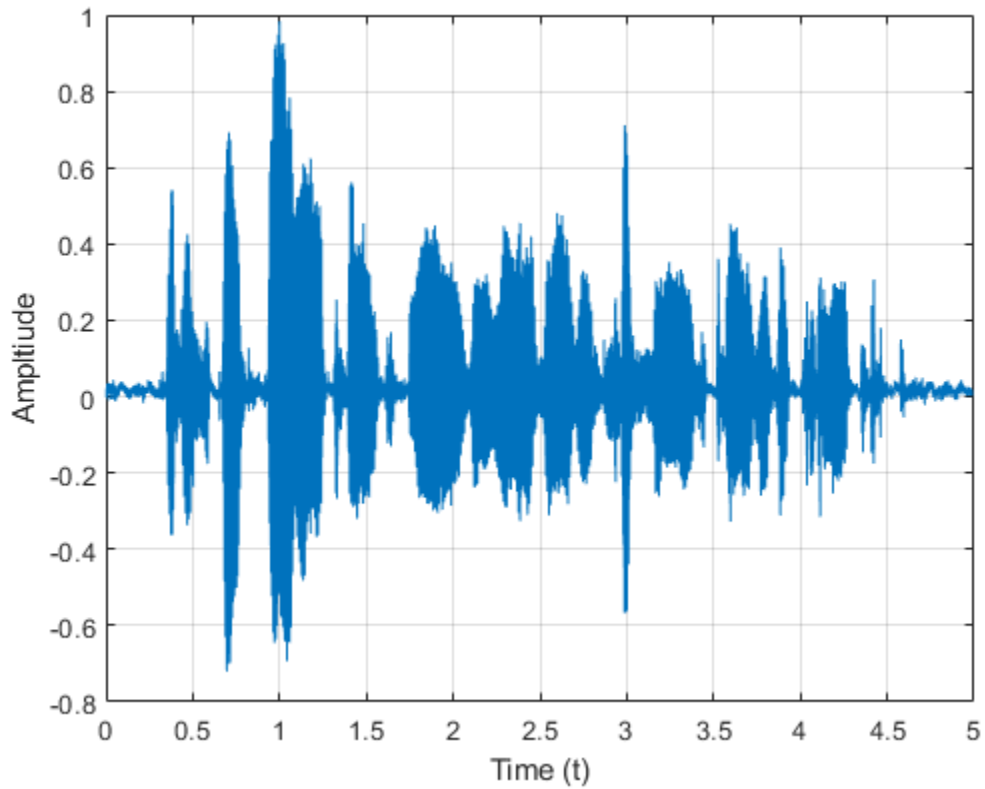
Preprocess Audio and Classify Sounds with YAMNet

Read in an audio signal.

```
[audioIn,fs] = audioread('SpeechDFT-16-8-mono-5secs.wav');
```

Plot and listen to the audio signal.

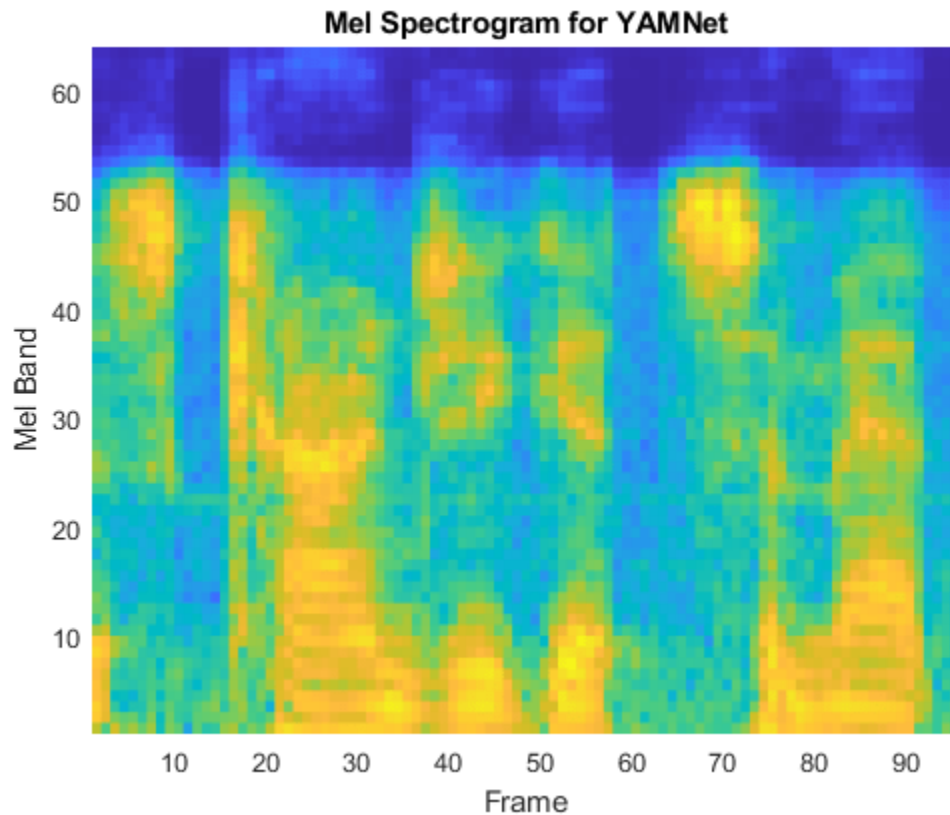
```
T = 1/fs;  
t = 0:T:(length(audioIn)*T) - T;  
plot(t,audioIn);  
grid on  
xlabel('Time (t)')  
ylabel('Amplitude')
```



```
soundsc(audioIn,fs)
```

Use `yamnetPreprocess` to extract mel spectrograms from the audio signal. Visualize an arbitrary spectrogram from the array.

```
melSpectYam = yamnetPreprocess(audioIn,fs);  
  
arbSpect = melSpectYam(:,:,1,randi(size(melSpectYam,4)));  
surf(arbSpect,'EdgeColor','none')  
view([90,-90])  
axis([1 size(arbSpect,1) 1 size(arbSpect,2)])  
xlabel('Mel Band')  
ylabel('Frame')  
title('Mel Spectrogram for YAMNet')  
axis tight
```



Create a YAMNet neural network (This requires Deep Learning Toolbox). Call `classify` with your YAMNet network and the preprocessed mel spectrogram images.

```
net = yamnet;
classes = classify(net,melSpectYam);
```

Classify the audio signal as the most frequently occurring sound.

```
mySound = mode(classes)
mySound = categorical
    Speech
```

Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `yamnetPreprocess` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

OP — Overlap percentage between consecutive mel spectrograms

50 (default) | scalar in the range [0,100)

Percentage overlap between consecutive mel spectrograms, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

Output Arguments

features — Mel spectrograms that can be fed to YAMNet pretrained network

96-by-64-by-1-by-*K* array

Mel spectrograms generated from `audioIn`, returned as a 96-by-64-by-1-by-*K* array, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz
- *K* -- Represents the number of mel spectrograms and depends on the length of `audioIn`, the number of channels in `audioIn`, as well as `OverlapPercentage`

Note Each 96-by-64-by-1 patch represents a single mel spectrogram image. For multichannel inputs, mel spectrograms are stacked along the fourth dimension.

Data Types: `single`

References

- [1] Gemmeke, Jort F., et al. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776-80. DOI.org (Crossref), doi:10.1109/ICASSP.2017.7952261.
- [2] Hershey, Shawn, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131-35. DOI.org (Crossref), doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

classifySound | vggish | vggishEmbeddings | vggishPreprocess | yamnet | yamnetGraph

Introduced in R2021a

vggishPreprocess

Preprocess audio for VGGish feature extraction

Syntax

```
features = vggishPreprocess(audioIn,fs)
features = vggishPreprocess(audioIn,fs,'OverlapPercentage',OP)
```

Description

`features = vggishPreprocess(audioIn,fs)` generates mel spectrograms from `audioIn` that can be fed to the VGGish pretrained network.

`features = vggishPreprocess(audioIn,fs,'OverlapPercentage',OP)` specifies the overlap percentage between consecutive audio frames.

For example, `vggishPreprocess(audioIn,fs,'OverlapPercentage',75)` applies a 75% overlap between consecutive frames used to generate the spectrograms.

Examples

Download VGGish Network

Download and unzip the Audio Toolbox™ model for VGGish.

Type `vggish` at the Command Window. If the Audio Toolbox model for VGGish is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the VGGish model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'VGGishDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/vggish.zip');
VGGishLocation = tempdir;
unzip(loc,VGGishLocation)
addpath(fullfile(VGGishLocation,'vggish'))
```

Check that the installation is successful by typing `vggish` at the Command Window. If the network is installed, then the function returns a `SeriesNetwork` (Deep Learning Toolbox) object.

```
vggish
```

```
ans =
  SeriesNetwork with properties:

    Layers: [24x1 nnet.cnn.layer.Layer]
  InputNames: {'InputBatch'}
  OutputNames: {'regressionoutput'}
```

Load Pretrained VGGish Network

Load a pretrained VGGish convolutional neural network and examine the layers and classes.

Use `vggish` to load the pretrained VGGish network. The output `net` is a `SeriesNetwork` (Deep Learning Toolbox) object.

```
net = vggish

net =
  SeriesNetwork with properties:

    Layers: [24x1 nnet.cnn.layer.Layer]
  InputNames: {'InputBatch'}
  OutputNames: {'regressionoutput'}
```

View the network architecture using the `Layers` property. The network has 24 layers. There are nine layers with learnable weights, of which six are convolutional layers and three are fully connected layers.

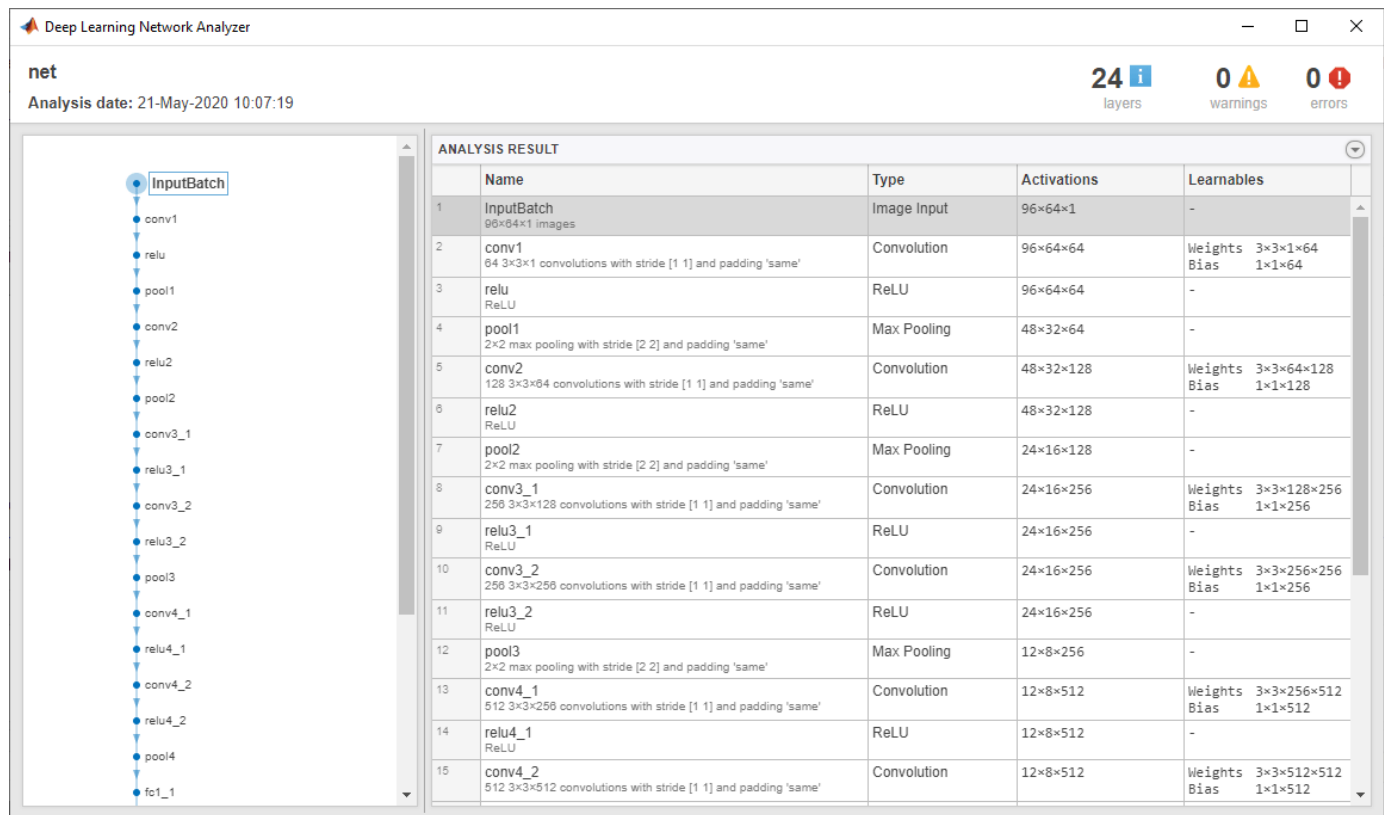
```
net.Layers
```

```
ans =
  24x1 Layer array with layers:

   1  'InputBatch'      Image Input      96x64x1 images
   2  'conv1'           Convolution      64 3x3x1 convolutions with stride [1 1] and padding
   3  'relu'            ReLU             ReLU
   4  'pool1'           Max Pooling      2x2 max pooling with stride [2 2] and padding
   5  'conv2'           Convolution      128 3x3x64 convolutions with stride [1 1] and padding
   6  'relu2'           ReLU             ReLU
   7  'pool2'           Max Pooling      2x2 max pooling with stride [2 2] and padding
   8  'conv3_1'         Convolution      256 3x3x128 convolutions with stride [1 1] and padding
   9  'relu3_1'         ReLU             ReLU
  10  'conv3_2'         Convolution      256 3x3x256 convolutions with stride [1 1] and padding
  11  'relu3_2'         ReLU             ReLU
  12  'pool3'           Max Pooling      2x2 max pooling with stride [2 2] and padding
  13  'conv4_1'         Convolution      512 3x3x256 convolutions with stride [1 1] and padding
  14  'relu4_1'         ReLU             ReLU
  15  'conv4_2'         Convolution      512 3x3x512 convolutions with stride [1 1] and padding
  16  'relu4_2'         ReLU             ReLU
  17  'pool4'           Max Pooling      2x2 max pooling with stride [2 2] and padding
  18  'fc1_1'           Fully Connected  4096 fully connected layer
  19  'relu5_1'         ReLU             ReLU
  20  'fc1_2'           Fully Connected  4096 fully connected layer
  21  'relu5_2'         ReLU             ReLU
  22  'fc2'             Fully Connected  128 fully connected layer
  23  'EmbeddingBatch' ReLU             ReLU
  24  'regressionoutput' Regression Output mean-squared-error
```

Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

```
analyzeNetwork(net)
```



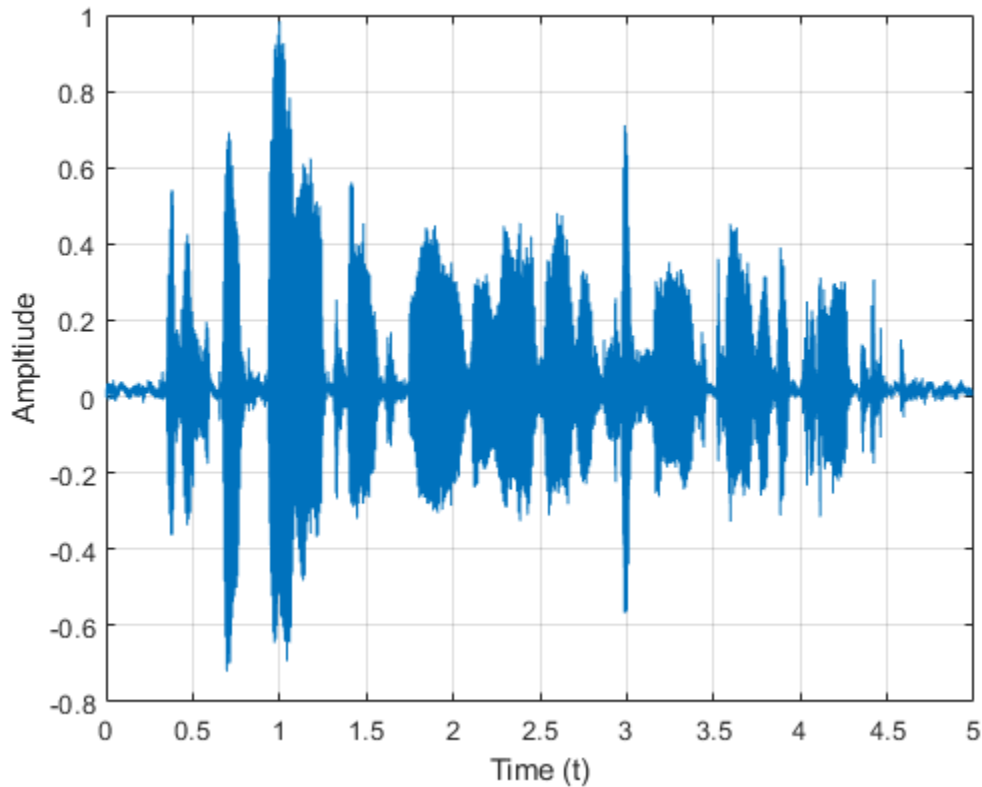
Extract Audio Embeddings with VGGish

Read in an audio signal.

```
[audioIn,fs] = audioread('SpeechDFT-16-8-mono-5secs.wav');
```

Plot and listen to the audio signal.

```
T = 1/fs;
t = 0:T:(length(audioIn)*T) - T;
plot(t,audioIn);
grid on
xlabel('Time (t)')
ylabel('Amplitude')
```



```
soundsc(audioIn, fs)
```

Use `vggishPreprocess` to extract mel spectrograms from the audio signal.

```
melSpectVgg = vggishPreprocess(audioIn, fs);
```

Create a VGGish network (This requires Deep Learning Toolbox). Call `predict` to use your VGGish network for audio feature embedding extraction from the preprocessed mel spectrogram images. The feature embeddings are returned as a `numFrames`-by-128 matrix, where `numFrames` is the number of individual spectrograms, and 128 is the number of elements in each feature vector.

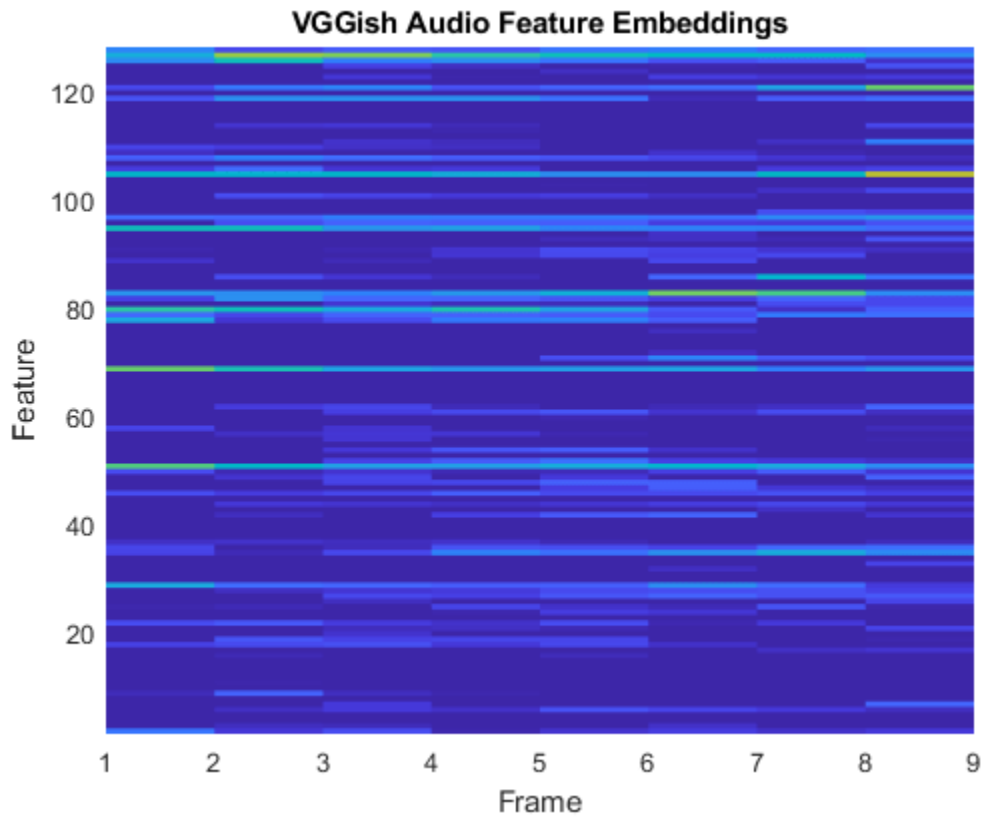
```
net = vggish;
embeddings = predict(net, melSpectVgg);
[numFrames, numFeatures] = size(embeddings)
```

```
numFrames = 9
```

```
numFeatures = 128
```

Visualize the VGGish feature embeddings.

```
surf(embeddings, 'EdgeColor', 'none')
view([90, -90])
axis([1 numFeatures 1 numFrames])
xlabel('Feature')
ylabel('Frame')
title('VGGish Audio Feature Embeddings')
```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `vggishPreprocess` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

OP — Overlap percentage between consecutive mel spectrograms

50 (default) | scalar in the range [0,100)

Percentage overlap between consecutive mel spectrograms, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

Output Arguments

features — Mel spectrograms that can be fed to the VGGish pretrained network

96-by-64-by-1-by- K array

Mel spectrograms generated from `audioIn`, returned as a 96-by-64-by-1-by- K array, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram.
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz.
- K -- Represents the number of mel spectrograms and depends on the length of `audioIn`, the number of channels in `audioIn`, as well as `OverlapPercentage`.

Note Each 96-by-64-by-1 patch represents a single mel spectrogram image. For multichannel inputs, mel spectrograms are stacked along the 4th dimension.

Data Types: `single`

References

- [1] Gemmeke, Jort F, et al. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776-80. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952261.
- [2] Hershey, Shawn, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131-35. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

C/C++ Code Generation

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GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

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See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

classifySound | vggish | vggishEmbeddings | yamnet | yamnetGraph | yamnetPreprocess

Introduced in R2021a

pitchnn

Estimate pitch with deep learning neural network

Syntax

```
f0 = pitchnn(audioIn,fs)
f0 = pitchnn(audioIn,fs,Name,Value)
```

```
[f0,loc] = pitchnn(____)
[f0,loc,activations] = pitchnn(____)
```

```
pitchnn(____)
```

Description

`f0 = pitchnn(audioIn,fs)` returns estimates of the fundamental frequency over time for `audioIn` with sample rate `fs`. Columns of the input are treated as individual channels.

`f0 = pitchnn(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` arguments. For example, `f0 = pitchnn(audioIn,fs,'ConfidenceThreshold',0.5)` sets the confidence threshold for each value of `f0` to 0.5.

`[f0,loc] = pitchnn(____)` returns the time values, `loc`, associated with each fundamental frequency estimate.

`[f0,loc,activations] = pitchnn(____)` returns the activations of a crepe pretrained network.

`pitchnn(____)` with no output arguments plots the estimated fundamental frequency over time.

Examples

Download CREPE Network

Download and unzip the Audio Toolbox™ model for CREPE.

Type `crepe` at the Command Window. If the Audio Toolbox model for CREPE is not installed, then the function provides a link to the location of the network weights. To download the model, click the link and unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the CREPE model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'crepeDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/crepe.zip');
crepeLocation = tempdir;
unzip(loc,crepeLocation)
addpath(fullfile(crepeLocation,'crepe'))
```


Check that the installation is successful by typing `crepe` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
crepe
```

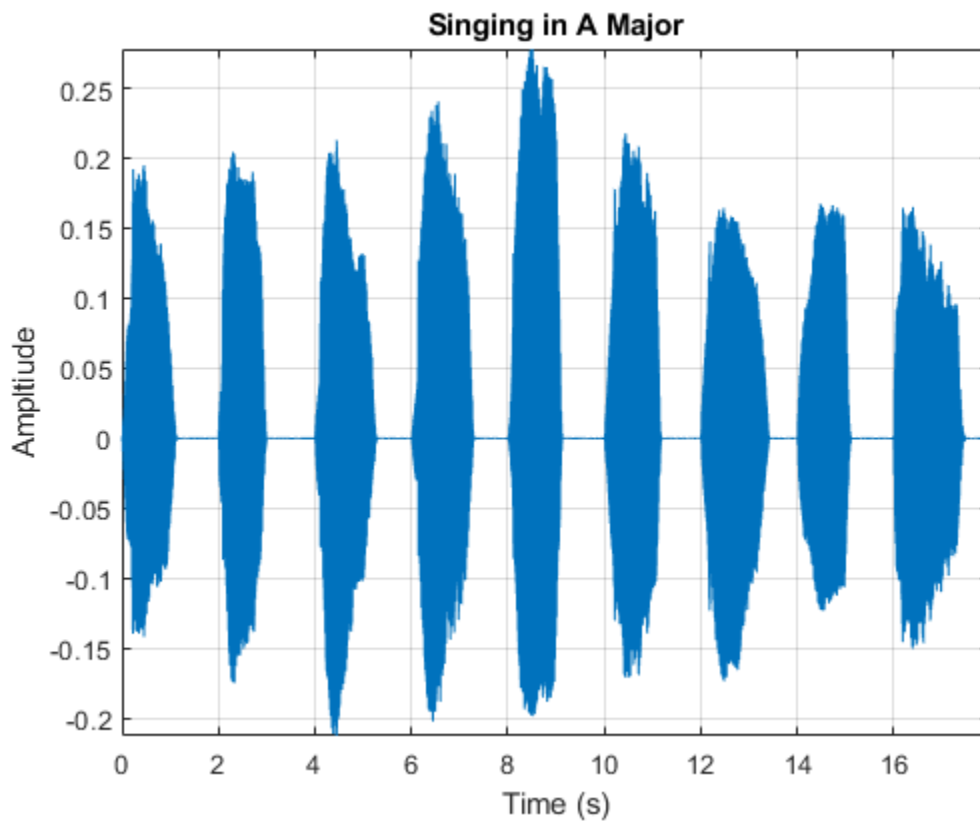
```
ans =  
  DAGNetwork with properties:  
  
    Layers: [34x1 nnet.cnn.layer.Layer]  
 Connections: [33x2 table]  
 InputNames: {'input'}  
 OutputNames: {'pitch'}
```

Pitch Estimation with `pitchnn`

The CREPE network requires you to preprocess your audio signals to generate buffered, overlapped, and normalized audio frames that can be used as input to the network. This example demonstrates the `pitchnn` function performing all of these steps for you.

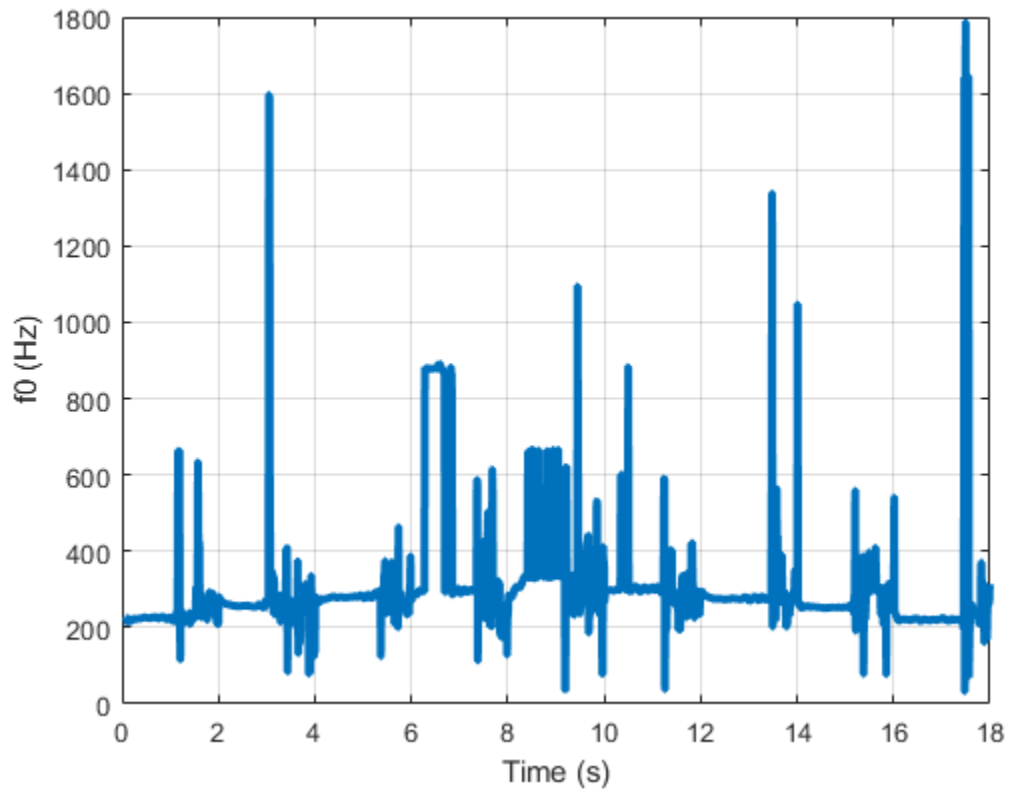
Read in an audio signal for pitch estimation. Visualize and listen to the audio. There are nine vocal utterances in the audio clip.

```
[audioIn,fs] = audioread('SingingAMajor-16-mono-18secs.ogg');  
soundsc(audioIn,fs)  
T = 1/fs;  
t = 0:T:(length(audioIn)*T) - T;  
plot(t,audioIn);  
grid on  
axis tight  
xlabel('Time (s)')  
ylabel('Amplitude')  
title('Singing in A Major')
```



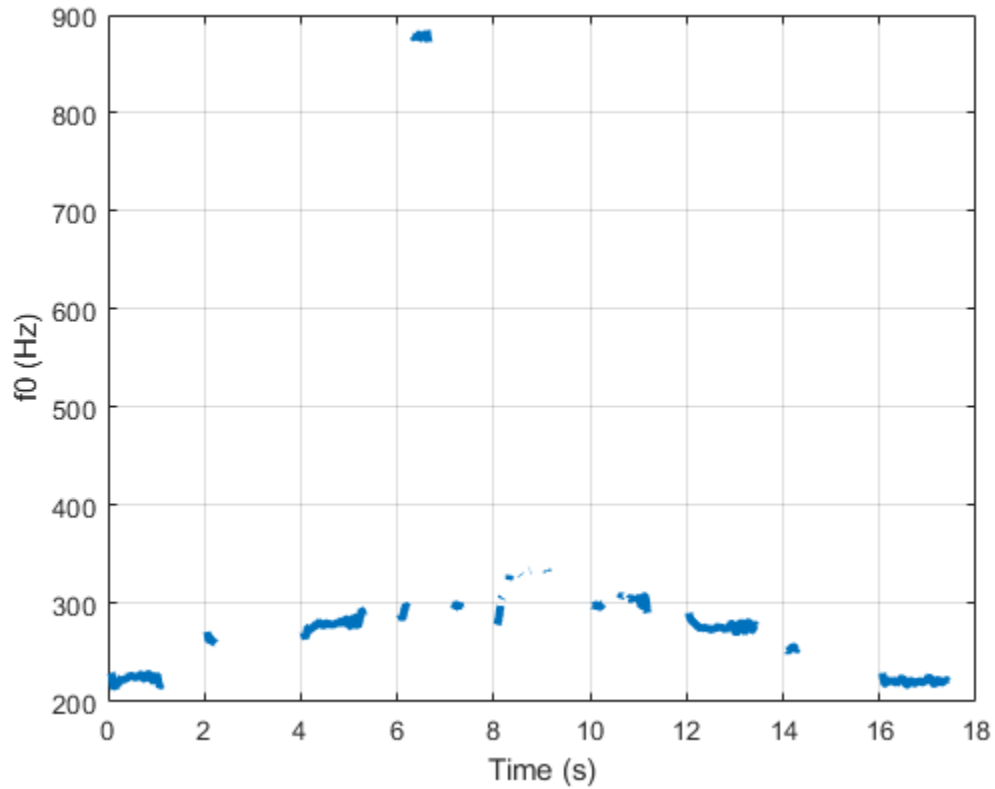
Use the `pitchnn` function to produce the pitch estimate using a CREPE network with `ModelCapacity` set to `tiny` and `ConfidenceThreshold` disabled. Calling `pitchnn` with no output arguments plots the pitch estimation over time. If you call `pitchnn` before downloading the model, an error is printed to the Command Window with a download link.

```
pitchnn(audioIn,fs,'ModelCapacity','tiny','ConfidenceThreshold',0)
```



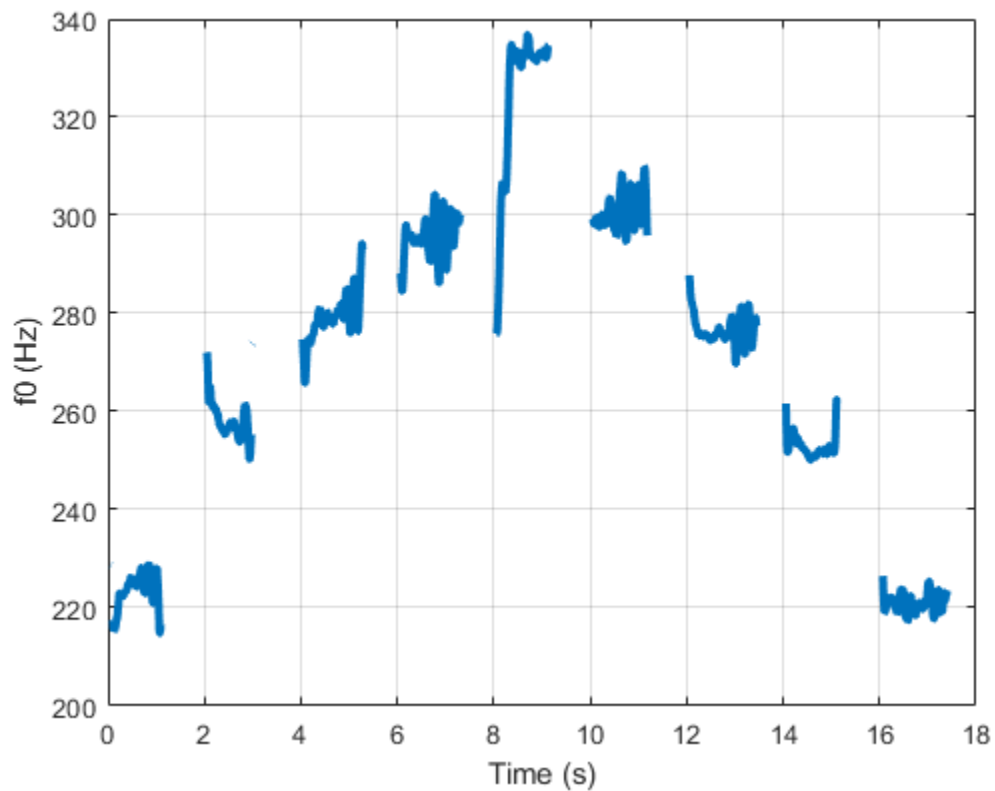
With confidence thresholding disabled, `pitchnn` provides a pitch estimate for every frame. Increase the `ConfidenceThreshold` to 0.8.

```
pitchnn(audioIn,fs,'ModelCapacity','tiny','ConfidenceThreshold',0.8)
```



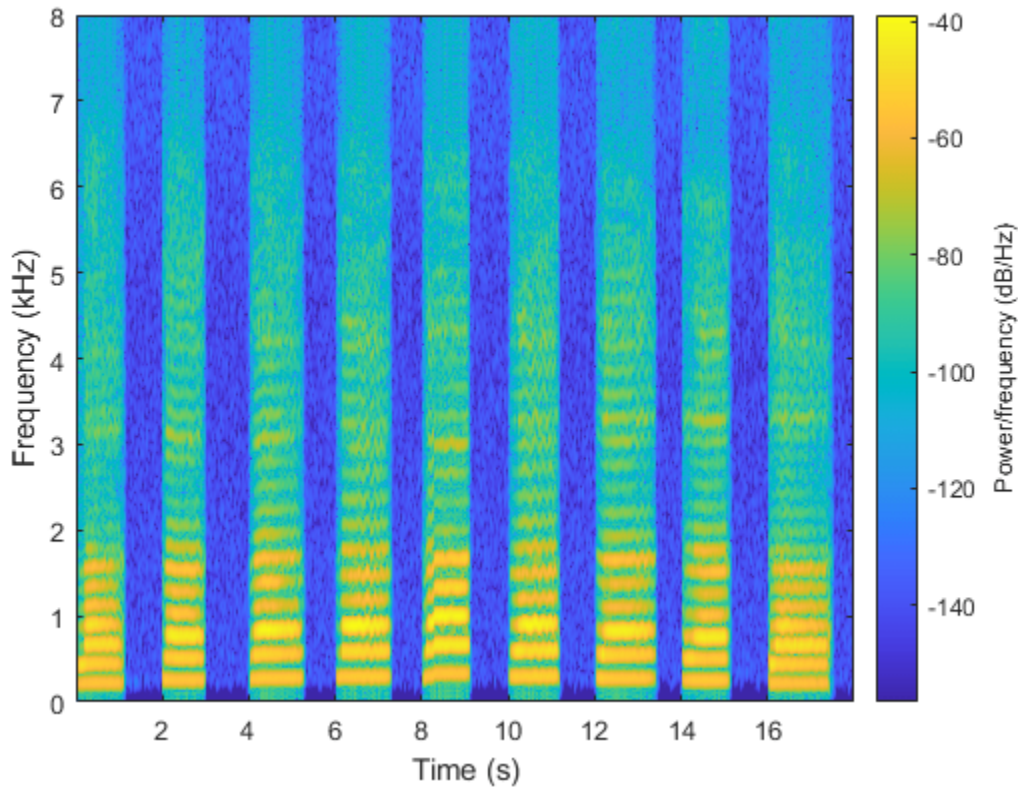
Call `pitchnn` with `ModelCapacity` set to `full`. There are nine primary pitch estimation groupings, each group corresponding with one of the nine vocal utterances.

```
pitchnn(audioIn, fs, 'ModelCapacity', 'full', 'ConfidenceThreshold', 0.8)
```



Call `spectrogram` and compare the frequency content of the signal with the pitch estimates from `pitchnn`. Use a frame size of 250 samples and an overlap of 225 samples or 90%. Use 4096 DFT points for the transform.

```
spectrogram(audioIn,250,225,4096,fs,'yaxis')
```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `pitchnn` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `pitchnn(audioIn, fs, 'OverlapPercentage', 50)` sets the percent overlap between consecutive audio frames to 50.

OverlapPercentage — Overlap percentage between consecutive audio frames

85 (default) | nonnegative scalar in the range [0,100)

Percentage overlap between consecutive audio frames, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

ConfidenceThreshold — Confidence threshold

0.5 (default) | nonnegative scalar in the range [0,1)

Confidence threshold for each value of `f0`, specified as a scalar in the range [0,1).

To disable threshold, set this argument to 0.

Note If the maximum value of the corresponding `activations` vector is less than `'ConfidenceThreshold'`, `f0` is NaN.

Data Types: `single` | `double`

ModelCapacity — Model Capacity

'full' (default) | 'tiny' | 'small' | 'medium' | 'large'

Model capacity, specified as 'tiny', 'small', 'medium', 'large', or 'full'.

Tip 'ModelCapacity' controls the complexity of the underlying deep learning neural network. The higher the model capacity, the greater the number of nodes and layers in the model.

Data Types: `string` | `char`

Output Arguments

f0 — Estimated fundamental frequency

N-by-*C* array

Estimated fundamental frequency in Hertz, returned as an *N*-by-*C* array, where *N* is the number of fundamental frequency estimates and *C* is the number of channels in `audioIn`.

Data Types: `single`

loc — Time values

1-by-*N* vector

Time values associated with each `f0` estimate, returned as a 1-by-*N* vector, where *N* is the number of fundamental frequency estimates. The time values correspond to the most recent samples used to compute the estimates.

Data Types: `single` | `double`

activations — CREPE network activations

N-by-360-by-*C* matrix

Activations from the CREPE network, returned as an N -by-360-by- C matrix, where N is the number of generated frames from the network and C is the number of channels in `audioIn`.

Data Types: `single` | `double`

References

- [1] Kim, Jong Wook, Justin Salamon, Peter Li, and Juan Pablo Bello. "Crepe: A Convolutional Representation for Pitch Estimation." In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 161-65. Calgary, AB: IEEE, 2018. <https://doi.org/10.1109/ICASSP.2018.8461329>.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

`crepe` | `crepePostprocess` | `crepePreprocess`

Introduced in R2021a

crepePostprocess

Postprocess output of CREPE deep learning network

Syntax

```
f0 = crepePostprocess(activations)
f0 = crepePostprocess(activations, 'ConfidenceThreshold', TH)
```

Description

`f0 = crepePostprocess(activations)` converts the output of a crepe pretrained network to pitch estimates in Hz.

`f0 = crepePostprocess(activations, 'ConfidenceThreshold', TH)` specifies the confidence threshold as a nonnegative scalar value less than 1.

For example, `f0 = crepePostprocess(activations, 'ConfidenceThreshold', 0.75)` specifies a confidence threshold of 0.75.

Examples

Download CREPE Network

Download and unzip the Audio Toolbox™ model for CREPE.

Type `crepe` at the Command Window. If the Audio Toolbox model for CREPE is not installed, then the function provides a link to the location of the network weights. To download the model, click the link and unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the CREPE model to your temporary directory.

```
downloadFolder = fullfile(tempdir, 'crepeDownload');
loc = websave(downloadFolder, 'https://ssd.mathworks.com/supportfiles/audio/crepe.zip');
crepeLocation = tempdir;
unzip(loc, crepeLocation)
addpath(fullfile(crepeLocation, 'crepe'))
```

Check that the installation is successful by typing `crepe` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
crepe
```

```
ans =
  DAGNetwork with properties:

    Layers: [34x1 nnet.cnn.layer.Layer]
  Connections: [33x2 table]
    InputNames: {'input'}
  OutputNames: {'pitch'}
```

Load Pretrained CREPE Network

Load a pretrained CREPE convolutional neural network and examine the layers and classes.

Use `crepe` to load the pretrained CREPE network. The output `net` is a `DAGNetwork` (Deep Learning Toolbox) object.

```
net = crepe
```

```
net =
  DAGNetwork with properties:

    Layers: [34x1 nnet.cnn.layer.Layer]
  Connections: [33x2 table]
  InputNames: {'input'}
  OutputNames: {'pitch'}
```

View the network architecture using the `Layers` property. The network has 34 layers. There are 13 layers with learnable weights, of which six are convolutional layers, six are batch normalization layers, and one is a fully connected layer.

```
net.Layers
```

```
ans =
  34x1 Layer array with layers:

   1  'input'           Image Input           1024x1x1 images
   2  'conv1'           Convolution           1024 512x1x1 convolutions with stride [4 1]
   3  'conv1_relu'      ReLU                  ReLU
   4  'conv1-BN'        Batch Normalization   Batch normalization with 1024 channels
   5  'conv1-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
   6  'conv1-dropout'   Dropout               25% dropout
   7  'conv2'           Convolution           128 64x1x1024 convolutions with stride [1 1]
   8  'conv2_relu'      ReLU                  ReLU
   9  'conv2-BN'        Batch Normalization   Batch normalization with 128 channels
  10  'conv2-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  11  'conv2-dropout'   Dropout               25% dropout
  12  'conv3'           Convolution           128 64x1x128 convolutions with stride [1 1]
  13  'conv3_relu'      ReLU                  ReLU
  14  'conv3-BN'        Batch Normalization   Batch normalization with 128 channels
  15  'conv3-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  16  'conv3-dropout'   Dropout               25% dropout
  17  'conv4'           Convolution           128 64x1x128 convolutions with stride [1 1]
  18  'conv4_relu'      ReLU                  ReLU
  19  'conv4-BN'        Batch Normalization   Batch normalization with 128 channels
  20  'conv4-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  21  'conv4-dropout'   Dropout               25% dropout
  22  'conv5'           Convolution           256 64x1x128 convolutions with stride [1 1]
  23  'conv5_relu'      ReLU                  ReLU
  24  'conv5-BN'        Batch Normalization   Batch normalization with 256 channels
  25  'conv5-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  26  'conv5-dropout'   Dropout               25% dropout
  27  'conv6'           Convolution           512 64x1x256 convolutions with stride [1 1]
  28  'conv6_relu'      ReLU                  ReLU
```

29	'conv6-BN'	Batch Normalization	Batch normalization with 512 channels
30	'conv6-maxpool'	Max Pooling	2x1 max pooling with stride [2 1] and padding
31	'conv6-dropout'	Dropout	25% dropout
32	'classifier'	Fully Connected	360 fully connected layer
33	'classifier_sigmoid'	Sigmoid	sigmoid
34	'pitch'	Regression Output	mean-squared-error

Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

```
analyzeNetwork(net)
```

The screenshot shows the 'Deep Learning Network Analyzer' window. On the left, a vertical flowchart represents the network architecture, starting with an 'input' node and followed by layers: conv1, conv1_relu, conv1-BN, conv1-maxpool, conv1-dropout, conv2, conv2_relu, conv2-BN, conv2-maxpool, conv2-dropout, conv3, conv3_relu, conv3-BN, conv3-maxpool, conv3-dropout, conv4, conv4_relu, conv4-BN, and conv4-maxpool. On the right, the 'ANALYSIS RESULT' table provides detailed information for each layer.

	Name	Type	Activations	Learnables
1	input 1024x1x1 images	Image Input	1024x1x1	-
2	conv1 1024 512x1x1 convolutions with stride [4 1] and padding 'same'	Convolution	256x1x1024	Weigh... 512x1x1x10... Bias 1x1x1024
3	conv1_relu ReLU	ReLU	256x1x1024	-
4	conv1-BN Batch normalization with 1024 channels	Batch Normalization	256x1x1024	Offset 1x1x1024 Scale 1x1x1024
5	conv1-maxpool 2x1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	128x1x1024	-
6	conv1-dropout 25% dropout	Dropout	128x1x1024	-
7	conv2 128 64x1x1024 convolutions with stride [1 1] and padding 'same'	Convolution	128x1x128	Weigh... 64x1x1024x1... Bias 1x1x128
8	conv2_relu ReLU	ReLU	128x1x128	-
9	conv2-BN Batch normalization with 128 channels	Batch Normalization	128x1x128	Offset 1x1x128 Scale 1x1x128
10	conv2-maxpool 2x1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	64x1x128	-
11	conv2-dropout 25% dropout	Dropout	64x1x128	-
12	conv3 128 64x1x128 convolutions with stride [1 1] and padding 'same'	Convolution	64x1x128	Weigh... 64x1x128x1... Bias 1x1x128
13	conv3_relu ReLU	ReLU	64x1x128	-
14	conv3-BN Batch normalization with 128 channels	Batch Normalization	64x1x128	Offset 1x1x128 Scale 1x1x128
15	conv3-maxpool 2x1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	32x1x128	-
16	conv3-dropout 25% dropout	Dropout	32x1x128	-
17	conv4 128 64x1x128 convolutions with stride [1 1] and padding 'same'	Convolution	32x1x128	Weigh... 64x1x128x1... Bias 1x1x128

Estimate Pitch Using CREPE Network

The CREPE network requires you to preprocess your audio signals to generate buffered, overlapped, and normalized audio frames that can be used as input to the network. This example walks through audio preprocessing using `crepePreprocess` and audio postprocessing with pitch estimation using `crepePostprocess`. The `pitchnn` function performs these steps for you.

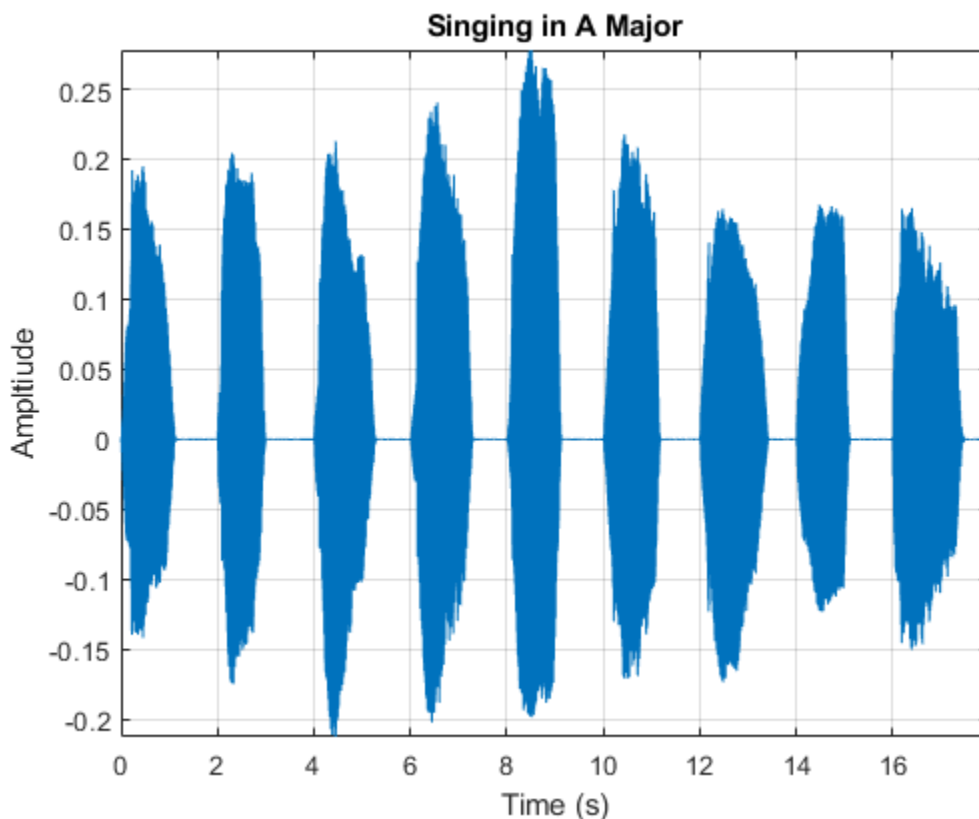
Read in an audio signal for pitch estimation. Visualize and listen to the audio. There are nine vocal utterances in the audio clip.

```
[audioIn,fs] = audioread('SingingAMajor-16-mono-18secs.ogg');
soundsc(audioIn,fs)
```

```

T = 1/fs;
t = 0:T:(length(audioIn)*T) - T;
plot(t,audioIn);
grid on
axis tight
xlabel('Time (s)')
ylabel('Amplitude')
title('Singing in A Major')

```



Use `crepePreprocess` to partition the audio into frames of 1024 samples with an 85% overlap between consecutive mel spectrograms. Place the frames along the fourth dimension.

```
[frames, loc] = crepePreprocess(audioIn, fs);
```

Create a CREPE network with `ModelCapacity` set to `tiny`. If you call `crepe` before downloading the model, an error is printed to the Command Window with a download link.

```
netTiny = crepe('ModelCapacity', 'tiny');
```

Predict the network activations.

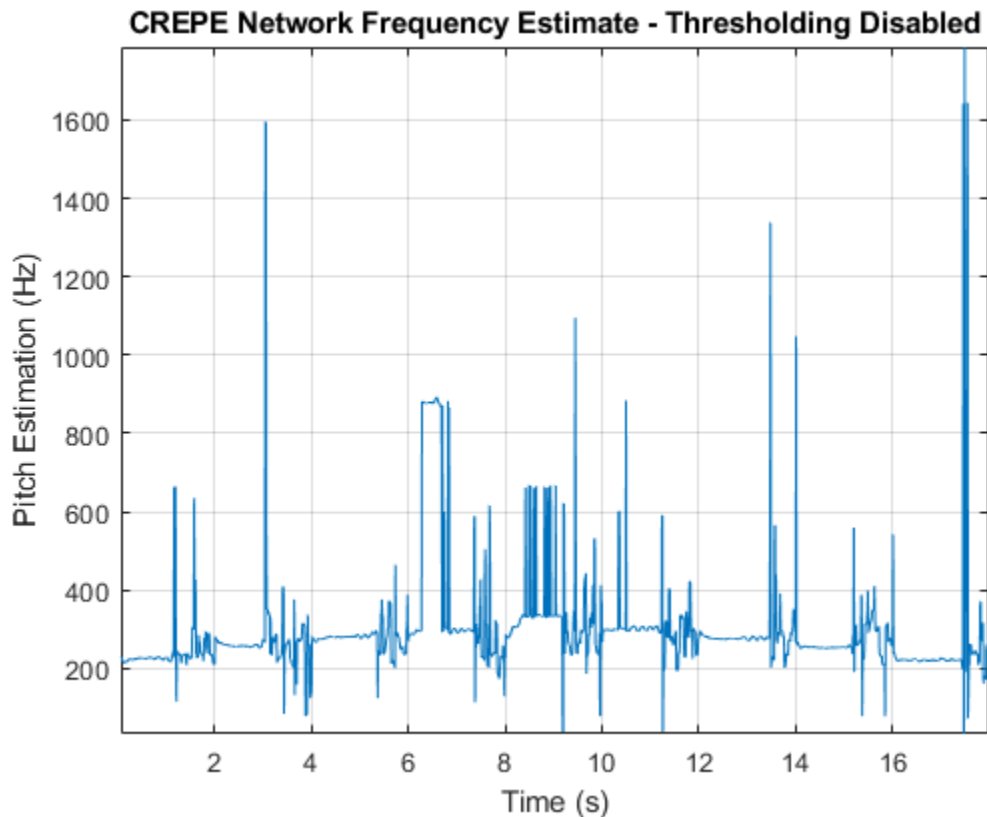
```
activationsTiny = predict(netTiny, frames);
```

Use `crepePostprocess` to produce the fundamental frequency pitch estimation in Hz. Disable confidence thresholding by setting `ConfidenceThreshold` to 0.

```
f0Tiny = crepePostprocess(activationsTiny, 'ConfidenceThreshold', 0);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny)
grid on
axis tight
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Disabled')
```

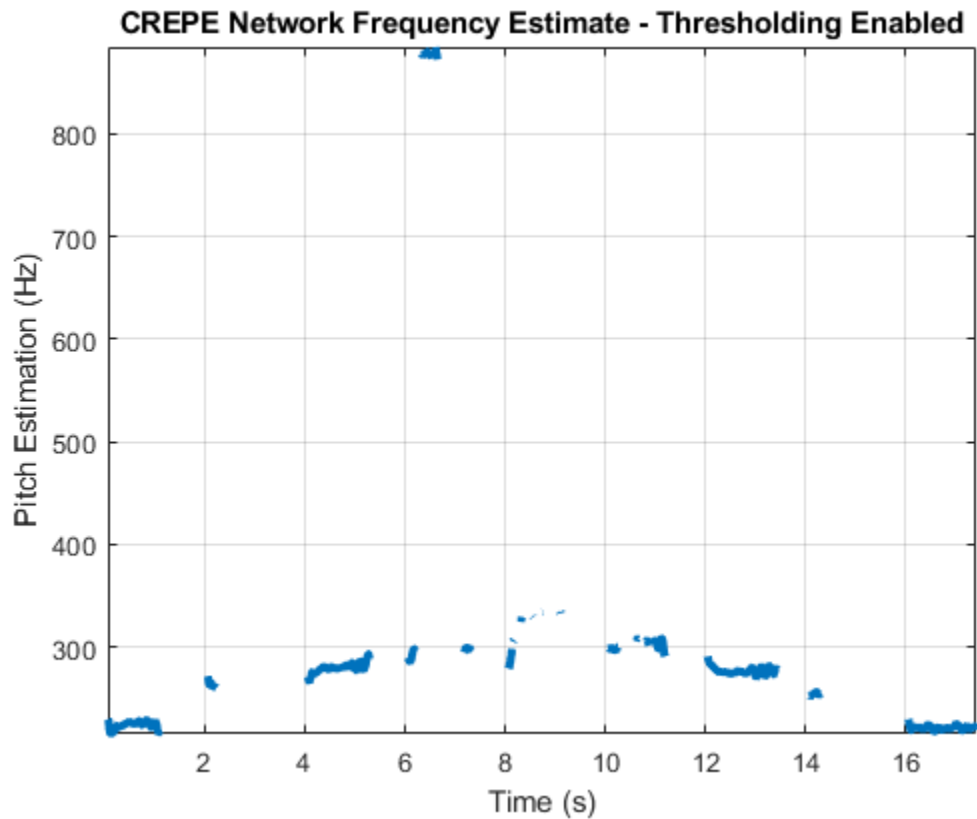


With confidence thresholding disabled, `crepePostprocess` provides a pitch estimate for every frame. Increase the `ConfidenceThreshold` to 0.8.

```
f0Tiny = crepePostprocess(activationsTiny,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny,'LineWidth',3)
grid on
axis tight
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Enabled')
```



Create a new CREPE network with `ModelCapacity` set to `full`.

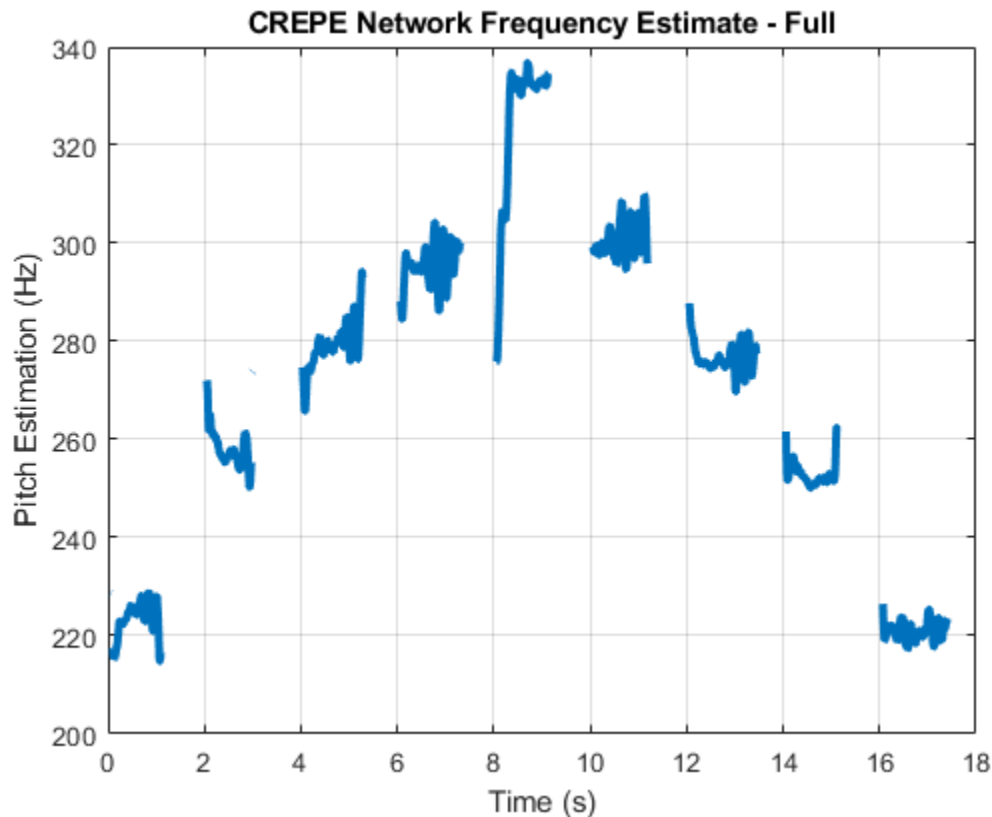
```
netFull = crepe('ModelCapacity','full');
```

Predict the network activations.

```
activationsFull = predict(netFull,frames);
f0Full = crepePostprocess(activationsFull,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation. There are nine primary pitch estimation groupings, each group corresponding with one of the nine vocal utterances.

```
plot(loc,f0Full,'LineWidth',3)
grid on
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Full')
```



Find the time elements corresponding to the last vocal utterance.

```
roundedLocVec = round(loc,2);
lastUtteranceBegin = find(roundedLocVec == 16);
lastUtteranceEnd = find(roundedLocVec == 18);
```

For simplicity, take the most frequently occurring pitch estimate within the utterance group as the fundamental frequency estimate for that timespan. Generate a pure tone with a frequency matching the pitch estimate for the last vocal utterance.

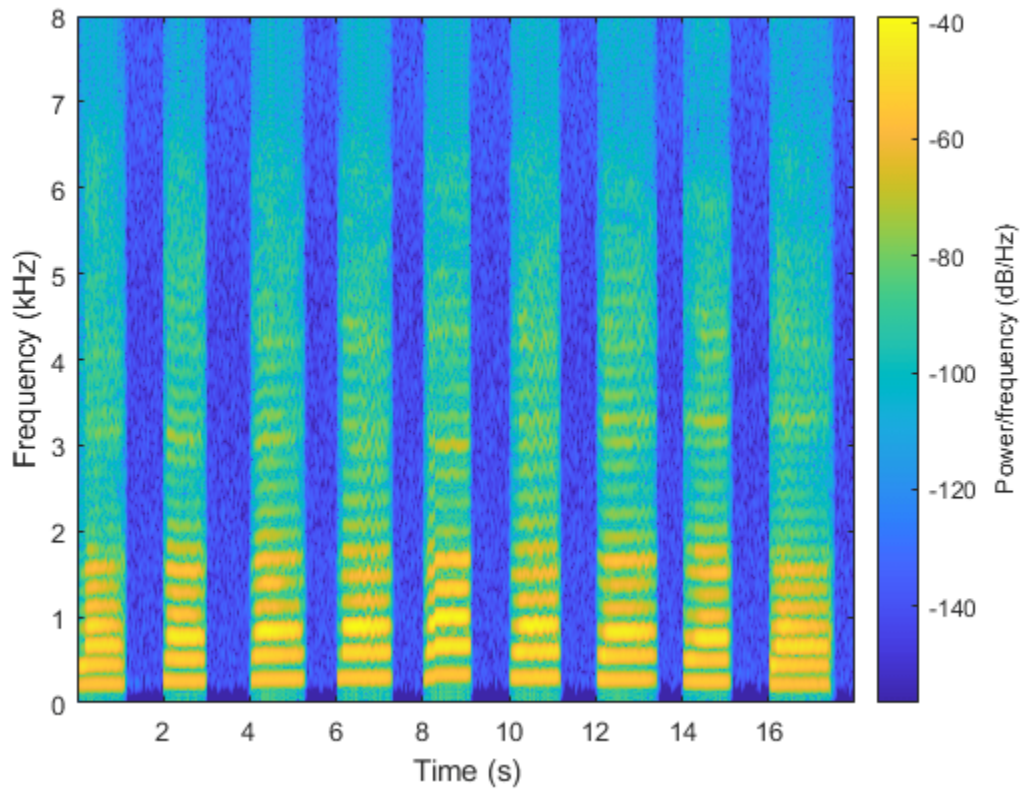
```
lastUtteranceEstimation = mode(f0Full(lastUtteranceBegin:lastUtteranceEnd))
lastUtteranceEstimation = single
217.2709
```

The value for `lastUtteranceEstimate` of 217.3 Hz. corresponds to the note A3. Overlay the synthesized tone on the last vocal utterance to audibly compare the two.

```
lastVocalUtterance = audioIn(fs*16:fs*18);
newTime = 0:T:2;
compareTone = cos(2*pi*lastUtteranceEstimation*newTime).';
soundsc(lastVocalUtterance + compareTone,fs);
```

Call `spectrogram` to more closely inspect the frequency content of the singing. Use a frame size of 250 samples and an overlap of 225 samples or 90%. Use 4096 DFT points for the transform. The `spectrogram` reveals that the vocal recording is actually a set of complex harmonic tones composed of multiple frequencies.

```
spectrogram(audioIn,250,225,4096,fs,'yaxis')
```



Input Arguments

activations — CREPE network output

N-by-360 matrix

Audio frames generated from a crepe pretrained network, specified as an *N*-by-360 matrix, where *N* is the number of generated frames.

Data Types: single | double

TH — Confidence threshold

0.5 (default) | nonnegative scalar in the range [0,1)

Confidence threshold for each value of *f0*, specified as the comma-separated pair consisting of 'ConfidenceThreshold' and a scalar in the range [0,1).

To disable thresholding, set TH to 0.

Note If the maximum value of the corresponding activations vector is less than TH, *f0* is NaN.

Data Types: single | double

Output Arguments

f0 — Estimated fundamental frequency

N-by-1 vector

Estimated fundamental frequency in Hertz, returned as an *N*-by-1 vector, where *N* is the number of generated frames.

Data Types: `single`

References

- [1] Kim, Jong Wook, Justin Salamon, Peter Li, and Juan Pablo Bello. “Crepe: A Convolutional Representation for Pitch Estimation.” In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 161–65. Calgary, AB: IEEE, 2018. <https://doi.org/10.1109/ICASSP.2018.8461329>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`crepe` | `pitchnn` | `crepePreprocess`

Introduced in R2021a

crepePreprocess

Preprocess audio for CREPE deep learning network

Syntax

```
frames = crepePreprocess(audioIn,fs)
frames = crepePreprocess(audioIn,fs,'OverlapPercentage',OP)

[frames,loc] = crepePreprocess( ___ )
```

Description

`frames = crepePreprocess(audioIn,fs)` generates frames from `audioIn` that can be fed to the CREPE pretrained deep learning network.

`frames = crepePreprocess(audioIn,fs,'OverlapPercentage',OP)` specifies the overlap percentage between consecutive audio frames.

For example, `frames = crepePreprocess(audioIn,fs,'OverlapPercentage',75)` applies a 75% overlap between consecutive frames used to generate the processed frames.

`[frames,loc] = crepePreprocess(___)` returns the time values, `loc`, associated with each frame.

Examples

Download CREPE Network

Download and unzip the Audio Toolbox™ model for CREPE.

Type `crepe` at the Command Window. If the Audio Toolbox model for CREPE is not installed, then the function provides a link to the location of the network weights. To download the model, click the link and unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the CREPE model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'crepeDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/crepe.zip');
crepeLocation = tempdir;
unzip(loc,crepeLocation)
addpath(fullfile(crepeLocation,'crepe'))
```

Check that the installation is successful by typing `crepe` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
crepe
```

```
ans =
  DAGNetwork with properties:
```

```

    Layers: [34x1 nnet.cnn.layer.Layer]
Connections: [33x2 table]
  InputNames: {'input'}
  OutputNames: {'pitch'}

```

Load Pretrained CREPE Network

Load a pretrained CREPE convolutional neural network and examine the layers and classes.

Use `crepe` to load the pretrained CREPE network. The output `net` is a `DAGNetwork` (Deep Learning Toolbox) object.

```
net = crepe
```

```

net =
  DAGNetwork with properties:

    Layers: [34x1 nnet.cnn.layer.Layer]
Connections: [33x2 table]
  InputNames: {'input'}
  OutputNames: {'pitch'}

```

View the network architecture using the `Layers` property. The network has 34 layers. There are 13 layers with learnable weights, of which six are convolutional layers, six are batch normalization layers, and one is a fully connected layer.

```
net.Layers
```

```

ans =
  34x1 Layer array with layers:

   1  'input'           Image Input           1024x1x1 images
   2  'conv1'           Convolution           1024 512x1x1 convolutions with stride [4 1]
   3  'conv1_relu'      ReLU                  ReLU
   4  'conv1-BN'        Batch Normalization   Batch normalization with 1024 channels
   5  'conv1-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
   6  'conv1-dropout'   Dropout               25% dropout
   7  'conv2'           Convolution           128 64x1x1024 convolutions with stride [1 1]
   8  'conv2_relu'      ReLU                  ReLU
   9  'conv2-BN'        Batch Normalization   Batch normalization with 128 channels
  10  'conv2-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  11  'conv2-dropout'   Dropout               25% dropout
  12  'conv3'           Convolution           128 64x1x128 convolutions with stride [1 1]
  13  'conv3_relu'      ReLU                  ReLU
  14  'conv3-BN'        Batch Normalization   Batch normalization with 128 channels
  15  'conv3-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  16  'conv3-dropout'   Dropout               25% dropout
  17  'conv4'           Convolution           128 64x1x128 convolutions with stride [1 1]
  18  'conv4_relu'      ReLU                  ReLU
  19  'conv4-BN'        Batch Normalization   Batch normalization with 128 channels
  20  'conv4-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  21  'conv4-dropout'   Dropout               25% dropout

```

22	'conv5'	Convolution	256 64×1×128 convolutions with stride [1 1] and padding 'same'
23	'conv5_relu'	ReLU	ReLU
24	'conv5-BN'	Batch Normalization	Batch normalization with 256 channels
25	'conv5-maxpool'	Max Pooling	2×1 max pooling with stride [2 1] and padding [0 0 0 0]
26	'conv5-dropout'	Dropout	25% dropout
27	'conv6'	Convolution	512 64×1×256 convolutions with stride [1 1] and padding 'same'
28	'conv6_relu'	ReLU	ReLU
29	'conv6-BN'	Batch Normalization	Batch normalization with 512 channels
30	'conv6-maxpool'	Max Pooling	2×1 max pooling with stride [2 1] and padding [0 0 0 0]
31	'conv6-dropout'	Dropout	25% dropout
32	'classifier'	Fully Connected	360 fully connected layer
33	'classifier_sigmoid'	Sigmoid	sigmoid
34	'pitch'	Regression Output	mean-squared-error

Use analyzeNetwork (Deep Learning Toolbox) to visually explore the network.

analyzeNetwork(net)

The screenshot shows the 'Deep Learning Network Analyzer' window. On the left is a vertical flow diagram of the network layers, starting from 'input' and ending with 'conv4-maxpool'. On the right is the 'ANALYSIS RESULT' table, which provides detailed information for each layer.

	Name	Type	Activations	Learnables
1	input 1024×1×1 images	Image Input	1024×1×1	-
2	conv1 1024 512×1×1 convolutions with stride [4 1] and padding 'same'	Convolution	256×1×1024	Weigh... 512×1×1×10... Bias 1×1×1024
3	conv1_relu ReLU	ReLU	256×1×1024	-
4	conv1-BN Batch normalization with 1024 channels	Batch Normalization	256×1×1024	Offset 1×1×1024 Scale 1×1×1024
5	conv1-maxpool 2×1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	128×1×1024	-
6	conv1-dropout 25% dropout	Dropout	128×1×1024	-
7	conv2 128 64×1×1024 convolutions with stride [1 1] and padding 'same'	Convolution	128×1×128	Weigh... 64×1×1024×1... Bias 1×1×128
8	conv2_relu ReLU	ReLU	128×1×128	-
9	conv2-BN Batch normalization with 128 channels	Batch Normalization	128×1×128	Offset 1×1×128 Scale 1×1×128
10	conv2-maxpool 2×1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	64×1×128	-
11	conv2-dropout 25% dropout	Dropout	64×1×128	-
12	conv3 128 64×1×128 convolutions with stride [1 1] and padding 'same'	Convolution	64×1×128	Weigh... 64×1×128×1... Bias 1×1×128
13	conv3_relu ReLU	ReLU	64×1×128	-
14	conv3-BN Batch normalization with 128 channels	Batch Normalization	64×1×128	Offset 1×1×128 Scale 1×1×128
15	conv3-maxpool 2×1 max pooling with stride [2 1] and padding [0 0 0 0]	Max Pooling	32×1×128	-
16	conv3-dropout 25% dropout	Dropout	32×1×128	-
17	conv4 128 64×1×128 convolutions with stride [1 1] and padding 'same'	Convolution	32×1×128	Weigh... 64×1×128×1... Bias 1×1×128

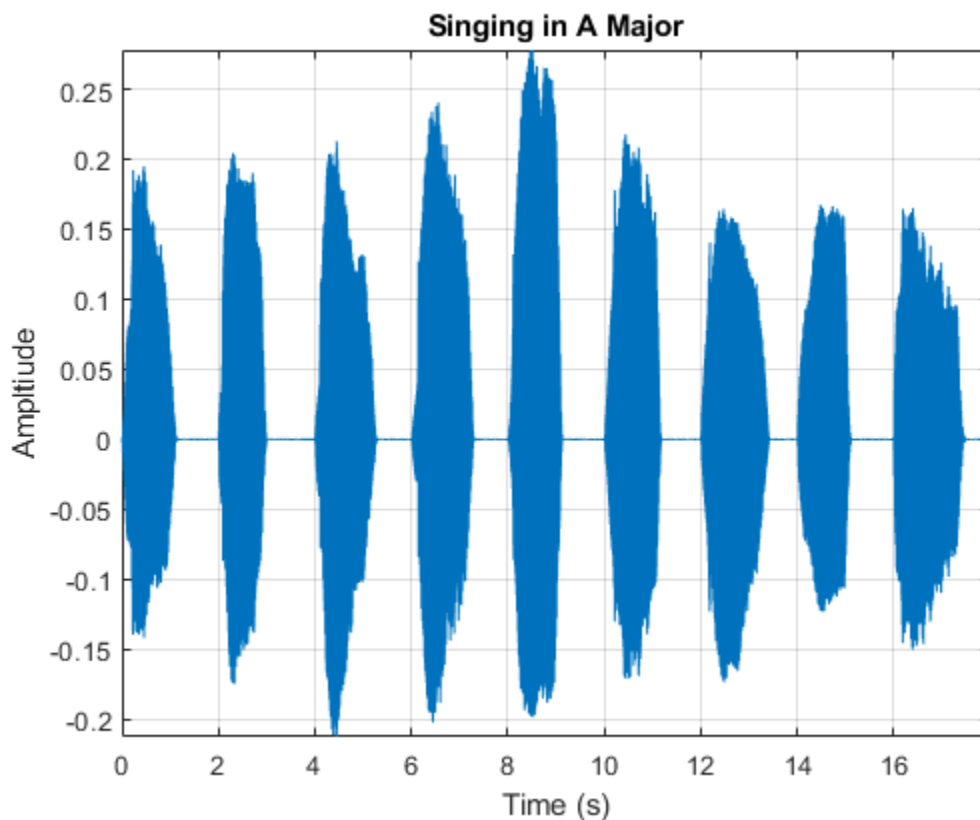
Estimate Pitch Using CREPE Network

The CREPE network requires you to preprocess your audio signals to generate buffered, overlapped, and normalized audio frames that can be used as input to the network. This example walks through

audio preprocessing using `crepePreprocess` and audio postprocessing with pitch estimation using `crepePostprocess`. The `pitchnn` function performs these steps for you.

Read in an audio signal for pitch estimation. Visualize and listen to the audio. There are nine vocal utterances in the audio clip.

```
[audioIn,fs] = audioread('SingingAMajor-16-mono-18secs.ogg');
soundsc(audioIn,fs)
T = 1/fs;
t = 0:T:(length(audioIn)*T) - T;
plot(t,audioIn);
grid on
axis tight
xlabel('Time (s)')
ylabel('Amplitude')
title('Singing in A Major')
```



Use `crepePreprocess` to partition the audio into frames of 1024 samples with an 85% overlap between consecutive mel spectrograms. Place the frames along the fourth dimension.

```
[frames,loc] = crepePreprocess(audioIn,fs);
```

Create a CREPE network with `ModelCapacity` set to `tiny`. If you call `crepe` before downloading the model, an error is printed to the Command Window with a download link.

```
netTiny = crepe('ModelCapacity','tiny');
```

Predict the network activations.

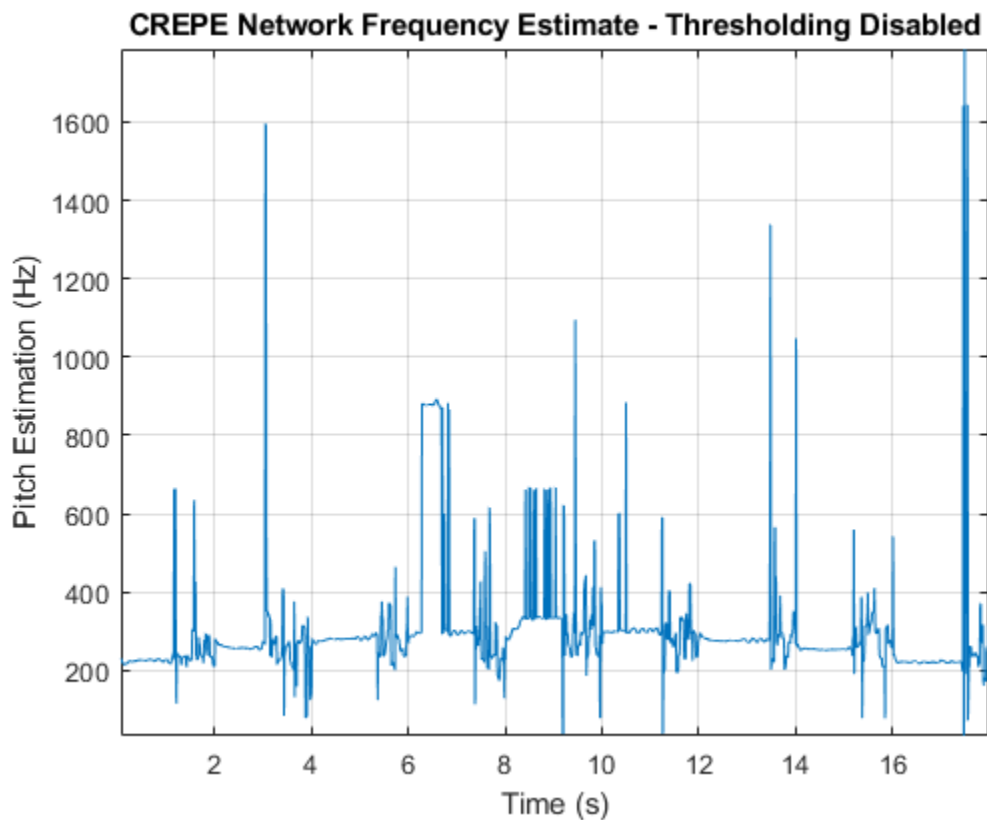
```
activationsTiny = predict(netTiny,frames);
```

Use `crepePostprocess` to produce the fundamental frequency pitch estimation in Hz. Disable confidence thresholding by setting `ConfidenceThreshold` to 0.

```
f0Tiny = crepePostprocess(activationsTiny,'ConfidenceThreshold',0);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny)
grid on
axis tight
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Disabled')
```



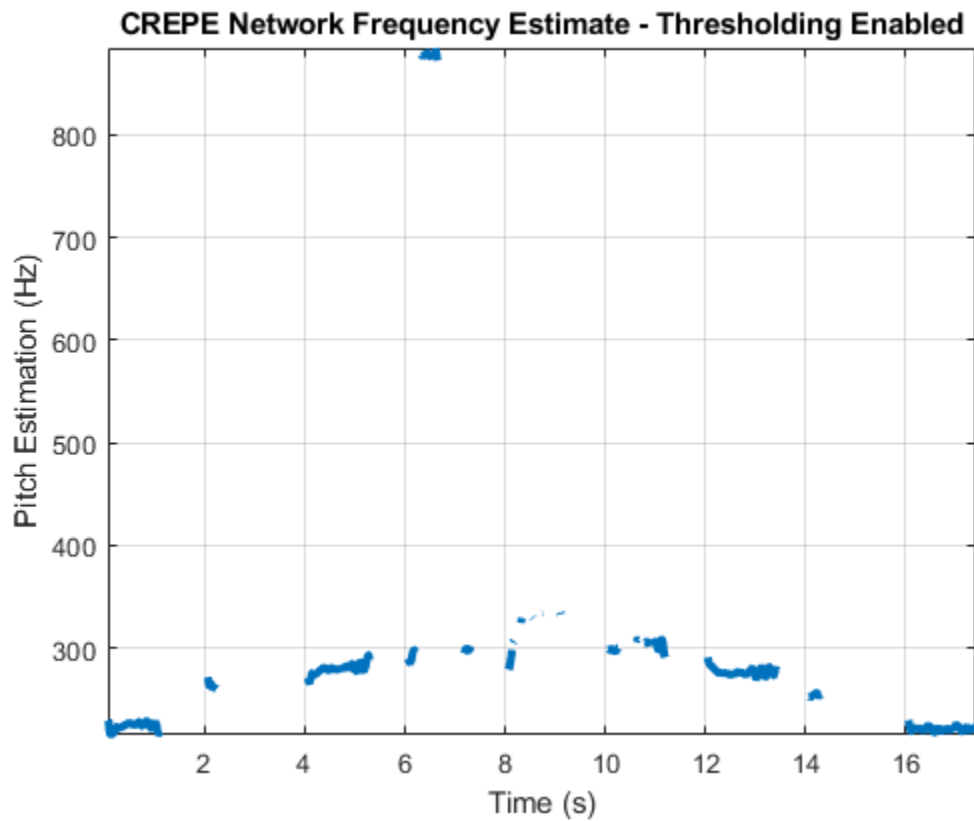
With confidence thresholding disabled, `crepePostprocess` provides a pitch estimate for every frame. Increase the `ConfidenceThreshold` to 0.8.

```
f0Tiny = crepePostprocess(activationsTiny,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny,'LineWidth',3)
grid on
axis tight
xlabel('Time (s)')
```

```
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Enabled')
```



Create a new CREPE network with `ModelCapacity` set to `full`.

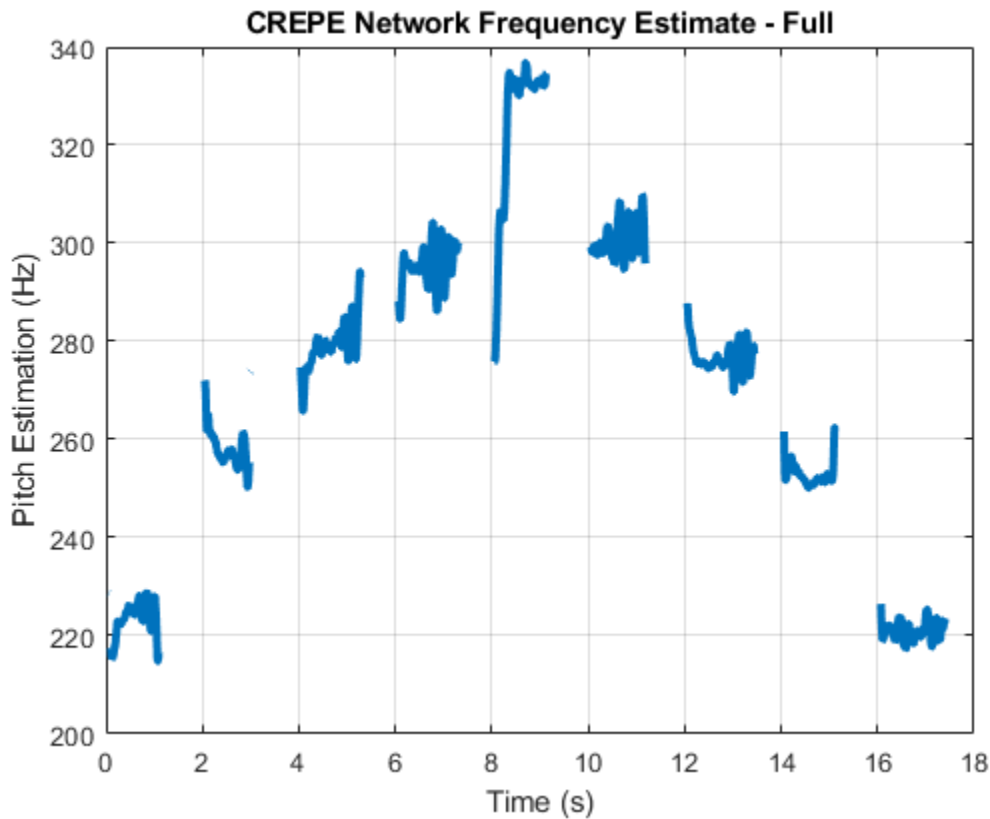
```
netFull = crepe('ModelCapacity','full');
```

Predict the network activations.

```
activationsFull = predict(netFull,frames);
f0Full = crepePostprocess(activationsFull,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation. There are nine primary pitch estimation groupings, each group corresponding with one of the nine vocal utterances.

```
plot(loc,f0Full,'LineWidth',3)
grid on
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Full')
```



Find the time elements corresponding to the last vocal utterance.

```
roundedLocVec = round(loc,2);
lastUtteranceBegin = find(roundedLocVec == 16);
lastUtteranceEnd = find(roundedLocVec == 18);
```

For simplicity, take the most frequently occurring pitch estimate within the utterance group as the fundamental frequency estimate for that timespan. Generate a pure tone with a frequency matching the pitch estimate for the last vocal utterance.

```
lastUtteranceEstimation = mode(f0Full(lastUtteranceBegin:lastUtteranceEnd))

lastUtteranceEstimation = single
    217.2709
```

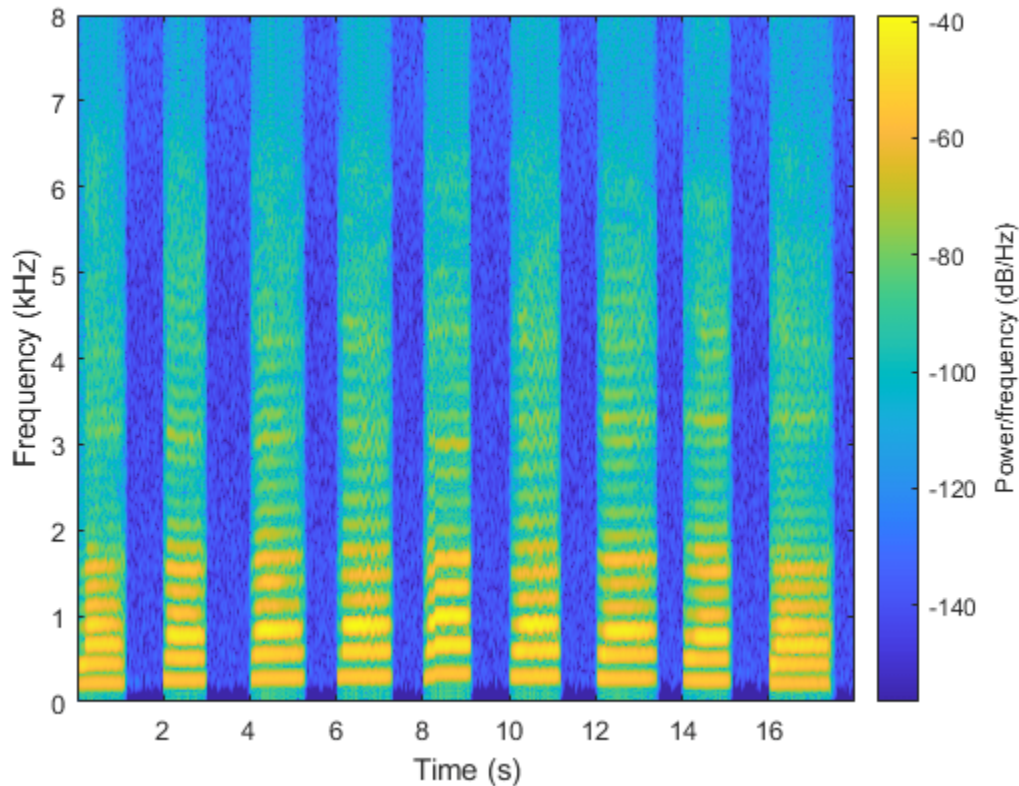
The value for `lastUtteranceEstimate` of 217.3 Hz. corresponds to the note A3. Overlay the synthesized tone on the last vocal utterance to audibly compare the two.

```
lastVocalUtterance = audioIn(fs*16:fs*18);
newTime = 0:T:2;
compareTone = cos(2*pi*lastUtteranceEstimation*newTime).';

soundsc(lastVocalUtterance + compareTone,fs);
```

Call `spectrogram` to more closely inspect the frequency content of the singing. Use a frame size of 250 samples and an overlap of 225 samples or 90%. Use 4096 DFT points for the transform. The `spectrogram` reveals that the vocal recording is actually a set of complex harmonic tones composed of multiple frequencies.


```
spectrogram(audioIn,250,225,4096,fs,'yaxis')
```



Input Arguments

audioIn – Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `crepePreprocess` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs – Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

OP – Overlap percentage between consecutive audio frames

85 (default) | nonnegative scalar in the range [0,100)

Percentage overlap between consecutive audio frames, specified as the comma-separated pair consisting of 'OverlapPercentage' and a scalar in the range [0,100).

Data Types: `single` | `double`

Output Arguments

frames — Audio frames that can be fed to CREPE pretrained network

1024-by-1-by-1-by- N array

Processed audio frames, returned as a 1024-by-1-by-1-by- N array, where N is the number of generated frames.

Note For multichannel inputs, generated frames are stacked along the 4th dimension according to channel. For example, if `audioIn` is a stereo signal, the number of generated frames for each channel is actually $N/2$. The first $N/2$ frames correspond to channel 1 and the subsequent $N/2$ frames correspond to channel 2.

Data Types: `single` | `double`

loc — Time values

1-by- N vector

Time values associated with each frame, returned as a 1-by- N vector, where N is the number of generated frames. The time values correspond to the most recent samples used to compute the frames.

Data Types: `single` | `double`

References

- [1] Kim, Jong Wook, Justin Salamon, Peter Li, and Juan Pablo Bello. "Crepe: A Convolutional Representation for Pitch Estimation." In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 161–65. Calgary, AB: IEEE, 2018. <https://doi.org/10.1109/ICASSP.2018.8461329>.

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See Also

`crepe` | `pitchnn` | `crepePostprocess`

Introduced in R2021a

crepe

CREPE neural network

Syntax

```
net = crepe
net = crepe('ModelCapacity',CAP)
```

Description

`net = crepe` returns a pretrained CREPE model.

This function requires both Audio Toolbox and Deep Learning Toolbox™.

`net = crepe('ModelCapacity',CAP)` specifies the model capacity.

For example, `net = crepe('ModelCapacity','small')` specifies the model capacity as small.

Examples

Download CREPE Network

Download and unzip the Audio Toolbox™ model for CREPE.

Type `crepe` at the Command Window. If the Audio Toolbox model for CREPE is not installed, then the function provides a link to the location of the network weights. To download the model, click the link and unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the CREPE model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'crepeDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/crepe.zip');
crepeLocation = tempdir;
unzip(loc,crepeLocation)
addpath(fullfile(crepeLocation,'crepe'))
```

Check that the installation is successful by typing `crepe` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
crepe
```

```
ans =
  DAGNetwork with properties:

    Layers: [34x1 nnet.cnn.layer.Layer]
  Connections: [33x2 table]
  InputNames: {'input'}
  OutputNames: {'pitch'}
```

Load Pretrained CREPE Network

Load a pretrained CREPE convolutional neural network and examine the layers and classes.

Use `crepe` to load the pretrained CREPE network. The output `net` is a `DAGNetwork` (Deep Learning Toolbox) object.

```
net = crepe
```

```
net =
  DAGNetwork with properties:

    Layers: [34x1 nnet.cnn.layer.Layer]
 Connections: [33x2 table]
  InputNames: {'input'}
 OutputNames: {'pitch'}
```

View the network architecture using the `Layers` property. The network has 34 layers. There are 13 layers with learnable weights, of which six are convolutional layers, six are batch normalization layers, and one is a fully connected layer.

```
net.Layers
```

```
ans =
  34x1 Layer array with layers:

   1 'input'           Image Input           1024x1x1 images
   2 'conv1'           Convolution            1024 512x1x1 convolutions with stride [4 1]
   3 'conv1_relu'      ReLU                  ReLU
   4 'conv1-BN'        Batch Normalization   Batch normalization with 1024 channels
   5 'conv1-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
   6 'conv1-dropout'   Dropout               25% dropout
   7 'conv2'           Convolution            128 64x1x1024 convolutions with stride [1 1]
   8 'conv2_relu'      ReLU                  ReLU
   9 'conv2-BN'        Batch Normalization   Batch normalization with 128 channels
  10 'conv2-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  11 'conv2-dropout'   Dropout               25% dropout
  12 'conv3'           Convolution            128 64x1x128 convolutions with stride [1 1]
  13 'conv3_relu'      ReLU                  ReLU
  14 'conv3-BN'        Batch Normalization   Batch normalization with 128 channels
  15 'conv3-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  16 'conv3-dropout'   Dropout               25% dropout
  17 'conv4'           Convolution            128 64x1x128 convolutions with stride [1 1]
  18 'conv4_relu'      ReLU                  ReLU
  19 'conv4-BN'        Batch Normalization   Batch normalization with 128 channels
  20 'conv4-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  21 'conv4-dropout'   Dropout               25% dropout
  22 'conv5'           Convolution            256 64x1x128 convolutions with stride [1 1]
  23 'conv5_relu'      ReLU                  ReLU
  24 'conv5-BN'        Batch Normalization   Batch normalization with 256 channels
  25 'conv5-maxpool'   Max Pooling           2x1 max pooling with stride [2 1] and padding [1 1]
  26 'conv5-dropout'   Dropout               25% dropout
  27 'conv6'           Convolution            512 64x1x256 convolutions with stride [1 1]
  28 'conv6_relu'      ReLU                  ReLU
  29 'conv6-BN'        Batch Normalization   Batch normalization with 512 channels
```

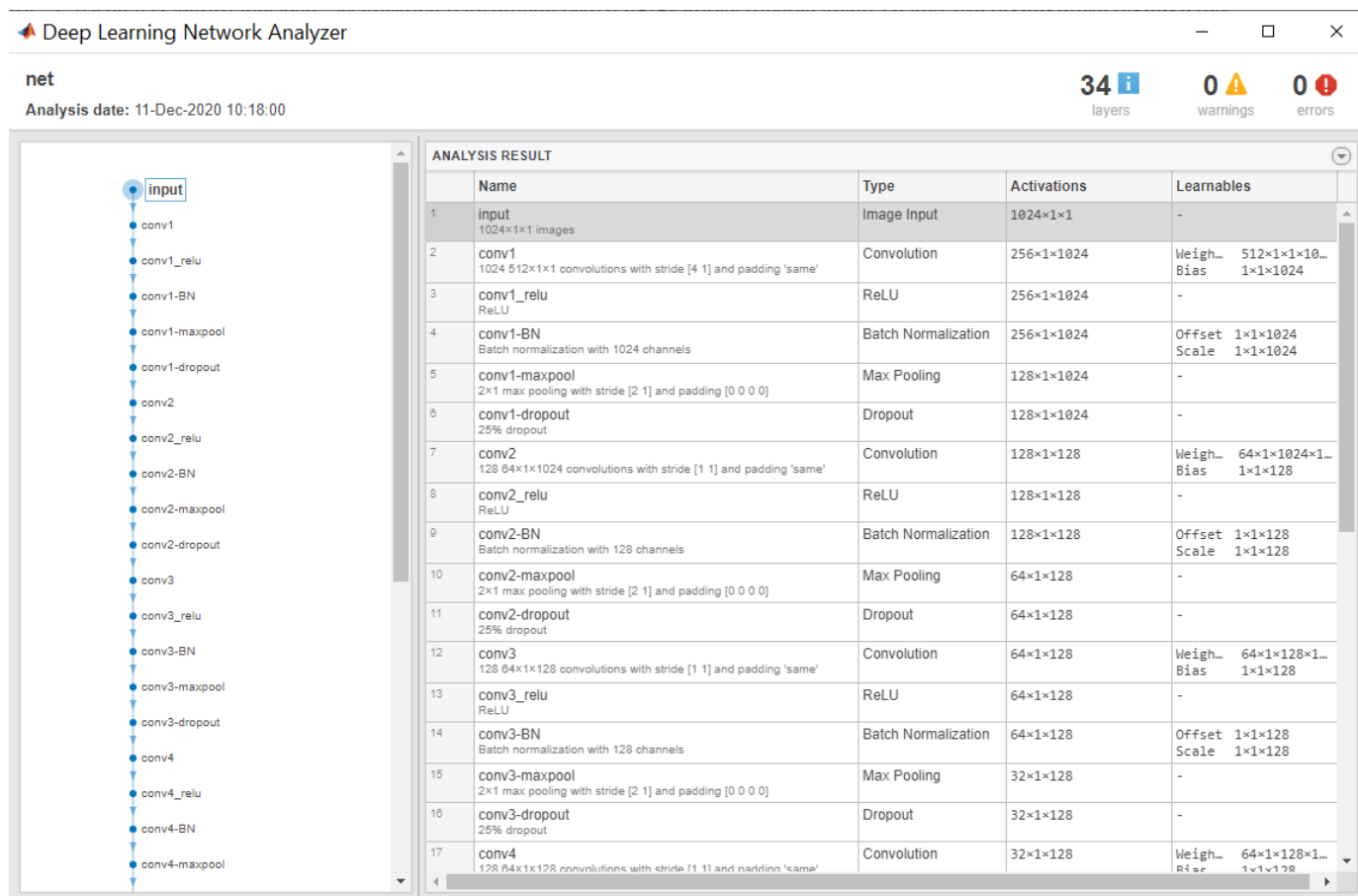
```

30 'conv6-maxpool'      Max Pooling      2x1 max pooling with stride [2 1] and padding
31 'conv6-dropout'     Dropout          25% dropout
32 'classifier'        Fully Connected  360 fully connected layer
33 'classifier_sigmoid' Sigmoid          sigmoid
34 'pitch'              Regression Output mean-squared-error

```

Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

```
analyzeNetwork(net)
```



Estimate Pitch Using CREPE Network

The CREPE network requires you to preprocess your audio signals to generate buffered, overlapped, and normalized audio frames that can be used as input to the network. This example walks through audio preprocessing using `crepePreprocess` and audio postprocessing with pitch estimation using `crepePostprocess`. The `pitchnn` function performs these steps for you.

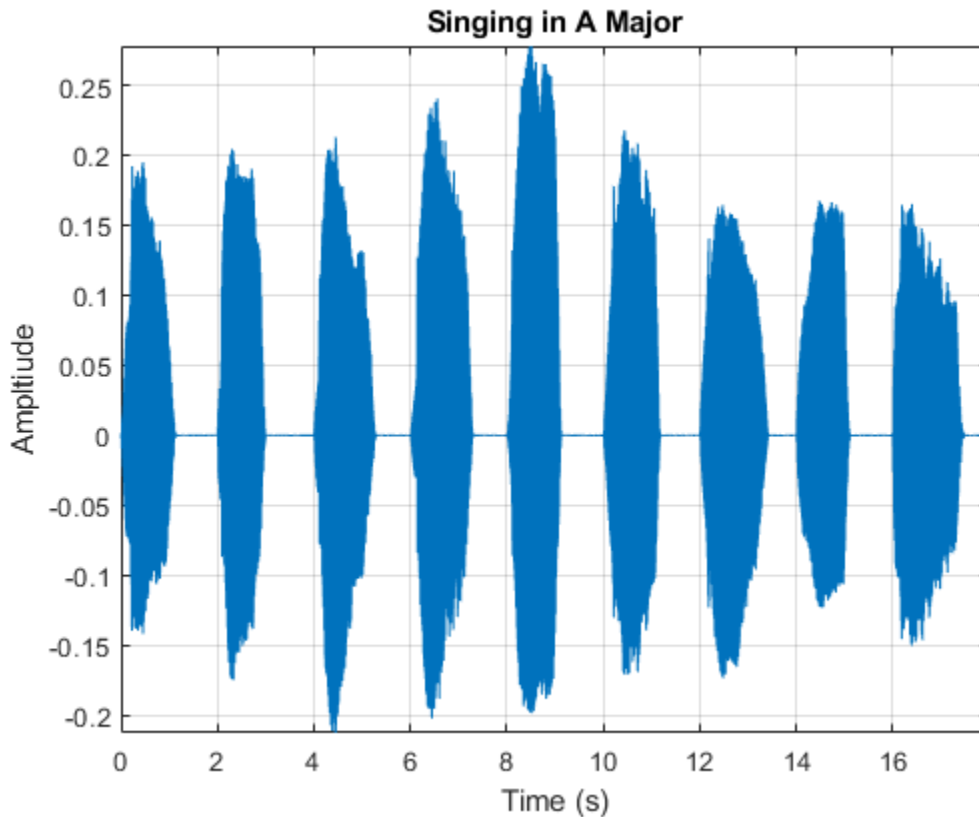
Read in an audio signal for pitch estimation. Visualize and listen to the audio. There are nine vocal utterances in the audio clip.

```
[audioIn,fs] = audioread('SingingAMajor-16-mono-18secs.ogg');
soundsc(audioIn,fs)
```

```

T = 1/fs;
t = 0:T:(length(audioIn)*T) - T;
plot(t, audioIn);
grid on
axis tight
xlabel('Time (s)')
ylabel('Amplitude')
title('Singing in A Major')

```



Use `crepePreprocess` to partition the audio into frames of 1024 samples with an 85% overlap between consecutive mel spectrograms. Place the frames along the fourth dimension.

```
[frames, loc] = crepePreprocess(audioIn, fs);
```

Create a CREPE network with `ModelCapacity` set to `tiny`. If you call `crepe` before downloading the model, an error is printed to the Command Window with a download link.

```
netTiny = crepe('ModelCapacity', 'tiny');
```

Predict the network activations.

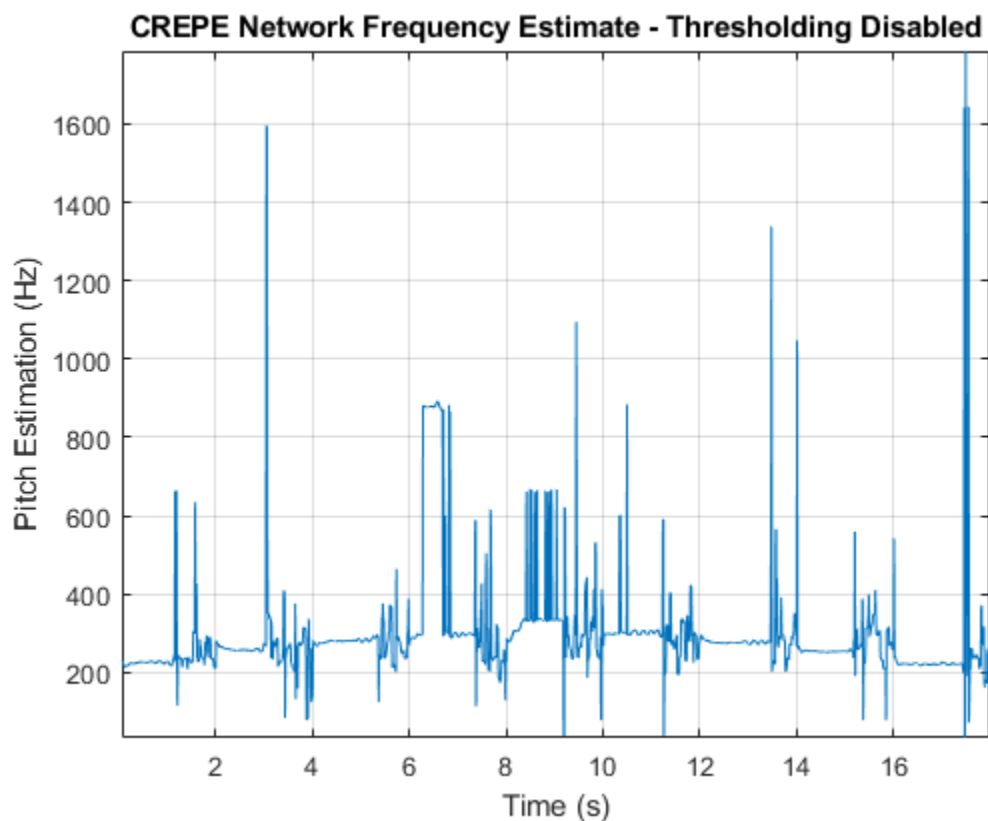
```
activationsTiny = predict(netTiny, frames);
```

Use `crepePostprocess` to produce the fundamental frequency pitch estimation in Hz. Disable confidence thresholding by setting `ConfidenceThreshold` to 0.

```
f0Tiny = crepePostprocess(activationsTiny, 'ConfidenceThreshold', 0);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny)
grid on
axis tight
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Disabled')
```

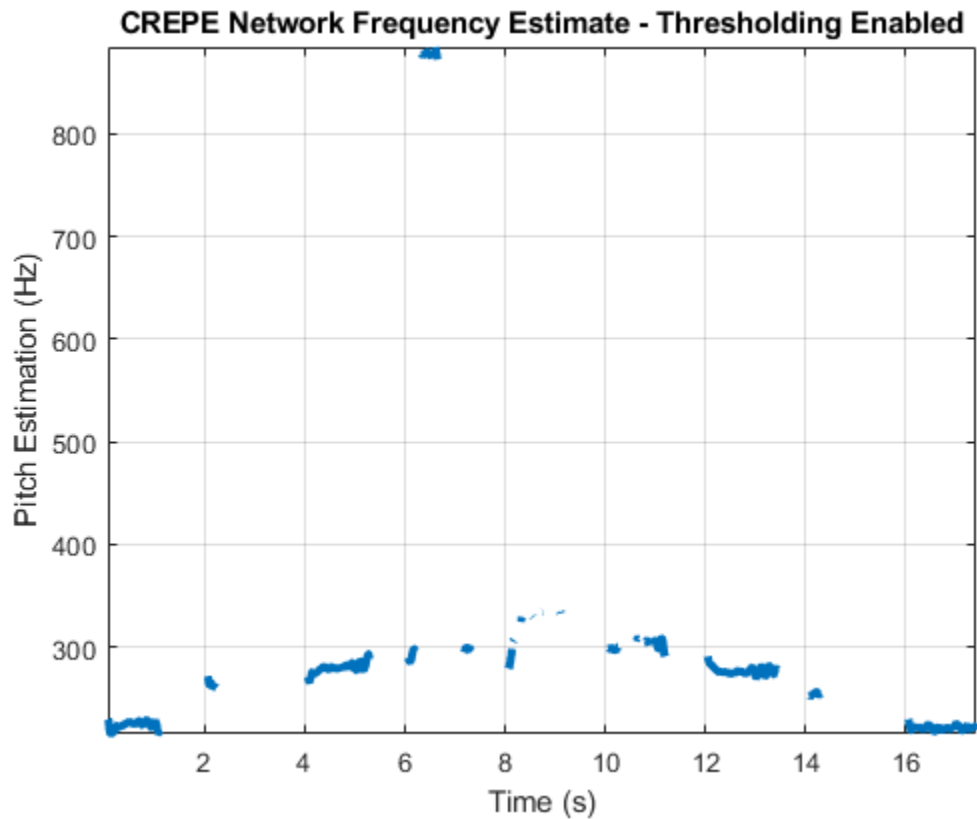


With confidence thresholding disabled, `crepePostprocess` provides a pitch estimate for every frame. Increase the `ConfidenceThreshold` to 0.8.

```
f0Tiny = crepePostprocess(activationsTiny,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation over time.

```
plot(loc,f0Tiny,'LineWidth',3)
grid on
axis tight
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Thresholding Enabled')
```



Create a new CREPE network with `ModelCapacity` set to `full`.

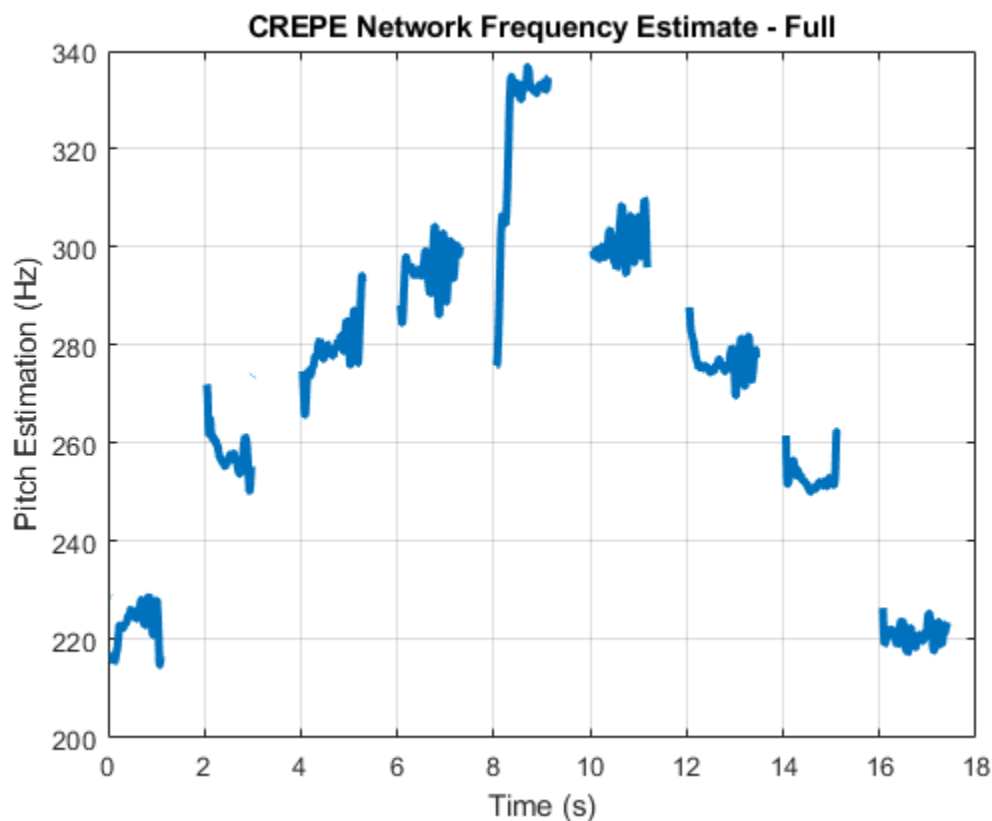
```
netFull = crepe('ModelCapacity','full');
```

Predict the network activations.

```
activationsFull = predict(netFull,frames);
f0Full = crepePostprocess(activationsFull,'ConfidenceThreshold',0.8);
```

Visualize the pitch estimation. There are nine primary pitch estimation groupings, each group corresponding with one of the nine vocal utterances.

```
plot(loc,f0Full,'LineWidth',3)
grid on
xlabel('Time (s)')
ylabel('Pitch Estimation (Hz)')
title('CREPE Network Frequency Estimate - Full')
```

Find the time elements corresponding to the last vocal utterance.

```
roundedLocVec = round(loc,2);
lastUtteranceBegin = find(roundedLocVec == 16);
lastUtteranceEnd = find(roundedLocVec == 18);
```

For simplicity, take the most frequently occurring pitch estimate within the utterance group as the fundamental frequency estimate for that timespan. Generate a pure tone with a frequency matching the pitch estimate for the last vocal utterance.

```
lastUtteranceEstimation = mode(f0Full(lastUtteranceBegin:lastUtteranceEnd))

lastUtteranceEstimation = single
    217.2709
```

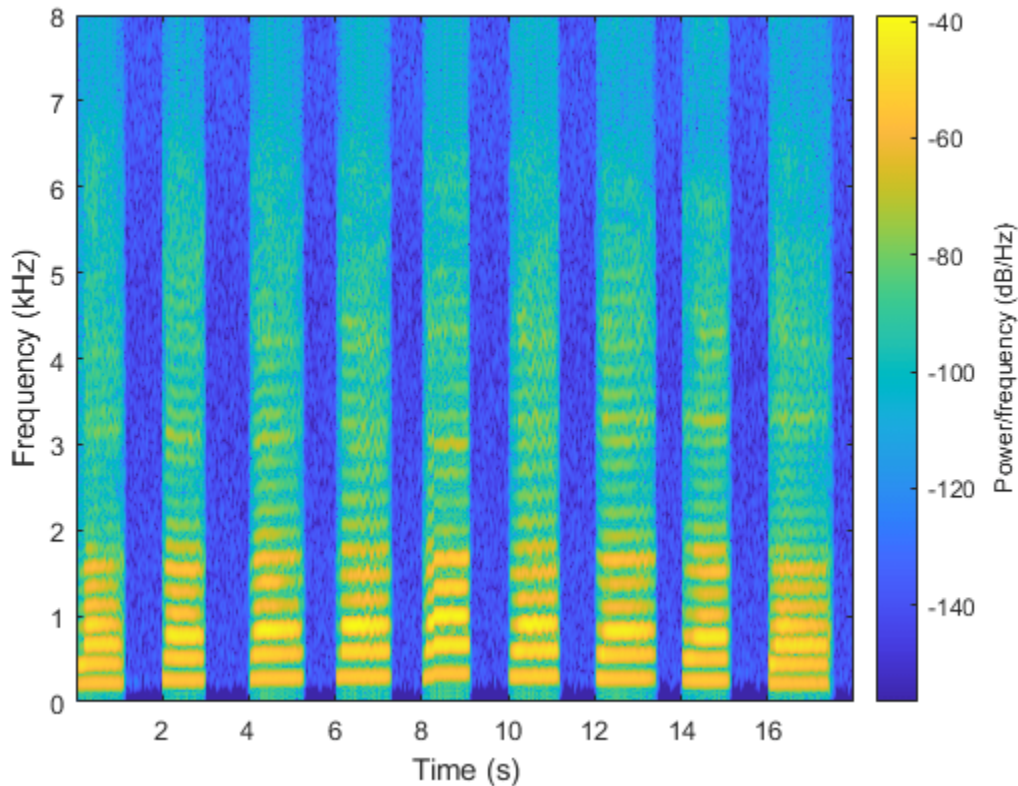
The value for `lastUtteranceEstimate` of 217.3 Hz. corresponds to the note A3. Overlay the synthesized tone on the last vocal utterance to audibly compare the two.

```
lastVocalUtterance = audioIn(fs*16:fs*18);
newTime = 0:T:2;
compareTone = cos(2*pi*lastUtteranceEstimation*newTime).';

soundsc(lastVocalUtterance + compareTone,fs);
```

Call `spectrogram` to more closely inspect the frequency content of the singing. Use a frame size of 250 samples and an overlap of 225 samples or 90%. Use 4096 DFT points for the transform. The `spectrogram` reveals that the vocal recording is actually a set of complex harmonic tones composed of multiple frequencies.

```
spectrogram(audioIn,250,225,4096,fs,'yaxis')
```



Input Arguments

CAP — Model Capacity

'full' (default) | 'tiny' | 'small' | 'medium' | 'large'

Model capacity, specified as the comma-separated pair consisting of 'ModelCapacity' and 'tiny', 'small', 'medium', 'large', or 'full'.

Tip 'ModelCapacity' controls the complexity of the underlying deep learning neural network. The higher the model capacity, the greater the number of nodes and layers in the model. Selecting the right model capacity for your data will help prevent under or overfitting.

Data Types: string | char

Output Arguments

net — Pretrained CREPE neural network

DAGNetwork object

Pretrained CREPE neural network, returned as a DAGNetwork object.

References

- [1] Kim, Jong Wook, Justin Salamon, Peter Li, and Juan Pablo Bello. "Crepe: A Convolutional Representation for Pitch Estimation." In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 161-65. Calgary, AB: IEEE, 2018. <https://doi.org/10.1109/ICASSP.2018.8461329>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Only the `activations` and `predict` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see "Load Pretrained Networks for Code Generation" (MATLAB Coder).

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- Only the `activations`, `classify`, `predict`, `predictAndUpdateState`, and `resetState` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see "Load Pretrained Networks for Code Generation" (GPU Coder).

See Also

`vggish` | `crepePreprocess` | `pitchnn` | `crepePostprocess`

Introduced in R2021a

openl3Embeddings

Extract OpenL3 feature embeddings

Syntax

```
embeddings = openl3Embeddings(audioIn,fs)
```

```
embeddings = openl3Embeddings(audioIn,fs,Name=Value)
```

Description

`embeddings = openl3Embeddings(audioIn,fs)` returns OpenL3 feature embeddings over time for audio input `audioIn` with sample rate `fs`. Columns of the input are treated as individual channels.

`embeddings = openl3Embeddings(audioIn,fs,Name=Value)` specifies options using one or more name-value arguments. For example, `embeddings = openl3Embeddings(audioIn,fs,OverlapPercentage=75)` applies a 75% overlap between consecutive frames used to create the audio embeddings.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download openl3Embeddings Functionality

Download and unzip the Audio Toolbox™ model for OpenL3.

Type `openl3Embeddings` at the command line. If the Audio Toolbox model for OpenL3 is not installed, the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the OpenL3 model to your temporary directory.

```
downloadFolder = fullfile(tempdir,"OpenL3Download");  
loc = websave(downloadFolder,"https://ssd.mathworks.com/supportfiles/audio/openl3.zip");  
OpenL3Location = tempdir;  
unzip(loc,OpenL3Location)  
addpath(fullfile(OpenL3Location,"openl3"))
```

Extract OpenL3 Embeddings

Read in an audio file.

```
[audioIn,fs] = audioread('MainStreetOne-16-16-mono-12secs.wav');
```

Call the `openl3Embeddings` function with the audio and sample rate to extract OpenL3 feature embeddings from the audio. Using the `openl3Embeddings` function requires installing the pretrained OpenL3 network. If the network is not installed, the function provides a link to download the pretrained model.

```
embeddings = openl3Embeddings(audioIn, fs);
```

The `openl3Embeddings` function returns a matrix of 512-element feature vectors over time.

```
[numHops, numElementsPerHop, numChannels] = size(embeddings)
```

```
numHops = 111
```

```
numElementsPerHop = 512
```

```
numChannels = 1
```

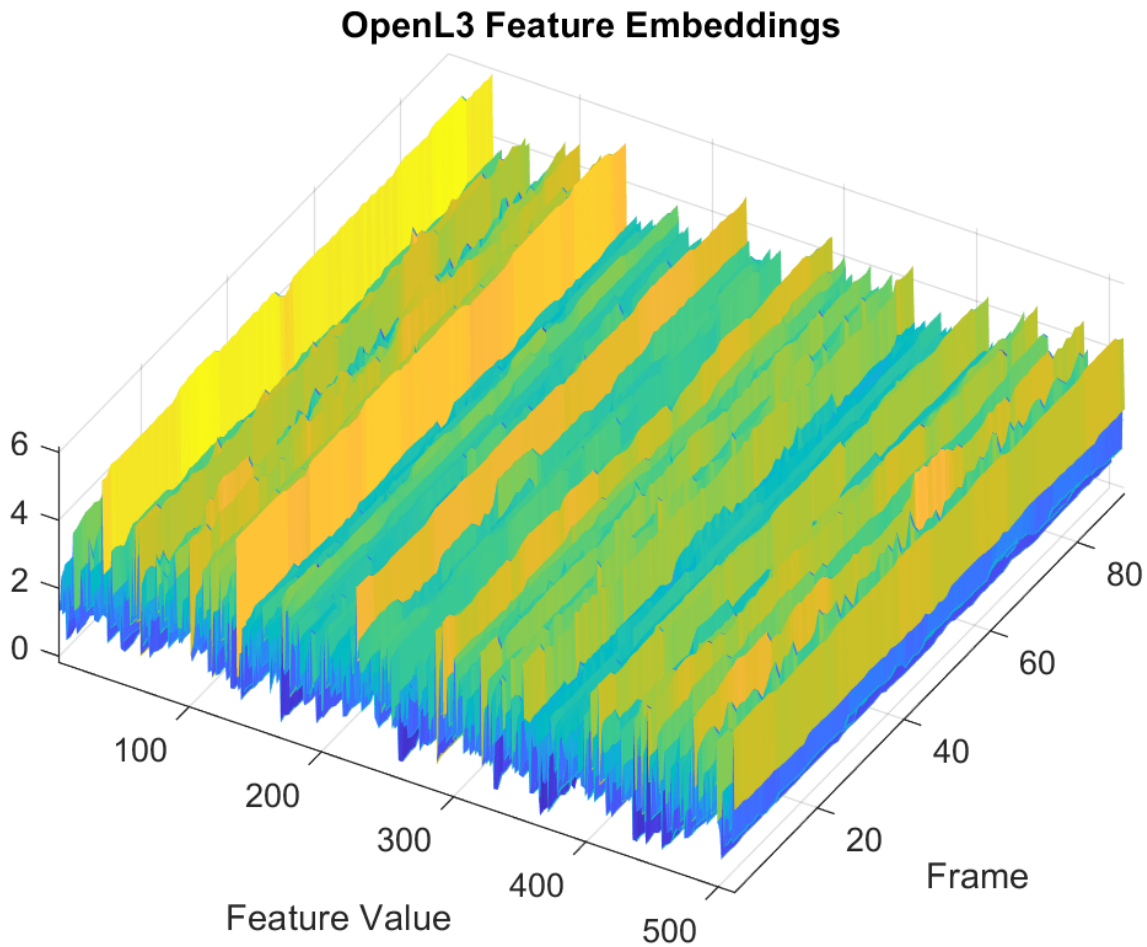
Decrease Time Resolution of OpenL3 Embeddings

Create a 10-second pink noise signal and then extract OpenL3 embeddings. The `openl3Embeddings` function extracts feature embeddings from mel spectrograms with 90% overlap. Using the `openl3Embeddings` function requires installing the pretrained OpenL3 network. If the network is not installed, the function provides a link to download the pretrained model.

```
fs = 16e3;  
dur = 10;  
audioIn = pinknoise(dur*fs, 1, "single");  
embeddings = openl3Embeddings(audioIn, fs);
```


Plot the OpenL3 feature embeddings over time.

```
surf(embeddings, EdgeColor="none")  
view([30 65])  
axis tight  
xlabel("Feature Index")  
ylabel("Frame")  
xlabel("Feature Value")  
title("OpenL3 Feature Embeddings")
```

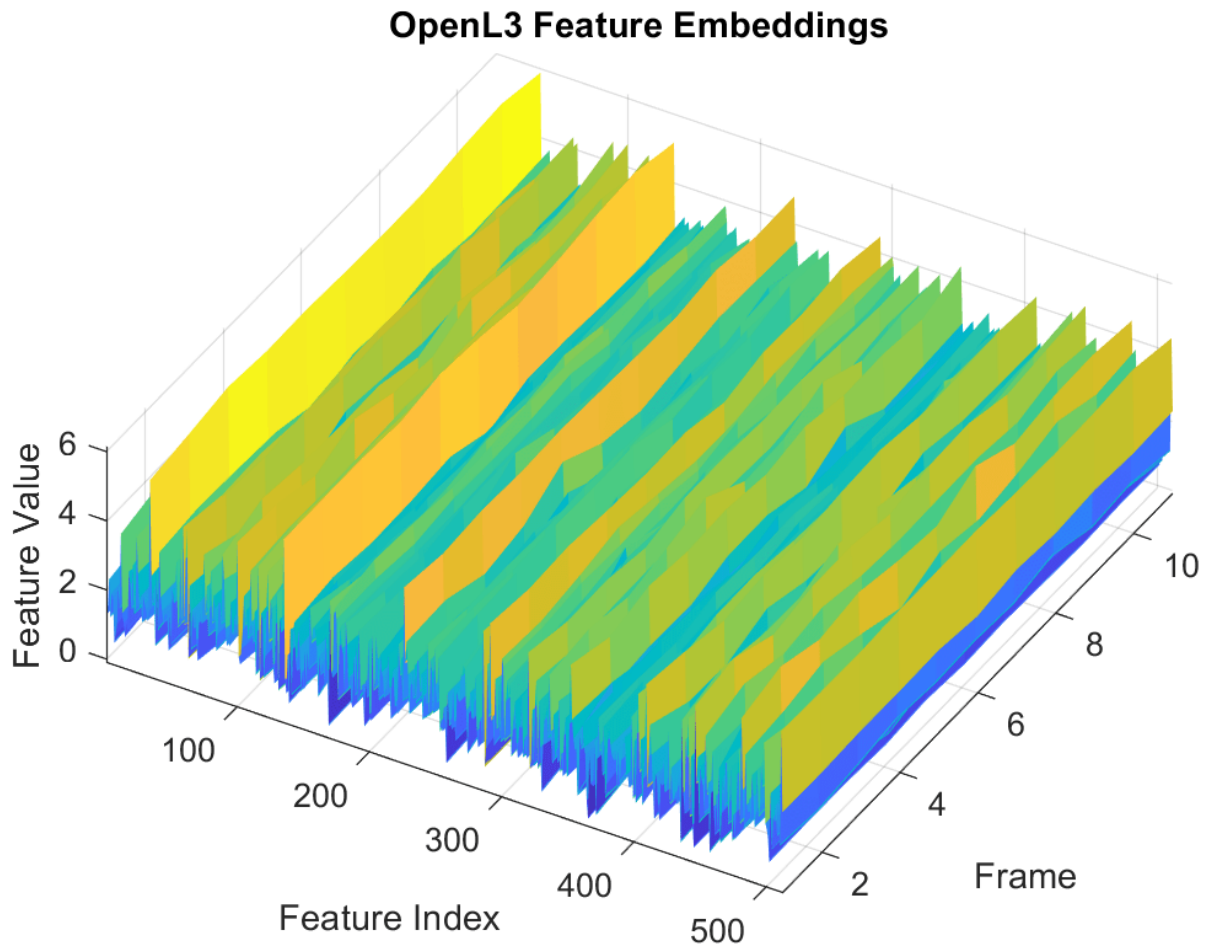


To decrease the resolution of OpenL3 feature embeddings over time, specify the percent overlap between mel spectrograms. Plot the results.

```

overlapPercentage = 10  ;
embeddings = openl3Embeddings(audioIn, fs, OverlapPercentage=overlapPercentage);
surf(embeddings, EdgeColor="none")
view([30 65])
axis tight
xlabel("Feature Index")
ylabel("Frame")
zlabel("Feature Value")
title("OpenL3 Feature Embeddings")

```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `openl3Embeddings` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `openL3Embeddings(audioIn, fs, SpectrumType="mel256")`

OverlapPercentage — Percentage overlap between consecutive spectrograms

90 (default) | scalar in the range [0,100)

Percentage overlap between consecutive spectrograms, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

SpectrumType — Spectrum type

"mel128" (default) | "mel256" | "linear"

Spectrum type generated from audio and used as input to the neural network, specified as "mel128", "mel256", or "linear".

Note The `SpectrumType` that you select controls the spectrogram used in the network. See `openL3` or `openL3Preprocess` for more details.

Data Types: `char` | `string`

EmbeddingLength — Embedding length

512 (default) | 6144

Length of the output audio embedding, specified as 512 or 6144.

Data Types: `single` | `double`

ContentType — Audio content type

"env" (default) | "music"

Audio content type the neural network is trained on, specified as "env" or "music".

Set `ContentType` to:

- "env" when you want to use a model trained on environmental data.
- "music" when you want to use a model trained on musical data.

Data Types: `char` | `string`

Output Arguments

embeddings — Compact representation of audio data

N-by-*L*-by-*C* array

Compact representation of audio data, returned as an *N*-by-*L*-by-*C* array, where:

- N -- Represents the number of buffered frames the audio signal is partitioned into and depends on the length of `audioIn` and the `OverlapPercentage`.
- L -- Represents the audio embedding length.
- C -- Represents the number of input channels.

Data Types: `single`

References

- [1] Cramer, Jason, et al. "Look, Listen, and Learn More: Design Choices for Deep Audio Embeddings." In *ICASSP 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2019, pp. 3852-56. *DOI.org (Crossref)*, doi:/10.1109/ICASSP.2019.8682475.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

`openl3Preprocess` | `openl3` | `vggish` | `classifySound` | `vggishEmbeddings` | `audioFeatureExtractor`

Introduced in R2022a

openl3Features

(To be removed) Extract OpenL3 features

Note The `openl3Features` function will be removed in a future release. Use `openl3Embeddings` instead. For more information, see “Compatibility Considerations”.

Syntax

```
embeddings = openl3Features(audioIn,fs)
```

```
embeddings = openl3Features(audioIn,fs,Name,Value)
```

Description

`embeddings = openl3Features(audioIn,fs)` returns OpenL3 feature embeddings over time for audio input `audioIn` with sample rate `fs`. Columns of the input are treated as individual channels.

`embeddings = openl3Features(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` arguments. For example, `embeddings = openl3Features(audioIn,fs,'OverlapPercentage',75)` applies a 75% overlap between consecutive frames used to create the audio embeddings.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download openl3Features Functionality

Download and unzip the Audio Toolbox™ model for OpenL3.

Type `openl3Features` at the command line. If the Audio Toolbox model for OpenL3 is not installed, the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the OpenL3 model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'OpenL3Download');  
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/openl3.zip');  
OpenL3Location = tempdir;  
unzip(loc,OpenL3Location)  
addpath(fullfile(OpenL3Location,'openl3'))
```

Extract OpenL3 Embeddings

Read in an audio file.

```
[audioIn,fs] = audioread('MainStreetOne-16-16-mono-12secs.wav');
```

Call the `openl3Features` function with the audio and sample rate to extract OpenL3 feature embeddings from the audio.

```
featureVectors = openl3Features(audioIn,fs);
```

The `openl3Features` function returns a matrix of 512-element feature vectors over time.

```
[numHops,numElementsPerHop,numChannels] = size(featureVectors)
```

```
numHops = 111
```

```
numElementsPerHop = 512
```

```
numChannels = 1
```

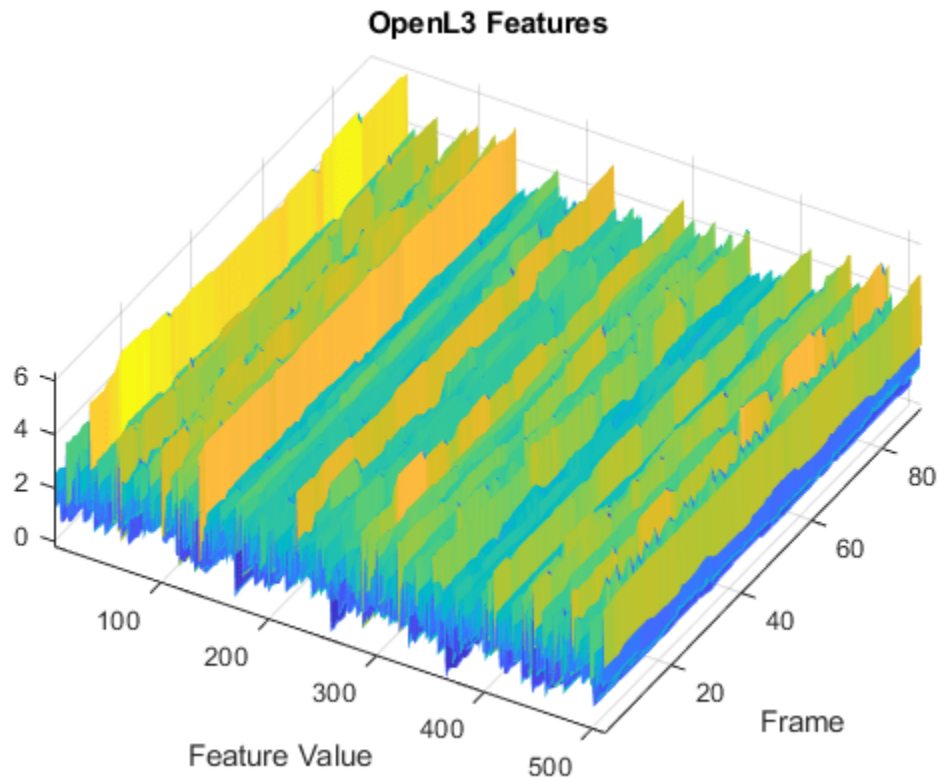
Decrease Time Resolution of OpenL3 Features

Create a 10-second pink noise signal and then extract OpenL3 features. The `openl3Features` function extracts features from mel spectrograms with 90% overlap.

```
fs = 16e3;  
dur = 10;  
audioIn = pinknoise(dur*fs,1,'single');  
features = openl3Features(audioIn,fs);
```


Plot the OpenL3 features over time.

```
surf(features,'EdgeColor','none')  
view([30 65])  
axis tight  
xlabel('Feature Index')  
ylabel('Frame')  
xlabel('Feature Value')  
title('OpenL3 Features')
```

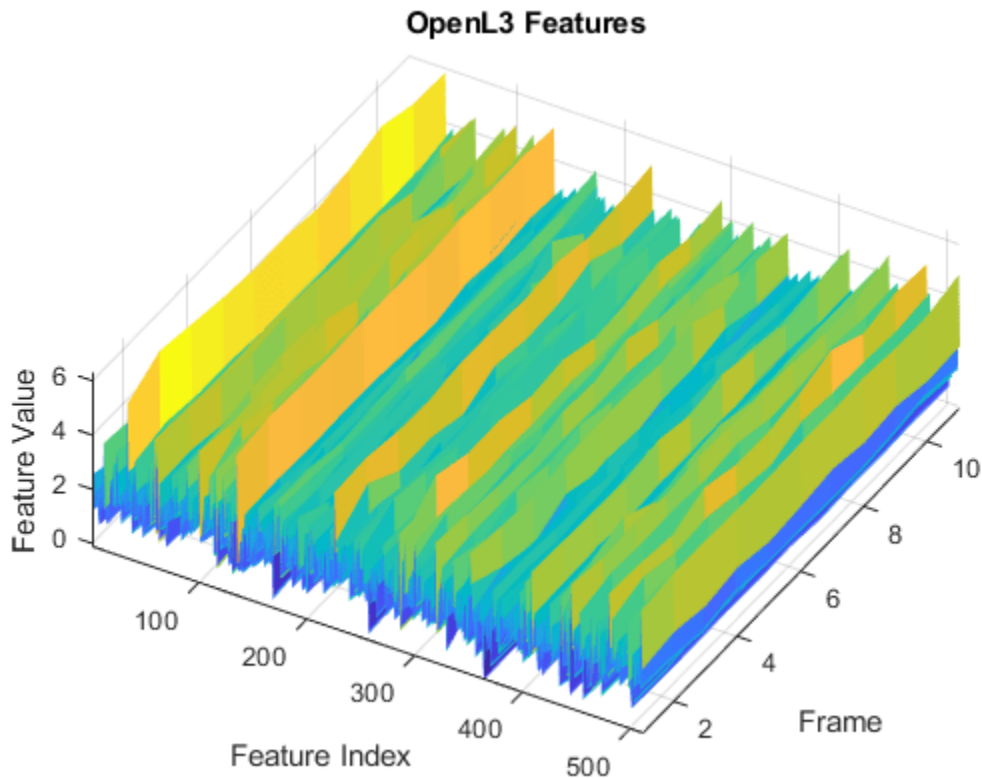


To decrease the resolution of OpenL3 features over time, specify the percent overlap between mel spectrograms. Plot the results.

```

overlapPercentage = 10  ;
features = openL3Features(audioIn,fs,'OverlapPercentage',overlapPercentage);
surf(features,'EdgeColor','none')
view([30 65])
axis tight
xlabel('Feature Index')
ylabel('Frame')
zlabel('Feature Value')
title('OpenL3 Features')

```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `openl3Features` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `openl3Features(audioIn,fs,'SpectrumType','mel256')`

OverlapPercentage — Percentage overlap between consecutive spectrograms

90 (default) | scalar in the range [0,100)

Percentage overlap between consecutive spectrograms, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

SpectrumType — Spectrum type

'mel128' (default) | 'mel256' | 'linear'

Spectrum type generated from audio and used as input to the neural network, specified as 'mel128', 'mel256', or 'linear'.

Note The `SpectrumType` that you select controls the spectrogram used in the network. See `openl3` or `openl3Preprocess` for more details.

Data Types: `char` | `string`

EmbeddingLength — Embedding length

512 (default) | 6144

Length of the output audio embedding, specified as '512' or '6144'.

Data Types: `single` | `double`

ContentType — Audio content type

'env' (default) | 'music'

Audio content type the neural network is trained on, specified as 'env' or 'music'.

Set `ContentType` to:

- 'env' when you want to use a model trained on environmental data.
- 'music' when you want to use a model trained on musical data.

Data Types: `char` | `string`

Output Arguments**embeddings — Compact representation of audio data**

N-by-*L*-by-*C* array

Compact representation of audio data, returned as an *N*-by-*L*-by-*C* array, where:

- *N* -- Represents the number of buffered frames the audio signal is partitioned into and depends on the length of `audioIn` and the `'OverlapPercentage'`.
- *L* -- Represents the audio embedding length.
- *C* -- Represents the number of input channels.

Data Types: `single`

Compatibility Considerations

openl3Features will be removed

Not recommended starting in R2022a

The `openl3Features` function will be removed in a future release. Use `openl3Embeddings` instead. Existing calls to `openl3Features` continue to run.

References

- [1] Cramer, Jason, et al. "Look, Listen, and Learn More: Design Choices for Deep Audio Embeddings." In *ICASSP 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2019, pp. 3852-56. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2019.8682475.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

`openl3Preprocess` | `openl3` | `vggish` | `classifySound` | `vggishEmbeddings` | `audioFeatureExtractor`

Introduced in R2021a

openl3Preprocess

Preprocess audio for OpenL3 feature extraction

Syntax

```
features = openl3Preprocess(audioIn,fs)
```

```
features = openl3Preprocess(audioIn,fs,Name,Value)
```

Description

`features = openl3Preprocess(audioIn,fs)` generates spectrograms from `audioIn` that can be fed to the OpenL3 pretrained network.

`features = openl3Preprocess(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` arguments. For example, `features = openl3Preprocess(audioIn,fs,'OverlapPercentage',75)` applies a 75% overlap between consecutive frames used to generate the spectrograms.

Examples

Download OpenL3 Network

Download and unzip the Audio Toolbox™ model for OpenL3.

Type `openl3` at the Command Window. If the Audio Toolbox model for OpenL3 is not installed, the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the OpenL3 model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'OpenL3Download');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/openl3.zip');
OpenL3Location = tempdir;
unzip(loc,OpenL3Location)
addpath(fullfile(OpenL3Location,'openl3'))
```

Check that the installation is successful by typing `openl3` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
openl3
```

```
ans =
  DAGNetwork with properties:

    Layers: [30x1 nnet.cnn.layer.Layer]
  Connections: [29x2 table]
    InputNames: {'in'}
  OutputNames: {'out'}
```


Extract OpenL3 Embeddings from Audio Signal

Use `openl3Preprocess` to extract embeddings from an audio signal.

Read in an audio signal.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

To extract spectrograms from the audio, call the `openl3Preprocess` function with the audio and sample rate. Use 50% overlap and set the spectrum type to linear. The `openl3Preprocess` function returns an array of 30 spectrograms produced using an FFT length of 512.

```
features = openl3Preprocess(audioIn,fs,'OverlapPercentage',50,'SpectrumType','linear');
[posFFTBins0vLap50,numHops0vLap50,~,numSpect0vLap50] = size(features)
```

```
posFFTBins0vLap50 = 257
```

```
numHops0vLap50 = 197
```

```
numSpect0vLap50 = 30
```

Call `openl3Preprocess` again, this time using the default overlap of 90%. The `openl3Preprocess` function now returns an array of 146 spectrograms.

```
features = openl3Preprocess(audioIn,fs,'SpectrumType','linear');
[posFFTBins0vLap90,numHops0vLap90,~,numSpect0vLap90] = size(features)
```

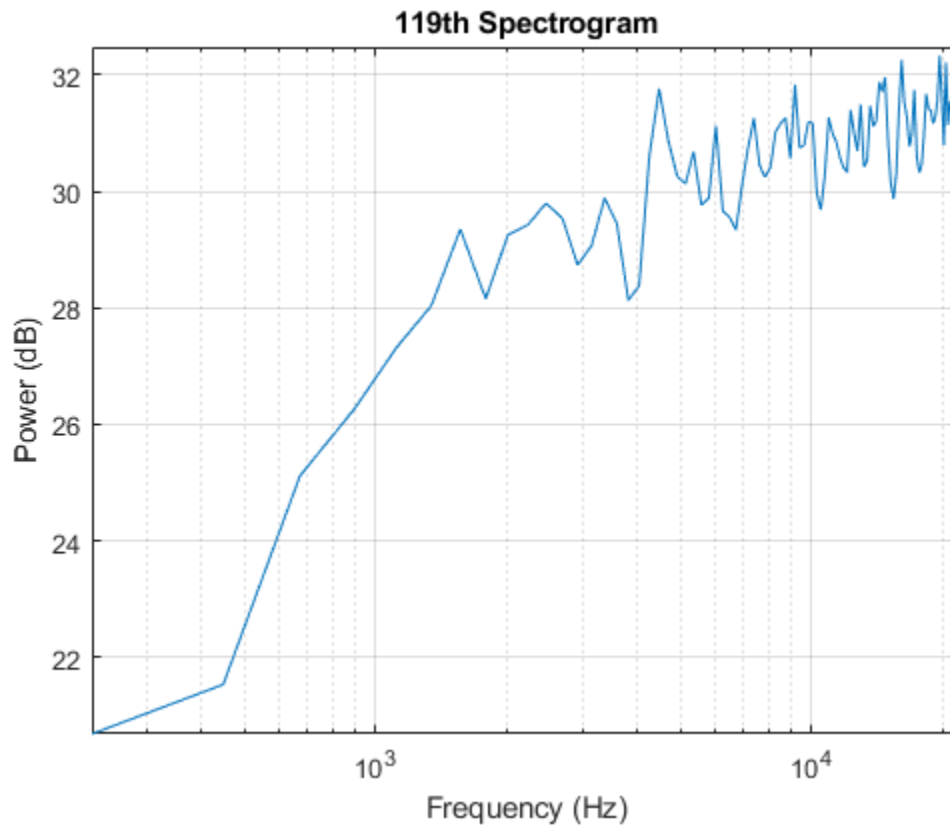
```
posFFTBins0vLap90 = 257
```

```
numHops0vLap90 = 197
```

```
numSpect0vLap90 = 146
```

Visualize one of the spectrograms at random.

```
randSpect = randi(numSpect0vLap90);
viewRandSpect = features(:,:,~,randSpect);
N = size(viewRandSpect,2);
binsToHz = (0:N-1)*fs/N;
nyquistBin = round(N/2);
semilogx(binsToHz(1:nyquistBin),mag2db(abs(viewRandSpect(1:nyquistBin))))
xlabel('Frequency (Hz)')
ylabel('Power (dB)');
title([num2str(randSpect),'th Spectrogram'])
axis tight
grid on
```

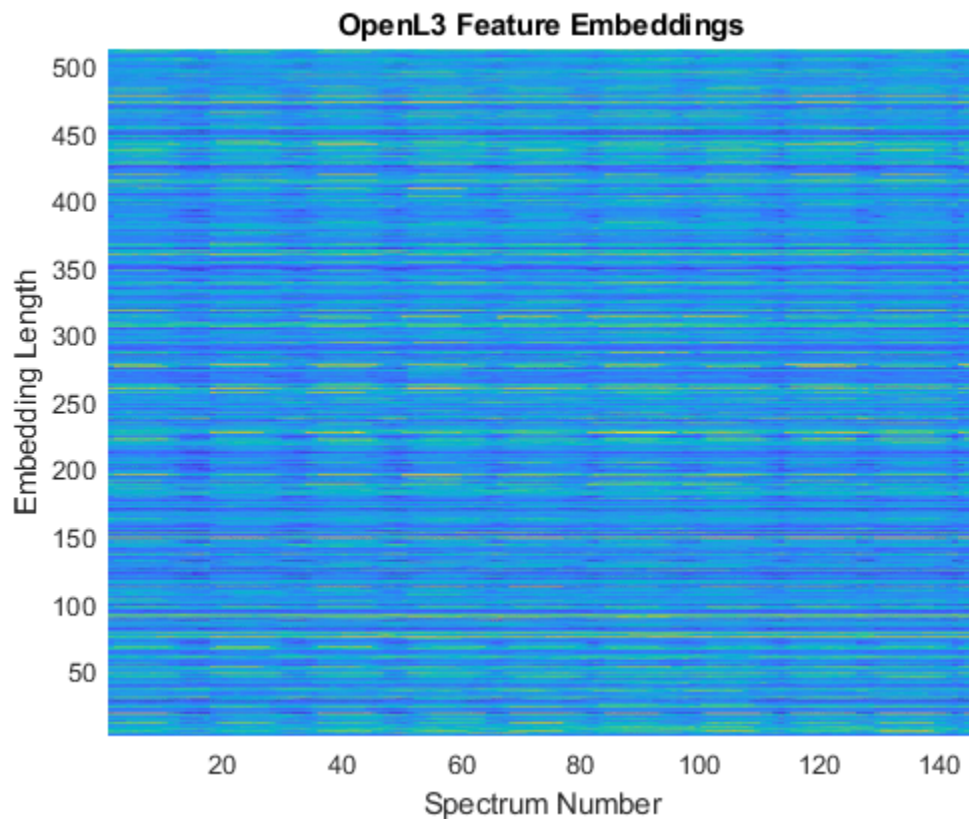


Create an OpenL3 network (this requires Deep Learning Toolbox) using the same 'SpectrumType'.

```
net = openl3('SpectrumType','linear');
```

Extract and visualize the audio embeddings.

```
embeddings = predict(net,features);  
surf(embeddings,'EdgeColor','none')  
view([90,-90])  
axis([1 numSpect0vLap90 1 numSpect0vLap90])  
xlabel('Embedding Length')  
ylabel('Spectrum Number')  
title('OpenL3 Feature Embeddings')  
axis tight
```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `openl3Preprocess` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `openl3Preprocess(audioIn, fs, 'SpectrumType', 'mel256')`

OverlapPercentage — Percentage overlap between consecutive spectrograms

90 (default) | scalar in the range [0,100)

Percentage overlap between consecutive spectrograms, specified as a scalar in the range [0,100).

Data Types: `single` | `double`**SpectrumType — Spectrum type**

'mel128' (default) | 'mel256' | 'linear'

Spectrum type generated from audio and used as input to the neural network, specified as one of these:

- 'mel128' -- Generates mel spectrograms using 128 mel bands.
- 'mel256' -- Generates mel spectrograms using 256 mel bands.
- 'linear' -- Generates positive one-sided spectrograms using an FFT length of 512.

Data Types: `char` | `string`**Output Arguments****features — Spectrograms that can be fed to OpenL3 pretrained network** N -by- M -by-1-by- K arraySpectrograms generated from `audioIn`, returned as an N -by- M -by-1-by- K array.

When you specify 'SpectrumType' as one of these:

- 'mel128' -- The dimensions are 128-by-199-by-1-by- K , where 128 is the number of mel bands and 199 is the number of time hops.
- 'mel256' -- The dimensions are 256-by-199-by-1-by- K , where 256 is the number of mel bands and 199 is the number of time hops.
- 'linear' -- The dimensions are 257-by-197-by-1-by- K , where 257 is the positive one-sided FFT length and 197 is the number of time hops.
- K represents the number of spectrograms and depends on the length of `audioIn`, the number of channels in `audioIn`, as well as `OverlapPercentage`.

Data Types: `single`**References**

- [1] Cramer, Jason, et al. "Look, Listen, and Learn More: Design Choices for Deep Audio Embeddings." In *ICASSP 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2019, pp. 3852-56. *DOI.org (Crossref)*, doi:/10.1109/ICASSP.2019.8682475.

Extended Capabilities**C/C++ Code Generation**

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`openl3` | `vggish` | `vggishEmbeddings` | `openl3Embeddings` | `classifySound` | `audioFeatureExtractor`

Introduced in R2021a

openl3

OpenL3 neural network

Syntax

```
net = openl3
net = openl3(Name,Value)
```

Description

`net = openl3` returns a pretrained OpenL3 model.

This function requires both Audio Toolbox and Deep Learning Toolbox.

`net = openl3(Name,Value)` specifies options using one or more `Name, Value` arguments. For example, `net = openl3('EmbeddingLength',6144)` specifies the output embedding length as 6144.

Examples

Download OpenL3 Network

Download and unzip the Audio Toolbox™ model for OpenL3.

Type `openl3` at the Command Window. If the Audio Toolbox model for OpenL3 is not installed, the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the OpenL3 model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'OpenL3Download');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/openl3.zip');
OpenL3Location = tempdir;
unzip(loc,OpenL3Location)
addpath(fullfile(OpenL3Location,'openl3'))
```

Check that the installation is successful by typing `openl3` at the Command Window. If the network is installed, then the function returns a `DAGNetwork` (Deep Learning Toolbox) object.

```
openl3
```

```
ans =
  DAGNetwork with properties:
    Layers: [30x1 nnet.cnn.layer.Layer]
    Connections: [29x2 table]
    InputNames: {'in'}
    OutputNames: {'out'}
```

Load Pretrained OpenL3 Network

Load a pretrained OpenL3 convolutional neural network and examine the layers and classes.

Use `openl3` to load the pretrained OpenL3 network. The output `net` is a `DAGNetwork` (Deep Learning Toolbox) object.

```
net = openl3

net =
  DAGNetwork with properties:

    Layers: [30x1 nnet.cnn.layer.Layer]
  Connections: [29x2 table]
  InputNames: {'in'}
  OutputNames: {'out'}
```

View the network architecture using the `Layers` property. The network has 30 layers. There are 16 layers with learnable weights, of which eight are batch normalization layers and eight are convolutional layers.

```
net.Layers

ans =
  30x1 Layer array with layers:

   1  'in'          Image Input          128x199x1 images
   2  'batch_normalization_81' Batch Normalization Batch normalization with 1 channels
   3  'conv2d_71'   Convolution          64 3x3x1 convolutions with stride [1
   4  'batch_normalization_82' Batch Normalization Batch normalization with 64 channels
   5  'activation_71' ReLU
   6  'conv2d_72'   Convolution          64 3x3x64 convolutions with stride [1
   7  'batch_normalization_83' Batch Normalization Batch normalization with 64 channels
   8  'activation_72' ReLU
   9  'max_pooling2d_41' Max Pooling          2x2 max pooling with stride [2 2] and
  10  'conv2d_73'   Convolution          128 3x3x64 convolutions with stride [1
  11  'batch_normalization_84' Batch Normalization Batch normalization with 128 channels
  12  'activation_73' ReLU
  13  'conv2d_74'   Convolution          128 3x3x128 convolutions with stride [1
  14  'batch_normalization_85' Batch Normalization Batch normalization with 128 channels
  15  'activation_74' ReLU
  16  'max_pooling2d_42' Max Pooling          2x2 max pooling with stride [2 2] and
  17  'conv2d_75'   Convolution          256 3x3x128 convolutions with stride [1
  18  'batch_normalization_86' Batch Normalization Batch normalization with 256 channels
  19  'activation_75' ReLU
  20  'conv2d_76'   Convolution          256 3x3x256 convolutions with stride [1
  21  'batch_normalization_87' Batch Normalization Batch normalization with 256 channels
  22  'activation_76' ReLU
  23  'max_pooling2d_43' Max Pooling          2x2 max pooling with stride [2 2] and
  24  'conv2d_77'   Convolution          512 3x3x256 convolutions with stride [1
  25  'batch_normalization_88' Batch Normalization Batch normalization with 512 channels
  26  'activation_77' ReLU
  27  'audio_embedding_layer' Convolution          512 3x3x512 convolutions with stride [1
  28  'max_pooling2d_44' Max Pooling          16x24 max pooling with stride [16 24]
  29  'flatten'     Keras Flatten        Flatten activations into 1-D assuming
  30  'out'         Regression Output     mean-squared-error
```

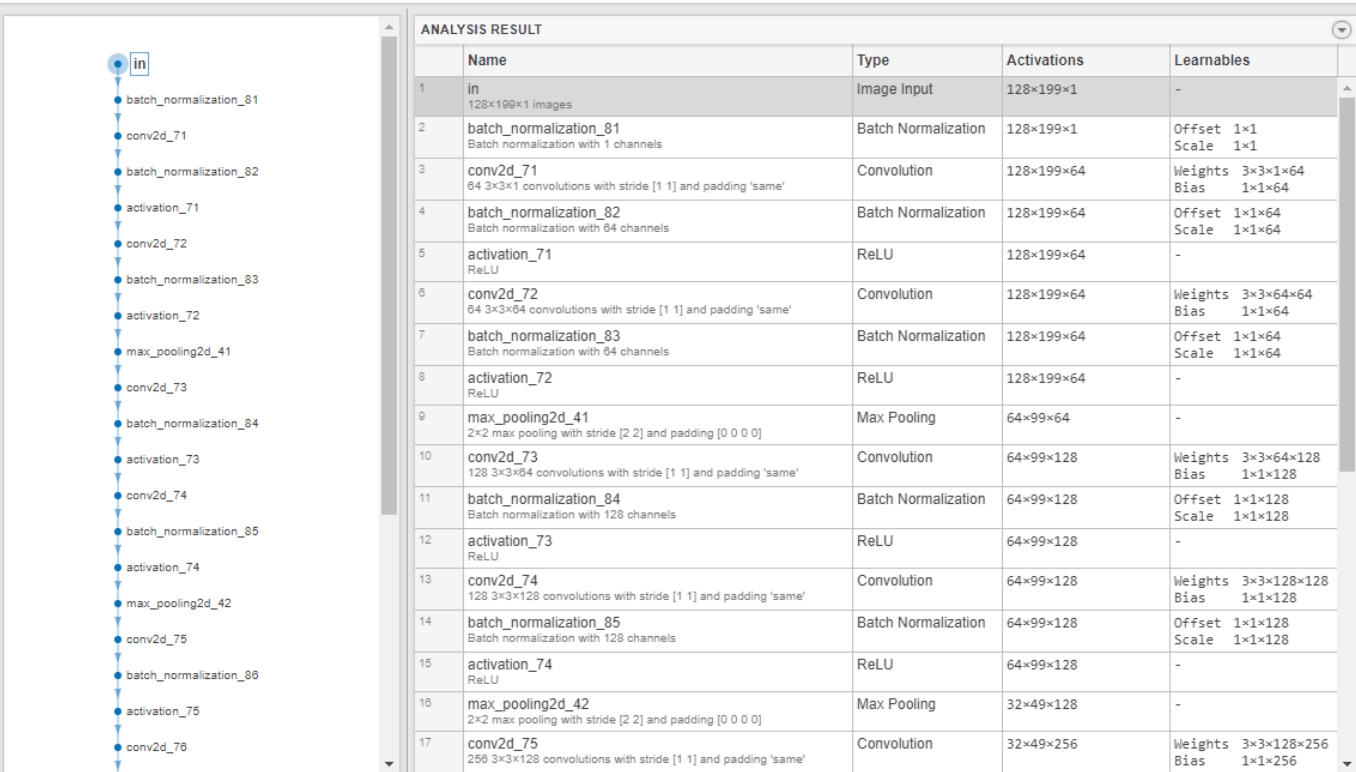
Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

`analyzeNetwork(net)`

Deep Learning Network Analyzer

net
Analysis date: 18-Dec-2020 16:54:35

30 layers 0 warnings 0 errors



	Name	Type	Activations	Learnables
1	in 128×199×1 images	Image Input	128×199×1	-
2	batch_normalization_81 Batch normalization with 1 channels	Batch Normalization	128×199×1	Offset 1×1 Scale 1×1
3	conv2d_71 64 3×3×1 convolutions with stride [1 1] and padding 'same'	Convolution	128×199×64	Weights 3×3×1×64 Bias 1×1×64
4	batch_normalization_82 Batch normalization with 64 channels	Batch Normalization	128×199×64	Offset 1×1×64 Scale 1×1×64
5	activation_71 ReLU	ReLU	128×199×64	-
6	conv2d_72 64 3×3×64 convolutions with stride [1 1] and padding 'same'	Convolution	128×199×64	Weights 3×3×64×64 Bias 1×1×64
7	batch_normalization_83 Batch normalization with 64 channels	Batch Normalization	128×199×64	Offset 1×1×64 Scale 1×1×64
8	activation_72 ReLU	ReLU	128×199×64	-
9	max_pooling2d_41 2×2 max pooling with stride [2 2] and padding [0 0 0 0]	Max Pooling	64×99×64	-
10	conv2d_73 128 3×3×64 convolutions with stride [1 1] and padding 'same'	Convolution	64×99×128	Weights 3×3×64×128 Bias 1×1×128
11	batch_normalization_84 Batch normalization with 128 channels	Batch Normalization	64×99×128	Offset 1×1×128 Scale 1×1×128
12	activation_73 ReLU	ReLU	64×99×128	-
13	conv2d_74 128 3×3×128 convolutions with stride [1 1] and padding 'same'	Convolution	64×99×128	Weights 3×3×128×128 Bias 1×1×128
14	batch_normalization_85 Batch normalization with 128 channels	Batch Normalization	64×99×128	Offset 1×1×128 Scale 1×1×128
15	activation_74 ReLU	ReLU	64×99×128	-
16	max_pooling2d_42 2×2 max pooling with stride [2 2] and padding [0 0 0 0]	Max Pooling	32×49×128	-
17	conv2d_75 256 3×3×128 convolutions with stride [1 1] and padding 'same'	Convolution	32×49×256	Weights 3×3×128×256 Bias 1×1×256

Extract OpenL3 Embeddings from Audio Signal

Use `openL3Preprocess` to extract embeddings from an audio signal.

Read in an audio signal.

```
[audioIn, fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

To extract spectrograms from the audio, call the `openL3Preprocess` function with the audio and sample rate. Use 50% overlap and set the spectrum type to linear. The `openL3Preprocess` function returns an array of 30 spectrograms produced using an FFT length of 512.

```
features = openL3Preprocess(audioIn, fs, 'OverlapPercentage', 50, 'SpectrumType', 'linear');  
[posFFtbins0vLap50, numHops0vLap50, ~, numSpect0vLap50] = size(features)
```

```
posFFtbins0vLap50 = 257
```

```
numHops0vLap50 = 197
```

```
numSpect0vLap50 = 30
```

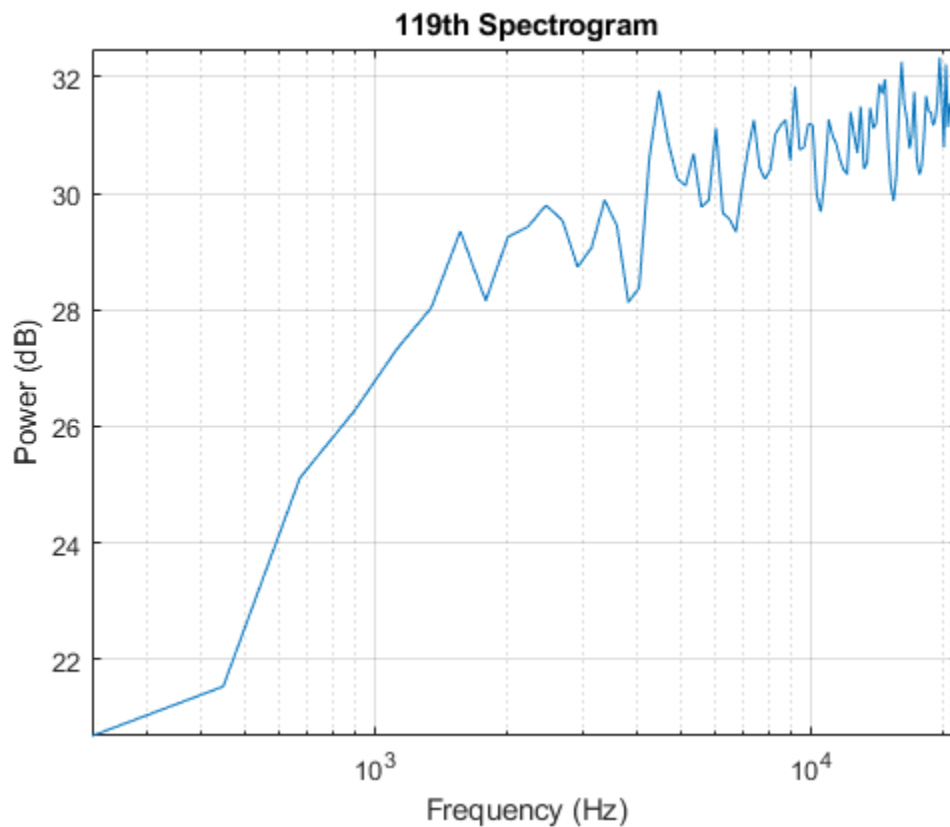

Call `openl3Preprocess` again, this time using the default overlap of 90%. The `openl3Preprocess` function now returns an array of 146 spectrograms.

```
features = openl3Preprocess(audioIn, fs, 'SpectrumType', 'linear');
[posFFTbins0vLap90, numHops0vLap90, ~, numSpect0vLap90] = size(features)

posFFTbins0vLap90 = 257
numHops0vLap90 = 197
numSpect0vLap90 = 146
```

Visualize one of the spectrograms at random.

```
randSpect = randi(numSpect0vLap90);
viewRandSpect = features(:, :, :, randSpect);
N = size(viewRandSpect, 2);
binsToHz = (0:N-1)*fs/N;
nyquistBin = round(N/2);
semilogx(binsToHz(1:nyquistBin), mag2db(abs(viewRandSpect(1:nyquistBin))))
xlabel('Frequency (Hz)')
ylabel('Power (dB)');
title([num2str(randSpect), 'th Spectrogram'])
axis tight
grid on
```

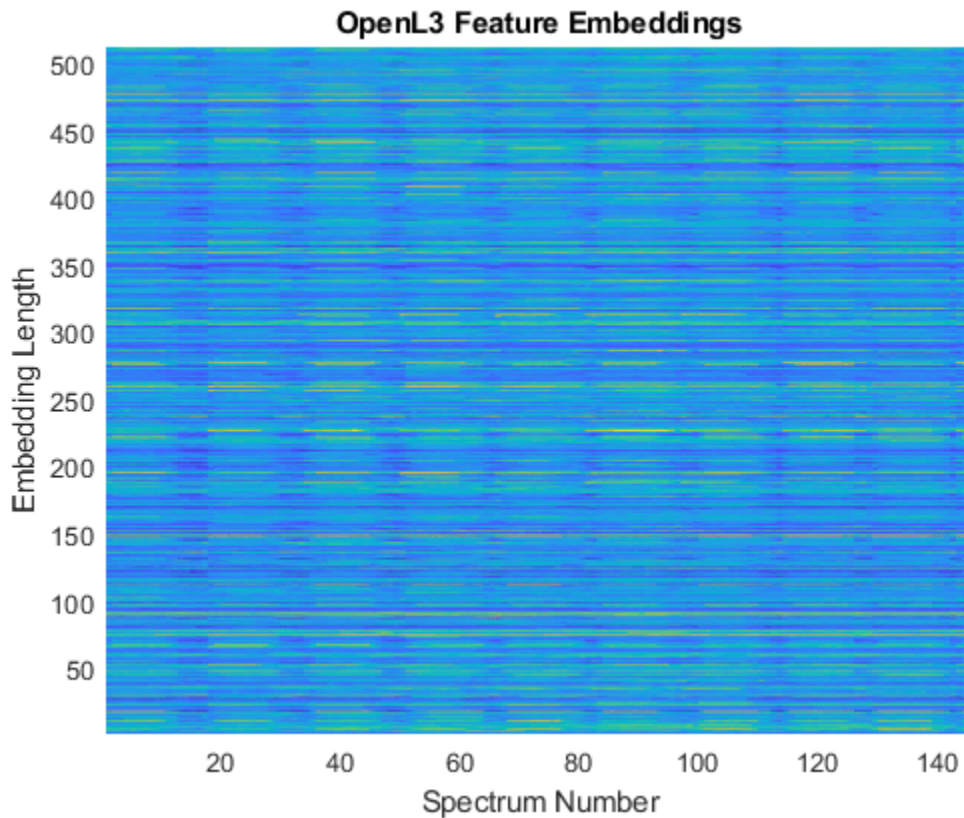


Create an OpenL3 network (this requires Deep Learning Toolbox) using the same 'SpectrumType'.

```
net = openl3('SpectrumType', 'linear');
```

Extract and visualize the audio embeddings.

```
embeddings = predict(net, features);
surf(embeddings, 'EdgeColor', 'none')
view([90, -90])
axis([1 numSpect0vLap90 1 numSpect0vLap90])
xlabel('Embedding Length')
ylabel('Spectrum Number')
title('OpenL3 Feature Embeddings')
axis tight
```



Input Arguments

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `openl3('EmbeddingLength', 6144)`

SpectrumType — Spectrum type

'mel128' (default) | 'mel256' | 'linear'

Spectrum type generated from audio and used as input to the neural network, specified as 'mel128', 'mel256', or 'linear'.

When using 'SpectrumType' and:

- 'mel128' -- The network accepts mel spectrograms with 128 mel bands as input. The input dimensions to the network are 128-by-199-by-1-by- K , where 128 is the number of mel bands and 199 is the number of time hops.
- 'mel256' -- The network accepts mel spectrograms with 256 mel bands as input. The input dimensions to the network are 256-by-199-by-1-by- K , where 256 is the number of mel bands and 199 is the number of time hops.
- 'linear' -- The network accepts positive one-sided spectrograms with an FFT length of 257. The input dimensions to the network are 257-by-197-by-1-by- K , where 257 is the positive one-sided FFT length and 197 is the number of time hops.

K represents the number of spectrograms. When preprocessing your data with `openl3Preprocess`, you must use the same 'SpectrumType'.

Data Types: char | string

EmbeddingLength — Embedding length

512 (default) | 6144

Length of the output audio embedding, specified as 512 or 6144.

Data Types: single | double

ContentType — Audio content type

'env' (default) | 'music'

Audio content type the neural network is trained on, specified as 'env' or 'music'.

Set ContentType to:

- 'env' when you want to use a model trained on environmental data.
- 'music' when you want to use a model trained on musical data.

Data Types: char | string

Output Arguments

net — Pretrained OpenL3 neural network

DAGNetwork object

Pretrained OpenL3 neural network, returned as a DAGNetwork object.

References

- [1] Cramer, Jason, et al. "Look, Listen, and Learn More: Design Choices for Deep Audio Embeddings." In *ICASSP 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2019, pp. 3852-56. *DOI.org (Crossref)*, doi:/10.1109/ICASSP.2019.8682475.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Only the `activations` and `predict` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (MATLAB Coder).

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- Only the `activations`, `classify`, `predict`, `predictAndUpdateState`, and `resetState` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (GPU Coder).

See Also

`openl3Preprocess` | `openl3Embeddings` | `vggish` | `classifySound` | `vggishEmbeddings` | `audioFeatureExtractor`

Introduced in R2021a

speakerRecognition

Pretrained speaker recognition system

Syntax

```
sr = speakerRecognition
```

Description

`sr = speakerRecognition` returns a pretrained speaker recognition system, 'ivec-english-16kHz'. The 'ivec-english-16kHz' system is an instance of an object of type `ivectorSystem` trained on the LibriSpeech data set.

Examples

Perform Speaker Verification

This example uses a pretrained speaker recognition system, 'ivec-english-16kHz'. The 'ivec-english-16kHz' system is an instance of `ivectorSystem` trained on the LibriSpeech data set.

Download the pretrained speaker recognition system into your temporary directory, whose location is specified by the MATLAB® `tempdir` command. If you want to place the data files in a folder different from `tempdir`, change the directory name. Add the temporary directory to the search path. Create an i-vector system.

```
fname = "ivec-english-16kHz.zip";
URL = "https://ssd.mathworks.com/supportfiles/audio/speakerRecognition/" + fname;

unzip(URL,tempdir);

addpath(tempdir)

sr = speakerRecognition;
```

Read two speech signals, each of which contains the phrase "volume up" spoken out loud several times with different intonations. In one of the signals, the speaker is male. In the other signal, the speaker is female.

Read each signal and split it into two parts. One of the parts is used to enroll the speaker. The other part is used for speaker verification and identification.

```
[bf,fs] = audioread("MaleVolumeUp-16-mono-6secs.ogg");
enrollBF = bf(1:3*fs);
testBF = bf(3*fs+1:end);
bfLabel = "BF";

[rd,fs] = audioread("FemaleVolumeUp-16-mono-11secs.ogg");
enrollRD = rd(1:5*fs);
testRD = rd(5*fs+1:end);
rdLabel = "RD";
```

Enroll the speakers into the speaker recognition system. This creates a template of the speaker that can be used for verification or identification.

```
enroll(sr, {enrollBF, enrollRD}, [bfLabel, rdLabel])
```

```
Extracting i-vectors ...done.  
Enrolling i-vectors .....done.  
Enrollment complete.
```

Call the `identify` function on the test data.

```
candidates = identify(sr, testBF)
```

```
candidates=2x2 table  
Label      Score  
-----  
BF          0.99474  
RD          0.0017846
```

```
candidates = identify(sr, testRD)
```

```
candidates=2x2 table  
Label      Score  
-----  
RD          0.24113  
BF          3.2741e-05
```

Call the `verify` function with the test data to confirm that the system correctly accepts or rejects speakers.

```
isVerified = verify(sr, testBF, bfLabel)
```

```
isVerified = logical  
1
```

```
isVerified = verify(sr, testBF, rdLabel)
```

```
isVerified = logical  
0
```

```
isVerified = verify(sr, testRD, rdLabel)
```

```
isVerified = logical  
1
```

```
isVerified = verify(sr, testRD, bfLabel)
```

```
isVerified = logical  
0
```

Call the `info` function to get information about how the model was trained.

info(sr)

Header

- This system was trained using the LibriSpeech train and development sets. LibriSpeech is an approximately 1000-hour corpus of read English speech sampled at 16 kHz.
- The detection error tradeoff was determined by enrolling one file from each speaker in the LibriSpeech test set, and then evaluating exhaustive pairs of the enrolled and remaining data.
- The system was calibrated using the train-clean-100 and dev-clean data of LibriSpeech.

i-vector system input

Input feature vector length: 60
Input data type: double

trainExtractor

Train signals: 286808
UBMNumComponents: 2048
UBMNumIterations: 10
TVSRank: 512
TVSNumIterations: 5

trainClassifier

Train signals: 286807
Train labels: 1 (91), 100043 (31) ... and 5652 more
NumEigenvectors: 200
PLDANumDimensions: 200
PLDANumIterations: 5

calibrate

Calibration signals: 31242
Calibration labels: 103 (102), 1034 (96) ... and 289 more

detectionErrorTradeoff

Evaluation signals: 5382
Evaluation labels: 102255 (46), 1066 (24) ... and 175 more

Remove the temporary directory from the search path.

rmpath(tempdir)

Output Arguments**sr — Pretrained speaker recognition system**

`ivectorSystem` object

Pretrained speaker recognition system, returned as an object of type `ivectorSystem`.

References

- [1] Panayotov, Vassil, Guoguo Chen, Daniel Povey, and Sanjeev Khudanpur. "Librispeech: An ASR Corpus Based on Public Domain Audio Books." In *2015 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 5206–10. South Brisbane, Queensland, Australia: IEEE, 2015. <https://doi.org/10.1109/ICASSP.2015.7178964>.

See Also

`classifySound` | `ivectorSystem` | `pitchnn`

Topics

“i-vector Score Normalization”

“i-vector Score Calibration”

External Websites

<https://www.openslr.org/12>

Introduced in R2021b

acousticRoughness

Perceived roughness of acoustic signal

Syntax

```
roughness = acousticRoughness(audioIn, fs)
roughness = acousticRoughness(audioIn, fs, calibrationFactor)
roughness = acousticRoughness(specificLoudnessIn)
roughness = acousticRoughness( ____, Name, Value)

[roughness, specificRoughness] = acousticRoughness( ____)
[roughness, specificRoughness, fMod] = acousticRoughness( ____)

acousticRoughness( ____)
```

Description

`roughness = acousticRoughness(audioIn, fs)` returns roughness strength in aspers based on Zwicker [1] and ISO 532-1 time-varying loudness [2].

`roughness = acousticRoughness(audioIn, fs, calibrationFactor)` specifies a nondefault microphone calibration factor used to compute loudness.

`roughness = acousticRoughness(specificLoudnessIn)` computes roughness using high-resolution time-varying specific loudness.

`roughness = acousticRoughness(____, Name, Value)` specifies options using one or more Name, Value pair arguments. For example, `roughness = acousticRoughness(audioIn, fs, 'SoundField', 'diffuse')` returns roughness assuming a diffuse sound field.

`[roughness, specificRoughness] = acousticRoughness(____)` also returns specific roughness strength.

`[roughness, specificRoughness, fMod] = acousticRoughness(____)` also returns the dominant modulation frequency detected by the algorithm.

`acousticRoughness(____)` with no output arguments plots roughness strength and specific roughness strength and displays the modulation frequency textually. If `audioIn` is stereo, the 3-D plot shows the sum of both channels.

Examples

Measure Acoustic Roughness

Measure acoustic roughness based on [1] on page 2-0 and ISO 532-1 [2] on page 2-0 . Assume a free-field reference pressure of 20 micropascals and a recording level calibration such that a 1 kHz tone registers as 100 dB on a SPL meter.

Read in a stereo audio file and convert to mono.

```
[audioInStereo,fs] = audioread('Engine-16-44p1-stereo-20sec.wav');
audioIn = (audioInStereo(:,1) + audioInStereo(:,2)) / 2;
```

Compute acoustic roughness on the mono audio signal and display the average value.

```
roughness = acousticRoughness(audioIn,fs);
meanRoughness = mean(roughness);
displayOutput = ['Average computed value of acoustic roughness is ',num2str(meanRoughness),' aspers'];
disp(displayOutput)
```

Average computed value of acoustic roughness is 0.13358 aspers.

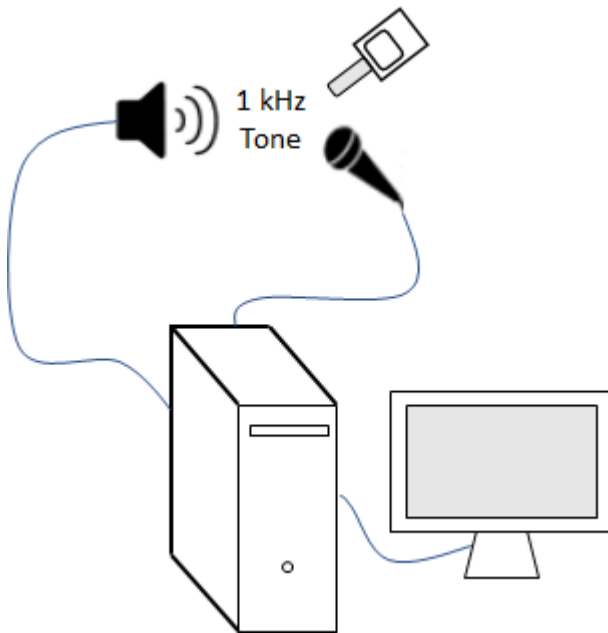
References

[1] Zwicker, Eberhard, and Hugo Fastl. *Psychoacoustics: Facts and Models*. Vol. 22. Springer Science & Business Media, 2013.

[2] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.

Roughness Measurements Using Calibrated Microphone

Set up an experiment as indicated by the diagram.



Create an `audioDeviceReader` object to read from the microphone and an `audioDeviceWriter` object to write to your speaker.

```
fs = 48e3;
deviceReader = audioDeviceReader(fs,"SamplesPerFrame",2048);
deviceWriter = audioDeviceWriter(fs);
```

Create an `audioOscillator` object to generate a 1 kHz sinusoid.

```
osc = audioOscillator("sine",1e3,"SampleRate",fs,"SamplesPerFrame",2048);
```

Create a `dsp.AsyncBuffer` object to buffer data acquired from the microphone.

```
dur = 5;
buff = dsp.AsyncBuffer(dur*fs);
```

For 5 seconds, play the sinusoid through your speaker and record using your microphone. While the audio streams, note the loudness as reported by your SPL meter. Once complete, read the contents of the buffer object.

```
numFrames = dur*(fs/osc.SamplesPerFrame);
for ii = 1:numFrames
    audioOut = osc();
    deviceWriter(audioOut);

    audioIn = deviceReader();
    write(buff,audioIn);
end
```

```
SPLreading = 69.7;
```

```
micRecording = read(buff);
```

To compute the calibration factor for the microphone, use the `calibrateMicrophone` function.

```
calibrationFactor = calibrateMicrophone(micRecording(fs+1:end),deviceReader.SampleRate,SPLreading);
```

You can now use the calibration factor you determined to measure the roughness of any sound that is acquired through the same microphone recording chain.

Perform the experiment again by adding 100% amplitude modulation at 40 Hz. To create the modulation signal, use the `audioOscillator` object and specify the amplitude as 0.5 and the DC offset as 0.5 to oscillate between 0 and 1.

```
mod = audioOscillator("sine",40,"SampleRate",fs, ...
    "Amplitude",0.5,"DCOffset",0.5,"SamplesPerFrame",2048);
```

```
dur = 5;
buff = dsp.AsyncBuffer(dur*fs);
numFrames = dur*(fs/osc.SamplesPerFrame);
for ii = 1:numFrames
    audioOut = osc().*mod();
    deviceWriter(audioOut);

    audioIn = deviceReader();
    write(buff,audioIn);
end
```

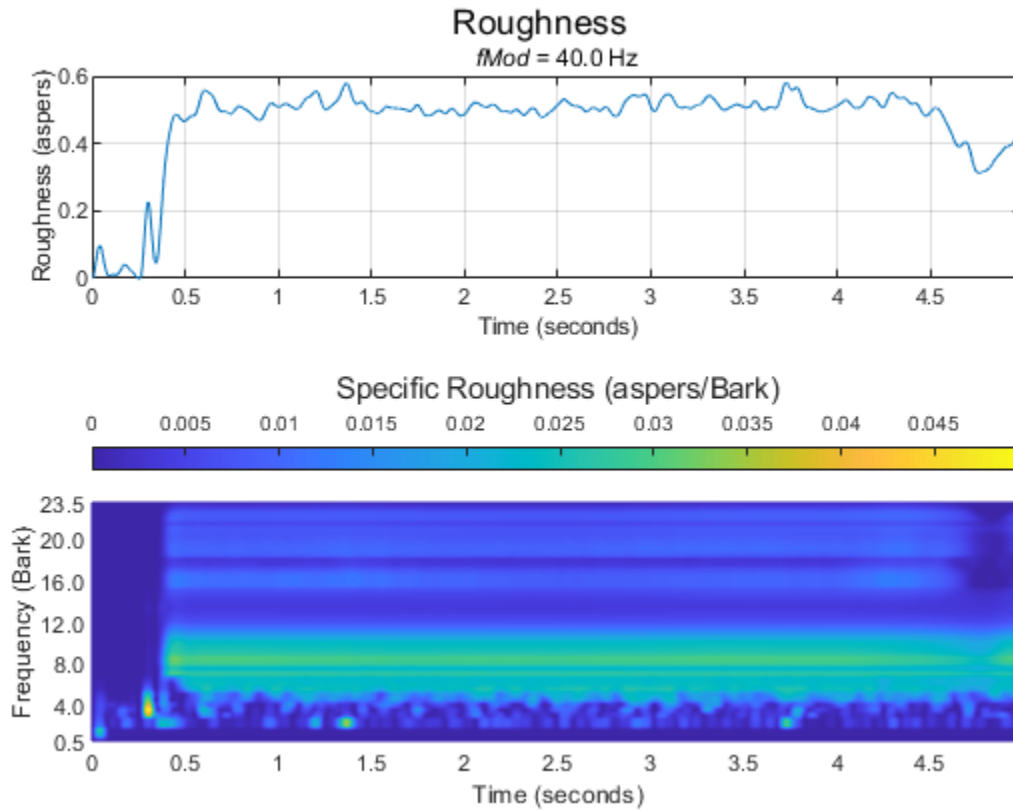
```
micRecording = read(buff);
```

Call the `acousticRoughness` function with the microphone recording, sample rate, and calibration factor. The roughness reported from `acousticRoughness` uses the true acoustic loudness measurement as specified by ISO 532-1. Display the average roughness strength over the 5 seconds and plot roughness and specific roughness.

```
roughness = acousticRoughness(micRecording,deviceReader.SampleRate,calibrationFactor);
fprintf('Average roughness = %d (asper)',mean(roughness(2001:end,:)))
```

Average roughness = 4.992723e-01 (asper)

```
acousticRoughness(micRecording,deviceReader.SampleRate,calibrationFactor)
```



Measure Roughness from Specific Loudness

Read in an audio file.

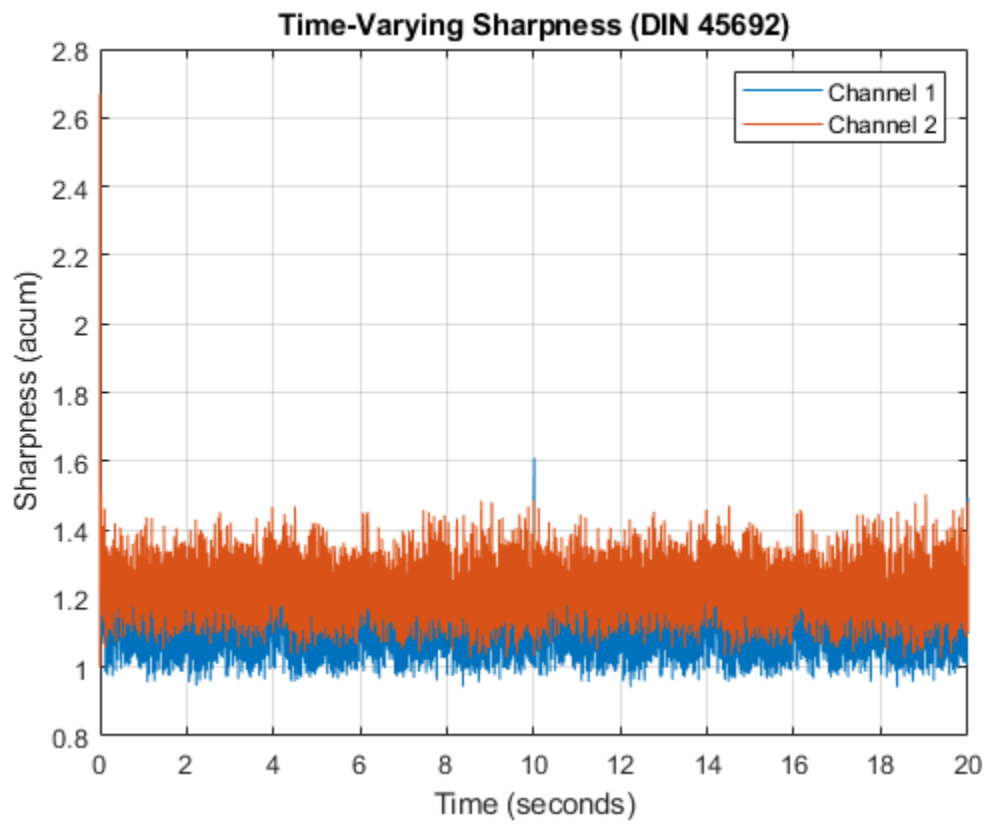
```
[audioIn,fs] = audioread("Engine-16-44p1-stereo-20sec.wav");
```

Call the `acousticLoudness` function using high time resolution to calculate the specific loudness.

```
[~,specificLoudnessHD] = acousticLoudness(audioIn,fs,'TimeVarying',true,'TimeResolution','high')
```

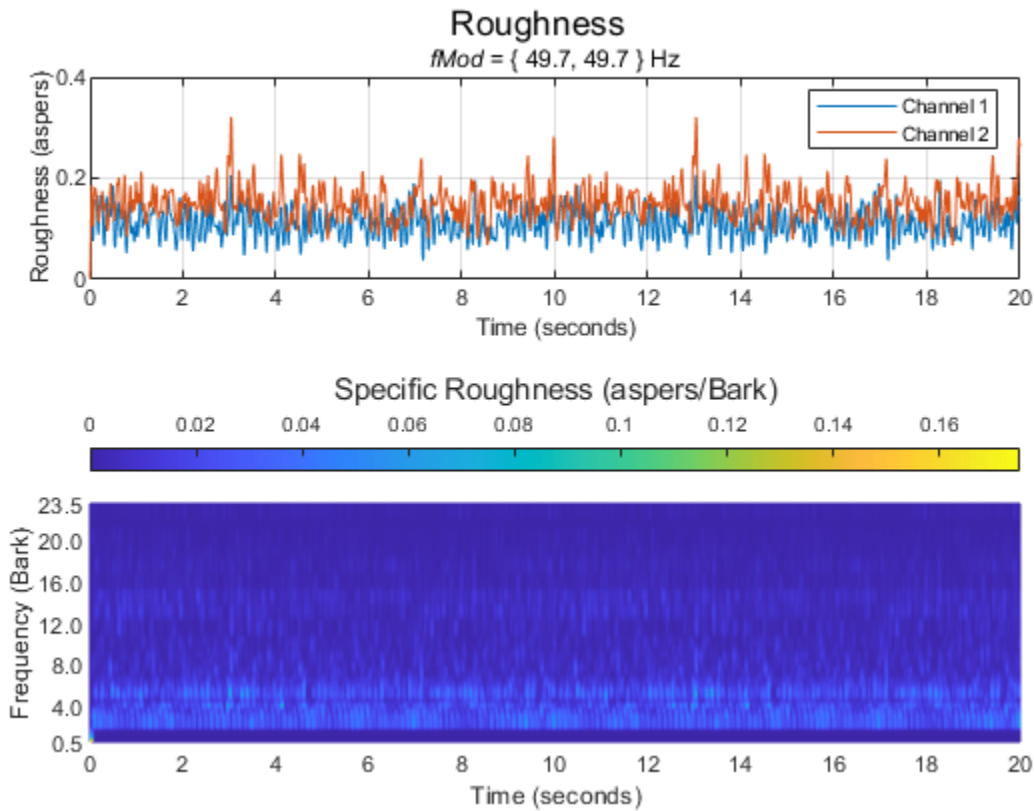
Call the `acousticSharpness` function using standard resolution specific loudness without any output arguments to plot the acoustic sharpness.

```
specificLoudness = specificLoudnessHD(1:4:end,:,:);
acousticSharpness(specificLoudness,'TimeVarying',true)
```



Call `acousticRoughness` without any outputs to plot the acoustic roughness.

```
acousticRoughness(specificLoudnessHD)
```



Effect of Frequency Modulation on Acoustic Roughness

Generate a pure tone with a 1500 Hz center frequency and approximately 700 Hz frequency deviation at a modulation frequency of 200 Hz.

```

fs = 48e3;

fMod = 200  ;
dur = 5  ;

numSamples = dur*fs;
t = (0:numSamples-1)/fs;

tone = sin(2*pi*t*fMod)';

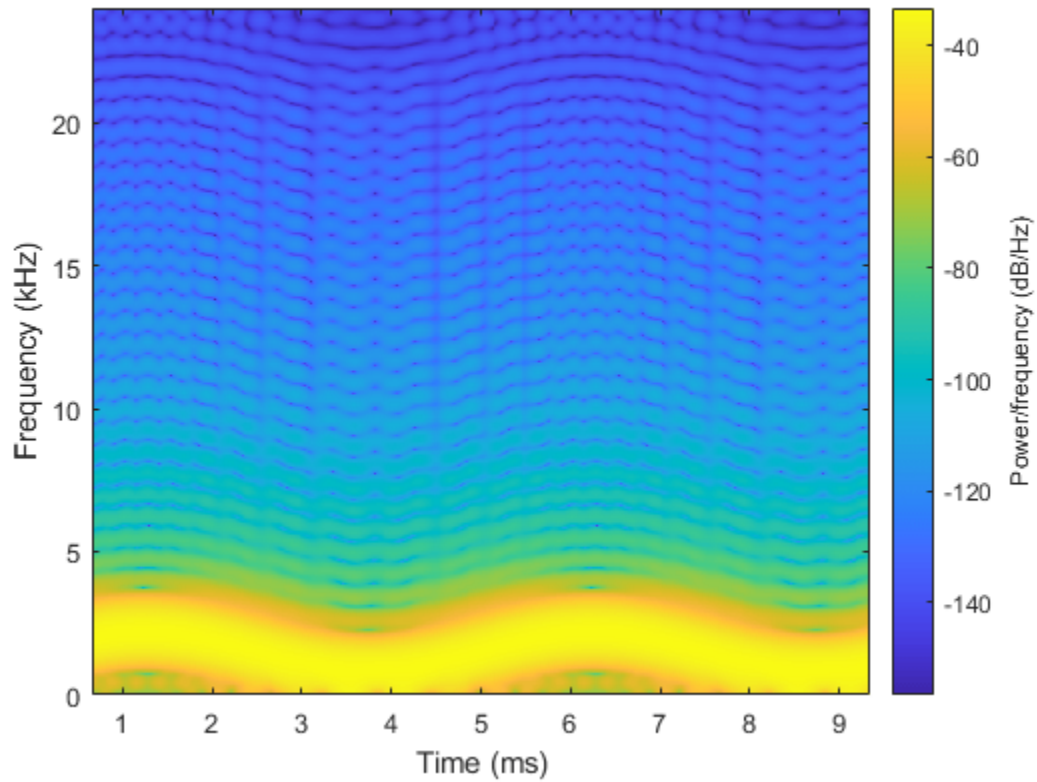
fc = 1500  ;
excursionRatio = 0.47  ;

excursion = 2*pi*(fc*excursionRatio/fs);
audioIn = modulate(tone,fc,fs,'fm',excursion);

```

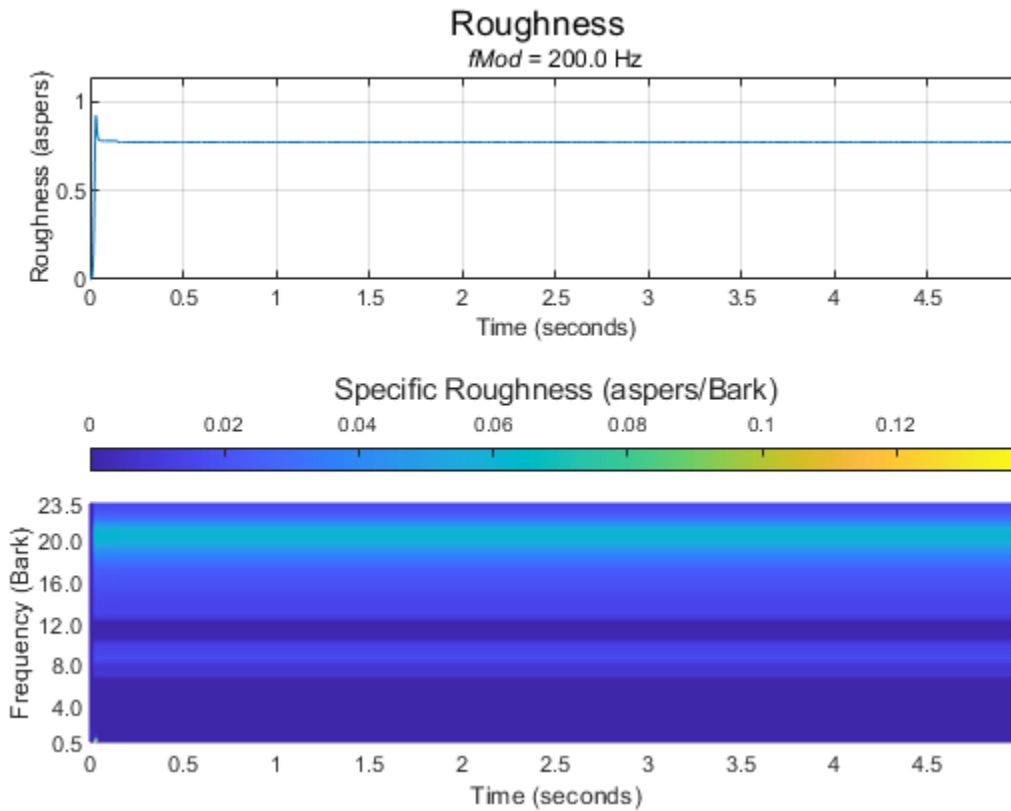
Listen to the audio and plot a spectrogram of the first 10 ms.

```
sound(audioIn, fs)  
spectrogram(audioIn(1:0.01*fs), hann(64, 'periodic'), 63, 1024, fs, 'yaxis')
```



Call the `acousticRoughness` function with no output arguments to plot the acoustic roughness strength.

```
acousticRoughness(audioIn, fs);
```



Specify Known Roughness Modulation Frequency

The `acousticRoughness` function enables you to specify a known roughness frequency. If you do not specify a known roughness frequency, the function auto detects the roughness.

Create a `dsp.AudioFileReader` object to read in an audio signal frame-by-frame. Create an `audioOscillator` object to create a modulation wave. Apply the modulation wave to the audio file.

```
fileReader = dsp.AudioFileReader('Engine-16-44p1-stereo-20sec.wav');
```

```
fMod = 72.41  ;
amplitude = 0.5  ;
```

```
osc = audioOscillator('sine',fMod, ...
    "DCOffset",0.5, ...
    "Amplitude",amplitude, ...
    "SampleRate",fileReader.SampleRate, ...
    "SamplesPerFrame",fileReader.SamplesPerFrame);
```

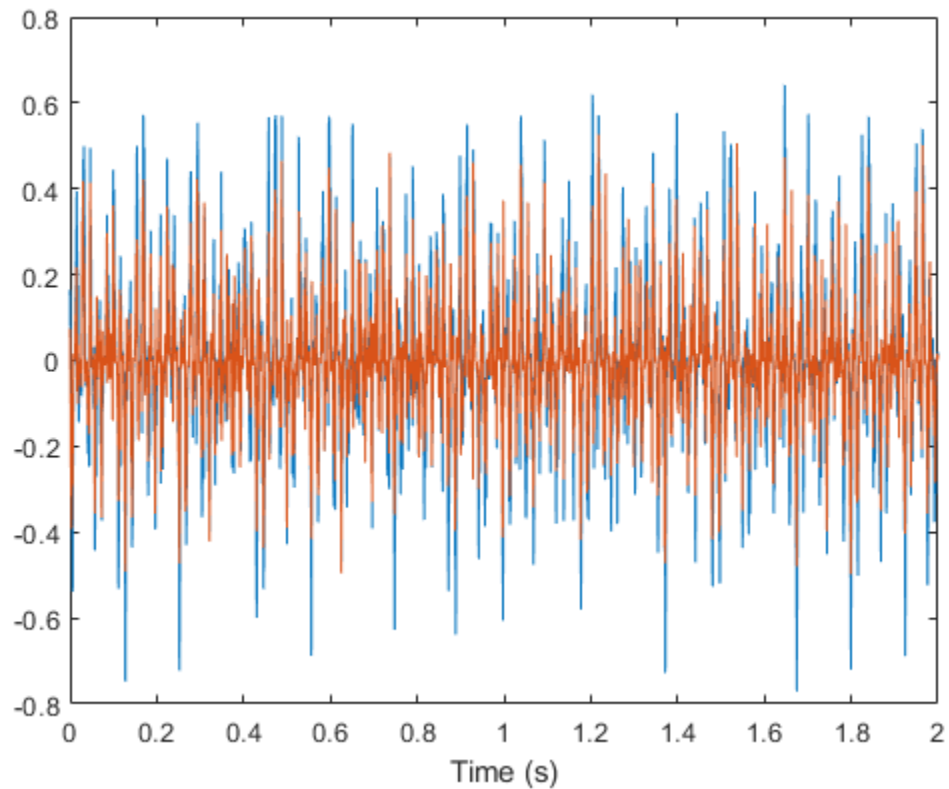
```
testSignal = [];
while ~isDone(fileReader)
    x = fileReader();
```



```
testSignal = [testSignal;osc().*fileReader()];  
end
```

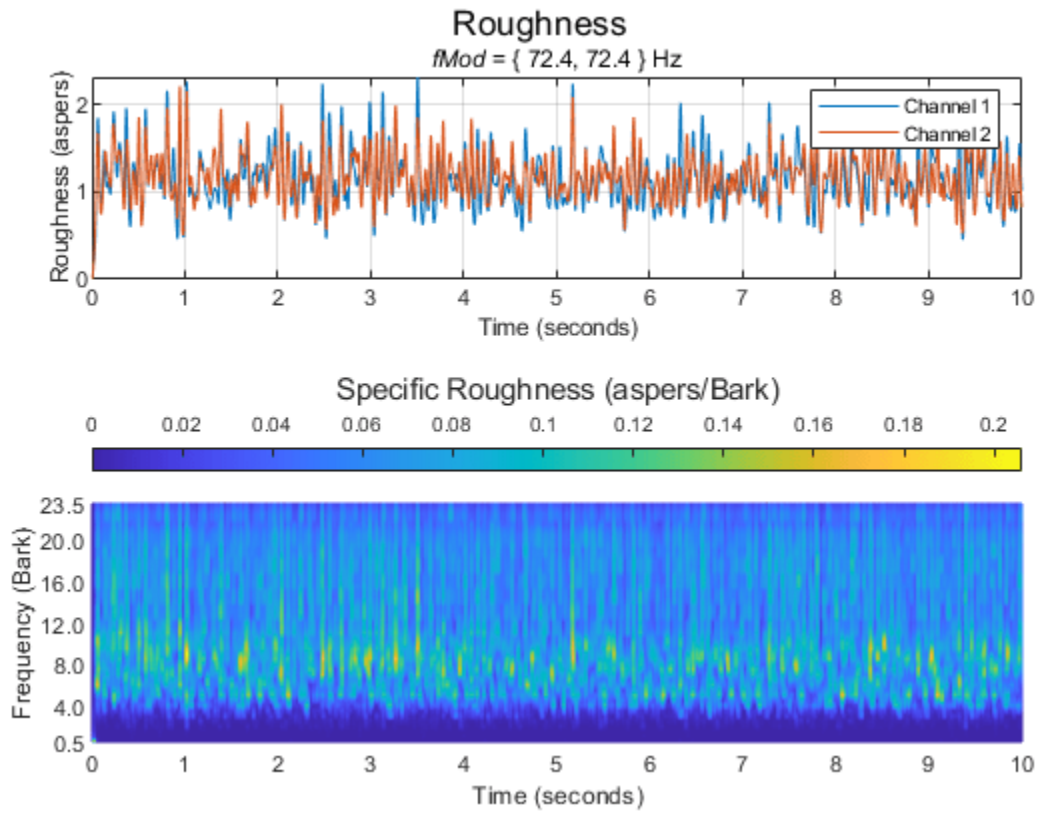
Listen to 2 seconds of the test signal and plot its waveform.

```
samplesToView = 1:2*fileReader.SampleRate;  
sound(testSignal(samplesToView,:),fileReader.SampleRate);  
  
plot(samplesToView/fileReader.SampleRate,testSignal(samplesToView,:))  
xlabel('Time (s)')
```



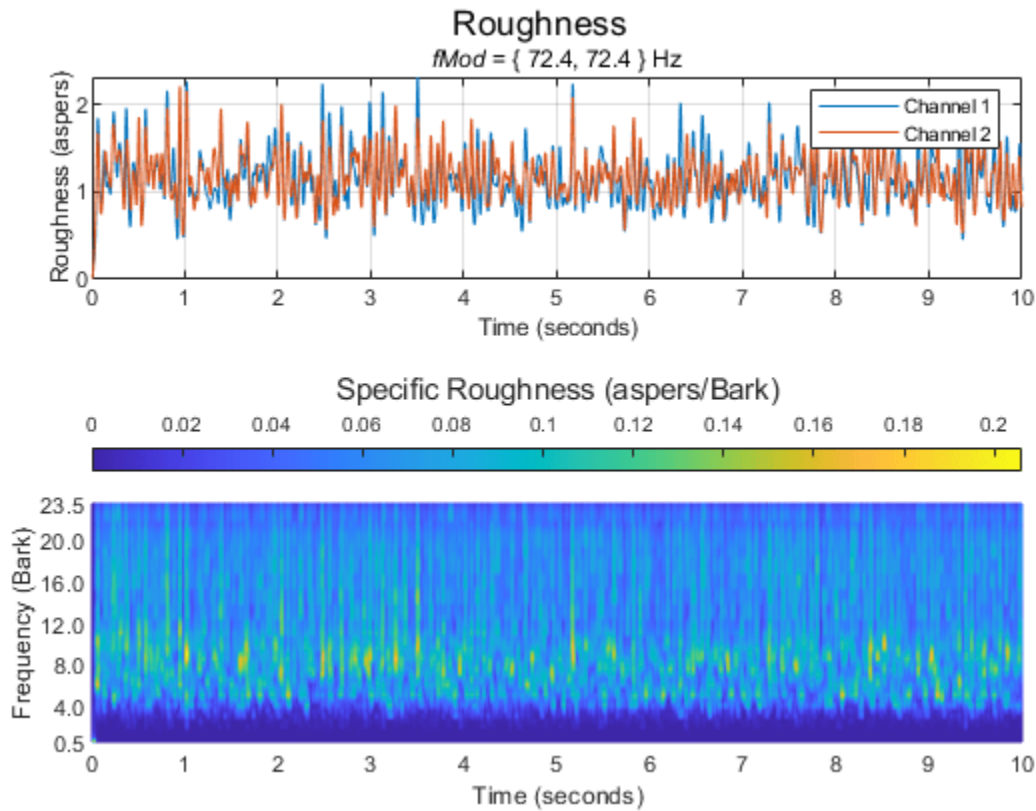
Plot the acoustic roughness. The detected frequency of the modulation is displayed textually.

```
acousticRoughness(testSignal,fileReader.SampleRate);
```



Specify the known modulation frequency and then plot the acoustic roughness again.

```
acousticRoughness(testSignal, fileReader.SampleRate, 'ModulationFrequency', fMod)
```



Input Arguments

audioIn – Audio input

column vector | two-column matrix

Audio input, specified as a column vector (mono) or matrix with two columns (stereo).

Tip To measure roughness strength given any modulation frequency, the recommended minimum signal duration is 0.5 seconds.

Data Types: single | double

fs – Sample rate (Hz)

positive scalar

Sample rate in Hz, specified as a positive scalar. The recommended sample rate for new recordings is 48 kHz.

Note The minimum acceptable sample rate is 8 kHz.

Data Types: single | double

calibrationFactor — Microphone calibration factor

sqrt(8) | positive scalar

Microphone calibration factor, specified as a positive scalar. The default calibration factor corresponds to a full-scale 1 kHz sine wave with a sound pressure level of 100 dB (SPL). To compute the calibration factor specific to your system, use the `calibrateMicrophone` function.

Data Types: single | double

specificLoudnessIn — Specific loudness (sones/Bark)*T*-by-240-by-*C*

Specific loudness in sones/Bark, specified as a *T*-by-240-by-*C* array, where:

- *T* is 1 per 0.5 ms of the time-varying signal (high resolution loudness).
- 240 is the number of Bark bins in the domain for specific loudness. The Bark bins are 0.1:0.1:24.
- *C* is the number of channels.

You can use the `acousticLoudness` function to calculate time varying specific loudness using this syntax.

```
[~,specificLoudness] = acousticLoudness(audioIn,fs,'TimeVarying',true,'TimeResolution','high');
```

Data Types: single | double

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `acousticRoughness(audioIn,fs,'ModulationFrequency',100)`

ModulationFrequency — Known roughness modulation frequency (Hz)

'auto-detect' (default) | scalar or two-element vector with values in the range [1,1000]

Known modulation frequency in Hz, specified as the comma-separated pair consisting of 'ModulationFrequency' and a scalar or two-element vector with values in the range [1,1000].

Set ModulationFrequency to:

- 'auto-detect' when you want the function to detect the modulation frequency automatically. When you select this option the function limits the search range to between 10 and 400 Hz.
- a scalar if the input is mono.
- a scalar or two-element vector if the input is stereo.

Data Types: single | double | char | string

SoundField — Sound field

'free' (default) | 'diffuse'

Sound field of audio recording, specified as the comma-separated pair of 'SoundField' and 'free' or 'diffuse'.

Data Types: char | string

PressureReference — Reference pressure (Pa)

20e-6 (default) | positive scalar

Reference pressure for dB calculation in pascals, specified as the comma-separated pair of 'PressureReference' and a positive scalar. The default value, 20 micropascals, is the common value of air.

Data Types: single | double

Output Arguments

roughness — Roughness strength (asper)

K -by-1 | K -by-2

Roughness strength in asper, returned as a K -by-1 column vector or K -by-2 matrix of independent channels. K corresponds to the time dimension.

Note Roughness is reported for each channel independently at every 0.5 ms interval.

Data Types: single | double

specificRoughness — Specific roughness strength (asper/Bark)

K -by-47 matrix | K -by-47-by-2 array

Specific roughness strength in asper/Bark, returned as a K -by-47 matrix or a K -by-47-by-2 array. The first dimension of `specificRoughness`, K , corresponds to the time dimension and matches the first dimension of `roughness`. The second dimension of `specificRoughness`, 47, corresponds to bands on the Bark scale, with centers in the range of [0.5, 23.5], in increments of 0.5. The third dimension of `specificRoughness` corresponds to the number of channels and matches the second dimension of `roughness`.

Data Types: single | double

fMod — Dominant modulation frequency (Hz)

scalar (mono input) | 1-by-2 vector (stereo input)

Dominant modulation frequency in Hz, returned as a scalar for mono input or a 1-by-2 vector for stereo input.

Data Types: single | double

Algorithms

Acoustic roughness strength is a perceptual measurement of modulations in amplitude or frequency that are too high to discern separately. The acoustic loudness algorithm is described in [2] and implemented in the `acousticLoudness` function. The acoustic roughness calculation is described in [1]. The algorithm for acoustic roughness defines the roughness of 1 asper as a 1 kHz tone at 60 dB with a 100% amplitude modulation at 70 Hz [3]. The algorithm is outlined as follows:

$$roughness = cal \int_{z=0}^{24} f_{mod} \Delta L dz$$

Where f_{mod} is the detected or known modulation frequency, cal is a constant ensuring unity roughness of the reference signal, and ΔL is the perceived modulation depth. If the modulation frequency is not specified when calling `acousticRoughness`, it is auto-detected by peak-picking a frequency-domain representation of the acoustic loudness. The perceived modulation depth ΔL is calculated by passing rectified specific loudness bands through $\frac{1}{2}$ octave filters centered around f_{mod} , followed by a lowpass filter to determine the envelope.

References

- [1] Zwicker, Eberhard, and Hugo Fastl. *Psychoacoustics: Facts and Models*. Vol. 22. Springer Science & Business Media, 2013.
- [2] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [3] Kalafata, Stamatina. "Sound Levels, Noise Source Identification and Perceptual Analysis in an Intensive Care Unit." Master's thesis, University of Gothenburg, 2014.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Sample rate must be known (constant) at compile-time.

See Also

`acousticFluctuation` | `acousticLoudness` | `acousticSharpness` | `calibrateMicrophone`

Topics

"Effect of Soundproofing on Perceived Noise Levels"

Introduced in R2021a

vggish

VGGish neural network

Syntax

```
net = vggish
```

Description

`net = vggish` returns a pretrained VGGish model.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download VGGish Network

Download and unzip the Audio Toolbox™ model for VGGish.

Type `vggish` at the Command Window. If the Audio Toolbox model for VGGish is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute these commands to download and unzip the VGGish model to your temporary directory.

```
downloadFolder = fullfile(tempdir, 'VGGishDownload');
loc = websave(downloadFolder, 'https://ssd.mathworks.com/supportfiles/audio/vggish.zip');
VGGishLocation = tempdir;
unzip(loc, VGGishLocation)
addpath(fullfile(VGGishLocation, 'vggish'))
```

Check that the installation is successful by typing `vggish` at the Command Window. If the network is installed, then the function returns a `SeriesNetwork` (Deep Learning Toolbox) object.

```
vggish
```

```
ans =
  SeriesNetwork with properties:

    Layers: [24×1 nnet.cnn.layer.Layer]
  InputNames: {'InputBatch'}
  OutputNames: {'regressionoutput'}
```

Load Pretrained VGGish Network

Load a pretrained VGGish convolutional neural network and examine the layers and classes.

Use `vggish` to load the pretrained VGGish network. The output `net` is a `SeriesNetwork` (Deep Learning Toolbox) object.

```
net = vggish

net =
  SeriesNetwork with properties:

    Layers: [24x1 nnet.cnn.layer.Layer]
  InputNames: {'InputBatch'}
  OutputNames: {'regressionoutput'}
```

View the network architecture using the `Layers` property. The network has 24 layers. There are nine layers with learnable weights, of which six are convolutional layers and three are fully connected layers.

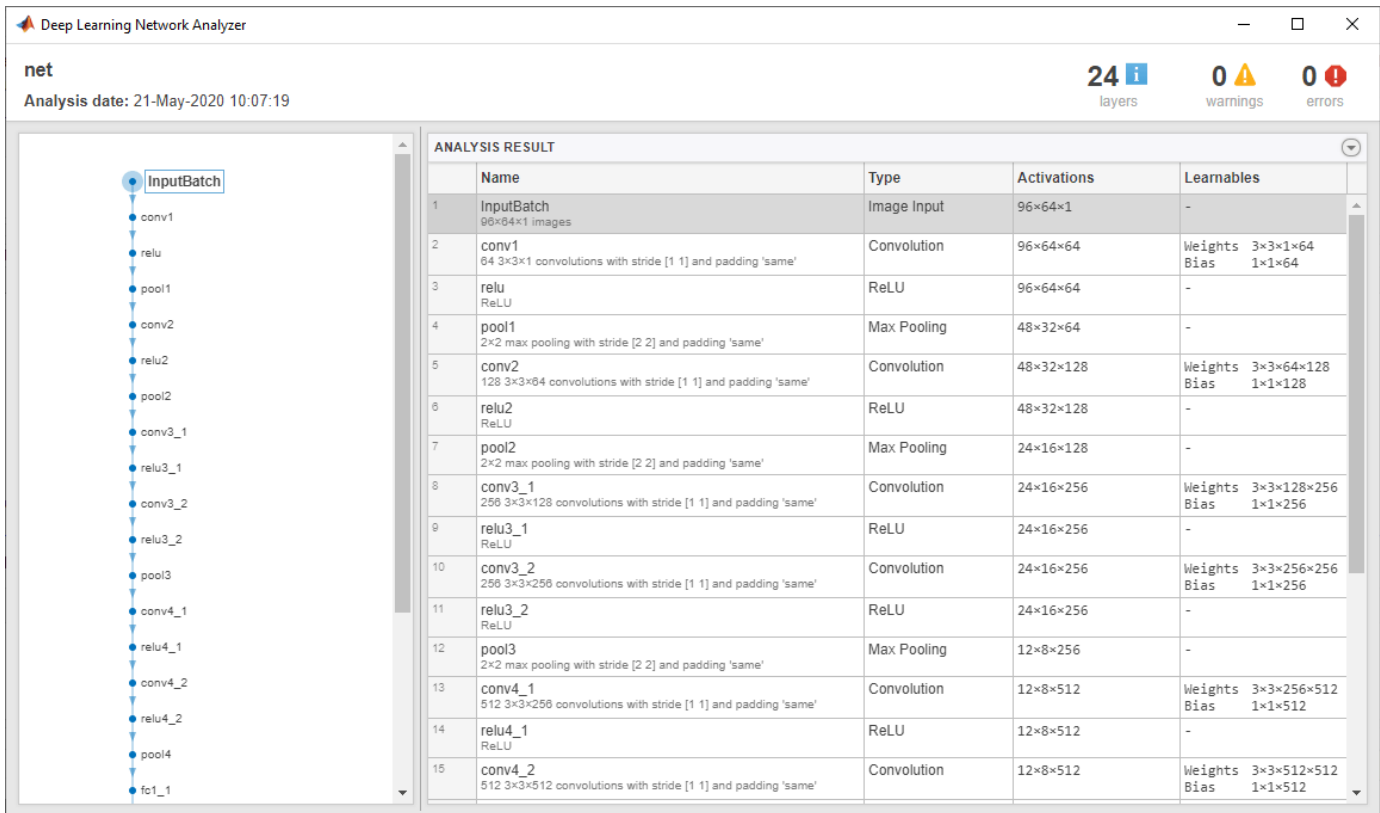
```
net.Layers
```

```
ans =
  24x1 Layer array with layers:

     1  'InputBatch'      Image Input      96x64x1 images
     2  'conv1'          Convolution      64 3x3x1 convolutions with stride [1 1] and padding
     3  'relu'           ReLU             ReLU
     4  'pool1'          Max Pooling      2x2 max pooling with stride [2 2] and padding
     5  'conv2'          Convolution      128 3x3x64 convolutions with stride [1 1] and padding
     6  'relu2'          ReLU             ReLU
     7  'pool2'          Max Pooling      2x2 max pooling with stride [2 2] and padding
     8  'conv3_1'        Convolution      256 3x3x128 convolutions with stride [1 1] and padding
     9  'relu3_1'        ReLU             ReLU
    10  'conv3_2'        Convolution      256 3x3x256 convolutions with stride [1 1] and padding
    11  'relu3_2'        ReLU             ReLU
    12  'pool3'          Max Pooling      2x2 max pooling with stride [2 2] and padding
    13  'conv4_1'        Convolution      512 3x3x256 convolutions with stride [1 1] and padding
    14  'relu4_1'        ReLU             ReLU
    15  'conv4_2'        Convolution      512 3x3x512 convolutions with stride [1 1] and padding
    16  'relu4_2'        ReLU             ReLU
    17  'pool4'          Max Pooling      2x2 max pooling with stride [2 2] and padding
    18  'fc1_1'          Fully Connected  4096 fully connected layer
    19  'relu5_1'        ReLU             ReLU
    20  'fc1_2'          Fully Connected  4096 fully connected layer
    21  'relu5_2'        ReLU             ReLU
    22  'fc2'            Fully Connected  128 fully connected layer
    23  'EmbeddingBatch' ReLU             ReLU
    24  'regressionoutput' Regression Output mean-squared-error
```

Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

```
analyzeNetwork(net)
```

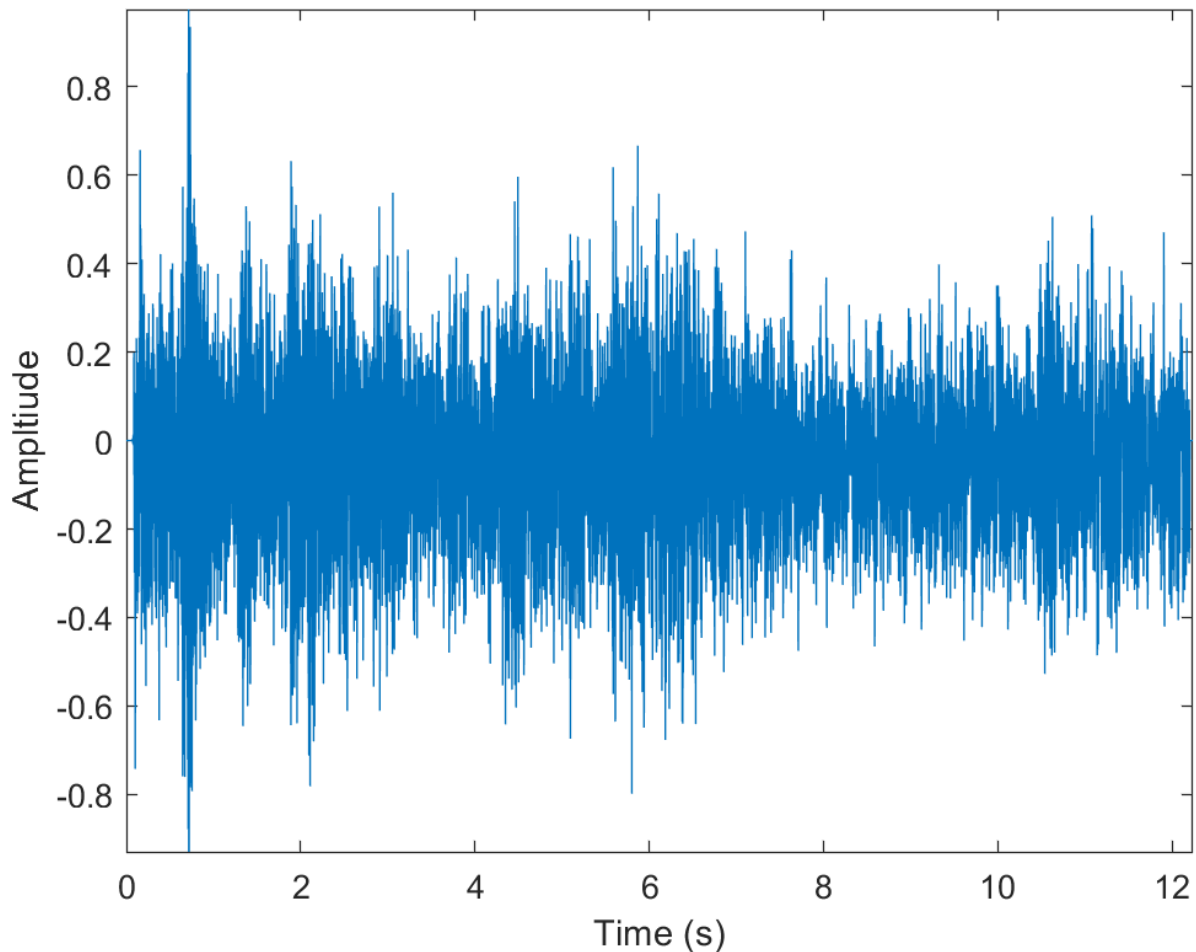
Extract Features Using VGGish

Read in an audio signal to extract feature embeddings from it.

```
[audioIn, fs] = audioread(Ambiance-16-44p1-...);
```

Plot and listen to the audio signal.

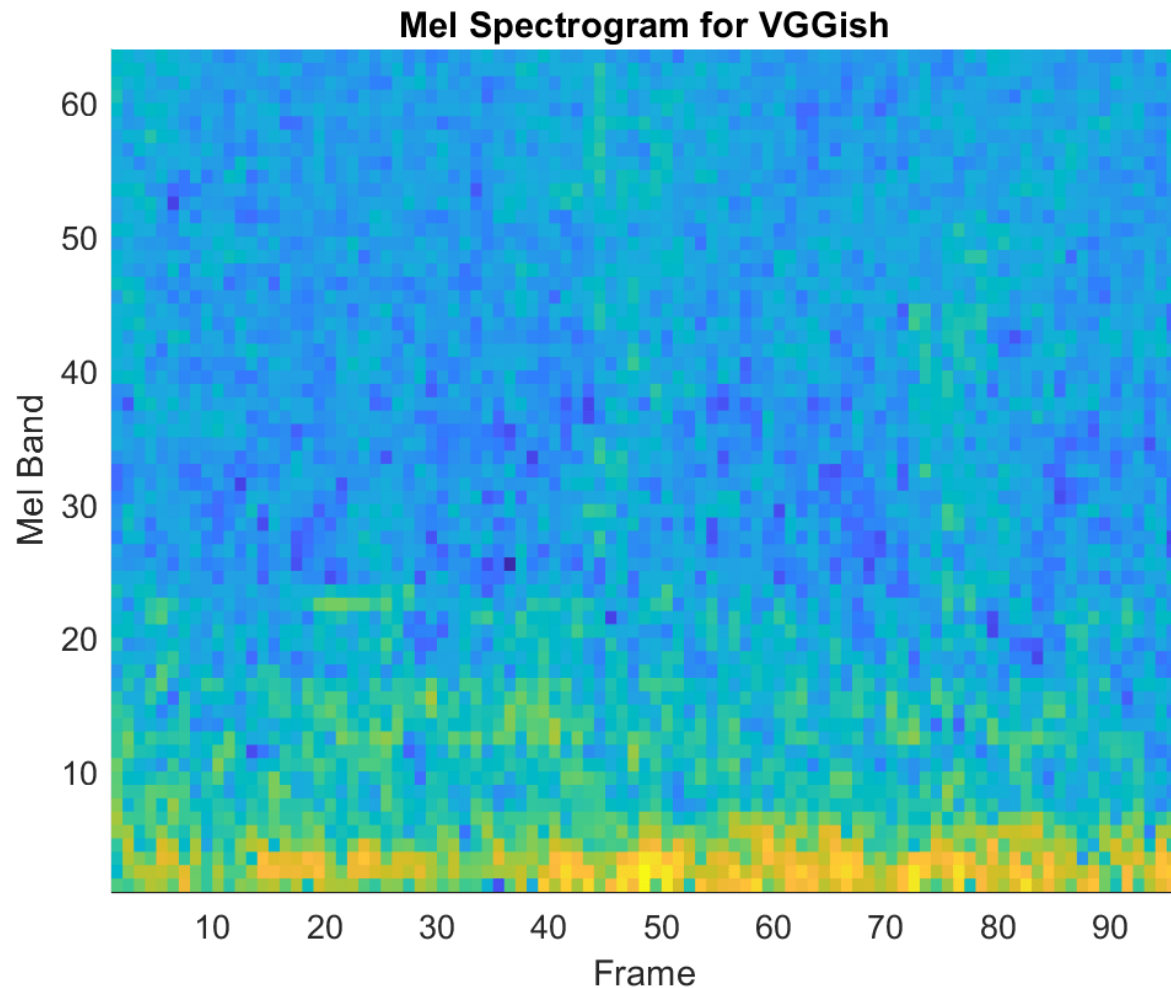
```
t = (0:numel(audioIn)-1)/fs;
plot(t, audioIn)
xlabel("Time (s)")
ylabel("Amplitude")
axis tight
```



```
% To play the sound, call soundsc(audioIn,fs)
```

VGGish requires you to preprocess the audio signal to match the input format used to train the network. The preprocessing steps include resampling the audio signal and computing an array of mel spectrograms. To learn more about mel spectrograms, see `melSpectrogram`. Use `vggishPreprocess` to preprocess the signal and extract the mel spectrograms to be passed to VGGish. Visualize one of these spectrograms chosen at random.

```
spectrograms = vggishPreprocess(audioIn,fs);  
  
arbitrarySpect = spectrograms(:,:,1,randi(size(spectrograms,4)));  
surf(arbitrarySpect,EdgeColor="none")  
view(90,-90)  
xlabel("Mel Band")  
ylabel("Frame")  
title("Mel Spectrogram for VGGish")  
axis tight
```



Create a VGGish neural network. Using the `vggish` function requires installing the pretrained VGGish network. If the network is not installed, the function provides a link to download the pretrained model.

```
net = vggish;
```

Call `predict` with the network on the preprocessed mel spectrogram images to extract feature embeddings. The feature embeddings are returned as a `numFrames`-by-128 matrix, where `numFrames` is the number of individual spectrograms and 128 is the number of elements in each feature vector.

```
features = predict(net,spectrograms);  
[numFrames,numFeatures] = size(features)
```

```
numFrames = 24
```

```
numFeatures = 128
```

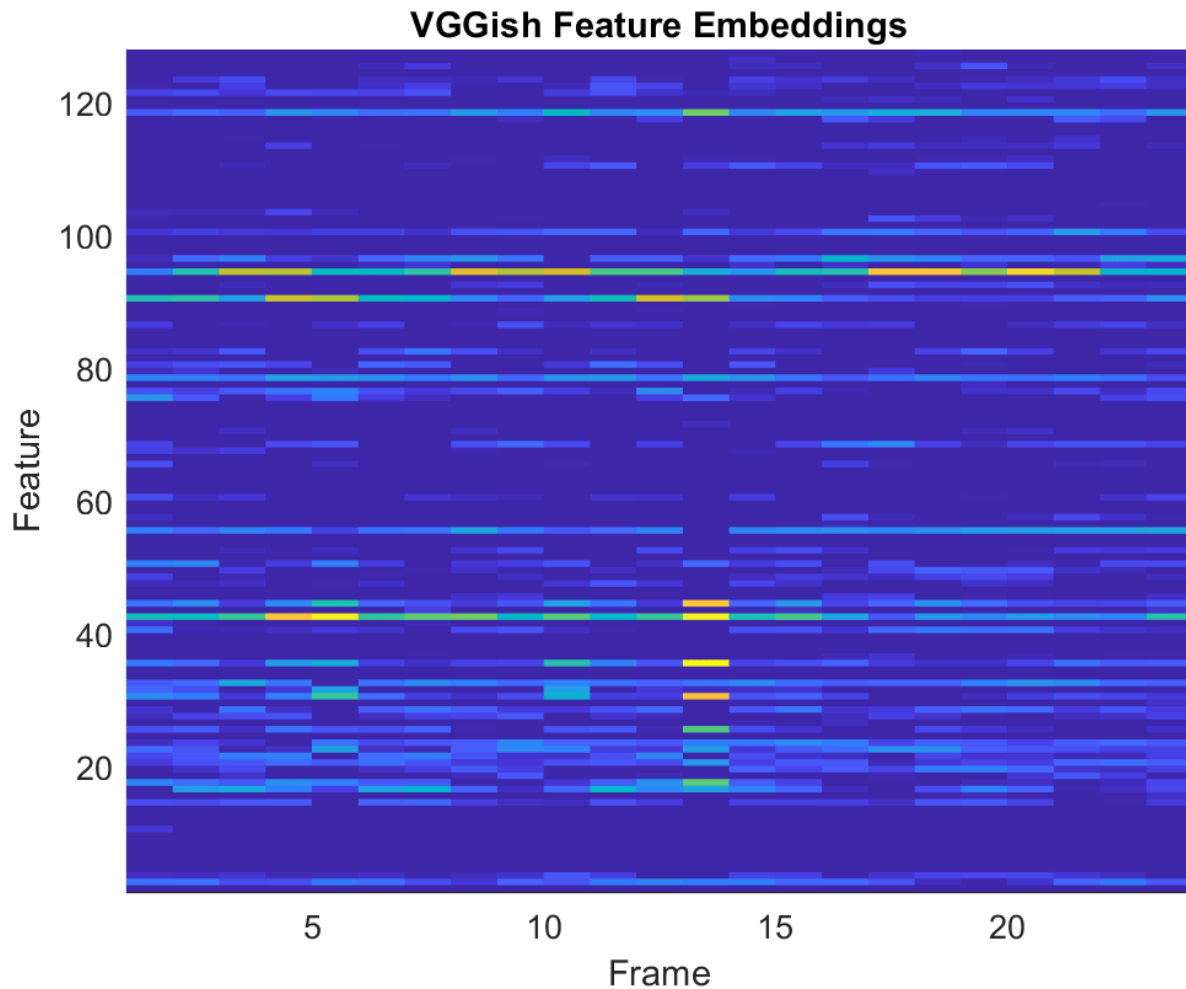
Visualize the VGGish feature embeddings.

```
surf(features,EdgeColor="none")  
view([90 -90])
```

```

xlabel("Feature")
ylabel("Frame")
title("VGGish Feature Embeddings")
axis tight

```



Transfer Learning Using VGGish

In this example, you transfer the learning in the VGGish regression model to an audio classification task.

Download and unzip the environmental sound classification data set. This data set consists of recordings labeled as one of 10 different audio sound classes (ESC-10).

```

url = 'http://ssd.mathworks.com/supportfiles/audio/ESC-10.zip';
downloadFolder = fullfile(tempdir, 'ESC-10');
datasetLocation = tempdir;

if ~exist(fullfile(tempdir, 'ESC-10'), 'dir')

```

```

loc = websave(downloadFolder,url);
unzip(loc,fullfile(tempdir,'ESC-10'))
end

```

Create an `audioDatastore` object to manage the data and split it into train and validation sets. Call `countEachLabel` to display the distribution of sound classes and the number of unique labels.

```

ads = audioDatastore(downloadFolder,'IncludeSubfolders',true,'LabelSource','foldernames');
labelTable = countEachLabel(ads)

```

```

labelTable=10x2 table
      Label      Count
      -----      -
chainsaw          40
clock_tick        40
crackling_fire    40
crying_baby       40
dog               40
helicopter        40
rain              40
rooster           38
sea_waves         40
sneezing          40

```

Determine the total number of classes.

```
numClasses = size(labelTable,1);
```

Call `splitEachLabel` to split the data set into training and validation sets. Inspect the distribution of labels in the training and validation sets.

```
[adsTrain, adsValidation] = splitEachLabel(ads,0.8);
```

```
countEachLabel(adsTrain)
```

```

ans=10x2 table
      Label      Count
      -----      -
chainsaw          32
clock_tick        32
crackling_fire    32
crying_baby       32
dog               32
helicopter        32
rain              32
rooster           30
sea_waves         32
sneezing          32

```

```
countEachLabel(adsValidation)
```

```

ans=10x2 table
      Label      Count
      -----      -

```

```

chainsaw          8
clock_tick        8
crackling_fire   8
crying_baby       8
dog               8
helicopter        8
rain              8
rooster           8
sea_waves         8
sneezing          8

```

The VGGish network expects audio to be preprocessed into log mel spectrograms. The supporting function `vggishPreprocess` on page 2-0 takes an `audioDatastore` object and the overlap percentage between log mel spectrograms as input, and returns matrices of predictors and responses suitable as input to the VGGish network.

```
overlapPercentage = 75 _____ ▾;
```

```
[trainFeatures,trainLabels] = vggishPreprocess(adsTrain,overlapPercentage);
[validationFeatures,validationLabels,segmentsPerFile] = vggishPreprocess(adsValidation,overlapPe
```

Load the VGGish model and convert it to a `layerGraph` (Deep Learning Toolbox) object.

```
net = vggish;

lgraph = layerGraph(net.Layers);
```

Use `removeLayers` (Deep Learning Toolbox) to remove the final regression output layer from the graph. After you remove the regression layer, the new final layer of the graph is a ReLU layer named 'EmbeddingBatch'.

```
lgraph = removeLayers(lgraph,'regressionoutput');
lgraph.Layers(end)
```

```
ans =
  ReLULayer with properties:
    Name: 'EmbeddingBatch'
```

Use `addLayers` (Deep Learning Toolbox) to add a `fullyConnectedLayer` (Deep Learning Toolbox), a `softmaxLayer` (Deep Learning Toolbox), and a `classificationLayer` (Deep Learning Toolbox) to the graph.

```
lgraph = addLayers(lgraph,fullyConnectedLayer(numClasses,'Name','FCFinal'));
lgraph = addLayers(lgraph,softmaxLayer('Name','softmax'));
lgraph = addLayers(lgraph,classificationLayer('Name','classOut'));
```

Use `connectLayers` (Deep Learning Toolbox) to append the fully connected, softmax, and classification layers to the layer graph.

```
lgraph = connectLayers(lgraph,'EmbeddingBatch','FCFinal');
lgraph = connectLayers(lgraph,'FCFinal','softmax');
lgraph = connectLayers(lgraph,'softmax','classOut');
```

To define training options, use `trainingOptions` (Deep Learning Toolbox).

```

miniBatchSize = 128;
options = trainingOptions('adam', ...
    'MaxEpochs',5, ...
    'MiniBatchSize',miniBatchSize, ...
    'Shuffle','every-epoch', ...
    'ValidationData',{validationFeatures,validationLabels}, ...
    'ValidationFrequency',50, ...
    'LearnRateSchedule','piecewise', ...
    'LearnRateDropFactor',0.5, ...
    'LearnRateDropPeriod',2);

```

To train the network, use `trainNetwork` (Deep Learning Toolbox).

```
[trainedNet, netInfo] = trainNetwork(trainFeatures,trainLabels,lgraph,options);
```

Training on single GPU.

Epoch	Iteration	Time Elapsed (hh:mm:ss)	Mini-batch Accuracy	Validation Accuracy	Mini-batch Loss	Validation Loss
1	1	00:00:00	10.94%	26.03%	2.2253	2.0
2	50	00:00:05	93.75%	83.75%	0.1884	0.7
3	100	00:00:10	96.88%	80.07%	0.1150	0.7
4	150	00:00:15	92.97%	81.99%	0.1656	0.7
5	200	00:00:20	92.19%	79.04%	0.1738	0.8
5	210	00:00:21	95.31%	80.15%	0.1389	0.8

Each audio file was split into several segments to feed into the VGGish network. Combine the predictions for each file in the validation set using a majority-rule decision.

```
validationPredictions = classify(trainedNet,validationFeatures);
```

```

idx = 1;
validationPredictionsPerFile = categorical;
for ii = 1:numel(adsValidation.Files)
    validationPredictionsPerFile(ii,1) = mode(validationPredictions(idx:idx+segmentsPerFile(ii))-
        idx = idx + segmentsPerFile(ii);
end

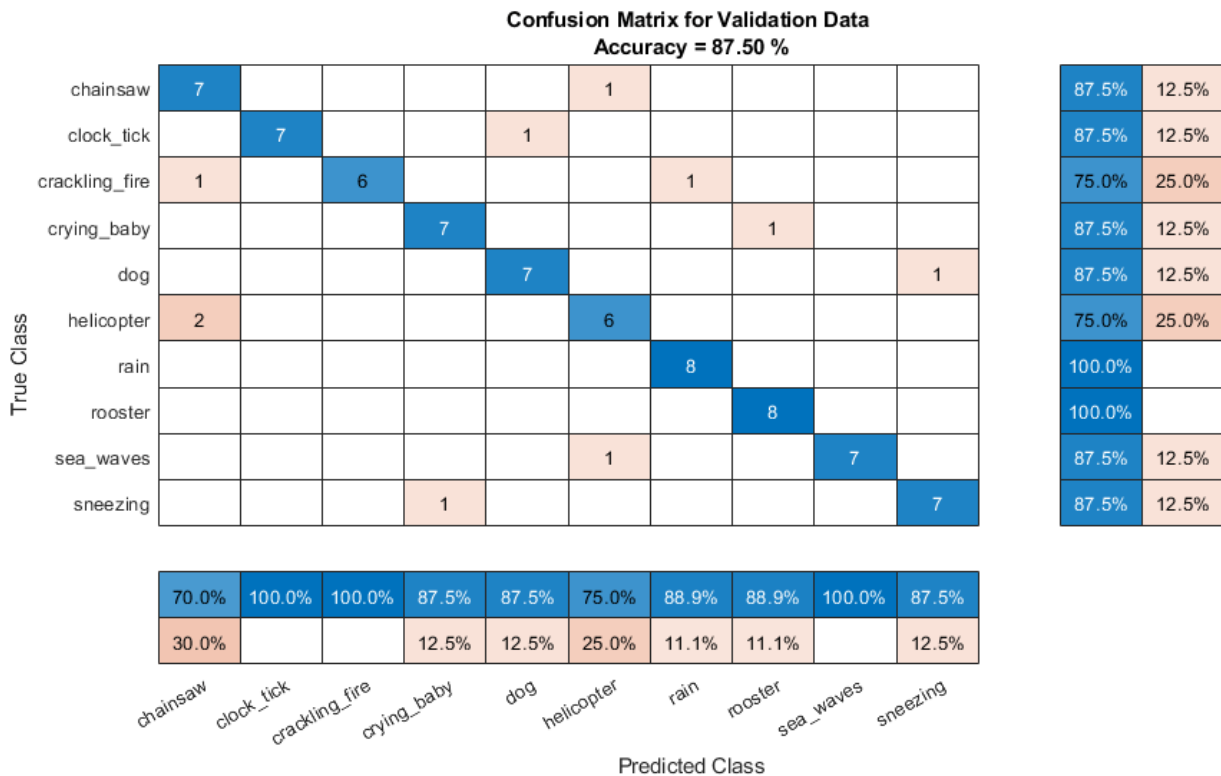
```

Use `confusionchart` (Deep Learning Toolbox) to evaluate the performance of the network on the validation set.

```

figure('Units','normalized','Position',[0.2 0.2 0.5 0.5]);
cm = confusionchart(adsValidation.Labels,validationPredictionsPerFile);
cm.Title = sprintf('Confusion Matrix for Validation Data \nAccuracy = %0.2f %%',mean(validationP
cm.ColumnSummary = 'column-normalized';
cm.RowSummary = 'row-normalized';

```



Supporting Functions

```
function [predictor, response, segmentsPerFile] = vggishPreprocess(ads, overlap)
% This function is for example purposes only and may be changed or removed
% in a future release.
```

```
% Create filter bank
FFTLength = 512;
numBands = 64;
fs0 = 16e3;
filterBank = designAuditoryFilterBank(fs0, ...
    'FrequencyScale', 'mel', ...
    'FFTLength', FFTLength, ...
    'FrequencyRange', [125 7500], ...
    'NumBands', numBands, ...
    'Normalization', 'none', ...
    'FilterBankDesignDomain', 'warped');
```

```
% Define STFT parameters
windowLength = 0.025 * fs0;
hopLength = 0.01 * fs0;
win = hann(windowLength, 'periodic');
```

```
% Define spectrogram segmentation parameters
segmentDuration = 0.96; % seconds
segmentRate = 100; % hertz
segmentLength = segmentDuration * segmentRate; % Number of spectrums per auditory spectrograms
segmentHopDuration = (100 - overlap) * segmentDuration / 100; % Duration (s) advanced between audi
segmentHopLength = round(segmentHopDuration * segmentRate); % Number of spectrums advanced between
```



```

% Preallocate cell arrays for the predictors and responses
numFiles = numel(ads.Files);
predictor = cell(numFiles,1);
response = predictor;
segmentsPerFile = zeros(numFiles,1);

% Extract predictors and responses for each file
for ii = 1:numFiles
    [audioIn,info] = read(ads);

    x = single(resample(audioIn,fs0,info.SampleRate));

    Y = stft(x, ...
            'Window',win, ...
            'OverlapLength',windowLength-hopLength, ...
            'FFTLength',FFTLength, ...
            'FrequencyRange','onesided');
    Y = abs(Y);

    logMelSpectrogram = log(filterBank*Y + single(0.01));

    % Segment log-mel spectrogram
    numHops = floor((size(Y,2)-segmentLength)/segmentHopLength) + 1;
    segmentedLogMelSpectrogram = zeros(segmentLength,numBands,1,numHops);
    for hop = 1:numHops
        segmentedLogMelSpectrogram(:,:,1,hop) = logMelSpectrogram(1+segmentHopLength*(hop-1):segmentLength,info.NumBands,hop);
    end

    predictor{ii} = segmentedLogMelSpectrogram;
    response{ii} = repelem(info.Label,numHops);
    segmentsPerFile(ii) = numHops;
end

% Concatenate predictors and responses into arrays
predictor = cat(4,predictor{:});
response = cat(2,response{:});
end

```

Output Arguments

net — Pretrained VGGish neural network

SeriesNetwork object

Pretrained VGGish neural network, returned as a SeriesNetwork object.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. 2017. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. 2017. "CNN Architectures for Large-Scale Audio Classification."

In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131-35. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Only the `activations` and `predict` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (MATLAB Coder).

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- Only the `activations`, `classify`, `predict`, `predictAndUpdateState`, and `resetState` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (GPU Coder).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

`audioFeatureExtractor` | `classifySound` | `melSpectrogram` | `vggishFeatures` | `vggishPreprocess` | `yamnet` | `yamnetGraph` | `yamnetPreprocess`

Introduced in R2020b

yamnet

YAMNet neural network

Syntax

```
net = yamnet
```

Description

`net = yamnet` returns a pretrained YAMNet model.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download YAMNet

Download and unzip the Audio Toolbox™ model for YAMNet.

Type `yamnet` at the Command Window. If the Audio Toolbox model for YAMNet is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the YAMNet model to your temporary directory.

```
downloadFolder = fullfile(tempdir, 'YAMNetDownload');  
loc = websave(downloadFolder, 'https://ssd.mathworks.com/supportfiles/audio/yamnet.zip');  
YAMNetLocation = tempdir;  
unzip(loc, YAMNetLocation)  
addpath(fullfile(YAMNetLocation, 'yamnet'))
```

Check that the installation is successful by typing `yamnet` at the Command Window. If the network is installed, then the function returns a `SeriesNetwork` (Deep Learning Toolbox) object.

```
yamnet
```

```
ans =  
SeriesNetwork with properties:  
  
    Layers: [86x1 nnet.cnn.layer.Layer]  
  InputNames: {'input_1'}  
 OutputNames: {'Sound'}
```

Load Pretrained YAMNet

Load a pretrained YAMNet convolutional neural network and examine the layers and classes.

Use `yamnet` to load the pretrained YAMNet network. The output net is a `SeriesNetwork` (Deep Learning Toolbox) object.

```
net = yamnet

net =
  SeriesNetwork with properties:

    Layers: [86x1 nnet.cnn.layer.Layer]
  InputNames: {'input_1'}
  OutputNames: {'Sound'}
```

View the network architecture using the `Layers` property. The network has 86 layers. There are 28 layers with learnable weights: 27 convolutional layers, and 1 fully connected layer.

```
net.Layers
```

```
ans =
  86x1 Layer array with layers:

   1  'input_1'           Image Input           96x64x1 images
   2  'conv2d'           Convolution           32 3x3x1 convolutions with stride
   3  'b'                Batch Normalization  Batch normalization with 32 channels
   4  'activation'       ReLU                  ReLU
   5  'depthwise_conv2d' Grouped Convolution  32 groups of 1 3x3x1 convolutions
   6  'L11'              Batch Normalization  Batch normalization with 32 channels
   7  'activation_1'     ReLU                  ReLU
   8  'conv2d_1'         Convolution           64 1x1x32 convolutions with stride
   9  'L12'              Batch Normalization  Batch normalization with 64 channels
  10  'activation_2'     ReLU                  ReLU
  11  'depthwise_conv2d_1' Grouped Convolution  64 groups of 1 3x3x1 convolutions
  12  'L21'              Batch Normalization  Batch normalization with 64 channels
  13  'activation_3'     ReLU                  ReLU
  14  'conv2d_2'         Convolution           128 1x1x64 convolutions with stride
  15  'L22'              Batch Normalization  Batch normalization with 128 channels
  16  'activation_4'     ReLU                  ReLU
  17  'depthwise_conv2d_2' Grouped Convolution  128 groups of 1 3x3x1 convolutions
  18  'L31'              Batch Normalization  Batch normalization with 128 channels
  19  'activation_5'     ReLU                  ReLU
  20  'conv2d_3'         Convolution           128 1x1x128 convolutions with stride
  21  'L32'              Batch Normalization  Batch normalization with 128 channels
  22  'activation_6'     ReLU                  ReLU
  23  'depthwise_conv2d_3' Grouped Convolution  128 groups of 1 3x3x1 convolutions
  24  'L41'              Batch Normalization  Batch normalization with 128 channels
  25  'activation_7'     ReLU                  ReLU
  26  'conv2d_4'         Convolution           256 1x1x128 convolutions with stride
  27  'L42'              Batch Normalization  Batch normalization with 256 channels
  28  'activation_8'     ReLU                  ReLU
  29  'depthwise_conv2d_4' Grouped Convolution  256 groups of 1 3x3x1 convolutions
  30  'L51'              Batch Normalization  Batch normalization with 256 channels
  31  'activation_9'     ReLU                  ReLU
  32  'conv2d_5'         Convolution           256 1x1x256 convolutions with stride
  33  'L52'              Batch Normalization  Batch normalization with 256 channels
  34  'activation_10'    ReLU                  ReLU
  35  'depthwise_conv2d_5' Grouped Convolution  256 groups of 1 3x3x1 convolutions
  36  'L61'              Batch Normalization  Batch normalization with 256 channels
  37  'activation_11'    ReLU                  ReLU
```

38	'conv2d_6'	Convolution	512 1x1x256 convolutions with str:
39	'L62'	Batch Normalization	Batch normalization with 512 chan
40	'activation_12'	ReLU	ReLU
41	'depthwise_conv2d_6'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
42	'L71'	Batch Normalization	Batch normalization with 512 chan
43	'activation_13'	ReLU	ReLU
44	'conv2d_7'	Convolution	512 1x1x512 convolutions with str:
45	'L72'	Batch Normalization	Batch normalization with 512 chan
46	'activation_14'	ReLU	ReLU
47	'depthwise_conv2d_7'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
48	'L81'	Batch Normalization	Batch normalization with 512 chan
49	'activation_15'	ReLU	ReLU
50	'conv2d_8'	Convolution	512 1x1x512 convolutions with str:
51	'L82'	Batch Normalization	Batch normalization with 512 chan
52	'activation_16'	ReLU	ReLU
53	'depthwise_conv2d_8'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
54	'L91'	Batch Normalization	Batch normalization with 512 chan
55	'activation_17'	ReLU	ReLU
56	'conv2d_9'	Convolution	512 1x1x512 convolutions with str:
57	'L92'	Batch Normalization	Batch normalization with 512 chan
58	'activation_18'	ReLU	ReLU
59	'depthwise_conv2d_9'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
60	'L101'	Batch Normalization	Batch normalization with 512 chan
61	'activation_19'	ReLU	ReLU
62	'conv2d_10'	Convolution	512 1x1x512 convolutions with str:
63	'L102'	Batch Normalization	Batch normalization with 512 chan
64	'activation_20'	ReLU	ReLU
65	'depthwise_conv2d_10'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
66	'L111'	Batch Normalization	Batch normalization with 512 chan
67	'activation_21'	ReLU	ReLU
68	'conv2d_11'	Convolution	512 1x1x512 convolutions with str:
69	'L112'	Batch Normalization	Batch normalization with 512 chan
70	'activation_22'	ReLU	ReLU
71	'depthwise_conv2d_11'	Grouped Convolution	512 groups of 1 3x3x1 convolutions
72	'L121'	Batch Normalization	Batch normalization with 512 chan
73	'activation_23'	ReLU	ReLU
74	'conv2d_12'	Convolution	1024 1x1x512 convolutions with st
75	'L122'	Batch Normalization	Batch normalization with 1024 cha
76	'activation_24'	ReLU	ReLU
77	'depthwise_conv2d_12'	Grouped Convolution	1024 groups of 1 3x3x1 convolutio
78	'L131'	Batch Normalization	Batch normalization with 1024 cha
79	'activation_25'	ReLU	ReLU
80	'conv2d_13'	Convolution	1024 1x1x1024 convolutions with s
81	'L132'	Batch Normalization	Batch normalization with 1024 cha
82	'activation_26'	ReLU	ReLU
83	'global_average_pooling2d'	Global Average Pooling	Global average pooling
84	'dense'	Fully Connected	521 fully connected layer
85	'softmax'	Softmax	softmax
86	'Sound'	Classification Output	crossentropyex with 'Speech' and 5

To view the names of the classes learned by the network, you can view the `Classes` property of the classification output layer (the final layer). View the first 10 classes by specifying the first 10 elements.

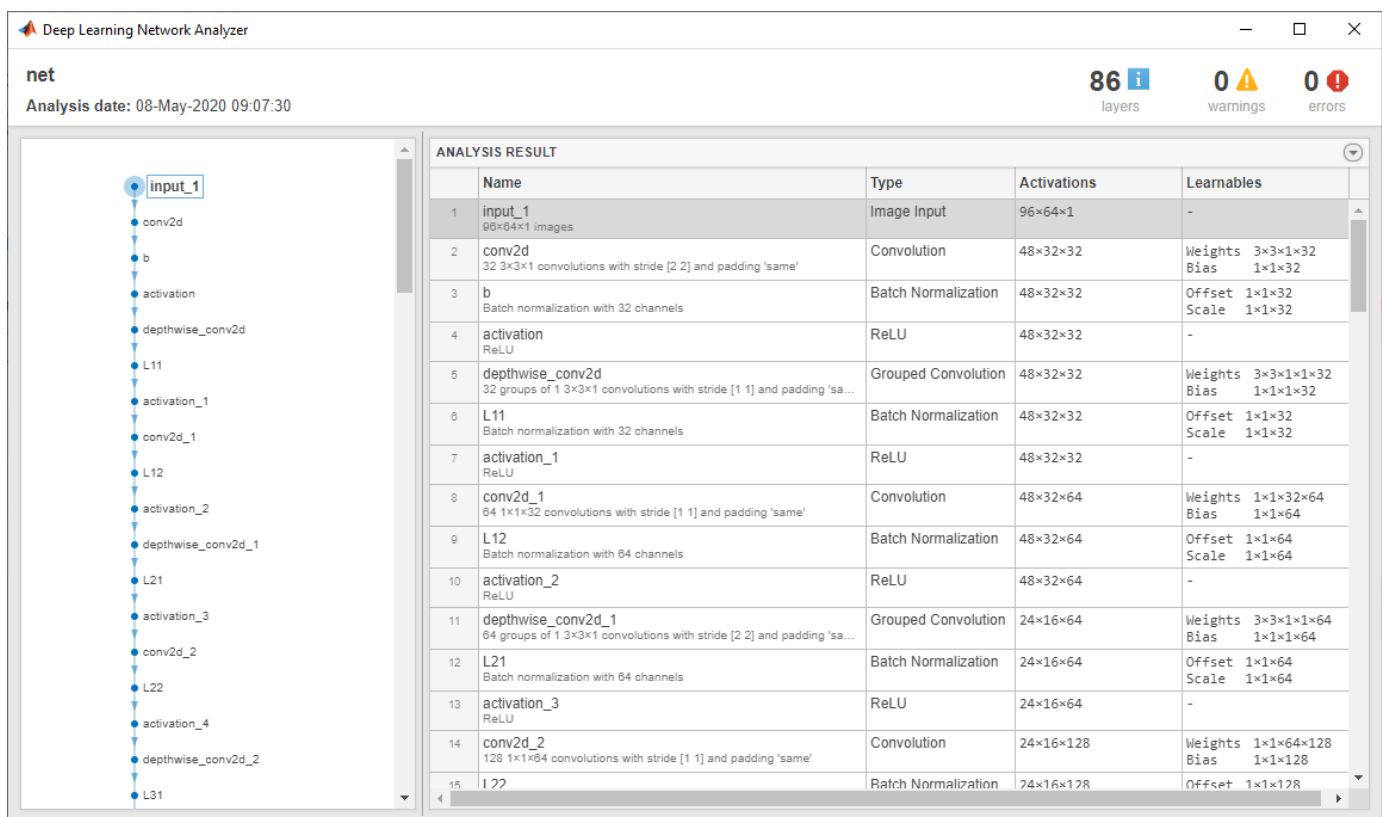
```
net.Layers(end).Classes(1:10)
```

```
ans = 10x1 categorical
      Speech
```

Child speech, kid speaking
 Conversation
 Narration, monologue
 Babbling
 Speech synthesizer
 Shout
 Bellow
 Whoop
 Yell

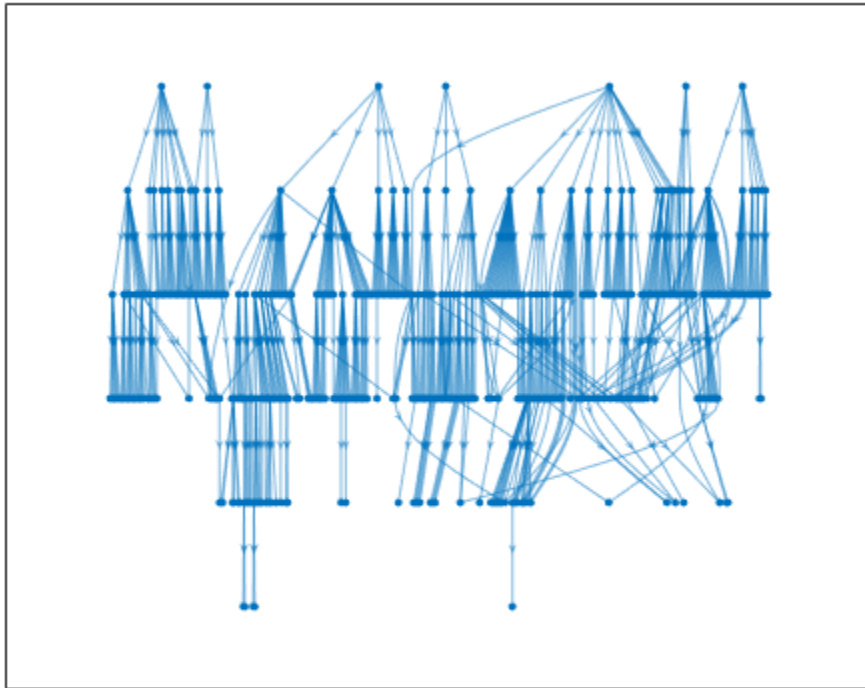
Use `analyzeNetwork` (Deep Learning Toolbox) to visually explore the network.

`analyzeNetwork(net)`



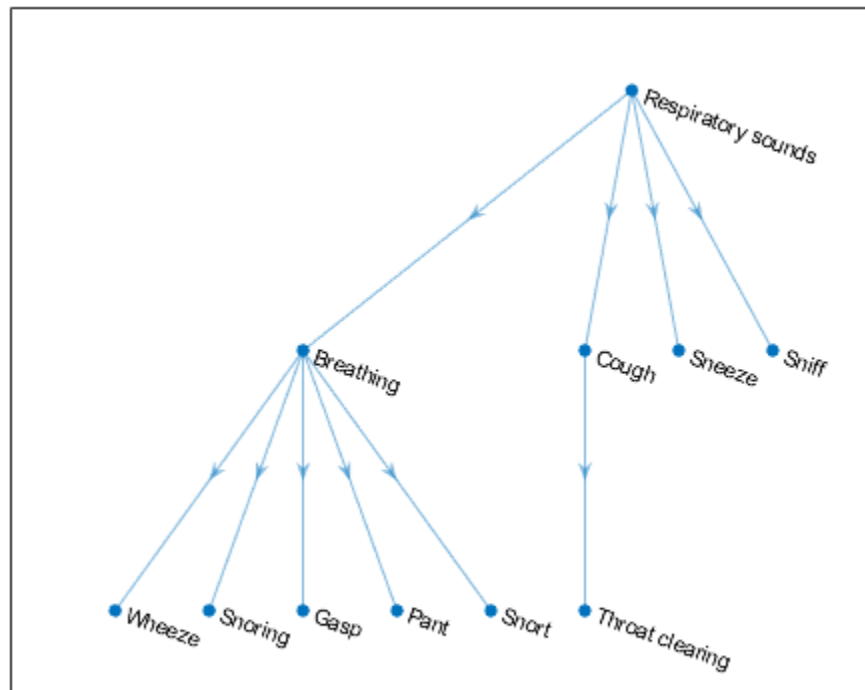
YAMNet was released with a corresponding sound class ontology, which you can explore using the `yamnetGraph` object.

```
ygraph = yamnetGraph;  
p = plot(ygraph);  
layout(p, 'layered')
```



The ontology graph plots all 521 possible sound classes. Plot a subgraph of the sounds related to respiratory sounds.

```
allRespiratorySounds = dfsearch(ygraph, "Respiratory sounds");  
ygraphSpeech = subgraph(ygraph, allRespiratorySounds);  
plot(ygraphSpeech)
```



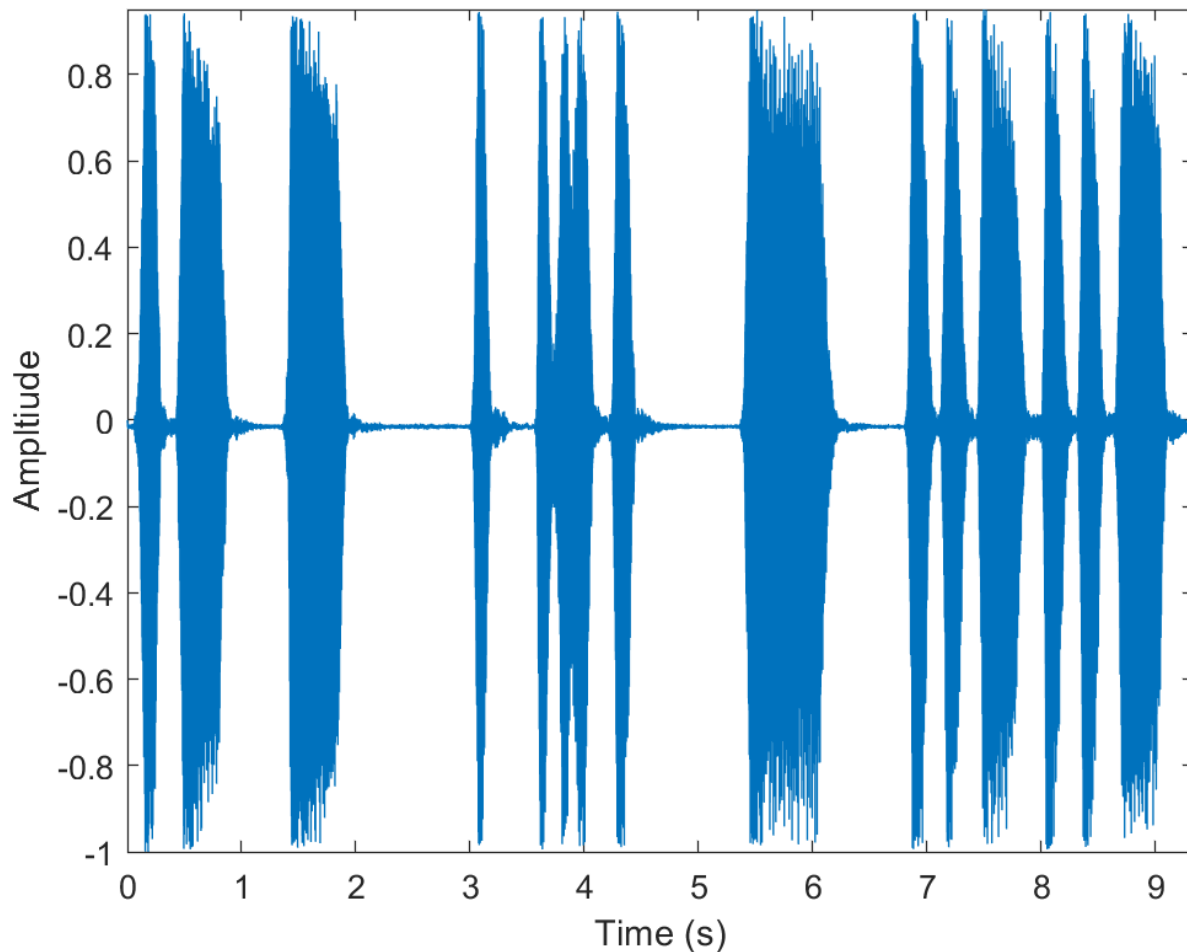
Classify Sounds Using YAMNet

Read in an audio signal to classify it.

```
[audioIn,fs] = audioread(TrainWhistle-16-44...);
```

Plot and listen to the audio signal.

```
t = (0:numel(audioIn)-1)/fs;  
plot(t,audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis tight
```

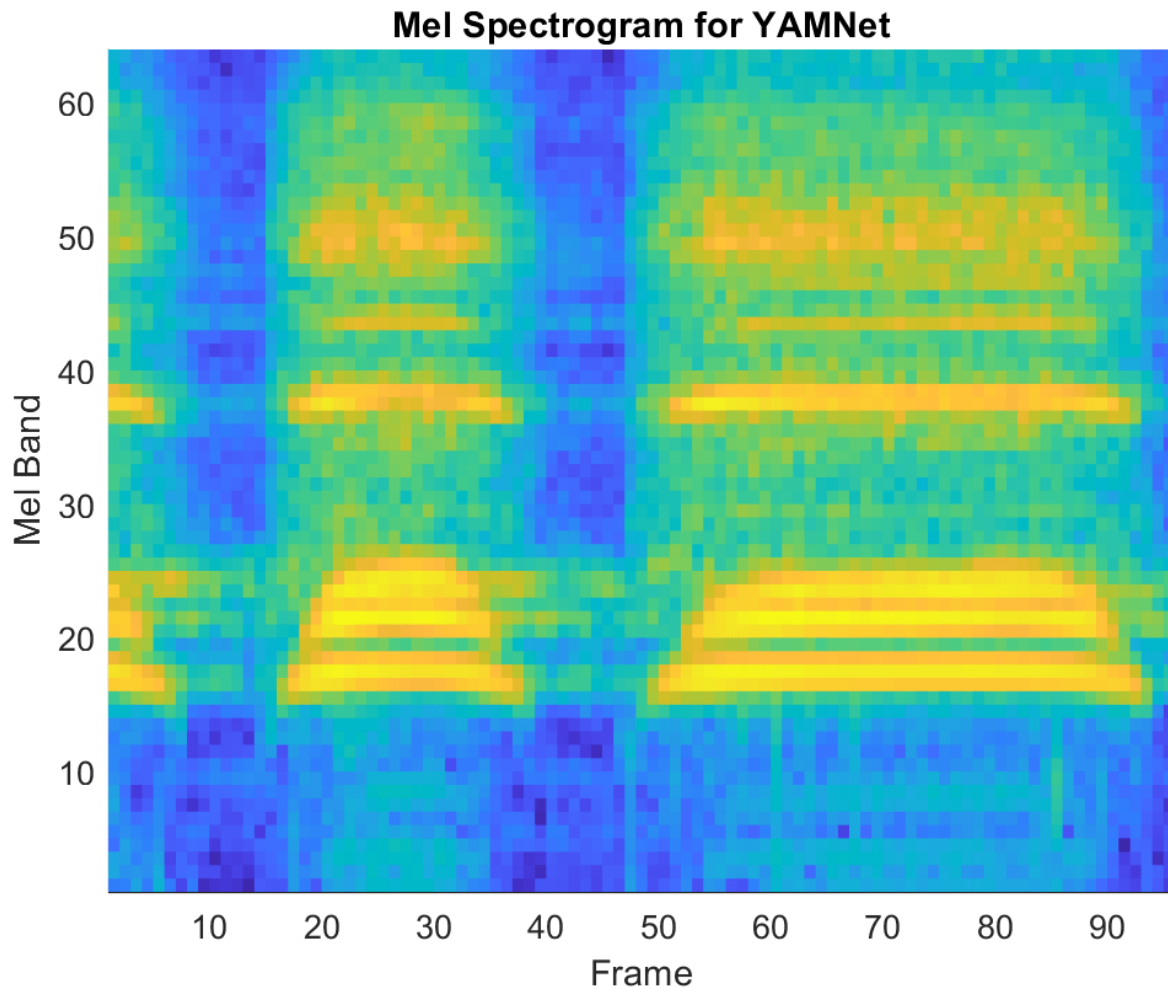



```
% To play the sound, call soundsc(audioIn,fs)
```

YAMNet requires you to preprocess the audio signal to match the input format used to train the network. The preprocessing steps include resampling the audio signal and computing an array of mel spectrograms. To learn more about mel spectrograms, see `melSpectrogram`. Use `yamnetPreprocess` to preprocess the signal and extract the mel spectrograms to be passed to YAMNet. Visualize one of these spectrograms chosen at random.

```
spectrograms = yamnetPreprocess(audioIn,fs);

arbitrarySpect = spectrograms(:,:,1,randi(size(spectrograms,4)));
surf(arbitrarySpect,EdgeColor="none")
view([90 -90])
xlabel("Mel Band")
ylabel("Frame")
title("Mel Spectrogram for YAMNet")
axis tight
```



Create a YAMNet neural network. Using the `yamnet` function requires installing the pretrained YAMNet network. If the network is not installed, the function provides a link to download the pretrained model. Call `classify` with the network on the preprocessed mel spectrogram images.

```
net = yamnet;  
classes = classify(net,spectrograms);
```

Calling `classify` returns a label for each of the spectrogram images in the input. Classify the sound as the most frequently occurring label in the output of `classify`.

```
mySound = mode(classes)
```

```
mySound = categorical  
Whistle
```

Transfer Learning Using YAMNet

Download and unzip the air compressor data set [1] on page 2-0 . This data set consists of recordings from air compressors in a healthy state or one of 7 faulty states.

```
url = 'https://www.mathworks.com/supportfiles/audio/AirCompressorDataset/AirCompressorDataset.zip';
downloadFolder = fullfile(tempdir,'aircompressordataset');
datasetLocation = tempdir;

if ~exist(fullfile(tempdir,'AirCompressorDataSet'),'dir')
    loc = websave(downloadFolder,url);
    unzip(loc,fullfile(tempdir,'AirCompressorDataSet'))
end
```

Create an `audioDatastore` object to manage the data and split it into train and validation sets.

```
ads = audioDatastore(downloadFolder,'IncludeSubfolders',true,'LabelSource','foldernames');

[adsTrain,adsValidation] = splitEachLabel(ads,0.8,0.2);
```

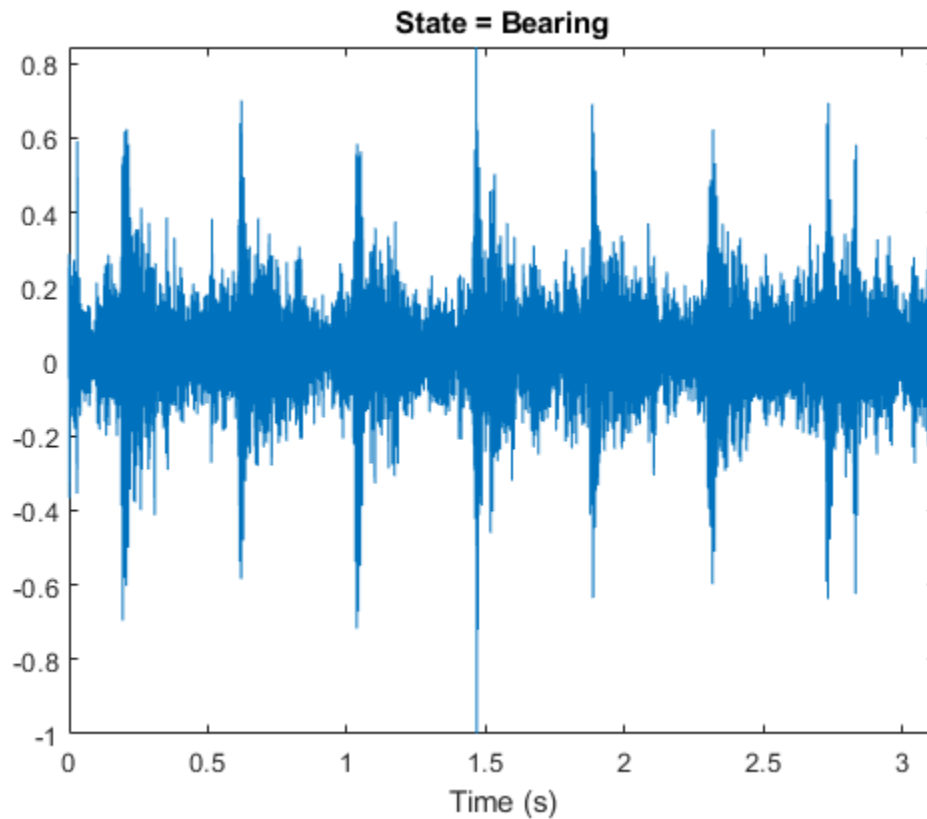
Read an audio file from the datastore and save the sample rate for later use. Reset the datastore to return the read pointer to the beginning of the data set. Listen to the audio signal and plot the signal in the time domain.

```
[x,fileInfo] = read(adsTrain);
fs = fileInfo.SampleRate;

reset(adsTrain)

sound(x,fs)

figure
t = (0:size(x,1)-1)/fs;
plot(t,x)
xlabel('Time (s)')
title('State = ' + string(fileInfo.Label))
axis tight
```



Extract Mel spectrograms from the train set using `yamnetPreprocess`. There are multiple spectrograms for each audio signal. Replicate the labels so that they are in one-to-one correspondence with the spectrograms.

```
emptyLabelVector = adsTrain.Labels;
emptyLabelVector(:) = [];

trainFeatures = [];
trainLabels = emptyLabelVector;
while hasdata(adsTrain)
    [audioIn,fileInfo] = read(adsTrain);
    features = yamnetPreprocess(audioIn,fileInfo.SampleRate);
    numSpectrums = size(features,4);
    trainFeatures = cat(4,trainFeatures,features);
    trainLabels = cat(2,trainLabels, repmat(fileInfo.Label,1,numSpectrums));
end
```

Extract features from the validation set and replicate the labels.

```
validationFeatures = [];
validationLabels = emptyLabelVector;
while hasdata(adsValidation)
    [audioIn,fileInfo] = read(adsValidation);
    features = yamnetPreprocess(audioIn,fileInfo.SampleRate);
    numSpectrums = size(features,4);
    validationFeatures = cat(4,validationFeatures,features);
    validationLabels = cat(2,validationLabels, repmat(fileInfo.Label,1,numSpectrums));
end
```

The air compressor data set has only eight classes.

Read in YAMNet and convert it to a `layerGraph` (Deep Learning Toolbox).

If YAMNet pretrained network is not installed on your machine, execute the following commands to download and unzip the YAMNet model to your temporary directory.

```
downloadFolder = fullfile(tempdir, 'YAMNetDownload');
loc = websave(downloadFolder, 'https://ssd.mathworks.com/supportfiles/audio/yamnet.zip');
YAMNetLocation = tempdir;
unzip(loc, YAMNetLocation)
addpath(fullfile(YAMNetLocation, 'yamnet'))
```

After you read in YAMNet and convert it to a `layerGraph` (Deep Learning Toolbox), replace the final `fullyConnectedLayer` (Deep Learning Toolbox) and the final `classificationLayer` (Deep Learning Toolbox) to reflect the new task.

```
uniqueLabels = unique(adsTrain.Labels);
numLabels = numel(uniqueLabels);

net = yamnet;

lgraph = layerGraph(net.Layers);

newDenseLayer = fullyConnectedLayer(numLabels, "Name", "dense");
lgraph = replaceLayer(lgraph, "dense", newDenseLayer);

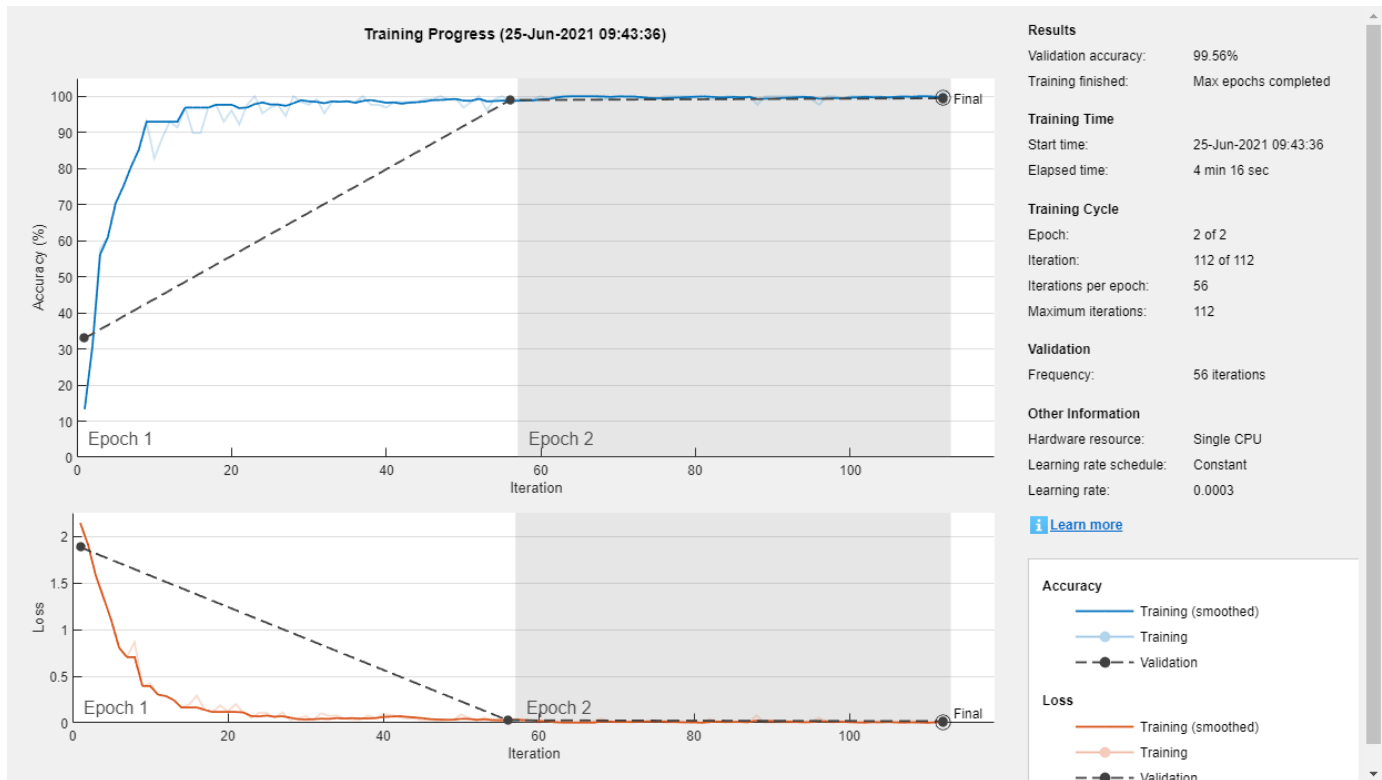
newClassificationLayer = classificationLayer("Name", "Sounds", "Classes", uniqueLabels);
lgraph = replaceLayer(lgraph, "Sound", newClassificationLayer);
```

To define training options, use `trainingOptions` (Deep Learning Toolbox).

```
miniBatchSize = 128;
validationFrequency = floor(numel(trainLabels)/miniBatchSize);
options = trainingOptions('adam', ...
    'InitialLearnRate', 3e-4, ...
    'MaxEpochs', 2, ...
    'MiniBatchSize', miniBatchSize, ...
    'Shuffle', 'every-epoch', ...
    'Plots', 'training-progress', ...
    'Verbose', false, ...
    'ValidationData', {single(validationFeatures), validationLabels}, ...
    'ValidationFrequency', validationFrequency);
```

To train the network, use `trainNetwork` (Deep Learning Toolbox).

```
airCompressorNet = trainNetwork(trainFeatures, trainLabels, lgraph, options);
```



Save the trained network to `airCompressorNet.mat`. You can now use this pre-trained network by loading the `airCompressorNet.mat` file.

```
save airCompressorNet.mat airCompressorNet
```

References

[1] Verma, Nishchal K., et al. "Intelligent Condition Based Monitoring Using Acoustic Signals for Air Compressors." *IEEE Transactions on Reliability*, vol. 65, no. 1, Mar. 2016, pp. 291-309. [DOI.org \(Crossref\)](#), doi:10.1109/TR.2015.2459684.

Output Arguments

`net` — Pretrained YAMNet neural network

`SeriesNetwork` object

Pretrained YAMNet neural network, returned as a `SeriesNetwork` object.

References

[1] Gemmeke, Jort F., et al. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776-80. [DOI.org \(Crossref\)](#), doi:10.1109/ICASSP.2017.7952261.

[2] Hershey, Shawn, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131-35. [DOI.org \(Crossref\)](#), doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- Only the `activations` and `predict` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (MATLAB Coder).

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

Usage notes and limitations:

- Only the `activations`, `classify`, `predict`, `predictAndUpdateState`, and `resetState` object functions are supported.
- To create a `SeriesNetwork` object for code generation, see “Load Pretrained Networks for Code Generation” (GPU Coder).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

`audioFeatureExtractor` | `classifySound` | `designAuditoryFilterBank` | `melSpectrogram` | `vggish` | `vggishPreprocess` | `yamnetGraph` | `yamnetPreprocess`

Introduced in R2020b

vggishEmbeddings

Extract VGGish feature embeddings

Syntax

```
embeddings = vggishEmbeddings(audioIn,fs)
embeddings = vggishEmbeddings(audioIn,fs,Name=Value)
```

Description

`embeddings = vggishEmbeddings(audioIn,fs)` returns VGGish feature embeddings over time for the audio input `audioIn` with sample rate `fs`. Columns of the input are treated as individual channels.

`embeddings = vggishEmbeddings(audioIn,fs,Name=Value)` specifies options using one or more name-value arguments. For example, `embeddings = vggishEmbeddings(audioIn,fs,ApplyPCA=true)` applies a principal component analysis (PCA) transformation to the audio embeddings.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download vggishEmbeddings Functionality

Download and unzip the Audio Toolbox™ model for VGGish.

Type `vggishEmbeddings` at the command line. If the Audio Toolbox model for VGGish is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the VGGish model to your temporary directory.

```
downloadFolder = fullfile(tempdir,"VGGishDownload");
loc = websave(downloadFolder,"https://ssd.mathworks.com/supportfiles/audio/vggish.zip");
VGGishLocation = tempdir;
unzip(loc,VGGishLocation)
addpath(fullfile(VGGishLocation,"vggish"))
```

Extract VGGish Embeddings

Read in an audio file.

```
[audioIn,fs] = audioread("MainStreetOne-16-16-mono-12secs.wav");
```

Call the `vggishEmbeddings` function with the audio and sample rate to extract VGGish feature embeddings from the audio. Using the `vggishEmbeddings` function requires installing the

pretrained VGGish network. If the network is not installed, the function provides a link to download the pretrained model.

```
embeddings = vggishEmbeddings(audioIn, fs);
```

The `vggishEmbeddings` function returns a matrix of 128-element feature vectors over time.

```
[numHops, numElementsPerHop, numChannels] = size(embeddings)
```

```
numHops = 23
```

```
numElementsPerHop = 128
```

```
numChannels = 1
```

Increase Time Resolution of VGGish Embeddings

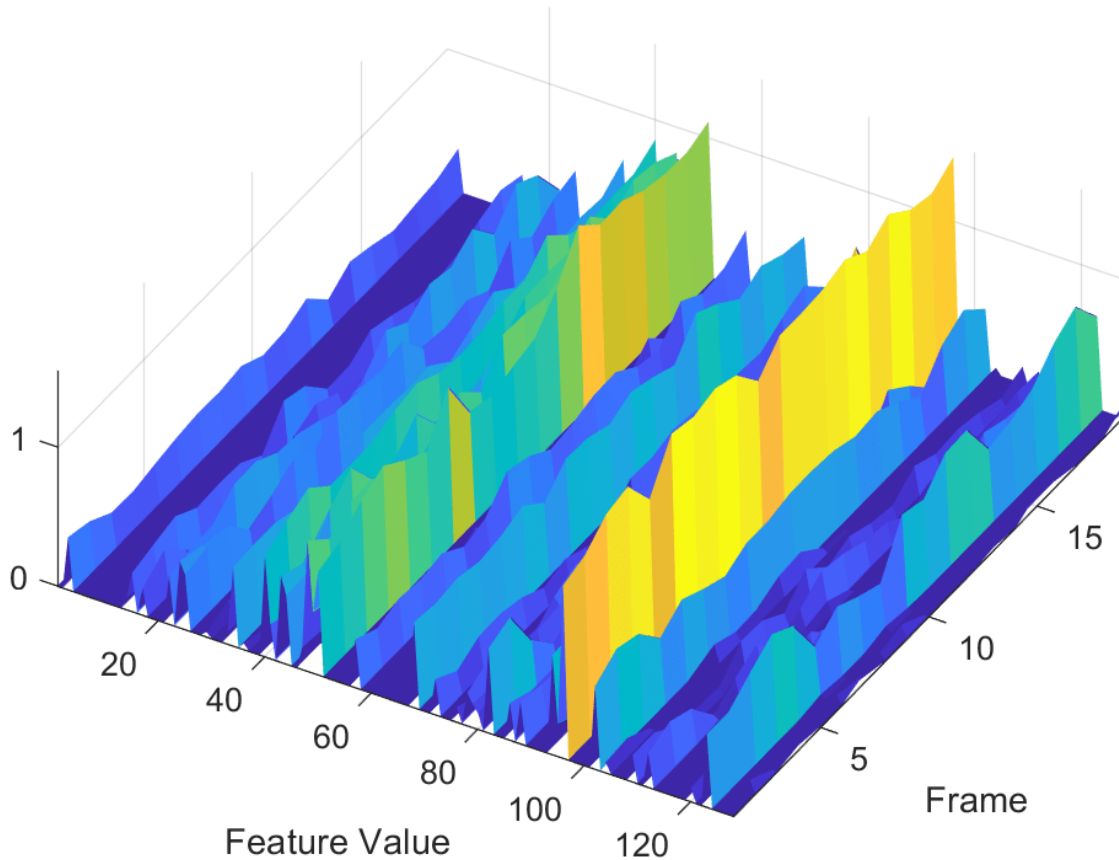
Create a 10-second pink noise signal and then extract VGGish embeddings. The `vggishEmbeddings` function extracts feature embeddings from mel spectrograms with 50% overlap. Using the `vggishEmbeddings` function requires installing the pretrained VGGish network. If the network is not installed, the function provides a link to download the pretrained model.

```
fs = 16e3;  
dur = 10;  
audioIn = pinknoise(dur*fs, 1, "single");  
embeddings = vggishEmbeddings(audioIn, fs);
```


Plot the VGGish feature embeddings over time.

```
surf(embeddings, EdgeColor="none")  
view([30 65])  
axis tight  
xlabel("Feature Index")  
ylabel("Frame")  
xlabel("Feature Value")  
title("VGGish Feature Embeddings")
```

VGGish Feature Embeddings

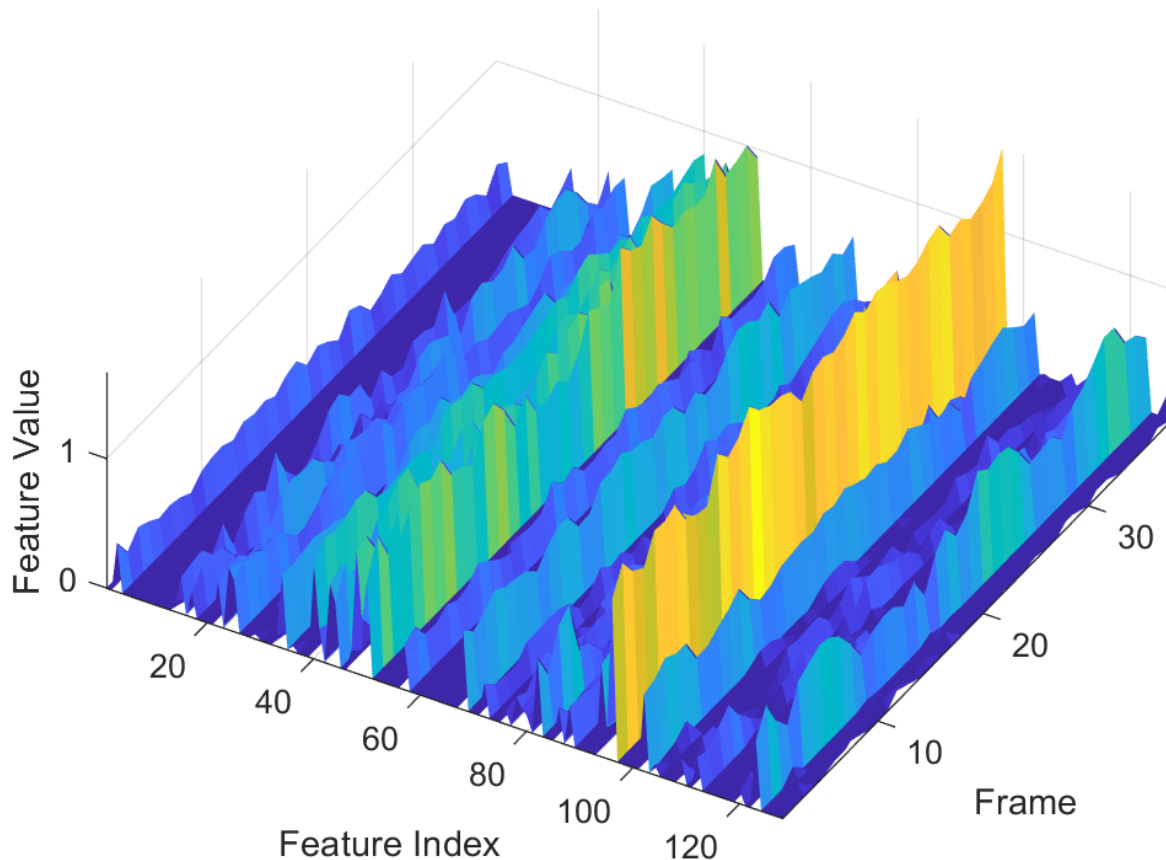


To increase the resolution of VGGish feature embeddings over time, specify the percent overlap between mel spectrograms. Plot the results.

```
overlapPercentage = 75  ;
embeddings = vggishEmbeddings(audioIn, fs, OverlapPercentage=overlapPercentage);

surf(embeddings, EdgeColor="none")
view([30 65])
axis tight
xlabel("Feature Index")
ylabel("Frame")
zlabel("Feature Value")
title("VGGish Feature Embeddings")
```

VGGish Feature Embeddings



Apply Principal Component Analysis to VGGish Embeddings

Read in an audio file, listen to it, and then extract VGGish feature embeddings from the audio. Using the `vggishEmbeddings` function requires installing the pretrained VGGish network. If the network is not installed, the function provides a link to download the pretrained model.

```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn, fs)

embeddings = vggishEmbeddings(audioIn, fs);
```

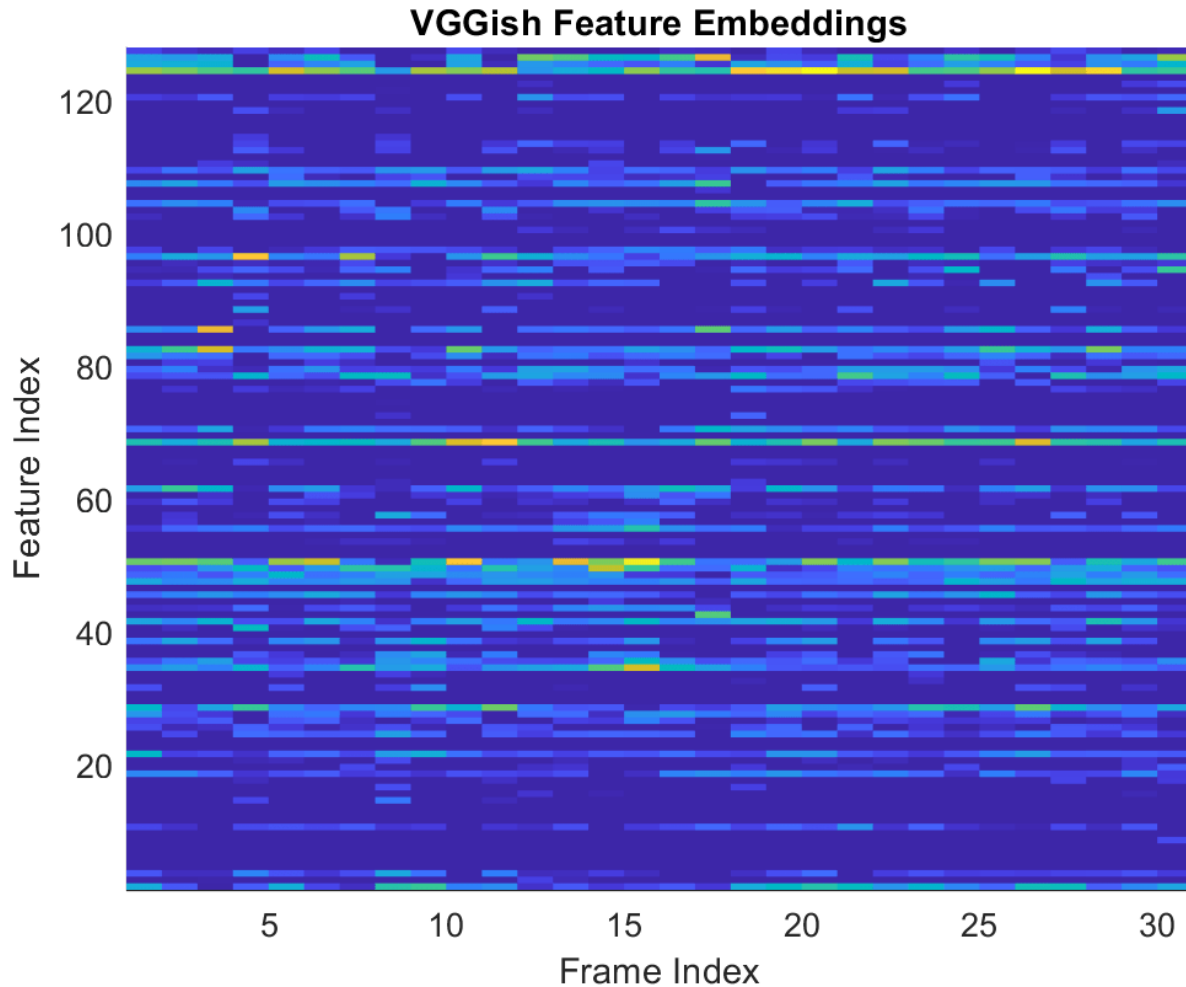
Visualize the VGGish feature embeddings over time. Many of the individual features are zero-valued and contain no useful information.

```
surf(embeddings, EdgeColor="none")
view([90, -90])
axis tight
```

```

xlabel("Feature Index")
ylabel("Frame Index")
title("VGGish Feature Embeddings")

```



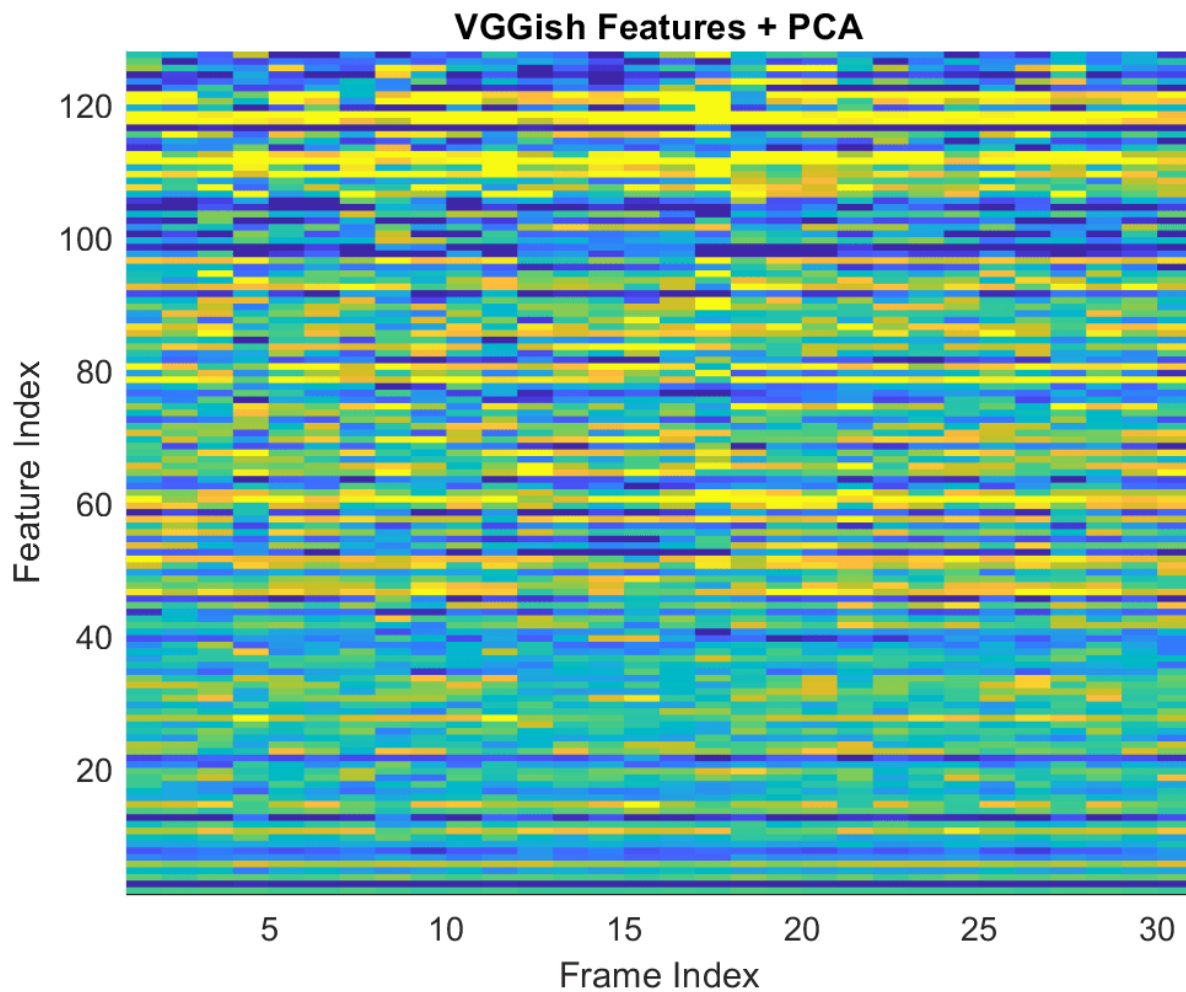
You can apply principal component analysis (PCA) to map the feature vectors into a space that emphasizes variation between the embeddings. Call the `vggishEmbeddings` function again and specify `ApplyPCA` as `true`. Visualize the VGGish feature embeddings after PCA.

```

embeddings = vggishEmbeddings(audioIn,fs,ApplyPCA=true);

surf(embeddings,EdgeColor="none")
view([90,-90])
axis tight
xlabel("Feature Index")
ylabel("Frame Index")
title("VGGish Features + PCA")

```



Use VGGish Embeddings for Deep Learning

Download and unzip the air compressor data set. This data set consists of recordings from air compressors in a healthy state or in one of seven faulty states.

```
datasetZipFile = matlab.internal.examples.downloadSupportFile("audio","AirCompressorDataset/AirC
datasetFolder = fullfile(fileparts(datasetZipFile),"AirCompressorDataset");
if ~exist(datasetFolder,"dir")
    unzip(datasetZipFile,fileparts(datasetZipFile));
end
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets.

```
ads = audioDatastore(datasetFolder,IncludeSubfolders=true,LabelSource="foldernames");
[adsTrain,adsValidation] = splitEachLabel(ads,0.8,0.2);
```

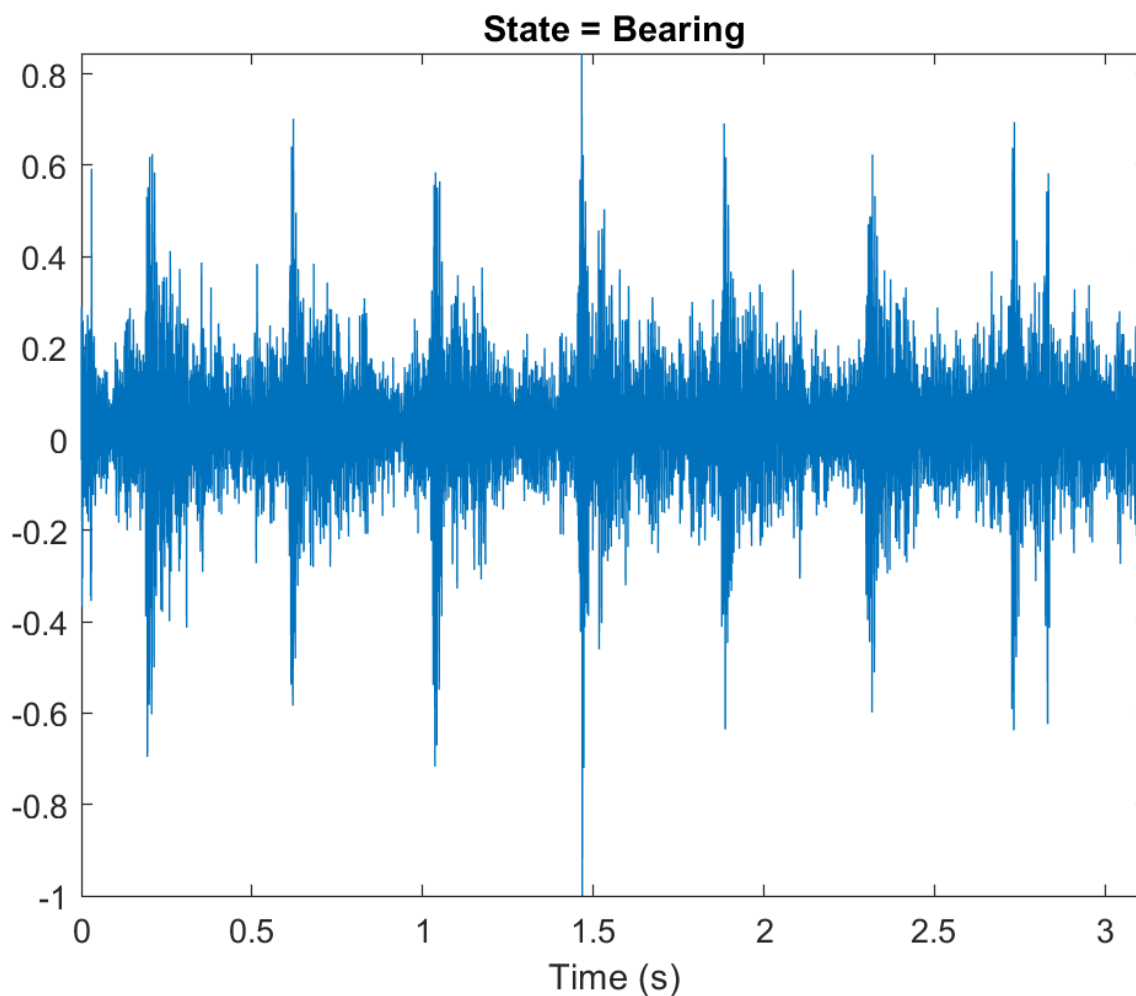
Read an audio file from the datastore and save the sample rate for later use. Reset the datastore to return the read pointer to the beginning of the data set. Listen to the audio signal and plot the signal in the time domain.

```
[x,fileInfo] = read(adsTrain);
fs = fileInfo.SampleRate;

reset(adsTrain)

sound(x, fs)

figure
t = (0:size(x,1)-1)/fs;
plot(t,x)
xlabel("Time (s)")
title("State = " + string(fileInfo.Label))
axis tight
```



Extract VGGish feature embeddings from the training and validation sets. Using the `vggishEmbeddings` function requires installing the pretrained VGGish network. If the network is

not installed, the function provides a link to download the pretrained model. Transpose the feature embeddings so that time is along rows.

```
trainFeatures = cell(1,numel(adsTrain.Files));
for idx = 1:numel(adsTrain.Files)
    [audioIn,fileInfo] = read(adsTrain);
    embeddings = vggishEmbeddings(audioIn,fileInfo.SampleRate);
    trainFeatures{idx} = embeddings';
end

validationFeatures = cell(1,numel(adsValidation.Files));
for idx = 1:numel(adsValidation.Files)
    [audioIn,fileInfo] = read(adsValidation);
    embeddings = vggishEmbeddings(audioIn,fileInfo.SampleRate);
    validationFeatures{idx} = embeddings';
end
```

Define a “Long Short-Term Memory Networks” (Deep Learning Toolbox) network.

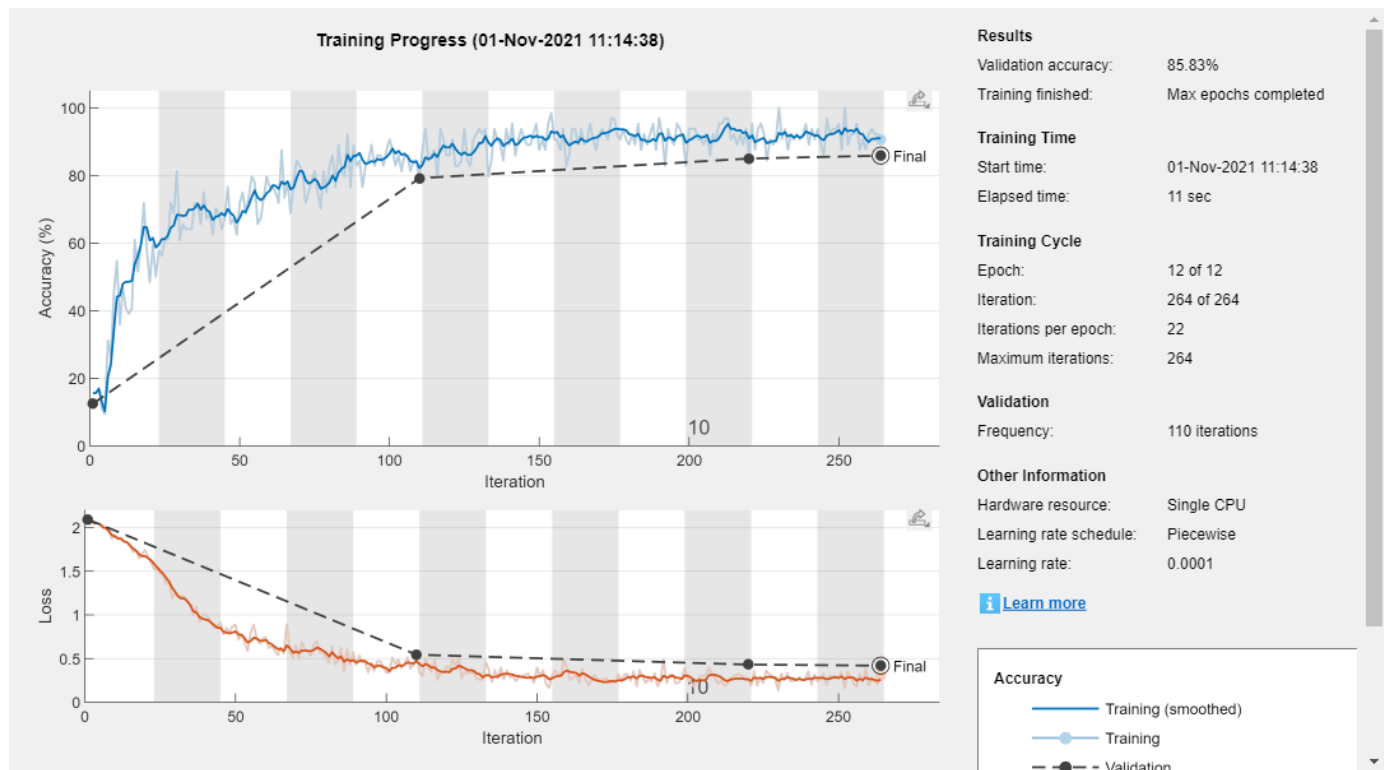
```
layers = [
    sequenceInputLayer(128)
    lstmLayer(100,OutputMode="last")
    fullyConnectedLayer(8)
    softmaxLayer
    classificationLayer];
```

To define training options, use `trainingOptions` (Deep Learning Toolbox).

```
miniBatchSize = 64;
validationFrequency = 5*floor(numel(trainFeatures)/miniBatchSize);
options = trainingOptions("adam", ...
    MaxEpochs=12, ...
    MiniBatchSize=miniBatchSize, ...
    Plots="training-progress", ...
    Shuffle="every-epoch", ...
    LearnRateSchedule="piecewise", ...
    LearnRateDropPeriod=6, ...
    LearnRateDropFactor=0.1, ...
    ValidationData={validationFeatures,adsValidation.Labels}, ...
    ValidationFrequency=validationFrequency, ...
    Verbose=false);
```

To train the network, use `trainNetwork` (Deep Learning Toolbox).

```
net = trainNetwork(trainFeatures,adsTrain.Labels,layers,options)
```



```
net =
  SeriesNetwork with properties:
    Layers: [5x1 nnet.cnn.layer.Layer]
    InputNames: {'sequenceinput'}
    OutputNames: {'classoutput'}
```

Visualize the confusion matrix for the validation set.

```
predictedClass = classify(net,validationFeatures);
figure
confusionchart(adsValidation.Labels,predictedClass)
```


Bearing	35	7					3	
Flywheel	3	40					2	
Healthy			43				2	
LIV				36		7		2
LOV				3	38	1	2	1
NRV				1		44		
Piston		8	3				34	
Riderbelt				3	1	2		39
	Bearing	Flywheel	Healthy	LIV	LOV	NRV	Piston	Riderbelt

Use VGGish Embeddings for Machine Learning

Download and unzip the air compressor data set [1] on page 2-0 . This data set consists of recordings from air compressors in a healthy state or in one of seven faulty states.

```
datasetZipFile = matlab.internal.examples.downloadSupportFile("audio", "AirCompressorDataset/AirC
datasetFolder = fullfile(fileparts(datasetZipFile), "AirCompressorDataset");
if ~exist(datasetFolder, "dir")
    unzip(datasetZipFile, fileparts(datasetZipFile));
end
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets.

```
ads = audioDatastore(datasetFolder, IncludeSubfolders=true, LabelSource="foldernames");
```

In this example, you classify signals as either healthy or faulty. Combine all of the faulty labels into a single label. Split the datastore into training and validation sets.

```
labels = ads.Labels;
labels(labels~=categorical("Healthy")) = categorical("Faulty");
ads.Labels = removecats(labels);
```

```
[adsTrain,adsValidation] = splitEachLabel(ads,0.8,0.2);
```

Extract VGGish feature embeddings from the training set. Each audio file corresponds to multiple VGGish features. Replicate the labels so that they are in one-to-one correspondence with the features. Using the `vggishEmbeddings` function requires installing the pretrained VGGish network. If the network is not installed, the function provides a link to download the pretrained model.

```
trainFeatures = [];
trainLabels = [];
for idx = 1:numel(adsTrain.Files)
    [audioIn,fileInfo] = read(adsTrain);
    embeddings = vggishEmbeddings(audioIn,fileInfo.SampleRate);
    trainFeatures = [trainFeatures;embeddings];
    trainLabels = [trainLabels;repelem(fileInfo.Label,size(embeddings,1))'];
end
```

Train a cubic support vector machine (SVM) using `fitcsvm` (Statistics and Machine Learning Toolbox). To explore other classifiers and their performances, use `Classification Learner` (Statistics and Machine Learning Toolbox).

```
faultDetector = fitcsvm( ...
    trainFeatures, ...
    trainLabels, ...
    KernelFunction="polynomial", ...
    PolynomialOrder=3, ...
    KernelScale="auto", ...
    BoxConstraint=1, ...
    Standardize=true, ...
    ClassNames=categories(trainLabels));
```

For each file in the validation set:

- 1 Extract VGGish feature embeddings.
- 2 For each VGGish feature vector in a file, use the trained classifier to predict whether the machine is healthy or faulty.
- 3 Take the mode of the predictions for each file.

```
predictions = [];
for idx = 1:numel(adsValidation.Files)
    [audioIn,fileInfo] = read(adsValidation);

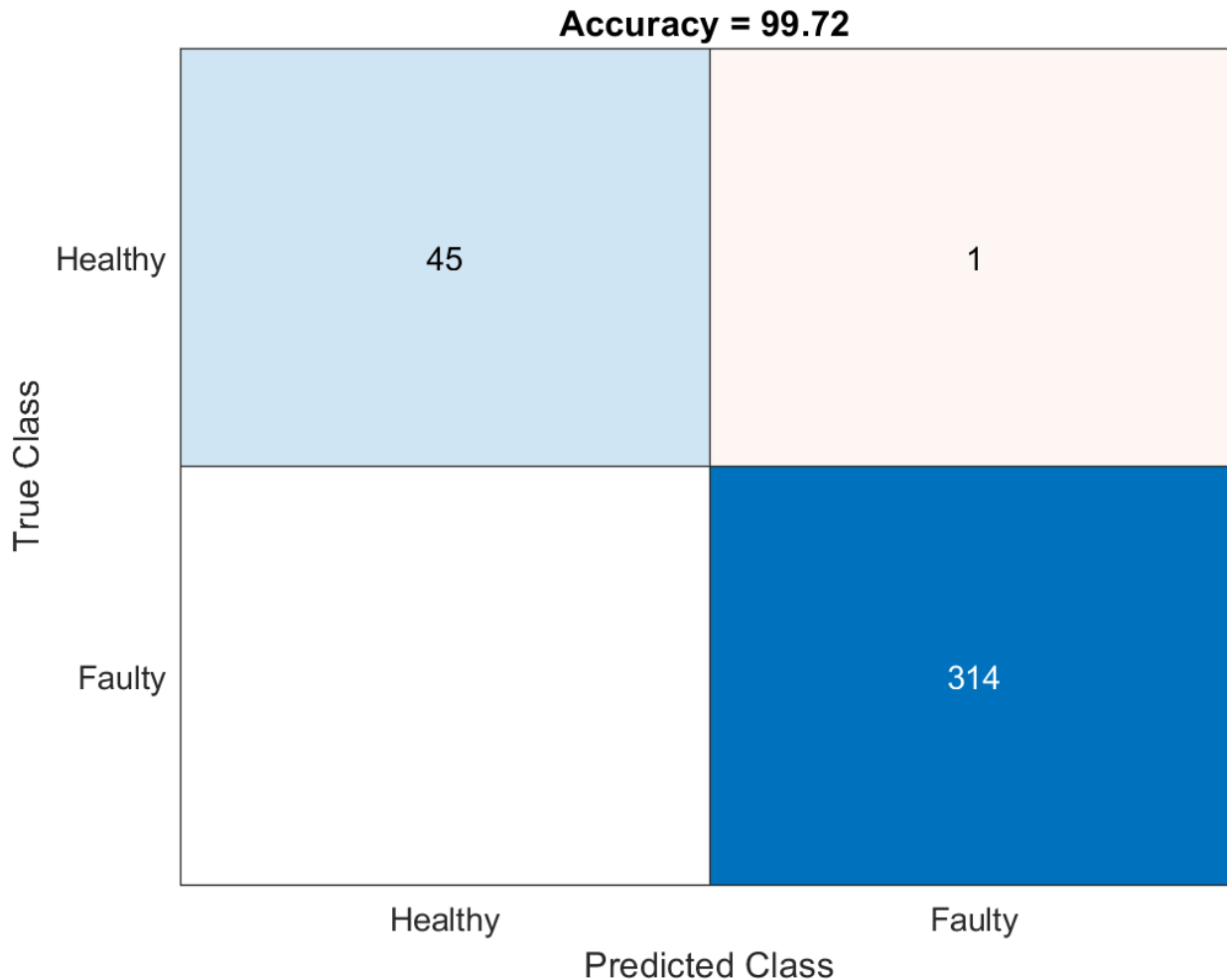
    embeddings = vggishEmbeddings(audioIn,fileInfo.SampleRate);

    predictionsPerFile = categorical(predict(faultDetector,embeddings));

    predictions = [predictions;mode(predictionsPerFile)];
end
```

Use `confusionchart` (Statistics and Machine Learning Toolbox) to display the performance of the classifier.

```
accuracy = sum(predictions==adsValidation.Labels)/numel(adsValidation.Labels);
cc = confusionchart(predictions,adsValidation.Labels);
cc.Title = sprintf("Accuracy = %0.2f %",accuracy*100);
```



References

[1] Verma, Nishchal K., Rahul Kumar Sevakula, Sonal Dixit, and Al Salour. 2016. "Intelligent Condition Based Monitoring Using Acoustic Signals for Air Compressors." *IEEE Transactions on Reliability* 65 (1): 291-309. <https://doi.org/10.1109/TR.2015.2459684>.

Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `vggishEmbeddings` treats the columns of the matrix as individual audio channels.

The duration of `audioIn` must be equal to or greater than 0.975 seconds.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `OverlapPercentage=75`

OverlapPercentage — Percentage overlap between consecutive audio frames

50 (default) | scalar in the range [0,100)

Percentage overlap between consecutive audio frames, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

ApplyPCA — Flag to apply PCA transformation to audio embeddings

false (default) | true

Flag to apply PCA transformation to audio embeddings, specified as either `true` or `false`.

Data Types: `logical`

Output Arguments**embeddings — Compact representation of audio data**

L -by-128-by- N array

Compact representation of audio data, returned as an L -by-128-by- N array, where:

- L -- Represents the number of frames the audio signal is partitioned into. This is determined by the `OverlapPercentage`.
- 128 -- Represents the audio embedding length.
- N -- Represents the number of channels.

Algorithms

The `vggishEmbeddings` function uses VGGish to extract feature embeddings from audio. The `vggishEmbeddings` function preprocesses the audio so that it is in the format required by VGGish and optionally postprocesses the embeddings.

Preprocess

- 1 Resample `audioIn` to 16 kHz and cast to single precision.

- 2 Compute a one-sided short time Fourier transform using a 25 ms periodic Hann window with a 10 ms hop, and a 512-point DFT. The audio is now represented by a 257-by- L array, where 257 is the number of bins in the one-sided spectra, and L depends on the length of the input.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude spectrum through a 64-band mel-spaced filter bank, then sum the magnitudes in each band. The audio is now represented by a single 64-by- L mel spectrogram.
- 5 Convert the mel spectrogram to a log scale.
- 6 Buffer the mel spectrogram into overlapped segments consisting of 96 spectra each. The audio is now represented by a 96-by-64-by-1-by- K array, where 96 is the number of spectra in the individual mel spectrograms, 64 is the number of mel bands, and the spectrograms are spaced along the fourth dimension for compatibility with the VGGish model. The number of mel spectrograms, K , depends on the input length and `OverlapPercentage`.

Feature Extraction

Pass the 96-by-64-by-1-by- K array of mel spectrograms through VGGish to return a K -by-128 matrix. The output from VGGish are the feature embeddings corresponding to each 0.975 s frame of audio data.

Postprocess

If `ApplyPCA` is set to `true`, the feature embeddings are postprocessed to match the postprocessing of the released AudioSet embeddings. The VGGish model was released with a precomputed principal component analysis (PCA) matrix and mean vector to apply a PCA transformation and whitening during inference. The postprocessing includes applying PCA, whitening, and quantization.

- 1 Subtract the precomputed 1-by-128 PCA mean vector from the K -by-128 feature matrix, and then premultiply the result by the precomputed 128-by-128 PCA matrix.
- 2 Clip the transformed and whitened embeddings to between -2 and 2, then quantize the result to values that can be represented by `uint8`.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. 2017. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. 2017. "CNN Architectures for Large-Scale Audio Classification." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131–35. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

audioFeatureExtractor | classifySound | vggish | vggishPreprocess | yamnet | yamnetGraph | yamnetPreprocess

Introduced in R2022a

vggishFeatures

(To be removed) Extract VGGish features

Note The `vggishFeatures` function will be removed in a future release. Use `vggishEmbeddings` instead. For more information, see “Compatibility Considerations”.

Syntax

```
embeddings = vggishFeatures(audioIn,fs)
embeddings = vggishFeatures(audioIn,fs,Name,Value)
```

Description

`embeddings = vggishFeatures(audioIn,fs)` returns VGGish feature embeddings over time for the audio input `audioIn` with sample rate `fs`. Columns of the input are treated as individual channels.

`embeddings = vggishFeatures(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` arguments. For example, `embeddings = vggishFeatures(audioIn,fs,'ApplyPCA',true)` applies a principal component analysis (PCA) transformation to the audio embeddings.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download vggishFeatures Functionality

Download and unzip the Audio Toolbox™ model for VGGish.

Type `vggishFeatures` at the command line. If the Audio Toolbox model for VGGish is not installed, then the function provides a link to the location of the network weights. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the VGGish model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'VGGishDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/vggish.zip');
VGGishLocation = tempdir;
unzip(loc,VGGishLocation)
addpath(fullfile(VGGishLocation,'vggish'))
```

Extract VGGish Embeddings

Read in an audio file.

```
[audioIn,fs] = audioread('MainStreetOne-16-16-mono-12secs.wav');
```

Call the `vggishFeatures` function with the audio and sample rate to extract VGGish feature embeddings from the audio.

```
featureVectors = vggishFeatures(audioIn,fs);
```

The `vggishFeatures` function returns a matrix of 128-element feature vectors over time.

```
[numHops,numElementsPerHop,numChannels] = size(featureVectors)
```

```
numHops = 23
```

```
numElementsPerHop = 128
```

```
numChannels = 1
```

Increase Time Resolution of VGGish Features

Create a 10-second pink noise signal and then extract VGGish features. The `vggishFeatures` function extracts features from mel spectrograms with 50% overlap.

```
fs = 16e3;
```

```
dur = 10;
```

```
audioIn = pinknoise(dur*fs,1,'single');
```

```
features = vggishFeatures(audioIn,fs);
```

Plot the VGGish features over time.

```
surf(features,'EdgeColor','none')
```

```
view([30 65])
```

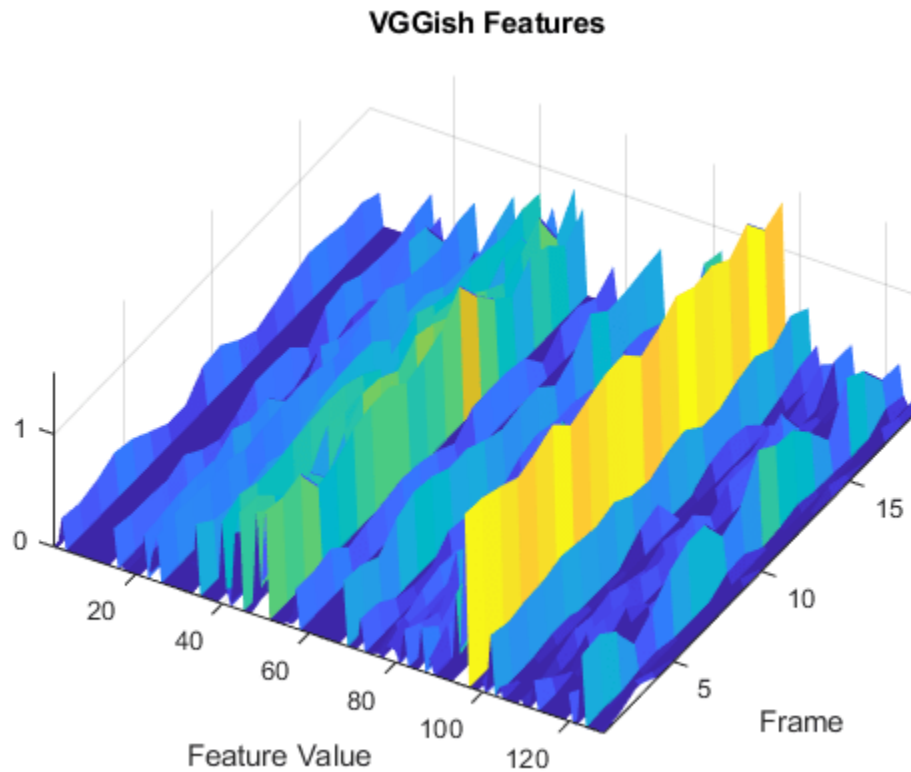
```
axis tight
```

```
xlabel('Feature Index')
```

```
ylabel('Frame')
```


```
xlabel('Feature Value')
```

```
title('VGGish Features')
```

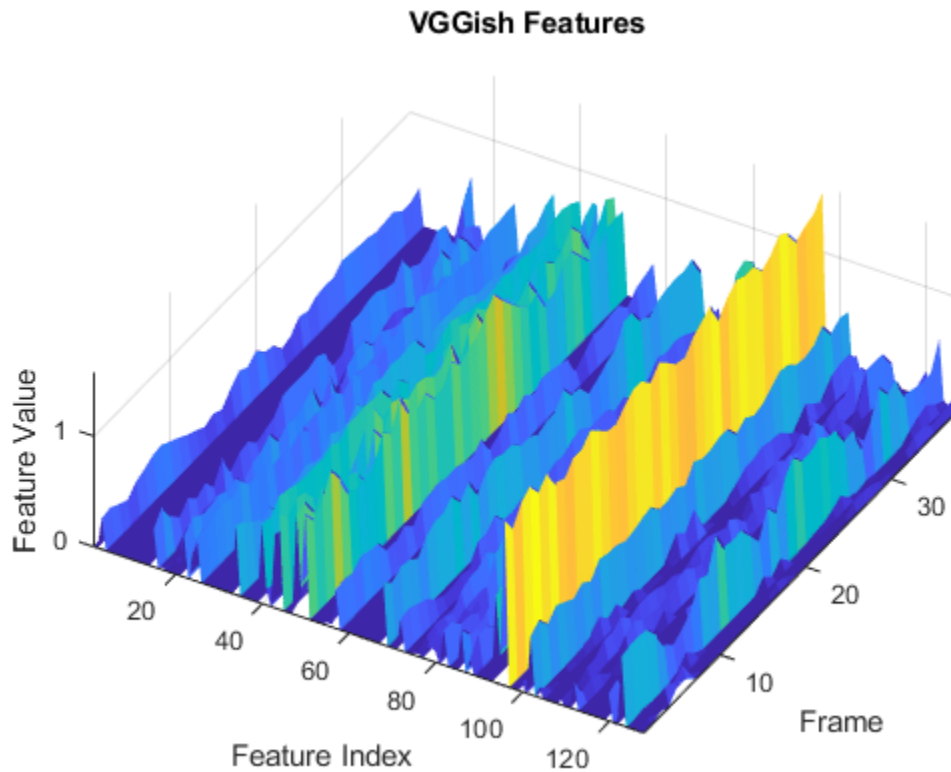
To increase the resolution of VGGish features over time, specify the percent overlap between mel spectrograms. Plot the results.

```

overlapPercentage = 75  ;
features = vggishFeatures(audioIn,fs,'OverlapPercentage',overlapPercentage);

surf(features,'EdgeColor','none')
view([30 65])
axis tight
xlabel('Feature Index')
ylabel('Frame')
zlabel('Feature Value')
title('VGGish Features')

```



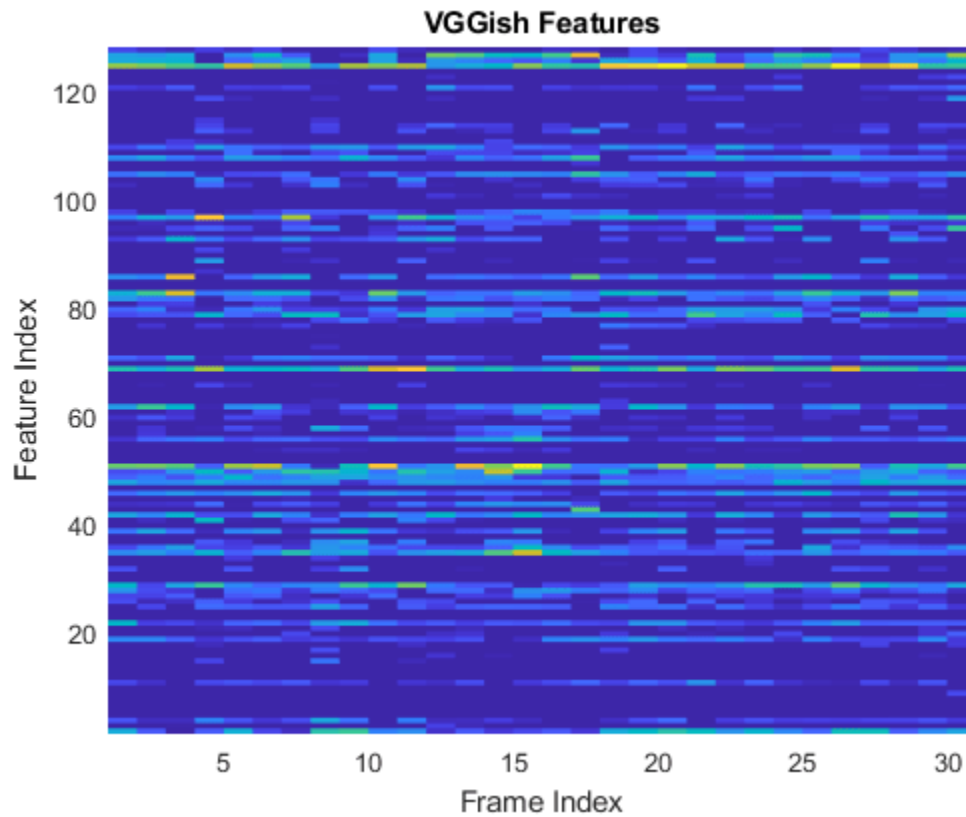
Apply Principal Component Analysis to VGGish Embeddings

Read in an audio file, listen to it, and then extract VGGish features from the audio.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');  
sound(audioIn,fs)  
  
features = vggishFeatures(audioIn,fs);
```

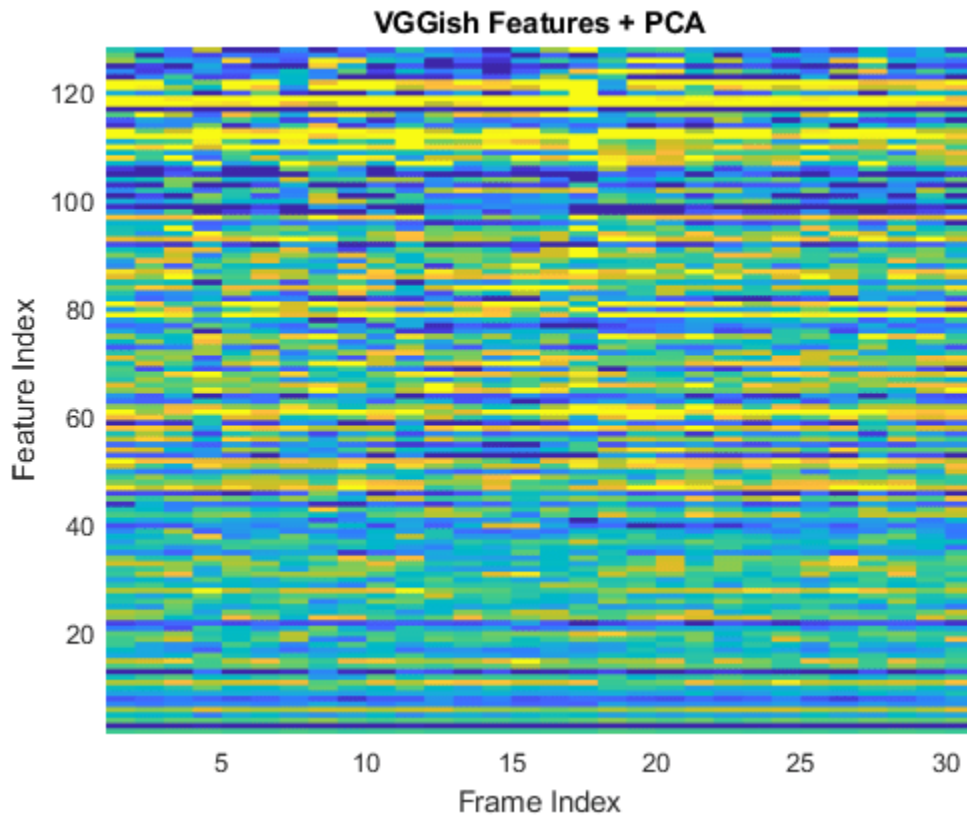
Visualize the VGGish features over time. Many of the individual features are zero-valued and contain no useful information.

```
surf(features,'EdgeColor','none')  
view([90,-90])  
axis tight  
xlabel('Feature Index')  
ylabel('Frame Index')  
title('VGGish Features')
```



You can apply principal component analysis (PCA) to map the feature vectors into a space that emphasizes variation between the embeddings. Call the `vggishFeatures` function again and specify `ApplyPCA` as `true`. Visualize the VGGish features after PCA.

```
features = vggishFeatures(audioIn,fs,'ApplyPCA',true);  
  
surf(features,'EdgeColor','none')  
view([90,-90])  
axis tight  
xlabel('Feature Index')  
ylabel('Frame Index')  
title('VGGish Features + PCA')
```



Use VGGish Embeddings for Deep Learning

Download and unzip the air compressor data set. This data set consists of recordings from air compressors in a healthy state or in one of seven faulty states.

```
url = 'https://www.mathworks.com/supportfiles/audio/AirCompressorDataset/AirCompressorDataset.zip';
downloadFolder = fullfile(tempdir,'aircompressordataset');
datasetLocation = tempdir;

if ~exist(fullfile(tempdir,'AirCompressorDataSet'),'dir')
    loc = websave(downloadFolder,url);
    unzip(loc,fullfile(tempdir,'AirCompressorDataSet'))
end
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets.

```
ads = audioDatastore(downloadFolder,'IncludeSubfolders',true,'LabelSource','foldernames');

[adsTrain,adsValidation] = splitEachLabel(ads,0.8,0.2);
```

Read an audio file from the datastore and save the sample rate for later use. Reset the datastore to return the read pointer to the beginning of the data set. Listen to the audio signal and plot the signal in the time domain.

```
[x,fileInfo] = read(adsTrain);
fs = fileInfo.SampleRate;
```

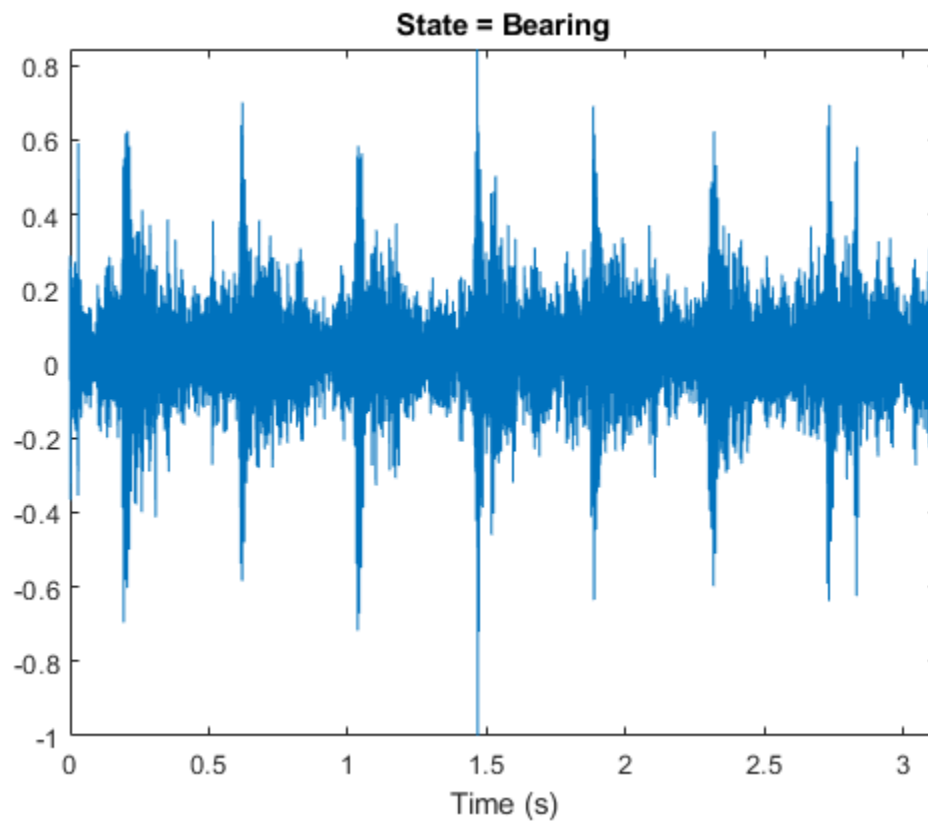
```

reset(adsTrain)

sound(x,fs)

figure
t = (0:size(x,1)-1)/fs;
plot(t,x)
xlabel('Time (s)')
title('State = ' + string(fileInfo.Label))
axis tight

```



Extract VGGish features from the training and validation sets. Transpose the features so that time is along rows.

```

trainFeatures = cell(1,numel(adsTrain.Files));
for idx = 1:numel(adsTrain.Files)
    [audioIn,fileInfo] = read(adsTrain);
    features = vggishFeatures(audioIn,fileInfo.SampleRate);
    trainFeatures{idx} = features';
end

validationFeatures = cell(1,numel(adsValidation.Files));
for idx = 1:numel(adsValidation.Files)
    [audioIn,fileInfo] = read(adsValidation);
    features = vggishFeatures(audioIn,fileInfo.SampleRate);
    validationFeatures{idx} = features';
end

```

Define a “Long Short-Term Memory Networks” (Deep Learning Toolbox) network.

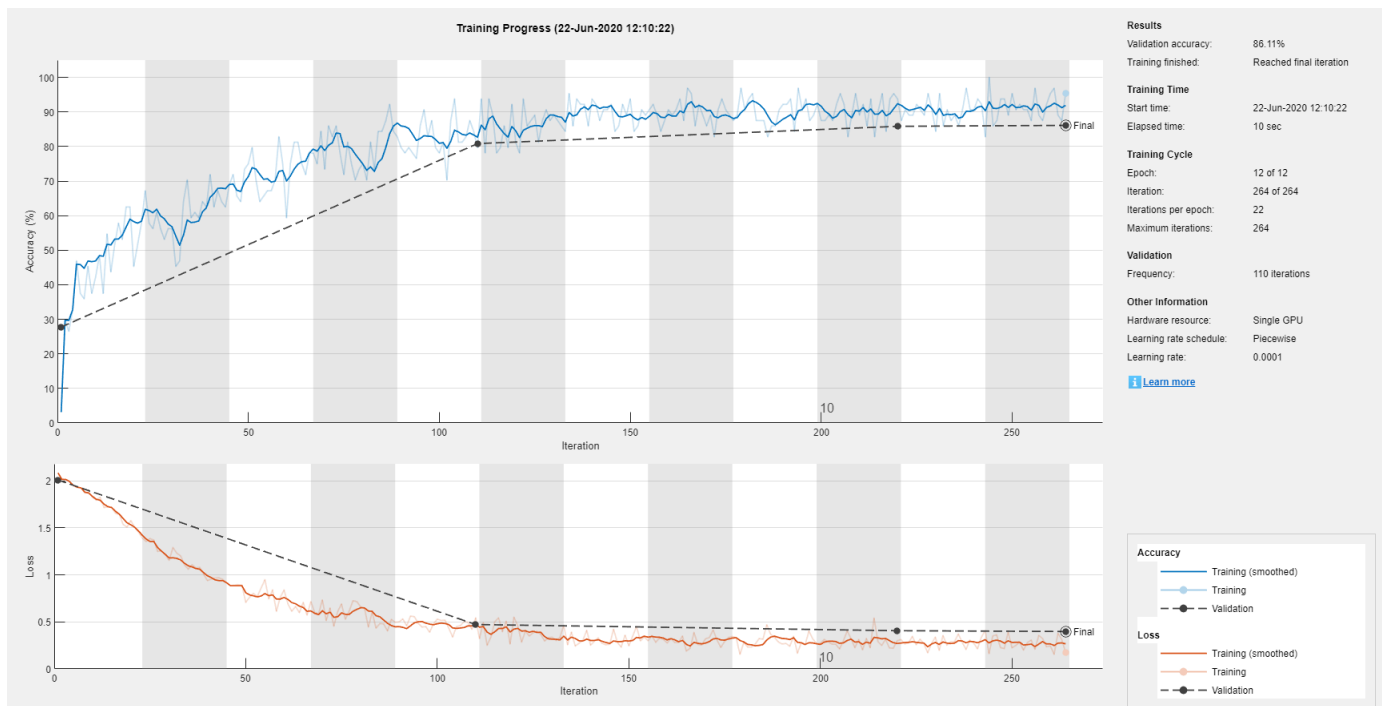
```
layers = [
    sequenceInputLayer(128)
    lstmLayer(100, 'OutputMode', 'last')
    fullyConnectedLayer(8)
    softmaxLayer
    classificationLayer];
```

To define training options, use `trainingOptions` (Deep Learning Toolbox).

```
miniBatchSize = 64;
validationFrequency = 5*floor(numel(trainFeatures)/miniBatchSize);
options = trainingOptions("adam", ...
    "MaxEpochs",12, ...
    "MiniBatchSize",miniBatchSize, ...
    "Plots","training-progress", ...
    "Shuffle","every-epoch", ...
    "LearnRateSchedule","piecewise", ...
    "LearnRateDropPeriod",6, ...
    "LearnRateDropFactor",0.1, ...
    "ValidationData",{validationFeatures,adsValidation.Labels}, ...
    "ValidationFrequency",validationFrequency, ...
    'Verbose',false);
```

To train the network, use `trainNetwork` (Deep Learning Toolbox).

```
net = trainNetwork(trainFeatures,adsTrain.Labels,layers,options)
```



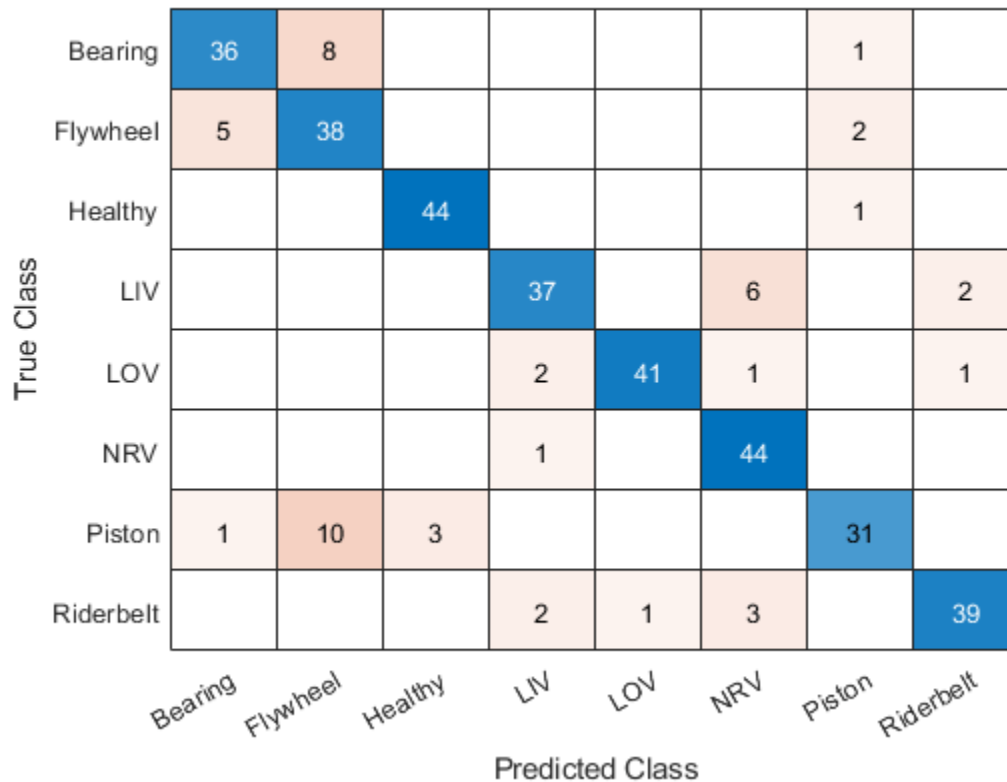
```
net =
    SeriesNetwork with properties:

        Layers: [5×1 nnet.cnn.layer.Layer]
```

```
InputNames: {'sequenceinput'}
OutputNames: {'classoutput'}
```

Visualize the confusion matrix for the validation set.

```
predictedClass = classify(net,validationFeatures);
confusionchart(adsValidation.Labels,predictedClass)
```



Use VGGish Embeddings for Machine Learning

Download and unzip the air compressor data set [1] on page 2-0 . This data set consists of recordings from air compressors in a healthy state or in one of seven faulty states.

```
url = 'https://www.mathworks.com/supportfiles/audio/AirCompressorDataset/AirCompressorDataset.zip';
downloadFolder = fullfile(tempdir,'aircompressordataset');
datasetLocation = tempdir;

if ~exist(fullfile(tempdir,'AirCompressorDataSet'),'dir')
    loc = websave(downloadFolder,url);
    unzip(loc,fullfile(tempdir,'AirCompressorDataSet'))
end
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets.

```
ads = audioDatastore(downloadFolder,'IncludeSubfolders',true,'LabelSource','foldernames');
```

In this example, you classify signals as either healthy or faulty. Combine all of the faulty labels into a single label. Split the datastore into training and validation sets.

```
labels = ads.Labels;
labels(labels~=categorical("Healthy")) = categorical("Faulty");
ads.Labels = removecats(labels);
```

```
[adsTrain,adsValidation] = splitEachLabel(ads,0.8,0.2);
```

Extract VGGish features from the training set. Each audio file corresponds to multiple VGGish features. Replicate the labels so that they are in one-to-one correspondence with the features.

```
trainFeatures = [];
trainLabels = [];
for idx = 1:numel(adsTrain.Files)
    [audioIn,fileInfo] = read(adsTrain);
    features = vggishFeatures(audioIn,fileInfo.SampleRate);
    trainFeatures = [trainFeatures;features];
    trainLabels = [trainLabels;repelem(fileInfo.Label,size(features,1))'];
end
```

Train a cubic support vector machine (SVM) using `fitsvm` (Statistics and Machine Learning Toolbox). To explore other classifiers and their performances, use Classification Learner (Statistics and Machine Learning Toolbox).

```
faultDetector = fitsvm( ...
    trainFeatures, ...
    trainLabels, ...
    'KernelFunction','polynomial', ...
    'PolynomialOrder',3, ...
    'KernelScale','auto', ...
    'BoxConstraint',1, ...
    'Standardize',true, ...
    'ClassNames',categories(trainLabels));
```

For each file in the validation set:

- 1 Extract VGGish features.
- 2 For each VGGish feature vector in a file, use the trained classifier to predict whether the machine is healthy or faulty.
- 3 Take the mode of the predictions for each file.

```
predictions = [];
for idx = 1:numel(adsValidation.Files)
    [audioIn,fileInfo] = read(adsValidation);

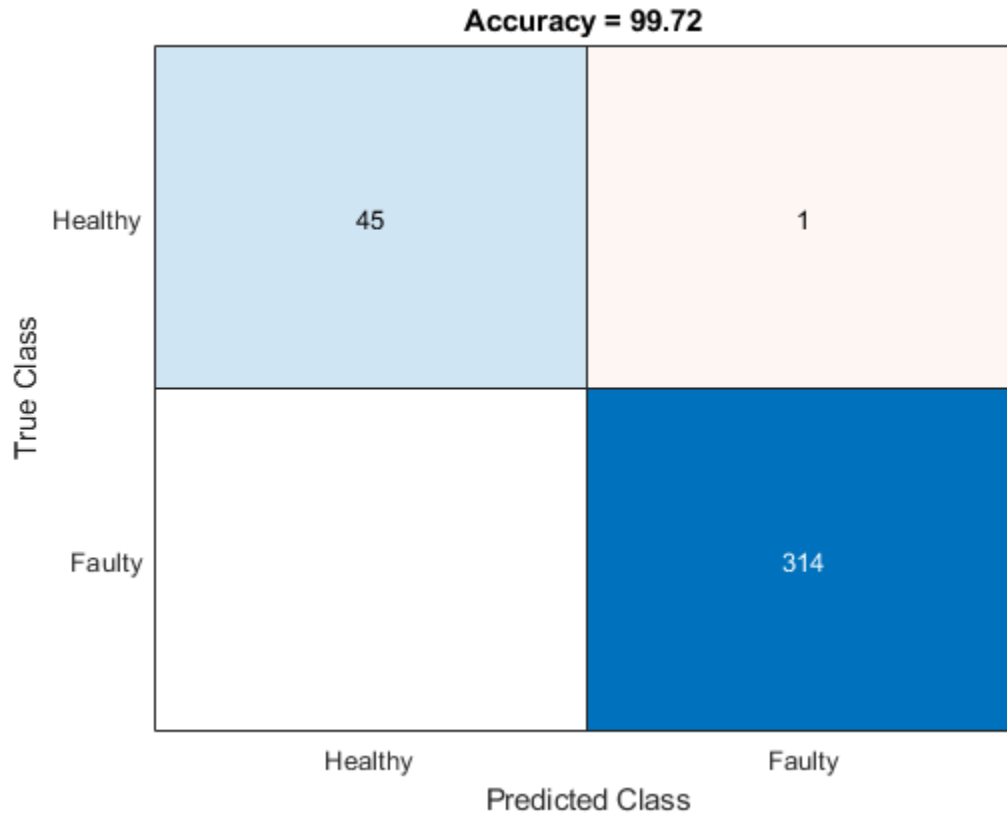
    features = vggishFeatures(audioIn,fileInfo.SampleRate);

    predictionsPerFile = categorical(predict(faultDetector,features));

    predictions = [predictions;mode(predictionsPerFile)];
end
```

Use `confusionchart` (Statistics and Machine Learning Toolbox) to display the performance of the classifier.


```
accuracy = sum(predictions==adsValidation.Labels)/numel(adsValidation.Labels);
cc = confusionchart(predictions,adsValidation.Labels);
cc.Title = sprintf('Accuracy = %0.2f %',accuracy*100);
```



References

[1] Verma, Nishchal K., Rahul Kumar Sevakula, Sonal Dixit, and Al Salour. 2016. "Intelligent Condition Based Monitoring Using Acoustic Signals for Air Compressors." *IEEE Transactions on Reliability* 65 (1): 291-309. <https://doi.org/10.1109/TR.2015.2459684>.

Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If you specify a matrix, `vggishFeatures` treats the columns of the matrix as individual audio channels.

The duration of `audioIn` must be equal to or greater than 0.975 seconds.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'OverlapPercentage', 75`

OverlapPercentage — Percentage overlap between consecutive audio frames

50 (default) | scalar in the range [0,100)

Percentage overlap between consecutive audio frames, specified as a scalar in the range [0,100).

Data Types: `single` | `double`

ApplyPCA — Flag to apply PCA transformation to audio embeddings

`false` (default) | `true`

Flag to apply PCA transformation to audio embeddings, specified as either `true` or `false`.

Data Types: `logical`

Output Arguments

embeddings — Compact representation of audio data

L -by-128-by- N array

Compact representation of audio data, returned as an L -by-128-by- N array, where:

- L -- Represents the number of frames the audio signal is partitioned into. This is determined by the `OverlapPercentage`.
- 128 -- Represents the audio embedding length.
- N -- Represents the number of channels.

Algorithms

The `vggishFeatures` function uses VGGish to extract feature embeddings from audio. The `vggishFeatures` function preprocesses the audio so that it is in the format required by VGGish and optionally postprocesses the embeddings.

Preprocess

- 1 Resample `audioIn` to 16 kHz and cast to single precision.
- 2 Compute a one-sided short time Fourier transform using a 25 ms periodic Hann window with a 10 ms hop, and a 512-point DFT. The audio is now represented by a 257-by- L array, where 257 is the number of bins in the one-sided spectra, and L depends on the length of the input.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude spectrum through a 64-band mel-spaced filter bank, then sum the magnitudes in each band. The audio is now represented by a single 64-by- L mel spectrogram.

- 5 Convert the mel spectrogram to a log scale.
- 6 Buffer the mel spectrogram into overlapped segments consisting of 96 spectra each. The audio is now represented by a 96-by-64-by-1-by- K array, where 96 is the number of spectra in the individual mel spectrograms, 64 is the number of mel bands, and the spectrograms are spaced along the fourth dimension for compatibility with the VGGish model. The number of mel spectrograms, K , depends on the input length and `OverlapPercentage`.

Feature Extraction

Pass the 96-by-64-by-1-by- K array of mel spectrograms through VGGish to return a K -by-128 matrix. The output from VGGish are the feature embeddings corresponding to each 0.975 s frame of audio data.

Postprocess

If `ApplyPCA` is set to `true`, the feature embeddings are postprocessed to match the postprocessing of the released AudioSet embeddings. The VGGish model was released with a precomputed principal component analysis (PCA) matrix and mean vector to apply a PCA transformation and whitening during inference. The postprocessing includes applying PCA, whitening, and quantization.

- 1 Subtract the precomputed 1-by-128 PCA mean vector from the K -by-128 feature matrix, and then premultiply the result by the precomputed 128-by-128 PCA matrix.
- 2 Clip the transformed and whitened embeddings to between -2 and 2, then quantize the result to values that can be represented by `uint8`.

Compatibility Considerations

vggishFeatures will be removed

Not recommended starting in R2022a

The `vggishFeatures` function will be removed in a future release. Use `vggishEmbeddings` instead. Existing calls to `vggishFeatures` continue to run.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. 2017. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. 2017. "CNN Architectures for Large-Scale Audio Classification." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131–35. New Orleans, LA: IEEE. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

audioFeatureExtractor | classifySound | vggish | vggishPreprocess | yamnet | yamnetGraph | yamnetPreprocess

Introduced in R2020b

yamnetGraph

Graph of YAMNet AudioSet ontology

Syntax

```
ygraph = yamnetGraph
[ygraph,classes] = yamnetGraph
```

Description

`ygraph = yamnetGraph` returns a directed graph of the AudioSet ontology.

`[ygraph,classes] = yamnetGraph` also returns a string array of classes supported by YAMNet.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download yamnetGraph

Download and unzip the Audio Toolbox™ support for YAMNet.

Type `yamnetGraph` at the Command Window. If the Audio Toolbox support for YAMNet is not installed, then the function provides a link to the download location. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the YAMNet model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'YAMNetDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/yamnet.zip');
YAMNetLocation = tempdir;
unzip(loc,YAMNetLocation)
addpath(fullfile(YAMNetLocation,'yamnet'))
```

Check that the installation is successful by typing `yamnetGraph` at the Command Window. If the network is installed, then the function returns a `digraph` object.

```
yamnetGraph
```

Identify Major Categories of Ontology

Create a `digraph` object that describes the AudioSet ontology.

```
ygraph = yamnetGraph

ygraph =
    digraph with properties:
```

```
Edges: [670×1 table]
Nodes: [632×1 table]
```

Visualize the ontology. The ontology consists of 632 separate classes with 670 connections.

```
p = plot(ygraph);
layout(p, 'layered')
```

Get the name of each sound class. If the sound class has no predecessors, identify it as a major category of the ontology.

```
nodeNames = ygraph.Nodes.Name;
topCategories = {};
for index = 1:numel(nodeNames)
    pre = predecessors(ygraph,nodeNames{index});
    if isempty(pre)
        topCategories{end+1} = nodeNames{index};
    end
end
```

Display the categories as an array of strings.

```
topCategories = string(topCategories)

topCategories = 1×7 string
    "Human sounds"    "Animal"    "Music"    "Natural sounds"    "Sounds of things"    "Source-a
```

Highlight and label the top categories on the digraph plot.

```
highlight(p,topCategories,"NodeColor","red","MarkerSize",8)
labelnode(p,topCategories,topCategories)
```

Plot Subgraph of Animal Sounds

Create a `digraph` object that represents the `AudioSet` ontology.

```
ygraph = yamnetGraph;
```

Use `dfsearch` to perform a depth-first graph search to identify all audio classes under the class `Animal`.

```
animalNodes = dfsearch(ygraph,"Animal");
```

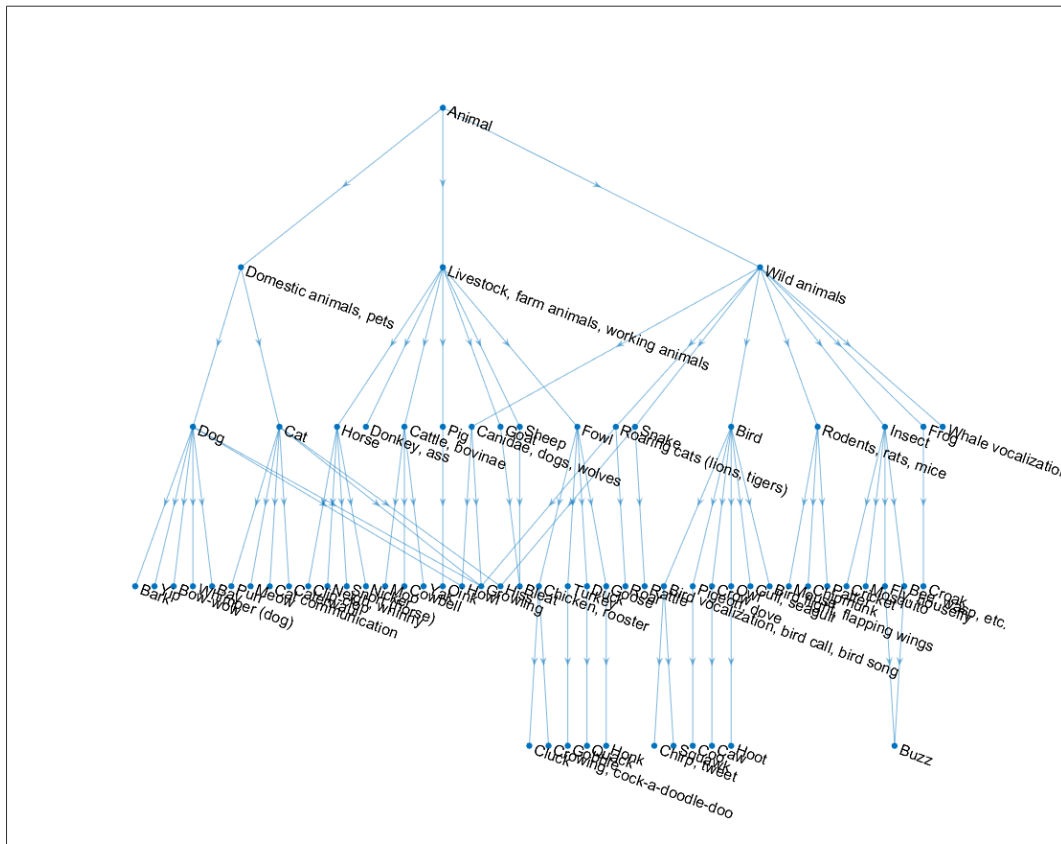
Use `subgraph` to create a new `digraph` object that only includes the identified audio classes. Plot the resulting directed edges graph.

```
animalGraph = subgraph(ygraph,animalNodes);
```

```
p = plot(animalGraph);
```

```
p.NodeFontSize = 12;
graphFigure = gcf;
```

```
old = graphFigure.Position;
set(graphFigure, 'position', [old(1),old(2),old(3)*3,old(4)*3])
```



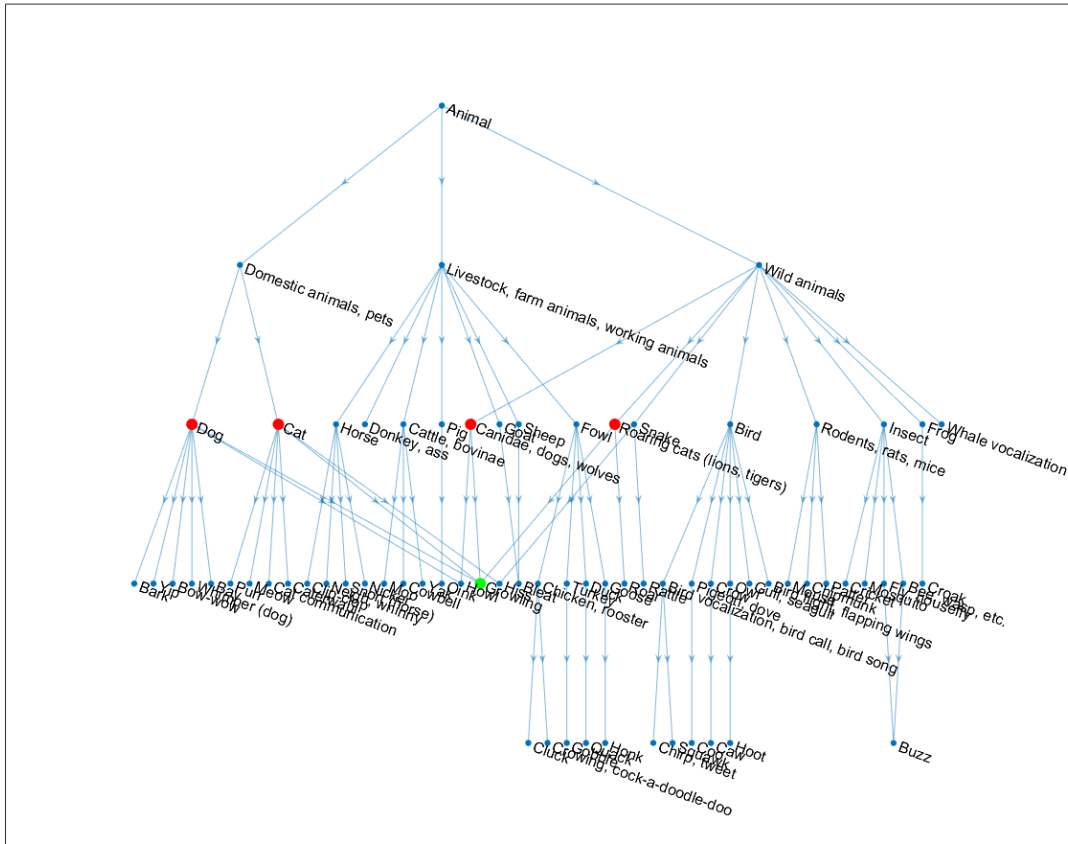
Use predecessors to determine all predecessors to the Growling sound. Highlight the predecessors on the plot.

```
preIDs = predecessors(animalGraph, "Growling")
```

```
preIDs = 4x1 string
    "Dog"
    "Cat"
    "Roaring cats (lions, tigers)"
    "Canidae, dogs, wolves"
```

Use highlight to highlight the Growling node and the predecessors on the plot.

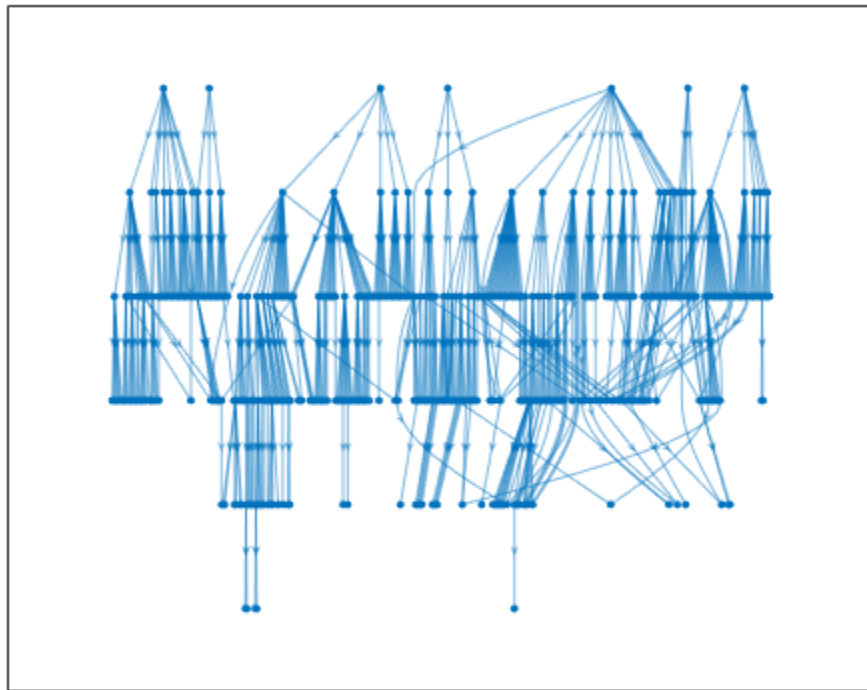
```
highlight(p, "Growling", 'NodeColor', 'g', 'MarkerSize', 8)
highlight(p, preIDs, 'NodeColor', 'r', 'MarkerSize', 8)
```



Visualize Sounds Supported by YAMNet

Create a digraph object that describes the AudioSet ontology. Also return the classes supported by YAMNet. Plot the directed graph.

```
[ygraph, classes] = yamnetGraph;
p = plot(ygraph);
layout(p, 'layered')
```

YAMNet predicts a subset of the full AudioSet ontology. Display the sound classes that are in the AudioSet ontology but are not possible outputs from the YAMNet network.

```
audiosetClasses = ygraph.Nodes.Name;
classDiff = setdiff(audiosetClasses,classes)
```

```
classDiff = 111x1 string
    "Acoustic environment"
    "Alto saxophone"
    "Background noise"
    "Bass (frequency range)"
    "Bass (instrument role)"
    "Bassline"
    "Bassoon"
    "Battle cry"
    "Bay"
    "Beat"
    "Birthday music"
    "Blare"
    "Booing"
    "Brief tone"
    "Bugle"
    "Cat communication"
    "Cellphone buzz, vibrating alert"
    "Channel, environment and background"
    "Chipmunk"
    "Chord"
    "Clavinet"
```

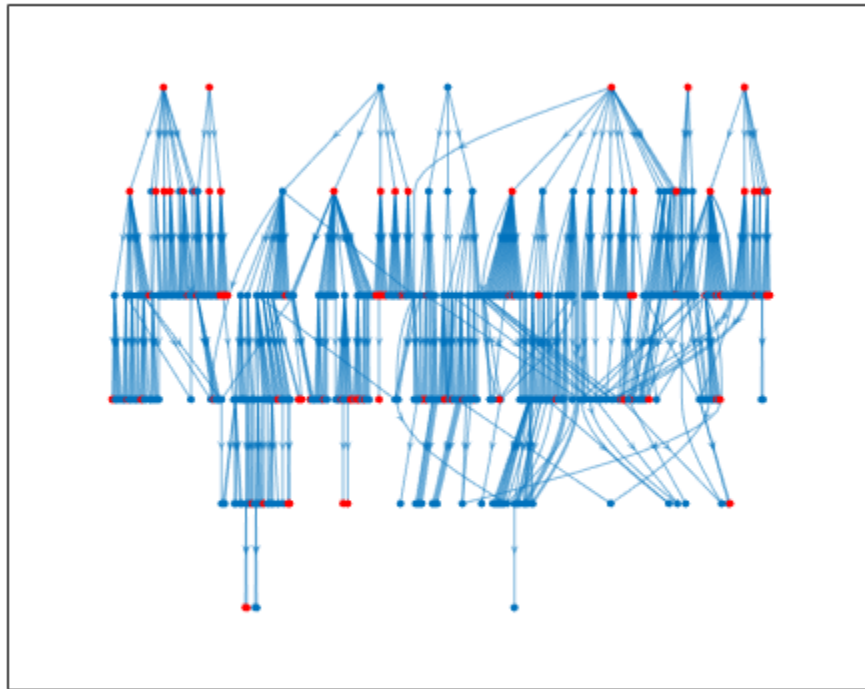
```

"Clunk"
"Compact disc"
"Coronet"
"Crash cymbal"
"Cumbia"
"Deformable shell"
"Digestive"
"Domestic sounds, home sounds"
"Donkey, ass"
⋮

```

Highlight the classes that are not possible outputs from YAMNet.

```
highlight(p,classDiff,'NodeColor','r')
```

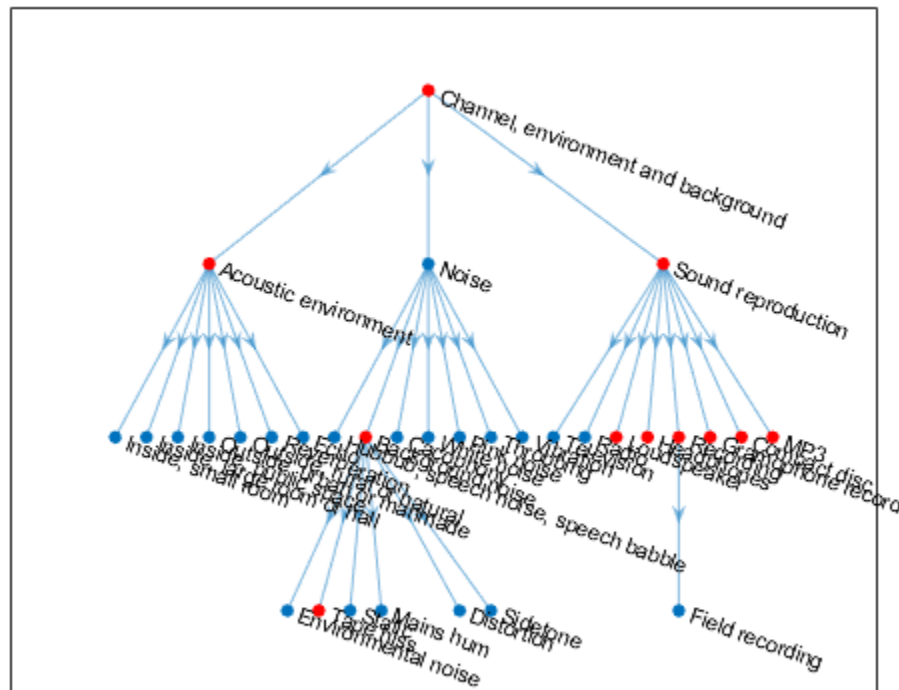


Analyze one of the major categories.

```

categoryToAnalyze =  ;
subsetNodes = dfsearch(ygraph,categoryToAnalyze);
ygraphSubset = subgraph(ygraph,subsetNodes);
classToHighlight = intersect(classDiff,ygraphSubset.Nodes.Name);
pSub = plot(ygraphSubset);
layout(pSub,'layered')
highlight(pSub,classToHighlight,'NodeColor','r')

```



Visualize Specificity of Sound Classes

Create a digraph object that describes the AudioSet ontology.

```
ygraph = yamnetGraph;
```

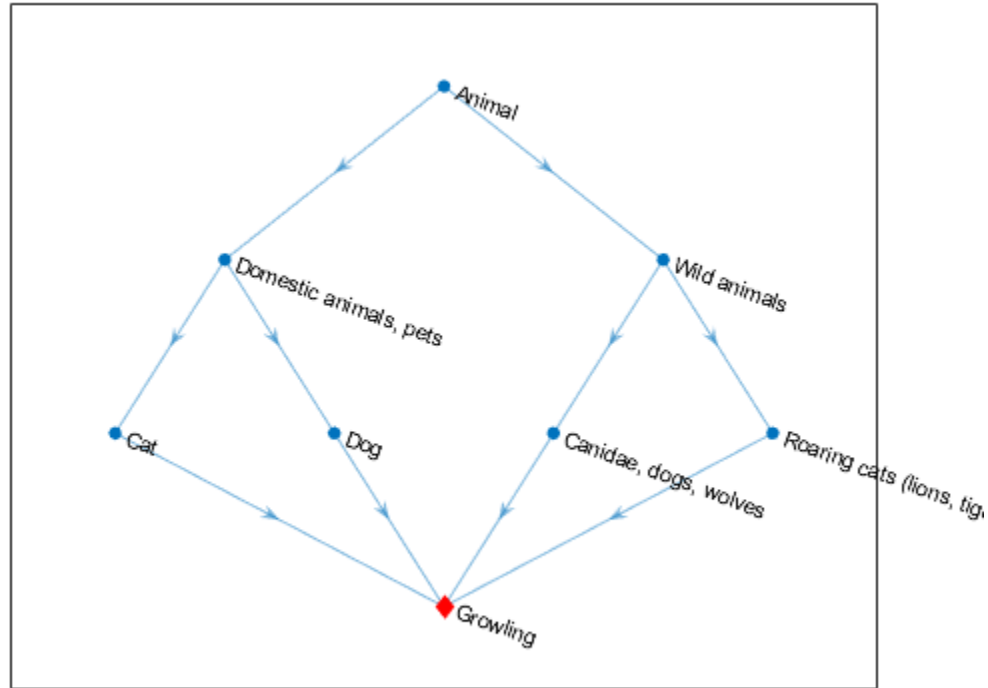
Specify a sound class to visualize, and specify the number of predecessors and successors. The available sound classes are only those that are supported as outputs from YAMNet. If you specify more predecessors or successors than those in the ontology, only the predecessors and successors in the ontology are shown.

```
soundClass =  ;
numPredecessors = 3  ;
numSuccessors = 0  ;

pred = nearest(ygraph,soundClass,numPredecessors,'Direction','incoming');
suc = nearest(ygraph,soundClass,numSuccessors,'Direction','outgoing');
subClasses = [soundClass;pred;suc];

ygraphSub = subgraph(ygraph,unique(subClasses));
p = plot(ygraphSub);
```

```
layout(p, 'layered')
highlight(p, soundClass, 'Marker', 'd', 'NodeColor', 'red', 'MarkerSize', 6)
```



Output Arguments

ygraph — AudioSet ontology graph with directed edges

digraph object

AudioSet ontology graph with directed edges, returned as a digraph object.

classes — Classes supported by YAMNet

string array

Classes supported by YAMNet, returned as a string array. The classes supported by YAMNet are a subset of the AudioSet ontology.

Tips

Google[®] provides a website where you can explore the AudioSet ontology and the corresponding data set: <https://research.google.com/audioset/ontology/index.html>.

References

- [1] Gemmeke, Jort F., et al. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776–80. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952261.
- [2] Hershey, Shawn, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131–35. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952132.

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

classifySound | vggish | vggishEmbeddings | vggishPreprocess | yamnet | yamnetPreprocess

Introduced in R2020b

classifySound

Classify sounds in audio signal

Syntax

```
sounds = classifySound(audioIn,fs)
sounds = classifySound(audioIn,fs,Name,Value)

[sounds,timestamps] = classifySound(____)
[sounds,timestamps,resultsTable] = classifySound(____)

classifySound(____)
```

Description

`sounds = classifySound(audioIn,fs)` returns the sound classes detected over time in the audio input, `audioIn`, with sample rate `fs`.

`sounds = classifySound(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Example: `sounds = classifySound(audioIn,fs,'SpecificityLevel','low')` classifies sounds using low specificity.

`[sounds,timestamps] = classifySound(____)` also returns time stamps associated with each detected sound.

`[sounds,timestamps,resultsTable] = classifySound(____)` also returns a table containing result details.

`classifySound(____)` with no output arguments creates a word cloud of the identified sounds in the audio signal.

This function requires both Audio Toolbox and Deep Learning Toolbox.

Examples

Download classifySound

Download and unzip the Audio Toolbox™ support for YAMNet.

If the Audio Toolbox support for YAMNet is not installed, then the first call to the function provides a link to the download location. To download the model, click the link. Unzip the file to a location on the MATLAB path.

Alternatively, execute the following commands to download and unzip the YAMNet model to your temporary directory.

```
downloadFolder = fullfile(tempdir,'YAMNetDownload');
loc = websave(downloadFolder,'https://ssd.mathworks.com/supportfiles/audio/yamnet.zip');
```

```

YAMNetLocation = tempdir;
unzip(loc,YAMNetLocation)
addpath(fullfile(YAMNetLocation,'yamnet'))

```

Identify Colored Noise

Generate 1 second of pink noise assuming a 16 kHz sample rate.

```

fs = 16e3;
x = pinknoise(fs);

```

Call `classifySound` with the pink noise signal and the sample rate.

```

identifiedSound = classifySound(x,fs)

identifiedSound =
"Pink noise"

```

Identify and Locate Sounds in Time

Read in an audio signal. Call `classifySound` to return the detected sounds and corresponding time stamps.

```

[audioIn,fs] = audioread('multipleSounds-16-16-mono-18secs.wav');
[sounds,timeStamps] = classifySound(audioIn,fs);

```

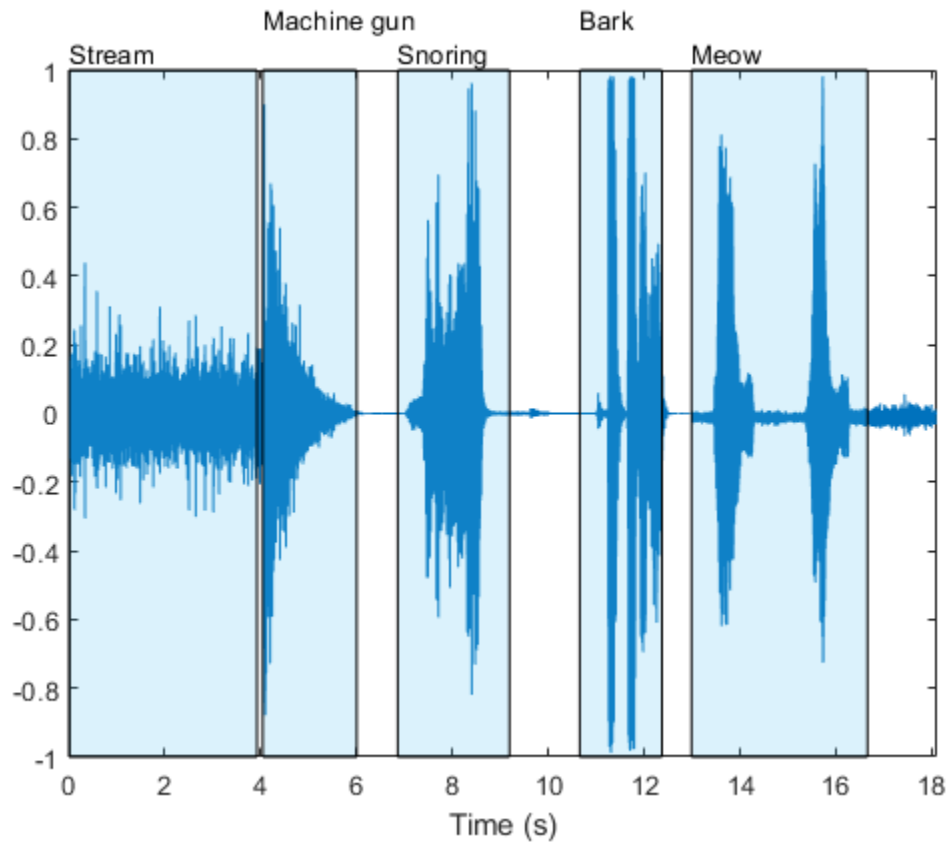
Plot the audio signal and label the detected sound regions.

```

t = (0:numel(audioIn)-1)/fs;
plot(t,audioIn)
xlabel('Time (s)')
axis([t(1),t(end),-1,1])

textHeight = 1.1;
for idx = 1:numel(sounds)
    patch([timeStamps(idx,1),timeStamps(idx,1),timeStamps(idx,2),timeStamps(idx,2)], ...
        [-1,1,1,-1], ...
        [0.3010 0.7450 0.9330], ...
        'FaceAlpha',0.2);
    text(timeStamps(idx,1),textHeight+0.05*(-1)^idx,sounds(idx))
end

```



Select a region and listen only to the selected region.

```
sampleStamps = floor(timeStamps*fs)+1;
```

```
soundEvent =  ;
```

```
isolatedSoundEvent = audioIn(sampleStamps(soundEvent,1):sampleStamps(soundEvent,2));
sound(isolatedSoundEvent,fs);
display('Detected Sound = ' + sounds(soundEvent))
```

```
"Detected Sound = Snoring"
```

Identify Only Specific Sounds

Read in an audio signal containing multiple different sound events.

```
[audioIn,fs] = audioread('multipleSounds-16-16-mono-18secs.wav');
```

Call `classifySound` with the audio signal and sample rate.

```
[sounds,~,soundTable] = classifySound(audioIn,fs);
```

The `sounds` string array contains the most likely sound event in each region.

```
sounds
```



```
sounds = 1x5 string
    "Stream"    "Machine gun"    "Snoring"    "Bark"    "Meow"
```

The `soundTable` contains detailed information regarding the sounds detected in each region, including score means and maximums over the analyzed signal.

`soundTable`

```
soundTable=5x2 table
    TimeStamps    Results
    _____    _____
         0         3.92    {4x3 table}
    4.0425    6.0025    {3x3 table}
         6.86    9.1875    {2x3 table}
    10.658    12.373    {4x3 table}
    12.985    16.66    {4x3 table}
```

View the last detected region.

```
soundTable.Results{end}
```

```
ans=4x3 table
    Sounds    AverageScores    MaxScores
    _____    _____    _____
    "Animal"    0.79514    0.99941
    "Domestic animals, pets"    0.80243    0.99831
    "Cat"    0.8048    0.99046
    "Meow"    0.6342    0.90177
```

Call `classifySound` again. This time, set `IncludedSounds` to `Animal` so that the function retains only regions in which the `Animal` sound class is detected.

```
[sounds,timeStamps,soundTable] = classifySound(audioIn,fs, ...
    'IncludedSounds','Animal');
```

The `sounds` array only returns sounds specified as included sounds. The `sounds` array now contains two instances of `Animal` that correspond to the regions declared as `Bark` and `Meow` previously.

`sounds`

```
sounds = 1x2 string
    "Animal"    "Animal"
```

The `soundTable` only includes regions where the specified sound classes were detected.

`soundTable`

```
soundTable=2x2 table
    TimeStamps    Results
    _____    _____
    10.658    12.373    {4x3 table}
```

```
12.985      16.66      {4x3 table}
```

View the last detected region in `soundTable`. The results table still includes statistics for all detected sounds in the region.

```
soundTable.Results{end}
```

```
ans=4x3 table
```

Sounds	AverageScores	MaxScores
"Animal"	0.79514	0.99941
"Domestic animals, pets"	0.80243	0.99831
"Cat"	0.8048	0.99046
"Meow"	0.6342	0.90177

To explore which sound classes are supported by `classifySound`, use `yamnetGraph`.

Exclude Specific Sounds

Read in an audio signal and call `classifySound` to inspect the most likely sounds arranged in chronological order of detection.

```
[audioIn,fs] = audioread("multipleSounds-16-16-mono-18secs.wav");
sounds = classifySound(audioIn,fs)
```

```
sounds = 1x5 string
    "Stream"    "Machine gun"    "Snoring"    "Bark"    "Meow"
```

Call `classifySound` again and set `ExcludedSounds` to `Meow` to exclude the sound `Meow` from the results. The segment previously classified as `Meow` is now classified as `Cat`, which is its immediate predecessor in the `AudioSet` ontology.

```
sounds = classifySound(audioIn,fs,"ExcludedSounds","Meow")
```

```
sounds = 1x5 string
    "Stream"    "Machine gun"    "Snoring"    "Bark"    "Cat"
```

Call `classifySound` again, and set `ExcludedSounds` to `Cat`. When you exclude a sound, all successors are also excluded. This means that excluding the sound `Cat` also excludes the sound `Meow`. The segment originally classified as `Meow` is now classified as `Domestic animals, pets`, which is the immediate predecessor to `Cat` in the `AudioSet` ontology.

```
sounds = classifySound(audioIn,fs,"ExcludedSounds","Cat")
```

```
sounds = 1x5 string
    "Stream"    "Machine gun"    "Snoring"    "Bark"    "Domestic animals, pets"
```

Call `classifySound` again and set `ExcludedSounds` to `Domestic animals, pets`. The sound class, `Domestic animals, pets` is a predecessor to both `Bark` and `Meow`, so by excluding it, the

sounds previously identified as Bark and Meow are now both identified as the predecessor of Domestic animals, pets, which is Animal.

```
sounds = classifySound(audioIn,fs,"ExcludedSounds","Domestic animals, pets")
```

```
sounds = 1×5 string
    "Stream"    "Machine gun"    "Snoring"    "Animal"    "Animal"
```

Call classifySound again and set ExcludedSounds to Animal. The sound class Animal has no predecessors.

```
sounds = classifySound(audioIn,fs,"ExcludedSounds","Animal")
```

```
sounds = 1×3 string
    "Stream"    "Machine gun"    "Snoring"
```

If you want to avoid detecting Meow and its predecessors, but continue detecting successors under the same predecessors, use the IncludedSounds option. Call yamnetGraph to get a list of all supported classes. Remove Meow and its predecessors from the array of all classes, and then call classifySound again.

```
[~,classes] = yamnetGraph;
classesToInclude = setxor(classes,["Meow","Cat","Domestic animals, pets","Animal"]);
sounds = classifySound(audioIn,fs,"IncludedSounds",classesToInclude)
```

```
sounds = 1×4 string
    "Stream"    "Machine gun"    "Snoring"    "Bark"
```

Generate Word Cloud

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread('multipleSounds-16-16-mono-18secs.wav');
sound(audioIn,fs)
```

Call classifySound with no output arguments to generate a word cloud of the detected sounds.

```
classifySound(audioIn,fs);
```



Modify default parameters of `classifySound` to explore the effect on the word cloud.

```

threshold = 0.1  ;
minimumSoundSeparation = 0.92  ;
minimumSoundDuration = 1.02  ;

classifySound(audioIn, fs, ...
    'Threshold', threshold, ...
    'MinimumSoundSeparation', minimumSoundSeparation, ...
    'MinimumSoundDuration', minimumSoundDuration);

```



Input Arguments

audioIn — Audio input

column vector

Audio input, specified as a one-channel signal (column vector).

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'Threshold',0.1`

Threshold — Confidence threshold for reporting sounds

0.35 (default) | scalar in the range (0,1)

Confidence threshold for reporting sounds, specified as the comma-separated pair consisting of 'Threshold' and a scalar in the range (0,1).

Data Types: single | double

MinimumSoundSeparation — Minimum separation between detected sound regions (s)

0.25 (default) | positive scalar

Minimum separation between consecutive regions of the same detected sound in seconds, specified as the comma-separated pair consisting of 'MinimumSoundSeparation' and a positive scalar. Regions closer than the minimum sound separation are merged.

Data Types: single | double

MinimumSoundDuration — Minimum duration of detected sound region (s)

0.5 (default) | positive scalar

Minimum duration of detected sound regions in seconds, specified as the comma-separated pair consisting of 'MinimumSoundDuration' and a positive scalar. Regions shorter than the minimum sound duration are discarded.

Data Types: single | double

IncludedSounds — Sounds to include in results

character vector | cell array of character vectors | string scalar | string array

Sounds to include in results, specified as the comma-separated pair consisting of 'IncludedSounds' and a character vector, cell array of character vectors, string scalar, or string array. Use `yamnetGraph` to inspect and analyze the sounds supported by `classifySound`. By default, all supported sounds are included.

This option cannot be used with the 'ExcludedSounds' option.

Data Types: char | string | cell

ExcludedSounds — Sounds to exclude from results

character vector | cell array of character vectors | string scalar | string array

Sounds to exclude from results, specified as the comma-separated pair consisting of 'ExcludedSounds' and a character vector, cell array of character vectors, string scalar, or string array. When you specify an excluded sound, any successors of the excluded sound are also excluded. Use `yamnetGraph` to inspect valid sound classes and their predecessors and successors according to the `AudioSet` ontology. By default, no sounds are excluded.

This option cannot be used with the 'IncludedSounds' option.

Data Types: char | string | cell

SpecificityLevel — Specificity of reported sounds

'high' (default) | 'low' | 'none'

Specificity of reported sounds, specified as the comma-separated pair consisting of 'SpecificityLevel' and 'high', 'low', or 'none'. Set `SpecificityLevel` to 'high' to make the function emphasize specific sound classes instead of general categories. Set `SpecificityLevel`

to 'low' to make the function return the most general sound categories instead of specific sound classes. Set `SpecificityLevel` to 'none' to make the function return the most likely sound, regardless of its specificity.

Data Types: `char` | `string`

Output Arguments

sounds — Sounds detected over time in audio input

string array

Sounds detected over time in audio input, returned as a string array containing the detected sounds in chronological order.

timestamps — Time stamps associated with detected sounds (s)

N-by-2 matrix

Time stamps associated with detected sounds in seconds, returned as an *N*-by-2 matrix. *N* is the number of detected sounds. Each row of `timestamps` contains the start and end times of the detected sound region.

resultsTable — Detailed results of sound classification

table

Detailed results of sound classification, returned as a table. The number of rows in the table is equal to the number of detected sound regions. The columns are as follows.

- `TimeStamps` -- Time stamps corresponding to each analyzed region.
- `Results` -- Table with three variables:
 - `Sounds` -- Sounds detected in each region.
 - `AverageScores` -- Mean network scores corresponding to each detected sound class in the region.
 - `MaxScores` -- Maximum network scores corresponding to each detected sound class in the region.

Algorithms

The `classifySound` function uses YAMNet to classify audio segments into sound classes described by the AudioSet ontology. The `classifySound` function preprocesses the audio so that it is in the format required by YAMNet and postprocesses YAMNet's predictions with common tasks that make the results more interpretable.

Preprocess

- 1 Resample `audioIn` to 16 kHz and cast to single precision.
- 2 Buffer into *L* overlapping segments. Each segment is 0.98 seconds and the segments are overlapped by 0.8575 seconds.
- 3 Pass each segment through a one-sided short time Fourier transform using a 25 ms periodic Hann window with a 10 ms hop and a 512-point DFT. The audio is now represented by a 257-by-96-by-*L* array, where 257 is the number of bins in the one-sided spectra and 96 is the number of spectra in the spectrograms.

- 4 Convert the complex spectral values to magnitude and discard phase information.
- 5 Pass the one-sided magnitude spectrum through a 64-band mel-spaced filter bank and then sum the magnitudes in each band. The audio is now represented by a 96-by-64-by-1-by-*L* array, where 96 is the number of spectra in the mel spectrogram, 64 is the number of mel bands, and the spectrograms are now spaced along the fourth dimension for compatibility with the YAMNet model.
- 6 Convert the mel spectrograms to a log scale.

Prediction

Pass the 96-by-64-by-1-by-*L* array of mel spectrograms through YAMNet to return an *L*-by-521 matrix. The output from YAMNet corresponds to confidence scores for each of the 521 sound classes over time.

Postprocess

Sound Event Region Detection

- 1 Pass each of the 521 confidence signals through a moving mean filter with a window length of 7.
- 2 Pass each of the signals through a moving median filter with a window length of 3.
- 3 Convert the confidence signals to binary masks using the specified `Threshold`.
- 4 Discard any sound shorter than `MinimumSoundDuration`.
- 5 Merge regions that are closer than `MinimumSoundSeparation`.

Consolidate Overlapping Sound Regions

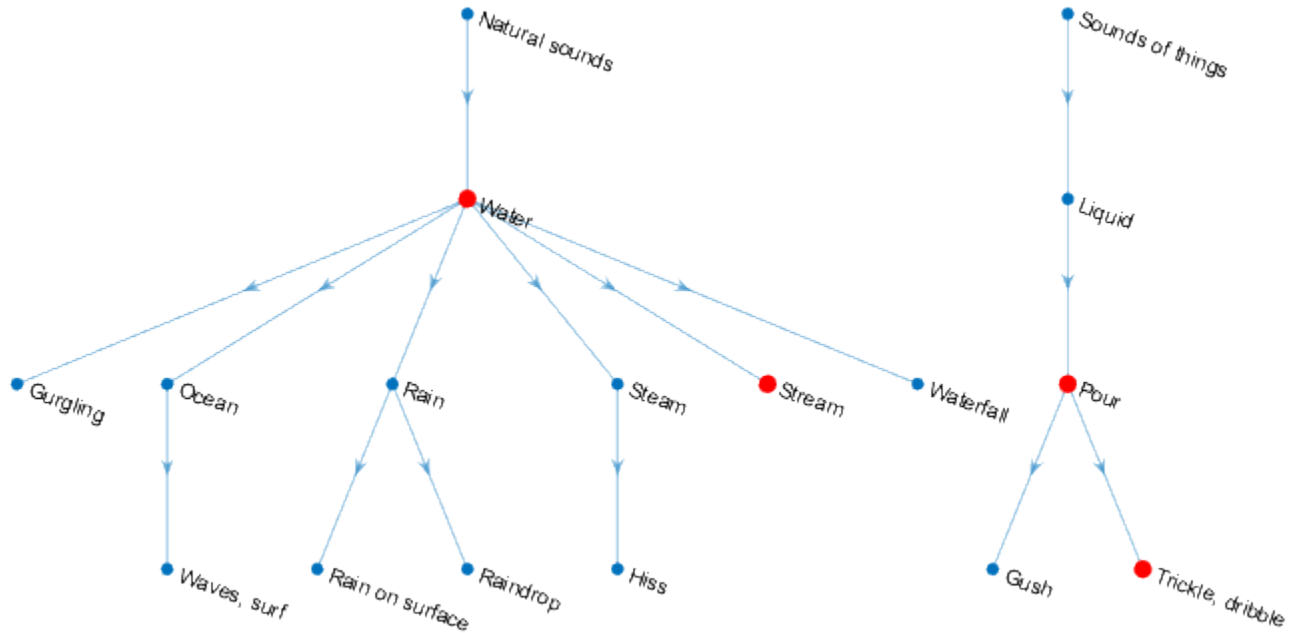
Consolidate identified sound regions that overlap by 50% or more into single regions. The region start time is the smallest start time of all sounds in the group. The region end time is the largest end time of all sounds in the group. The function returns time stamps, sounds classes, and the mean and maximum confidence of the sound classes within the region in the `resultsTable`.

Select Specificity of Sound Group

You can set the specificity level of your sound classification using the `SpecificityLevel` option. For example, assume there are four sound classes in a sound group with the following corresponding mean scores over the sound region:

- Water -- 0.82817
- Stream -- 0.81266
- Trickle, dribble -- 0.23102
- Pour -- 0.20732

The sound classes, Water, Stream, Trickle, dribble, and Pour are situated in AudioSet ontology as indicated by the graph:



The function returns the sound class for the sound group in the sounds output argument depending on the SpecificityLevel:

- "high" (default) -- In this mode, Stream is preferred to Water, and Trickle, dribble is preferred to Pour. Stream has a higher mean score over the region, so the function returns Stream in the sounds output for the region.
- "low" -- In this mode, the most general ontological category for the sound class with the highest mean confidence over the region is returned. For Trickle, dribble and Pour, the most general category is Sounds of things. For Stream and Water, the most general category is Natural sounds. Because Water has the highest mean confidence over the sound region, the function returns Natural sounds.
- "none" -- In this mode, the function returns the sound class with the highest mean confidence score, which in this example is Water.

References

- [1] Gemmeke, Jort F., et al. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776-80. DOI.org (Crossref), doi:10.1109/ICASSP.2017.7952261.
- [2] Hershey, Shawn, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131-35. DOI.org (Crossref), doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet | YAMNet Preprocess

Functions

vggish | vggishEmbeddings | vggishPreprocess | yamnet | yamnetGraph | yamnetPreprocess

Introduced in R2020b

acousticFluctuation

Perceived fluctuation strength of acoustic signal

Syntax

```
fluctuation = acousticFluctuation(audioIn, fs)
fluctuation = acousticFluctuation(audioIn, fs, calibrationFactor)
fluctuation = acousticFluctuation(specificLoudnessIn)
fluctuation = acousticFluctuation( ____, Name, Value)

[fluctuation, specificFluctuation] = acousticFluctuation( ____)
[fluctuation, specificFluctuation, fMod] = acousticFluctuation( ____)

acousticFluctuation( ____)
```

Description

`fluctuation = acousticFluctuation(audioIn, fs)` returns fluctuation strength in vacil based on Zwicker et al. [1] and ISO 532-1 time-varying loudness [2].

`fluctuation = acousticFluctuation(audioIn, fs, calibrationFactor)` specifies a nondefault microphone calibration factor used to compute loudness.

`fluctuation = acousticFluctuation(specificLoudnessIn)` computes fluctuation using time-varying specific loudness.

`fluctuation = acousticFluctuation(____, Name, Value)` specifies options using one or more Name, Value pair arguments.

Example: `fluctuation = acousticFluctuation(audioIn, fs, 'SoundField', 'diffuse')` returns fluctuation assuming a diffuse sound field.

`[fluctuation, specificFluctuation] = acousticFluctuation(____)` also returns specific fluctuation strength.

`[fluctuation, specificFluctuation, fMod] = acousticFluctuation(____)` also returns the dominant modulation frequency.

`acousticFluctuation(____)` with no output arguments plots fluctuation strength and specific fluctuation strength and displays the modulation frequency textually. If the input is stereo, the 3-D plot shows the sum of both channels.

Examples

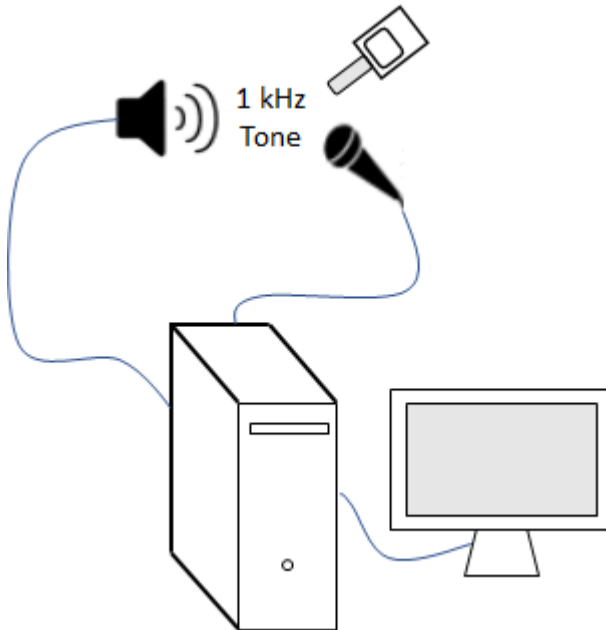
Measure Acoustic Fluctuation

Measure acoustic fluctuation based on Zwicker et al [2] and ISO 532-1 [1]. Assume the recording level is calibrated such that a 1 kHz tone registers as 100 dB on an SPL meter.

```
[audioIn,fs] = audioread('WashingMachine-16-44p1-stereo-10secs.wav');
fluctuation = acousticFluctuation(audioIn,fs);
```

Fluctuation Measurements Using Calibrated Microphone

Set up an experiment as indicated by the diagram.



Create an `audioDeviceReader` object to read from the microphone and an `audioDeviceWriter` object to write to your speaker.

```
fs = 48e3;
deviceReader = audioDeviceReader(fs,"SamplesPerFrame",2048);
deviceWriter = audioDeviceWriter(fs);
```

Create an `audioOscillator` object to generate a 1 kHz sinusoid.

```
osc = audioOscillator("sine",1e3,"SampleRate",fs,"SamplesPerFrame",2048);
```

Create a `dsp.AsyncBuffer` object to buffer data acquired from the microphone.

```
dur = 5;
buff = dsp.AsyncBuffer(dur*fs);
```

For five seconds, play the sinusoid through your speaker and record using your microphone. While the audio streams, note the loudness as reported by your SPL meter. Once complete, read the contents of the buffer object.

```
numFrames = dur*(fs/osc.SamplesPerFrame);
for ii = 1:numFrames
    audioOut = osc();
    deviceWriter(audioOut);
```

```

    audioIn = deviceReader();
    write(buff, audioIn);
end

```

```
SPLreading = 60.4;
```

```
micRecording = read(buff);
```

To compute the calibration factor for the microphone, use the `calibrateMicrophone` function.

```
calibrationFactor = calibrateMicrophone(micRecording(fs+1:end,:), deviceReader.SampleRate, SPLreading);
```

You can now use the calibration factor you determined to measure the fluctuation of any sound that is acquired through the same microphone recording chain.

Perform the experiment again, this time, add 100% amplitude modulation at 4 Hz. To create the modulation signal, use `audioOscillator` and specify the amplitude as 0.5 and the DC offset as 0.5 to oscillate between 0 and 1.

```
mod = audioOscillator("sine", 4, "SampleRate", fs, ...
    "Amplitude", 0.5, "DCOffset", 0.5, "SamplesPerFrame", 2048);
```

```
dur = 5;
buff = dsp.AsyncBuffer(dur*fs);
numFrames = dur*(fs/osc.SamplesPerFrame);
for ii = 1:numFrames
    audioOut = osc().*mod();
    deviceWriter(audioOut);
end

```

```

    audioIn = deviceReader();
    write(buff, audioIn);
end

```

```
end
```

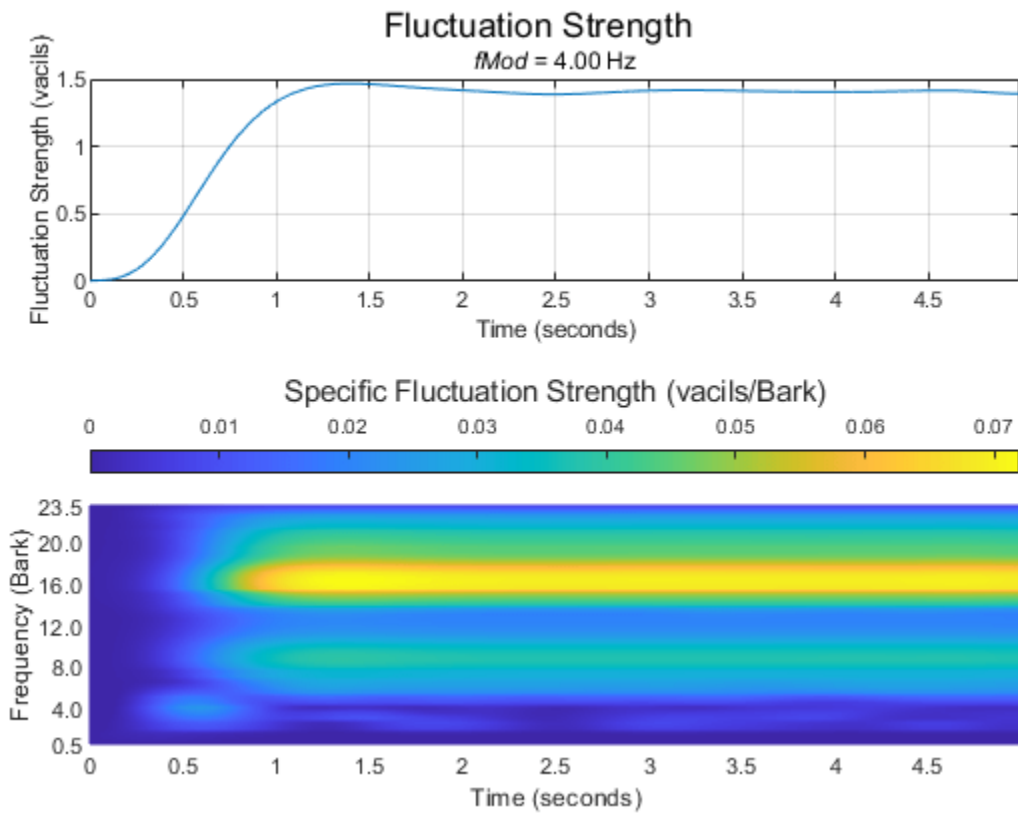
```
micRecording = read(buff);
```

Call `acousticFluctuation` with the microphone recording, sample rate, and calibration factor. The fluctuation reported from `acousticFluctuation` uses the true acoustic loudness measurement as specified by 532-1. Display the average fluctuation strength over the 5 seconds.

```
fluctuation = acousticFluctuation(micRecording, deviceReader.SampleRate, calibrationFactor);
fprintf('Average fluctuation = %d (vacil)', mean(fluctuation(501:end,:)))
```

```
Average fluctuation = 1.413824e+00 (vacil)
```

```
acousticFluctuation(micRecording, deviceReader.SampleRate, calibrationFactor)
```



Measure Fluctuation from Specific Loudness

Read in an audio file.

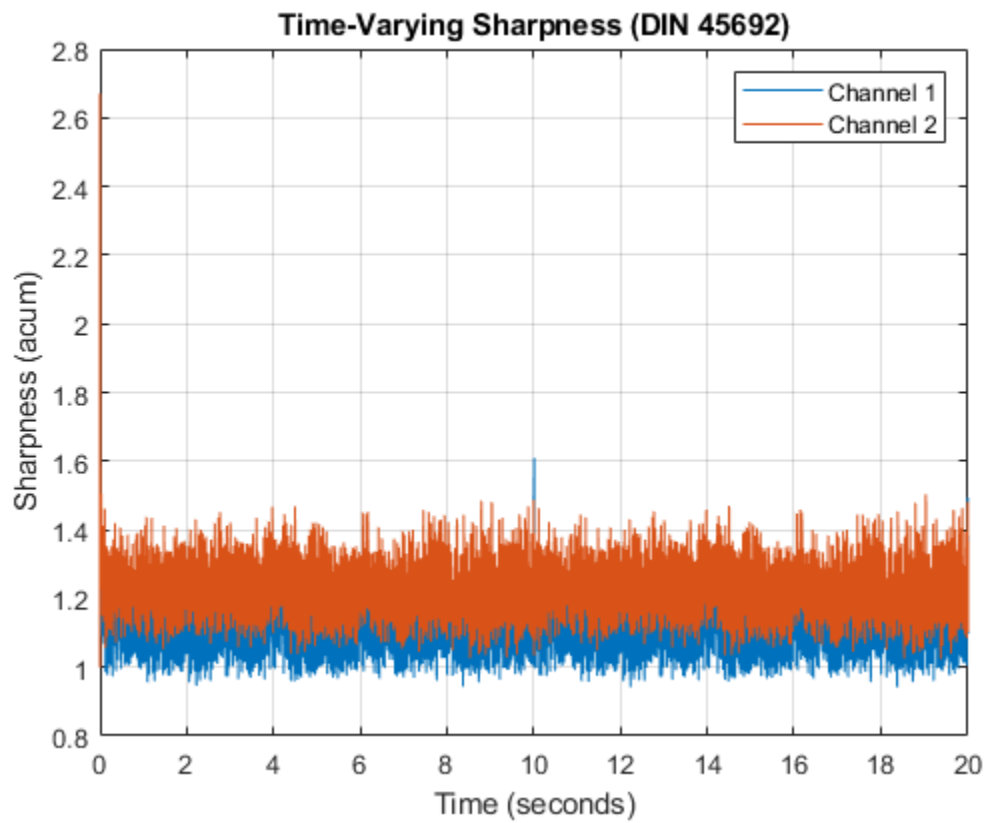
```
[audioIn,fs] = audioread("Engine-16-44p1-stereo-20sec.wav");
```

Call `acousticLoudness` to calculate the specific loudness.

```
[~,specificLoudness] = acousticLoudness(audioIn,fs,'TimeVarying',true);
```

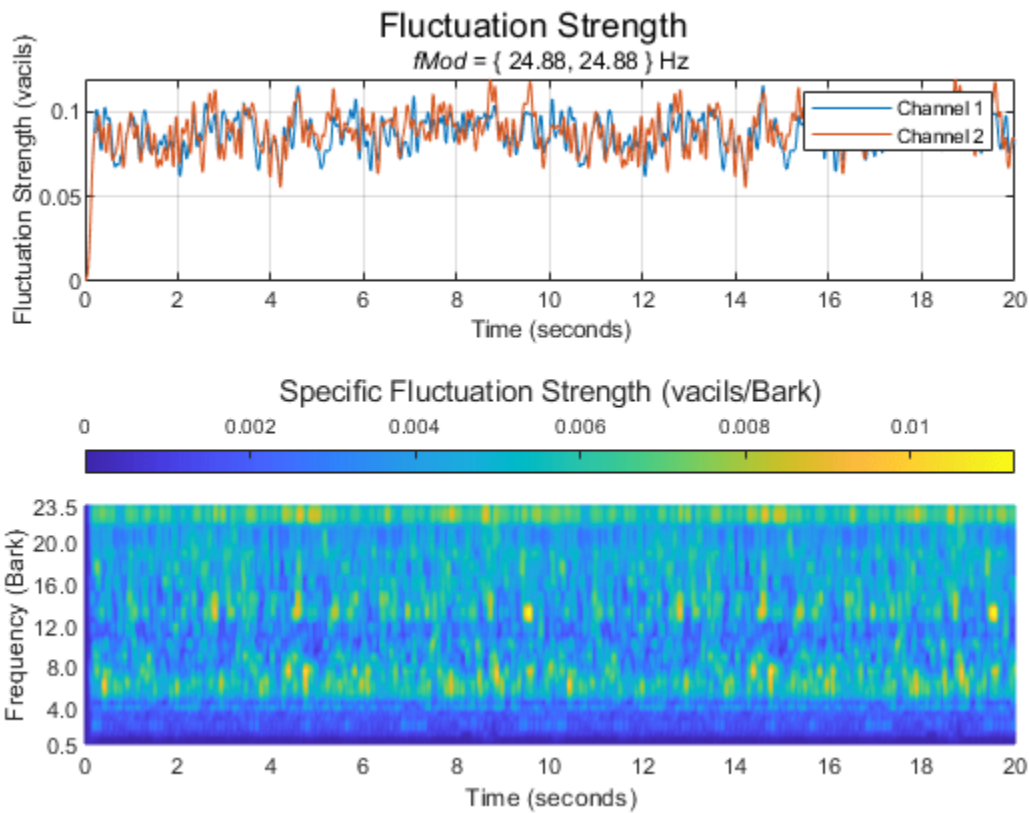
Call `acousticSharpness` without any outputs to plot the acoustic sharpness.

```
acousticSharpness(specificLoudness,'TimeVarying',true)
```



Call `acousticFluctuation` without any outputs to plot the acoustic fluctuation.

```
acousticFluctuation(specificLoudness)
```



Effect of Frequency Modulation on Acoustic Fluctuation

Generate a pure tone with a 1500 Hz center frequency and approximately 700 Hz frequency deviation at a modulation frequency of 0.25 Hz.

```

fs = 48e3;

fMod = 0.25 ;
dur = 20 ;

numSamples = dur*fs;
t = (0:numSamples-1)/fs;

tone = sin(2*pi*t*fMod)';

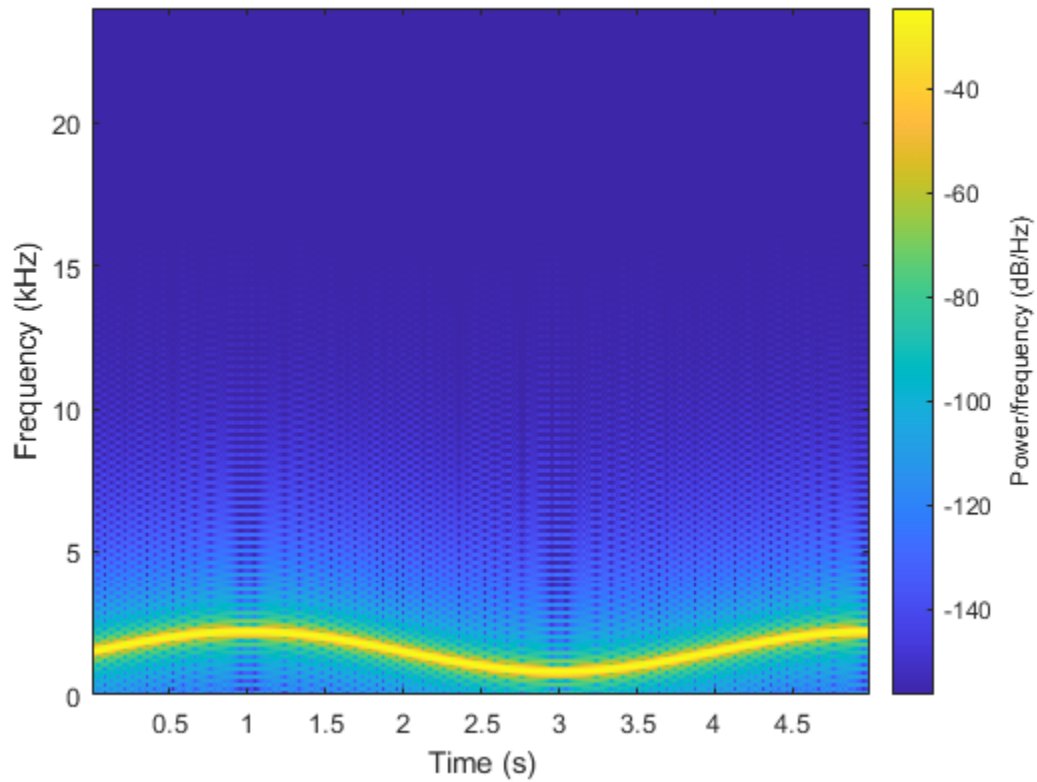
fc = 1500 ;
excursionRatio = 0.47 ;

excursion = 2*pi*(fc*excursionRatio/fs);
audioIn = modulate(tone,fc,fs,'fm',excursion);

```

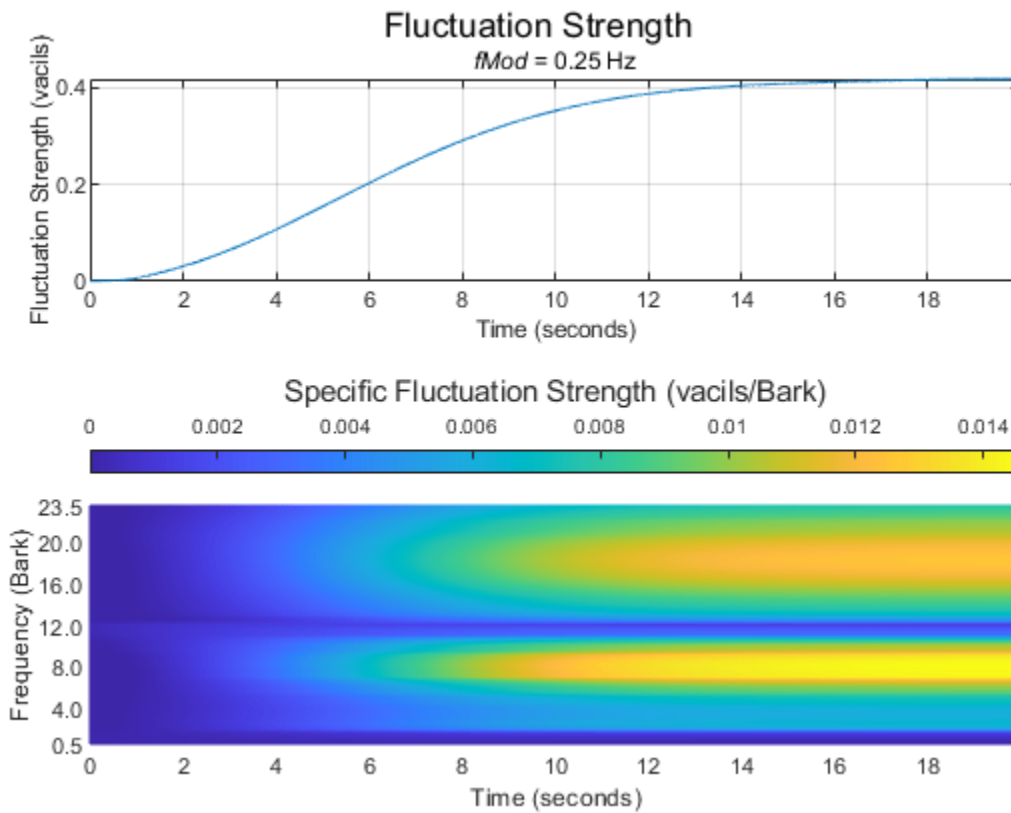

Listen to the first 5 seconds of the audio and plot the spectrogram.

```
sound(audioIn(1:5*fs), fs)  
spectrogram(audioIn(1:5*fs), hann(512, 'periodic'), 256, 1024, fs, 'yaxis')
```



Call `acousticFluctuation` with no output arguments to plot the acoustic fluctuation strength.

```
acousticFluctuation(audioIn, fs);
```



Specify Known Modulation Frequency

The `acousticFluctuation` function enables you to specify a known fluctuation frequency. If you do not specify a known fluctuation frequency, the function auto-detects the fluctuation.

Create a `dsp.AudioFileReader` object to read in an audio signal frame-by-frame. Create an `audioOscillator` object to create a modulation wave. Apply the modulation wave to the audio file.

```
fileReader = dsp.AudioFileReader('Engine-16-44p1-stereo-20sec.wav');
```

```
fmod = 10.8  ;  
amplitude = 0.15  ;
```

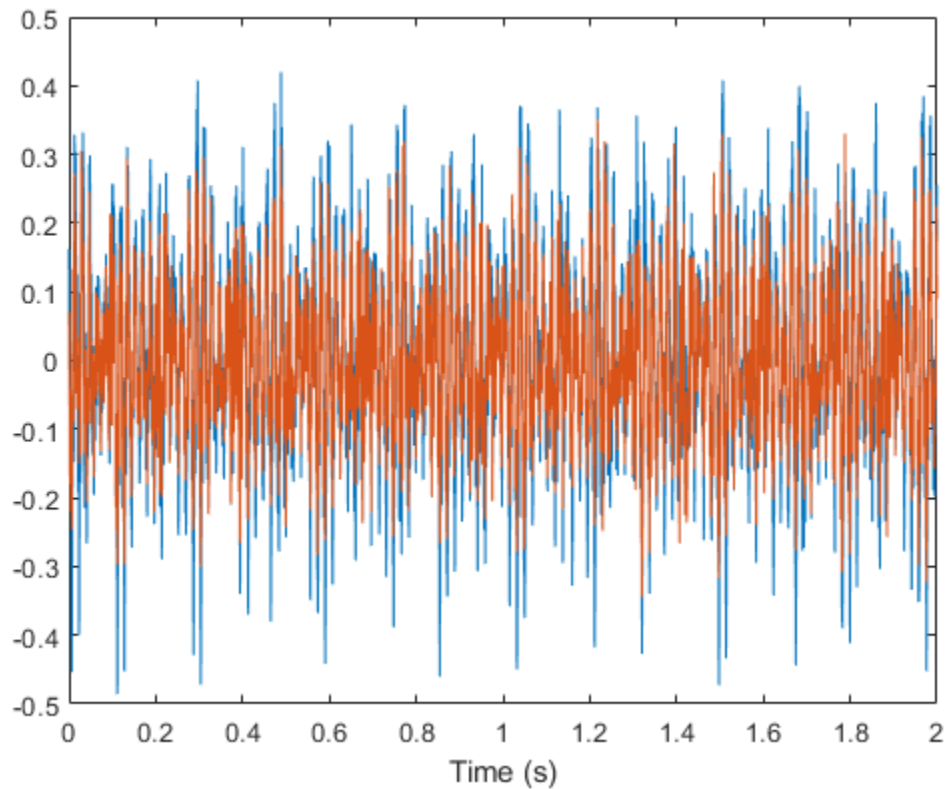
```
osc = audioOscillator('sine',fmod, ...  
    "DCOffset",0.5, ...  
    "Amplitude",amplitude, ...  
    "SampleRate",fileReader.SampleRate, ...  
    "SamplesPerFrame",fileReader.SamplesPerFrame);
```

```
testSignal = [];  
while ~isDone(fileReader)  
    x = fileReader();
```

```
testSignal = [testSignal;osc().*fileReader()];  
end
```

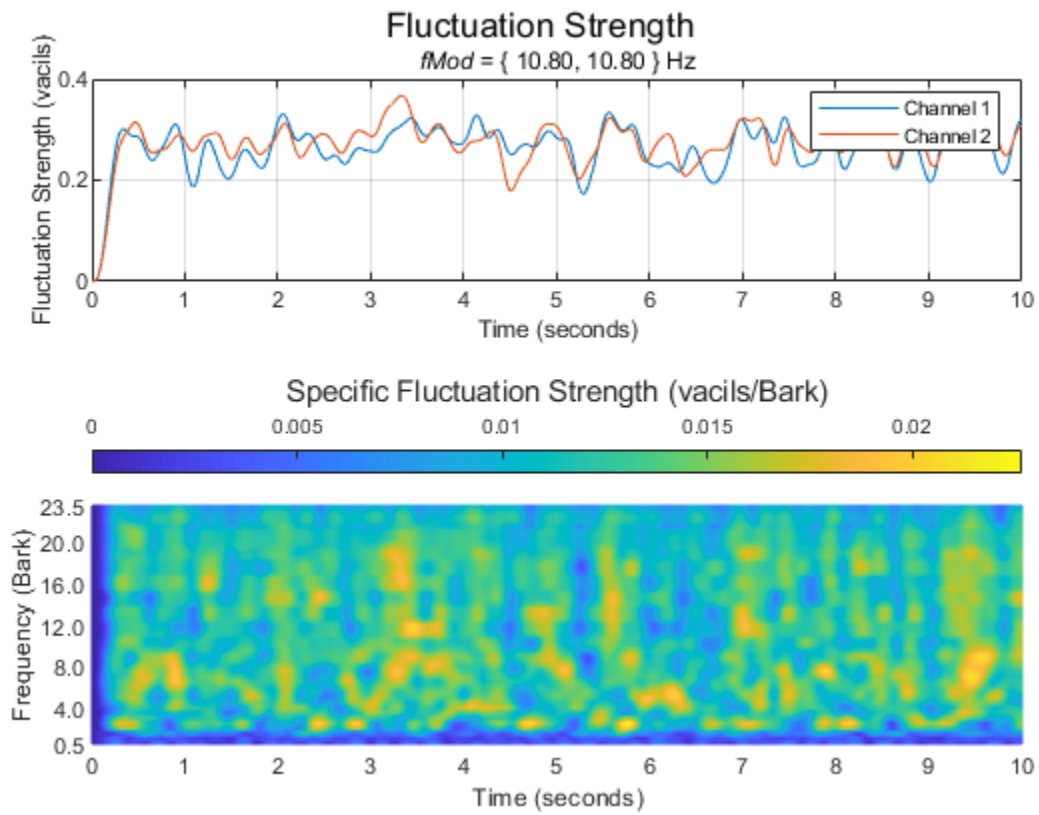
Listen to two seconds of the test signal and plot its waveform.

```
samplesToView = 1:2*fileReader.SampleRate;  
sound(testSignal(samplesToView,:),fileReader.SampleRate);  
  
plot(samplesToView/fileReader.SampleRate,testSignal(samplesToView,:))  
xlabel('Time (s)')
```



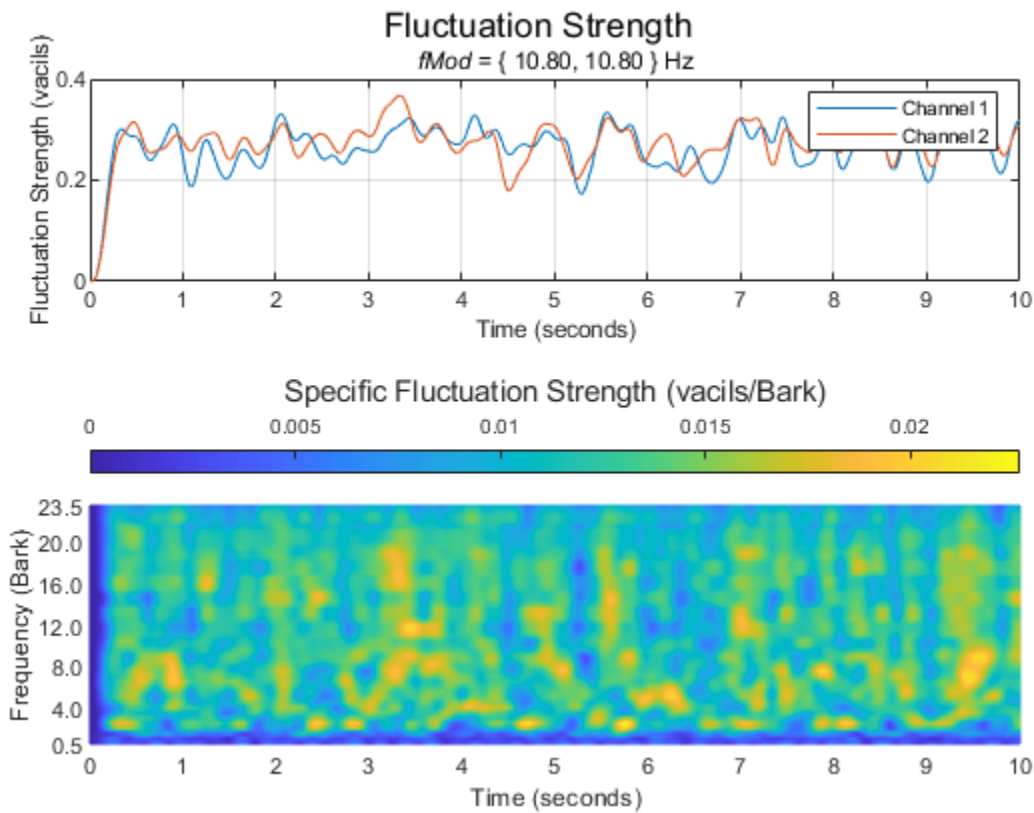
Plot the acoustic fluctuation. The detected frequency of the modulation is displayed textually.

```
acousticFluctuation(testSignal,fileReader.SampleRate);
```



Specify the known modulation frequency and then plot the acoustic fluctuation again.

```
acousticFluctuation(testSignal, fileReader.SampleRate, 'ModulationFrequency', fmod)
```



Input Arguments

audioIn — Audio input

column vector | two-column matrix

Audio input, specified as a column vector (mono) or matrix with two columns (stereo).

Tip To measure fluctuation strength given any modulation frequency, the recommended minimum signal duration is 10 seconds.

Data Types: single | double

fs — Sample rate (Hz)

positive scalar

Sample rate in Hz, specified as a positive scalar. The recommended sample rate for new recordings is 48 kHz.

Note The minimum acceptable sample rate is 8 kHz.

Data Types: single | double

calibrationFactor — Microphone calibration factor

sqrt(8) (default) | positive scalar

Microphone calibration factor, specified as a positive scalar. The default calibration factor corresponds to a full-scale 1 kHz sine wave with a sound pressure level of 100 dB (SPL). To compute the calibration factor specific to your system, use the `calibrateMicrophone` function.

Data Types: single | double

specificLoudnessIn — Specific loudness (sones/Bark)*T*-by-240-by-*C*

Specific loudness in sones/Bark, specified as a *T*-by-240-by-*C* array, where:

- *T* is one per 2 ms of the time-varying signal.
- 240 is the number of Bark bins in the domain for specific loudness. The Bark bins are 0.1:0.1:24.
- *C* is the number of channels.

You can use the `acousticLoudness` function to calculate time-varying specific loudness using this syntax:

```
[~,specificLoudness] = acousticLoudness(audioIn,fs,'TimeVarying',true);
```

Data Types: single | double

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `acousticFluctuation(audioIn,fs,'ModulationFrequency',50)`

ModulationFrequency — Known modulation frequency (Hz)

'auto-detect' (default) | scalar or two-element vector with values in the range [0.1,100]

Known modulation frequency in Hz, specified either 'auto-detect' or as a scalar or two-element vector with values in the range [0.1,100]. If `ModulationFrequency` is set to 'auto-detect', then the function limits the search range to between 0.2 and 64 Hz. If the input is mono, then the modulation frequency must be specified as a scalar. If the input is stereo, then the modulation frequency can be specified as either a scalar or two-element vector.

Data Types: single | double | char | string

SoundField — Sound field

'free' (default) | 'diffuse'

Sound field of audio recording, specified as 'free' or 'diffuse'.

Data Types: char | string

PressureReference — Reference pressure (Pa)

20e-6 (default) | positive scalar

Reference pressure for dB calculation in pascals, specified as a positive scalar. The default value, 20 micropascals, is the common value of air.

Data Types: `single` | `double`

Output Arguments

fluctuation — Fluctuation strength (vacil)

K -by-1 | K -by-2

Fluctuation strength in vacil, returned as a K -by-1 column vector or K -by-2 matrix of independent channels. K corresponds to the time dimension.

Data Types: `single` | `double`

specificFluctuation — Specific fluctuation strength (vacil/Bark)

K -by-47 matrix | K -by-47-by-2 array

Specific fluctuation strength in vacil/Bark, returned as a K -by-47 matrix or a K -by-47-by-2 array. The first dimension of `specificFluctuation`, K , corresponds to the time dimension and matches the first dimension of `fluctuation`. The second dimension of `specificFluctuation`, 47, corresponds to bands on the Bark scale, with centers from 0.5 to 23.5, inclusive, in 0.5 increments. The third dimension of `specificFluctuation` corresponds to the number of channels and matches the second dimension of `fluctuation`.

Data Types: `single` | `double`

fMod — Dominant modulation frequency (Hz)

scalar (mono input) | 1-by-2 vector (stereo input)

Dominant modulation frequency in Hz, returned as a scalar for mono input or a 1-by-2 vector for stereo input.

Data Types: `single` | `double`

Algorithms

Acoustic fluctuation strength is a perceptual measurement of slow modulations in amplitude or frequency. The acoustic loudness algorithm is described in [1] and implemented in the `acousticLoudness` function. The acoustic fluctuation calculation is described in [2]. The algorithm for acoustic fluctuation is outlined as follows.

$$fluctuation = \frac{0.008 \int_{z=0}^{24} \Delta L dz}{\left(\frac{f_{mod}}{4}\right) + \left(\frac{4}{f_{mod}}\right)}$$

Where f_{mod} is the detected or known modulation frequency and ΔL is the perceived modulation depth. If the modulation frequency is not specified when calling `acousticFluctuation`, it is auto-detected by peak-picking a frequency-domain representation of the acoustic loudness. The perceived modulation depth, ΔL , is calculated by passing rectified specific loudness bands through $\frac{1}{2}$ octave filters centered around f_{mod} , followed by a lowpass filter to determine the envelope.

References

- [1] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [2] Zwicker, Eberhard, and H. Fastl. *Psychoacoustics: Facts and Models*. 2nd updated ed, Springer, 1999.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

[acousticLoudness](#) | [acousticSharpness](#) | [calibrateMicrophone](#) | [acousticRoughness](#)

Topics

"Effect of Soundproofing on Perceived Noise Levels"

Introduced in R2020b

cepstralCoefficients

Extract cepstral coefficients

Syntax

```
coeffs = cepstralCoefficients(S)
coeffs = cepstralCoefficients(S,Name,Value)
```

Description

`coeffs = cepstralCoefficients(S)` returns the cepstral coefficients over time. The input, `S`, must be a real-valued spectrogram or auditory spectrogram.

`coeffs = cepstralCoefficients(S,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

For example, `coeffs = cepstralCoefficients(S,'Rectification','cubic-root')` uses cubic-root rectification to calculate the coefficients.

Examples

Mel Frequency Cepstral Coefficients

Read an audio file into the workspace.

```
[audioIn,fs] = audioread('SpeechDFT-16-8-mono-5secs.wav');
```

Convert the audio signal to a frequency-domain representation using 30 ms windows with 15 ms overlap. Because the input is real and therefore the spectrum is symmetric, you can use just one side of the frequency domain representation without any loss of information. Convert the complex spectrum to the magnitude spectrum: phase information is discarded when calculating mel frequency cepstral coefficients (MFCC).

```
windowLength = round(0.03*fs);
overlapLength = round(0.015*fs);
S = stft(audioIn,"Window",hann(windowLength,"periodic"),"OverlapLength",overlapLength,"Frequency");
S = abs(S);
```

Design a one-sided frequency-domain mel filter bank. Apply the filter bank to the frequency-domain representation to create a mel spectrogram.

```
filterBank = designAuditoryFilterBank(fs,'FFTLength',windowLength);
melSpec = filterBank*S;
```

Call `cepstralCoefficients` with the mel spectrogram to create MFCC.

```
melcc = cepstralCoefficients(melSpec);
```

Gammatone Frequency Cepstral Coefficients

Read an audio signal and convert it to a one-sided magnitude short-time Fourier transform. Use a 50 ms periodic Hamming window with a 10 ms hop.

```
[audioIn,fs] = audioread('NoisySpeech-16-22p5-mono-5secs.wav');

windowLength = round(0.05*fs);
hopLength = round(0.01*fs);
overlapLength = windowLength - hopLength;

S = stft(audioIn,"Window",hamming(windowLength,'periodic'),"OverlapLength",overlapLength,"FrequencyScale","erbs");
S = abs(S);
```

Design a one-sided frequency-domain gammatone filter bank. Apply the filter bank to the frequency-domain representation to create a gammatone spectrogram.

```
filterBank = designAuditoryFilterBank(fs,'FFTLength',windowLength,"FrequencyScale","erb");
gammaSpec = filterBank*S;
```

Call `cepstralCoefficients` with the gammatone spectrogram to create gammatone frequency cepstral coefficients. Use a cubic-root rectification.

```
gammacc = cepstralCoefficients(gammaSpec,"Rectification","cubic-root");
```


Custom Cepstral Coefficients


Cepstral coefficients are commonly used as compact representations of audio signals. Generally, they are calculated after an audio signal is passed through a filter bank and the energy in the individual filters is summed. Researchers have proposed various filter banks based on psychoacoustic experiments (such as mel, Bark, and ERB). Using the `cepstralCoefficients` function, you can define your own custom filter bank and then analyze the resulting cepstral coefficients.


Read in an audio file for analysis.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

Design a filter bank that consists of 20 triangular filters with band edges over the range 62.5 Hz to 8000 Hz. Spread the filters evenly in the log domain. For simplicity, design the filters in bins. Most popular auditory filter banks are designed in a continuous domain, such as Hz, mel, or Bark, and then warped back to bins.

```
numFilters = 20  ;

filterbankStart = 62.5  ;

filterbankEnd = 8000  ;

numBandEdges = numFilters + 2;
NFFT = 1024;
filterBank = zeros(numFilters,NFFT);

bandEdges = logspace(log10(filterbankStart),log10(filterbankEnd),numBandEdges);
```

```

bandEdgesBins = round((bandEdges/fs)*NFFT) + 1;

for ii = 1:numFilters
    filt = triang(bandEdgesBins(ii+2)-bandEdgesBins(ii));
    leftPad = bandEdgesBins(ii);
    rightPad = NFFT - numel(filt) - leftPad;
    filterBank(ii,:) = [zeros(1,leftPad),filt',zeros(1,rightPad)];
end

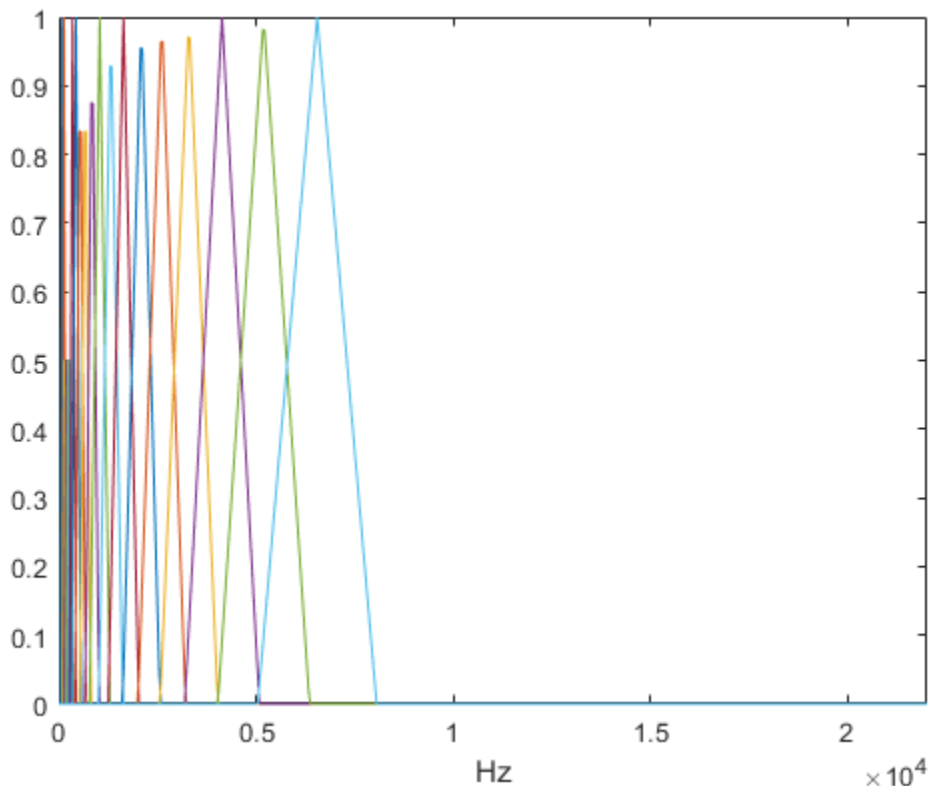
```

Plot the filter bank.

```

frequencyVector = (fs/NFFT)*(0:NFFT-1);
plot(frequencyVector,filterBank');
xlabel('Hz')
axis([0 frequencyVector(NFFT/2) 0 1])

```



Transform the audio signal using the `stft` function, and then apply the custom filter bank. Apply the filter bank to the frequency-domain representation to create a custom auditory spectrogram. Plot the spectrogram.

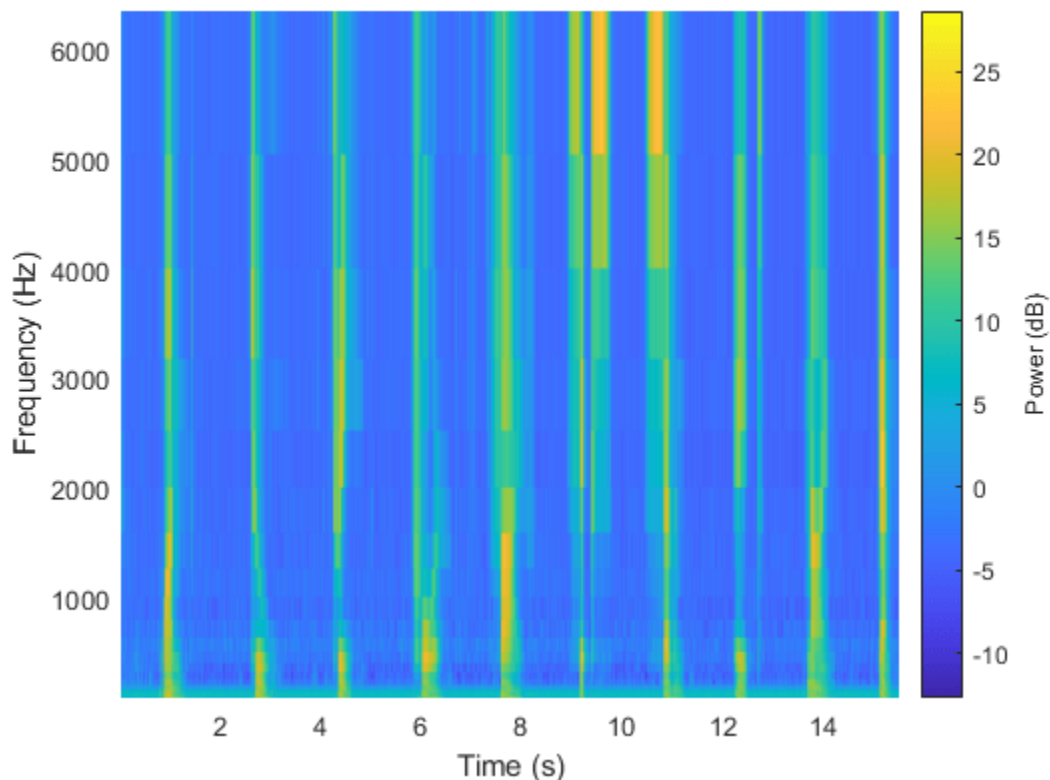
```

[S,~,t] = stft(audioIn,fs,"Window",hann(NFFT,'periodic'),'FrequencyRange',"twosided");
S = abs(S);
spec = filterBank*S;

surf(t,bandEdges(2:end-1),10*log10(spec),'EdgeColor','none')
view([0,90])
axis([t(1) t(end) bandEdges(2) bandEdges(end-1)])
xlabel('Time (s)')

```

```
ylabel('Frequency (Hz)')
c = colorbar;
c.Label.String = 'Power (dB)';
```



Call `cepstralCoefficients` with the custom auditory spectrogram to create custom cepstral coefficients.

```
ccc = cepstralCoefficients(S);
```

Extract Cepstral Coefficients from Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio frame-by-frame. Create a `dsp.AsyncBuffer` object to buffer the input into overlapped frames.

```
fileReader = dsp.AudioFileReader("Ambiance-16-44p1-mono-12secs.wav");
buff = dsp.AsyncBuffer;
```

Design a two-sided mel filter bank that is compatible with 30 ms windows.

```
windowLength = round(0.03*fileReader.SampleRate);
filterBank = designAuditoryFilterBank(fileReader.SampleRate,"FFTLength",windowLength,"OneSided",
```

In an audio stream loop:

- 1 Read a frame of data from the audio file.

- 2 Write the frame of data to the buffer.
- 3 If enough data is available for a hop, read a 30 ms frame of data from the buffer with a 20 ms overlap between frames.
- 4 Transform the data to a magnitude spectrum.
- 5 Apply the mel filter bank to create a mel spectrum.
- 6 Call `cepstralCoefficients` to return the mel frequency cepstral coefficients (MFCC).

```
win = hann(windowLength, 'periodic');
overlapLength = round(0.02*fileReader.SampleRate);
hopLength = windowLength - overlapLength;

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff, audioIn);
    while buff.NumUnreadSamples > hopLength
        x = read(buff, windowLength, overlapLength);
        X = abs(fft(x.*win));
        melSpectrum = filterBank*X;
        melcc = cepstralCoefficients(melSpectrum);
    end
end
```

Input Arguments

S — Spectrogram or auditory spectrogram

matrix | 3-D array

Spectrogram or auditory spectrogram, specified as an L -by- M matrix or L -by- M -by- N 3-D array, where:

- L -- Number of frequency bands
- M -- Number of frames
- N -- Number of channels

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'NumCoeffs', 16`

NumCoeffs — Number of cepstral coefficients returned

13 (default) | positive integer greater than one

Number of coefficients returned for each window of data, specified as the comma-separated pair consisting of `'NumCoeffs'` and a positive integer greater than one.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Rectification — Type of nonlinear rectification`'log' (default) | 'cubic-root' | 'none'`

Type of nonlinear rectification applied prior to the discrete cosine transform, specified as the comma-separated pair consisting of 'Rectification' and 'log', 'cubic-root', or 'none'.

Data Types: `char` | `string`

Output Arguments**coeffs — Cepstral coefficients**`matrix` | 3-D array

Cepstral coefficients, returned as an M -by- B matrix or M -by- B -by- N array, where:

- M -- Number of frames (columns) of the input.
- B -- Number of coefficients returned per frame. This is determined by `NumCoeffs`.
- N -- Number of channels (pages) of the input.

Data Types: `single` | `double`

Algorithms

Given a time-frequency representation, the `cepstralCoefficients` function performs the following operations on each spectrum, individually, as described in [1]:

- 1 Rectifies the spectrum by applying a logarithm or cubic-root, as specified by the `Rectification` parameter.
- 2 Transforms the rectified spectrum using the DCT-II transform.
- 3 Returns the first `NumCoeffs` from the cepstral representation.

References

[1] Rabiner, Lawrence R., and Ronald W. Schafer. *Theory and Applications of Digital Speech Processing*. Upper Saddle River, NJ: Pearson, 2010.

Extended Capabilities**C/C++ Code Generation**

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`mfcc` | `gtcc` | `audioDelta` | `designAuditoryFilterBank` | `melSpectrogram` | `audioFeatureExtractor` | `stft`

Introduced in R2020b

audioDelta

Compute delta features

Syntax

```
delta = audioDelta(x)
delta = audioDelta(x,deltaWindowLength)
delta = audioDelta(x,deltaWindowLength,initialCondition)
[delta,finalCondition] = audioDelta(x, ___)
```

Description

`delta = audioDelta(x)` returns the delta features of input `x`. Columns of `x` are treated as independent channels.

`delta = audioDelta(x,deltaWindowLength)` specifies the delta window length.

`delta = audioDelta(x,deltaWindowLength,initialCondition)` specifies the initial condition of the filter.

`[delta,finalCondition] = audioDelta(x, ___)` also returns the final condition of the filter.

Examples

Delta of Audio Features

Read in an audio file.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

Create an `audioFeatureExtractor` object to extract some spectral features over time from the audio. Call `extract` to extract the audio features.

```
afe = audioFeatureExtractor('SampleRate',fs, ...
    'spectralCentroid',true, ...
    'spectralSlope',true);
```

```
audioFeatures = extract(afe,audioIn);
```

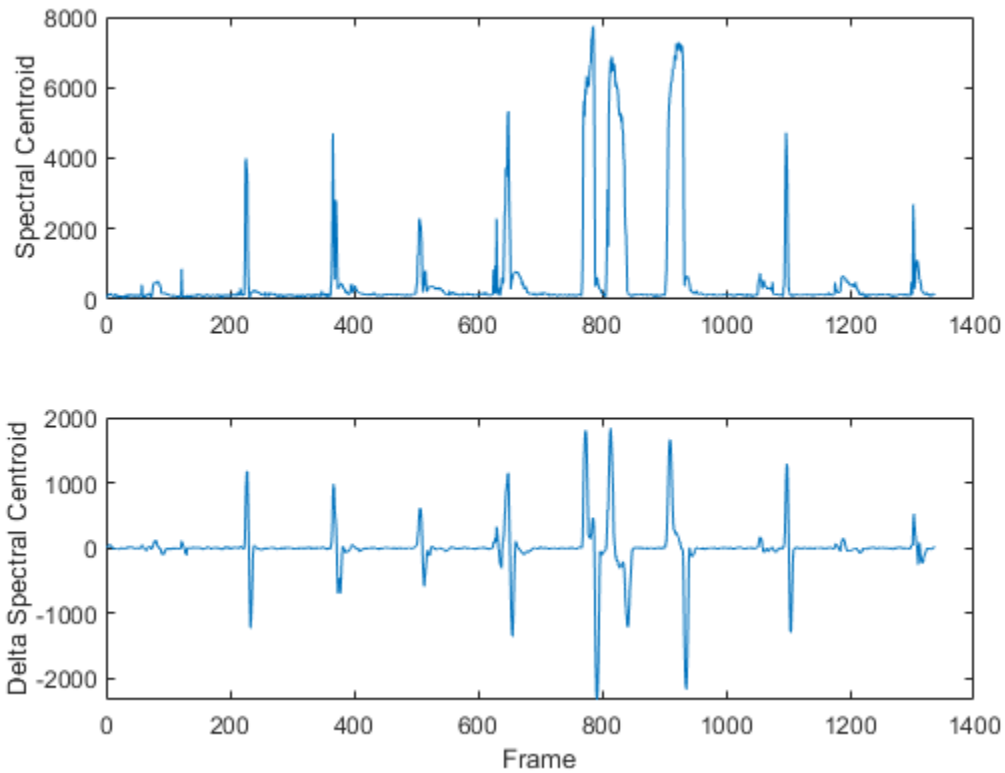
Call `audioDelta` to approximate the first derivative of the spectral features over time.

```
deltaAudioFeatures = audioDelta(audioFeatures);
```

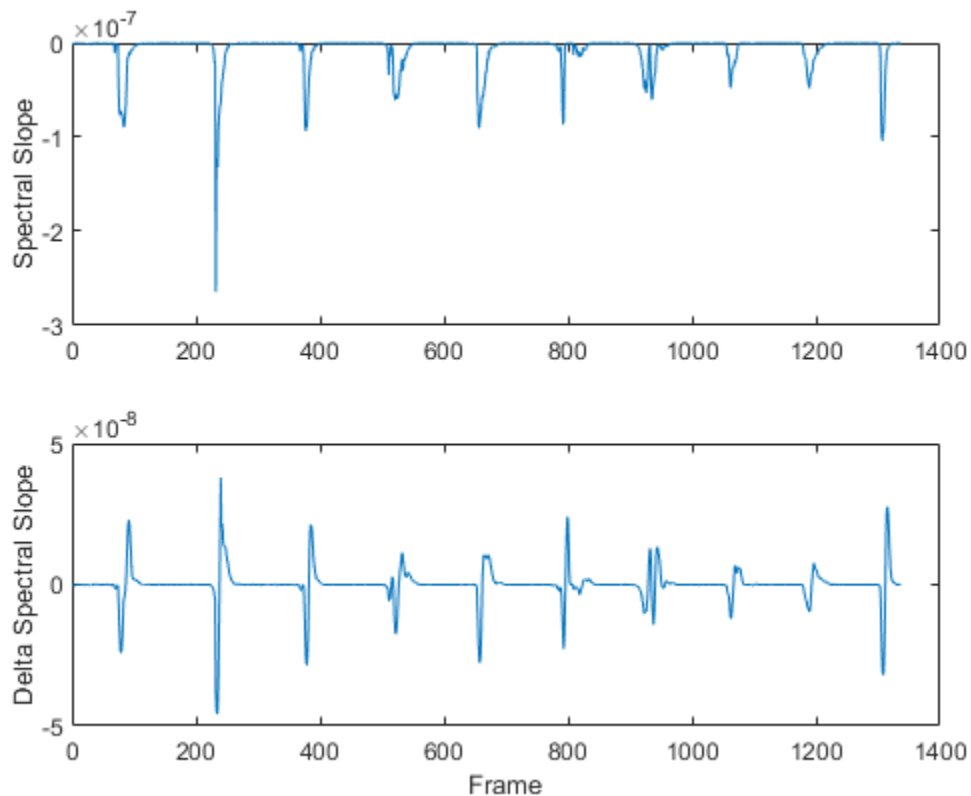
Plot the spectral features and the delta of the spectral features.

```
map = info(afe);
tiledlayout(2,1)
nexttile
plot(audioFeatures(:,map.spectralCentroid))
ylabel('Spectral Centroid')
nexttile
```

```
plot(deltaAudioFeatures(:,map.spectralCentroid))  
ylabel('Delta Spectral Centroid')  
xlabel('Frame')
```



```
tiledlayout(2,1)  
nexttile  
plot(audioFeatures(:,map.spectralSlope))  
ylabel('Spectral Slope')  
nexttile  
plot(deltaAudioFeatures(:,map.spectralSlope))  
ylabel('Delta Spectral Slope')  
xlabel('Frame')
```

Delta and Delta-Delta of MFCC

The delta and delta-delta of mel frequency cepstral coefficients (MFCC) are often used with the MFCC for machine learning and deep learning applications.

Read in an audio file.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Use the `designAuditoryFilterBank` function to design a one-sided frequency-domain mel filter bank.

```
analysisWindowLength = round(fs*0.03);
fb = designAuditoryFilterBank(fs,"FFTLength",analysisWindowLength);
```

Use the `stft` function to convert the audio signal to a complex, one-sided frequency-domain representation. Convert the STFT to magnitude and apply the frequency-domain filtering.


```
[S,~,t] = stft(audioIn,fs,"Window",hann(analysisWindowLength,"periodic"),"FrequencyRange","onesided");
auditorySTFT = fb*abs(S);
```

Call the `cepstralCoefficients` function to extract the MFCC.


```
melcc = cepstralCoefficients(auditorySTFT);
```

Call the `audioDelta` function to compute the delta MFCC. Call `audioDelta` again to compute the delta-delta MFCC. Plot the results.

```

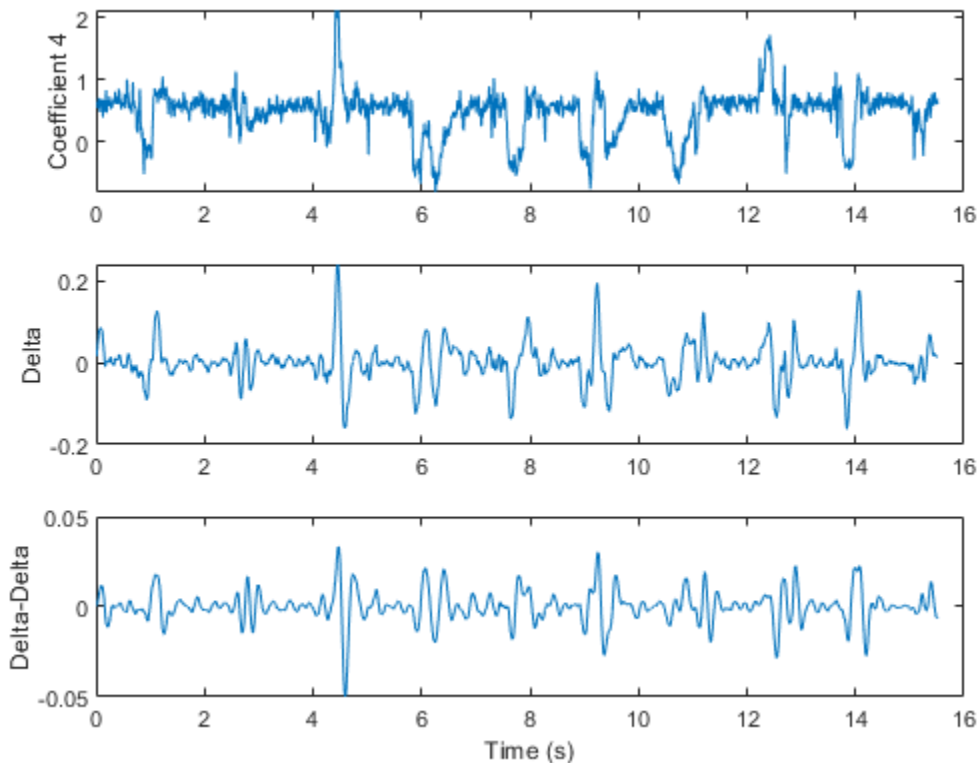
deltaWindowLength = 21 ;

melccDelta = audioDelta(melcc,deltaWindowLength);
melccDeltaDelta = audioDelta(melccDelta,deltaWindowLength);

coefficientToDisplay = 4 ;

tiledlayout(3,1)
nexttile
plot(t,melcc(:,coefficientToDisplay+1))
ylabel('Coefficient ' + string(coefficientToDisplay))
nexttile
plot(t,melccDelta(:,coefficientToDisplay+1))
ylabel('Delta')
nexttile
plot(t,melccDeltaDelta(:,coefficientToDisplay+1))
xlabel('Time (s)')
ylabel('Delta-Delta')

```



Delta of Streaming Signals

You can calculate the delta of streaming signals by passing state in and out of the `audioDelta` function.

Create a `dsp.AudioFileReader` object to read an audio file frame-by-frame. Create an `audioDeviceWriter` object to write audio to your speaker. Create a `timescope` object to visualize the change in harmonic ratio over time.

```
fileReader = dsp.AudioFileReader("FemaleSpeech-16-8-mono-3secs.wav", "SamplesPerFrame", 32, "PlayCo
deviceWriter = audioDeviceWriter("SampleRate", fileReader.SampleRate);
scope = timescope("SampleRate", fileReader.SampleRate/fileReader.SamplesPerFrame, ...
    "TimeSpanSource", "Property", ...
    "TimeSpan", 3, ...
    "YLimits", [-1, 1], ...
    "Title", "Delta of Harmonic Ratio");
```

While the audio file has unread frames of data:

- 1 Read a frame from the audio file
- 2 Calculate the harmonic ratio of that frame
- 3 Calculate the delta of the harmonic ratio
- 4 Write the audio frame to your speaker
- 5 Write the change in the harmonic ratio to your scope

On each call to `audioDelta`, overwrite the previous state. Initialize the state using an empty array.

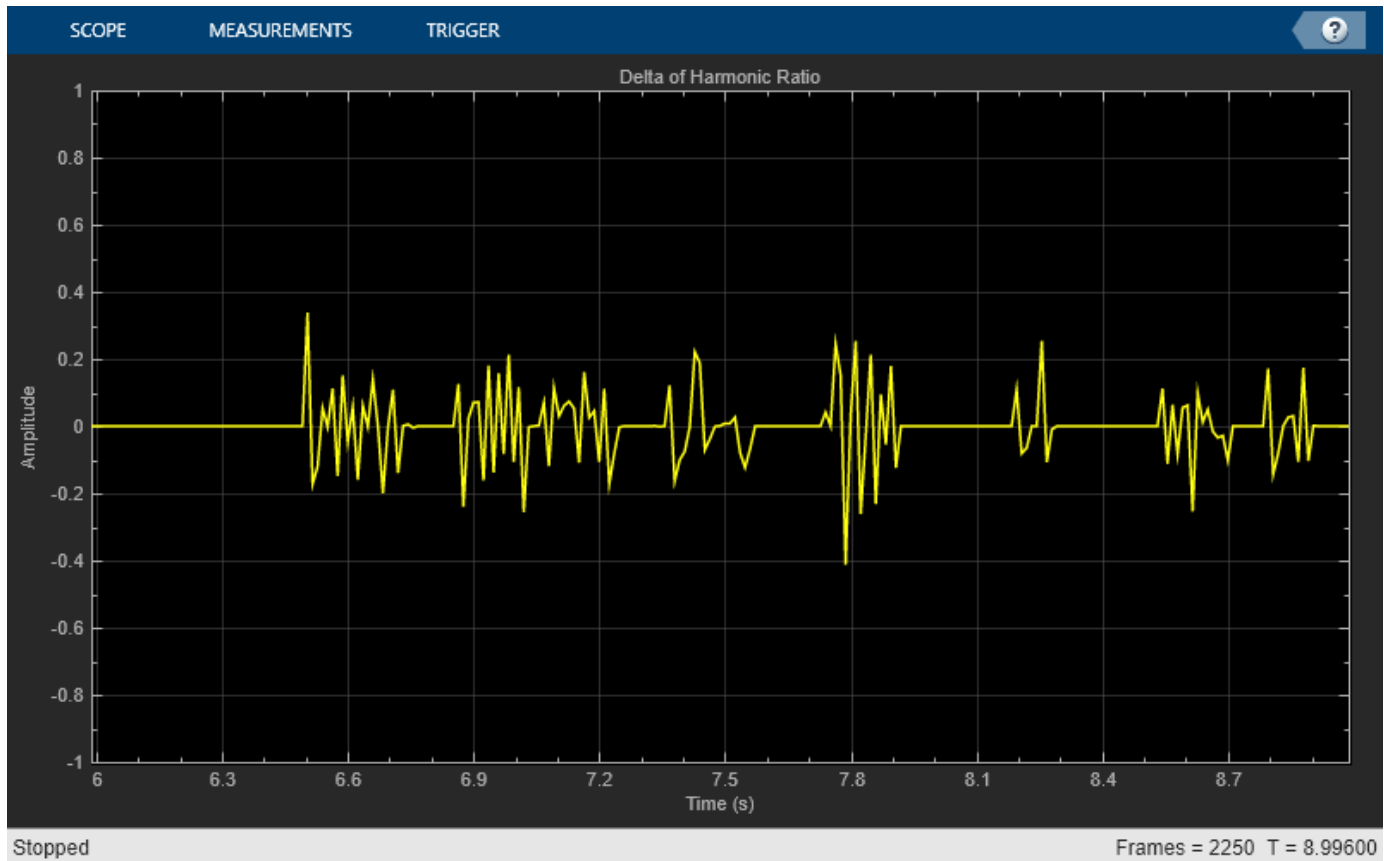
```
z = [];
while ~isDone(fileReader)
    audioIn = fileReader();

    hr = harmonicRatio(audioIn, fileReader.SampleRate, "Window", hann(fileReader.SamplesPerFrame, 'p

    [deltaHR, z] = audioDelta(hr, 5, z);

    deviceWriter(audioIn);

    scope(deltaHR)
end
release(scope)
```



Input Arguments

x — Audio feature

scalar | vector | matrix | array

Audio feature, specified as a scalar, vector, or matrix. Columns of the input are treated as independent channels.

Data Types: single | double

deltaWindowLength — Window length over which to calculate delta

9 (default) | odd integer

Window length over which to calculate delta, specified as an odd integer equal to or greater than 3.

Data Types: single | double

initialCondition — Initial condition of filter

[] (default) | vector | matrix | array

Initial condition of the filter used to calculate the delta, specified as a vector, matrix, or multi-dimensional array. The first dimension of `initialCondition` must equal `deltaWindowLength-1`. The remaining dimensions of `initialCondition` must match the remaining dimensions of the input `x`. The default initial condition, `[]`, is equivalent to initializing the state with all zeros.

Data Types: `single` | `double`

Output Arguments

delta — Delta of audio features

vector | matrix | array

Delta of audio features, returned as a vector or matrix with the same dimensions as the input `x`.

Data Types: `single` | `double`

finalCondition — Final condition of filter

vector | matrix | array

Final condition of filter, returned as a vector, matrix, or multi-dimensional array. The final condition is returned as the same size as the `initialCondition`.

Data Types: `single` | `double`

Algorithms

The `audioDelta` function uses a least-squares approximation of the local slope over a region centered on sample `x(k)`, which includes `M` samples before the current sample and `M` samples after the current sample.

$$\text{delta} = \frac{\sum_{k=-M}^M k x(k)}{\sum_{k=-M}^M k^2}$$

`M` is equal to `floor(deltaWindowLength/2)`. For details, see [1].

References

- [1] Rabiner, Lawrence R., and Ronald W. Schafer. *Theory and Applications of Digital Speech Processing*. Upper Saddle River, NJ: Pearson, 2010.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`mfcc` | `gtcc` | **Extract Audio Features** | `designAuditoryFilterBank` | `stft` | `cepstralCoefficients`

Introduced in R2020b

showaudioblockdatatypetable

Simulink block data type support table

Syntax

```
showaudioblockdatatypetable
```

Description

`showaudioblockdatatypetable` shows a table of characteristics for Audio Toolbox blocks. The table lists capabilities and limitations about blocks, such as support for code generation and variable-sized input.

Examples

Show Block Characteristics for Audio Toolbox™

Show a table of Audio Toolbox™ block characteristics. The table opens in a separate window.

```
showaudioblockdatatypetable
```

```
Loading Audio Toolbox Library.
```

See Also

Topics

“Real-Time Audio in Simulink”

Introduced in R2016a

audioPluginGridLayout

Specify layout for audio plugin UI

Syntax

```
gridLayout = audioPluginGridLayout
gridLayout = audioPluginGridLayout(Name, Value)
```

Description

`gridLayout = audioPluginGridLayout` creates an object that specifies the layout grid for an audio plugin graphical user interface. Use the plugin grid layout object, `gridLayout`, as an argument to `audioPluginInterface` in your plugin class definition. `audioPluginGridLayout` specifies only the grid. The placement of individual graphical elements is specified using `audioPluginParameter`.

To learn how to design a graphic user interface, see “Design User Interface for Audio Plugin”.

For example plugins, see “Audio Plugin Example Gallery”.

`gridLayout = audioPluginGridLayout(Name, Value)` specifies `audioPluginGridLayout` properties using one or more `Name, Value` pair arguments.

Examples

Use Default Audio Plugin Grid Layout

The default audio plugin grid layout specifies a 2-by-2 grid. Call `audioPluginGridLayout` with no arguments to view the default settings.

```
audioPluginGridLayout
```

```
ans =
```

```
audioPluginGridLayout with properties:
```

```
    RowHeight: [100 100]
   ColumnWidth: [100 100]
    RowSpacing: 10
   ColumnSpacing: 10
        Padding: [10 10 10 10]
```

`noisifyClassic` uses a default grid layout by passing `audioPluginGridLayout`, without any arguments, to `audioPluginInterface`. When you use `audioPluginGridLayout`, you must specify the position of each `audioPluginParameter` on the grid using `Layout`. Display names corresponding to parameters occupy cells on the grid also. The default grid contains only four cells and `noisifyClassic` has four parameters, so you must set `DisplayNameLocation` to `none` to fit

all elements on the grid. `audioPluginGridLayout` is passed to the `audioPluginInterface`. Save `noisifyClassic` to your current folder.

```

classdef noisifyClassic < audioPlugin
    properties
        DropoutLeft = false
        DropoutRight = false
        NoiseLeftGain = 0
        NoiseRightGain = 0
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('DropoutLeft', ...
                'Layout',[2,1], ...
                'DisplayNameLocation','none'), ...
            audioPluginParameter('DropoutRight', ...
                'Layout',[2,2], ...
                'DisplayNameLocation','none'), ...
            audioPluginParameter('NoiseLeftGain', ...
                'Layout',[1,1], ...
                'DisplayNameLocation','none'), ...
            audioPluginParameter('NoiseRightGain', ...
                'Layout',[1,2], ...
                'DisplayNameLocation','none'), ...
            ...
            audioPluginGridLayout)
    end
    methods
        function out = process(plugin,in)
            r = size(in,1);
            dropRate = 0.1;

            if plugin.DropoutLeft
                idx = randperm(r,round(r*dropRate));
                in(idx,1) = 0;
            end
            if plugin.DropoutRight
                idx = randperm(r,round(r*dropRate));
                in(idx,2) = 0;
            end

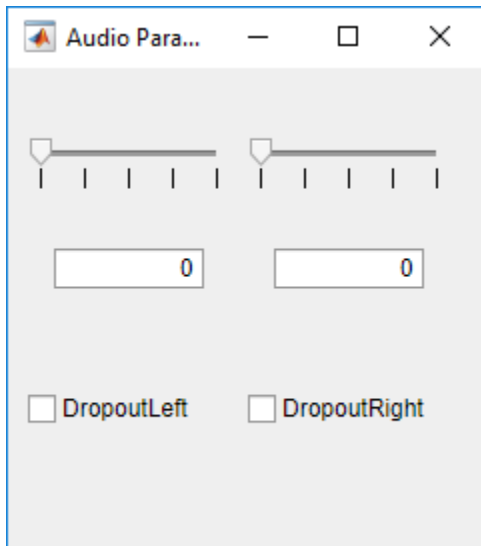
            in(:,1) = in(:,1) + plugin.NoiseLeftGain*(2*rand(r,1,'like',in)-1);
            in(:,2) = in(:,2) + plugin.NoiseRightGain*(2*rand(r,1,'like',in)-1);

            out = in;
        end
    end
end
end

```

You can quickly iterate on your UI design by using `parameterTuner` to visualize the plugin UI. Call `parameterTuner` on `noisifyClassic`.

```
parameterTuner(noisifyClassic)
```

Design Audio Plugin Grid Layout

The example plugin, `noisify`, adds noise to your audio signal channel-wise at a specified gain (per channel) and dropout rate.

```

classdef noisifyOriginal < audioPlugin
    properties
        DropoutLeft = false;
        DropoutRight = false;
        NoiseLeftGain = 0;
        NoiseRightGain = 0;
        DropoutRate = 0.1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface(...
            audioPluginParameter('DropoutLeft'), ...
            audioPluginParameter('DropoutRight'), ...
            audioPluginParameter('NoiseLeftGain'), ...
            audioPluginParameter('NoiseRightGain'), ...
            audioPluginParameter('DropoutRate'))
    end
    methods
        function out = process(plugin,in)
            r = size(in,1);

            if plugin.DropoutLeft
                idx = randperm(r,round(r*plugin.DropoutRate));
                in(idx,1) = 0;
            end
            if plugin.DropoutRight
                idx = randperm(r,round(r*plugin.DropoutRate));
                in(idx,2) = 0;
            end

            in(:,1) = in(:,1) + plugin.NoiseLeftGain*randn(r,1,'like',in);
        end
    end
end

```

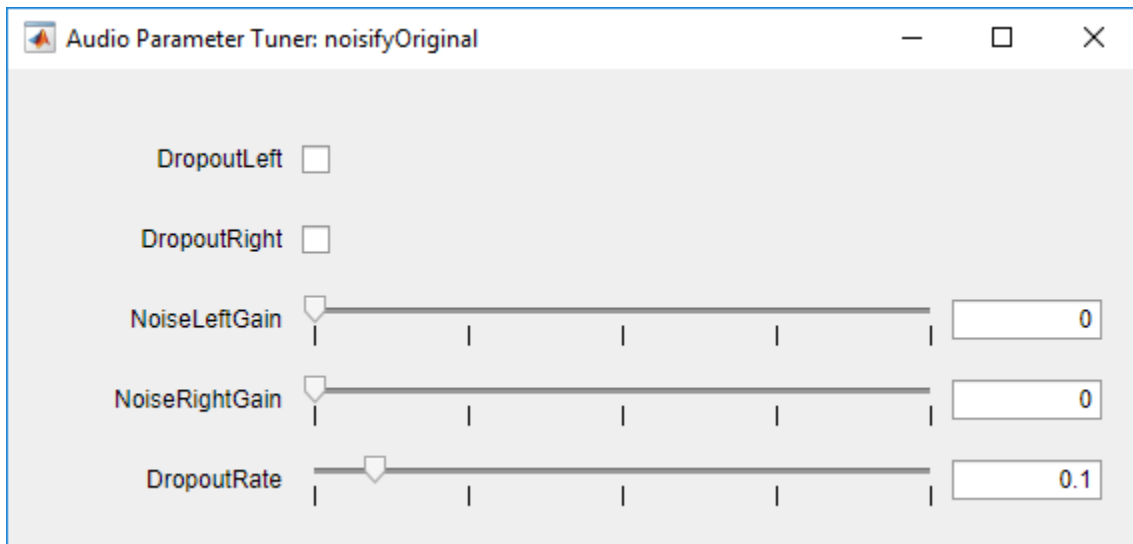
```

        in(:,2) = in(:,2) + plugin.NoiseRightGain*randn(r,1,'like',in);
        out = in;
    end
end
end

```

To see the corresponding UI for the plugin, call `parameterTuner` with the plugin. When you generate an audio plugin and deploy it to a DAW, the DAW uses a default UI that is similar to the default UI of `parameterTuner`.

```
parameterTuner(noisifyOriginal)
```



You can create a more intuitive and visually pleasing UI using `audioPluginInterface`, `audioPluginGridLayout`, and `audioPluginParameter`. For example, to create a more intuitive UI for `noisifyOriginal`, you could update the `audioPluginInterface` as follows:

```

classdef noisify < audioPlugin
    properties
        DropoutLeft = false;
        DropoutRight = false;
        NoiseLeftGain = 0;
        NoiseRightGain = 0;
        DropoutRate = 0.1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface(...
            audioPluginParameter('DropoutLeft', ...
                'Layout',[4,1], ...
                'DisplayName','Dropout (L)', ...
                'DisplayNameLocation','above', ...
                'Style','vrockert'), ...
            audioPluginParameter('DropoutRight', ...
                'Layout',[4,4], ...
                'DisplayName','Dropout (R)', ...
                'DisplayNameLocation','above', ...

```

```

        'Style','vrockert'), ...
    audioPluginParameter('NoiseLeftGain', ...
        'DisplayName','Noise Gain (L)', ...
        'Layout',[2,1;2,2], ...
        'DisplayNameLocation','above', ...
        'Style','rotaryknob'), ...
    audioPluginParameter('NoiseRightGain', ...
        'Layout',[2,3;2,4], ...
        'DisplayName','Noise Gain (R)', ...
        'DisplayNameLocation','above', ...
        'Style','rotaryknob'), ...
    audioPluginParameter('DropoutRate', ...
        'Layout',[4,2;4,3], ...
        'DisplayName','Dropout Rate', ...
        'DisplayNameLocation','below', ...
        'Style','vslider'), ...
    ...
    audioPluginGridLayout( ...
        'RowHeight',[15,150,15,150,15], ...
        'ColumnWidth',[100,40,40,100], ...
        'RowSpacing',30))
end
methods
function out = process(plugin,in)
    r = size(in,1);

    if plugin.DropoutLeft
        idx = randperm(r,round(r*plugin.DropoutRate));
        in(idx,1) = 0;
    end
    if plugin.DropoutRight
        idx = randperm(r,round(r*plugin.DropoutRate));
        in(idx,2) = 0;
    end

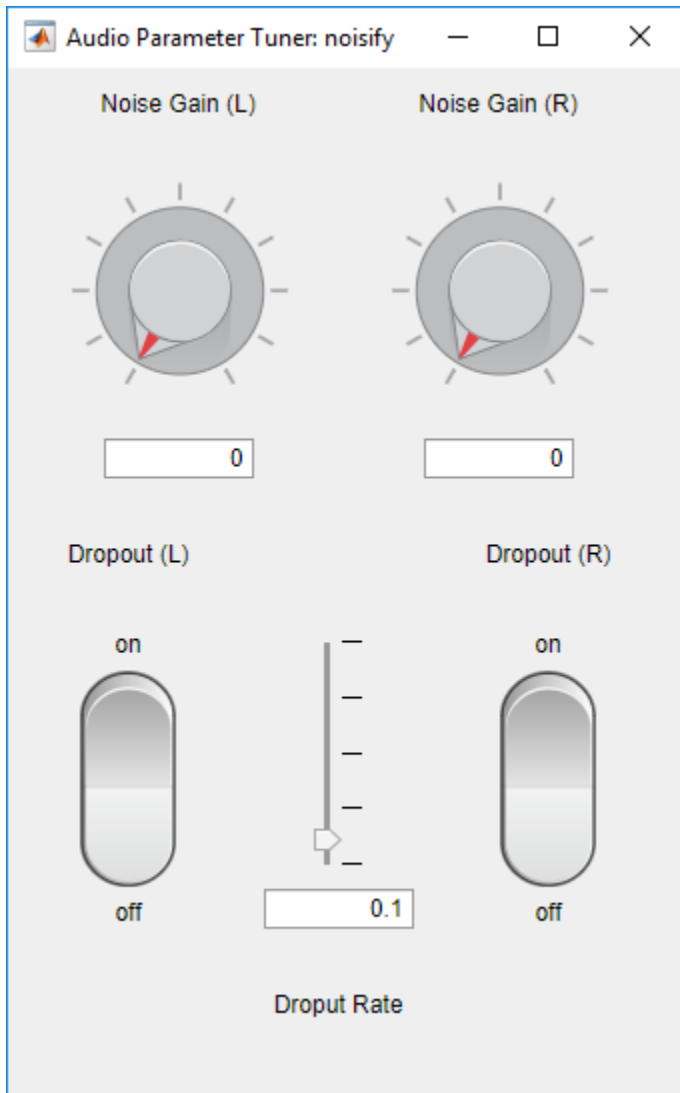
    in(:,1) = in(:,1) + plugin.NoiseLeftGain*randn(r,1,'like',in);
    in(:,2) = in(:,2) + plugin.NoiseRightGain*randn(r,1,'like',in);

    out = in;
end
end
end
end

```

You can quickly iterate on your UI design by using `parameterTuner` to visualize incremental changes. Call `parameterTuner` on `noisify`. When you generate an audio plugin and deploy it to a DAW, the DAW uses the enhanced UI.

```
parameterTuner(noisify)
```



Input Arguments

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'RowHeight', [50,200,150]` species a grid with three rows. The first row is 50 pixels high, the second row is 200 pixels high, and the third row is 150 pixels high.

RowHeight — Height of each row (pixels)

`[100, 100]` (default) | row vector of positive integers

Height in pixels of each row in the grid, specified as a comma-separated pair consisting of `'RowHeight'` and a row vector of positive integers.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ColumnWidth — Width of each column (pixels)

[100, 100] (default) | row vector of positive integers

Width in pixels of each column in the grid, specified as a comma-separated pair consisting of 'ColumnWidth' and a row vector of positive integers.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

RowSpacing — Distance between rows (pixels)

10 (default) | nonnegative integer

Distance between rows in pixels, specified as a comma-separated pair consisting of 'RowSpacing' and a nonnegative integer.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ColumnSpacing — Distance between columns (pixels)

10 (default) | nonnegative integer

Distance between columns in pixels, specified as a comma-separated pair consisting of 'ColumnSpacing' and a nonnegative integer.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Padding — Padding around the outer perimeter of grid (pixels)

[10, 10, 10, 10] (default) | [left, bottom, right, top]

Padding around the outer perimeter of the grid in pixels, specified as a comma-separated pair consisting of 'Padding' and a four-element row vector of nonnegative integers. The elements of the vector are interpreted as [left, bottom, right, top], where:

- left -- Distance in pixels from the left edge of the grid to the left edge of the parent container.
- bottom -- Distance in pixels from the bottom edge of the grid to the bottom edge of the parent container.
- right -- Distance in pixels from the right edge of the grid to the right edge of the parent container.
- top -- Distance in pixels from the top edge of the grid to the top edge of the parent container.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also

[audioPlugin](#) | [audioPluginSource](#) | [audioPluginInterface](#) | [validateAudioPlugin](#) | [generateAudioPlugin](#) | [audioPluginParameter](#) | **Audio Test Bench** | [parameterTuner](#)

Topics

“Design User Interface for Audio Plugin”

“Audio Plugin Example Gallery”

“Audio Plugins in MATLAB”

“Export a MATLAB Plugin to a DAW”

Introduced in R2019b

pinknoise

Generate pink noise

Syntax

```
X = pinknoise(n)
X = pinknoise(sz1,sz2)
X = pinknoise(sz)
X = pinknoise( ____,typename)
X = pinknoise( ____, 'like', p)
```

Description

`X = pinknoise(n)` returns a pink noise column vector of length `n`.

`X = pinknoise(sz1,sz2)` returns a `sz1`-by-`sz2` matrix. Each channel (column) of the output `X` is an independent pink noise signal.

`X = pinknoise(sz)` returns a vector or matrix with dimensions defined by the elements of vector `sz`. `sz` must be a one- or two-element row vector of positive integers. Each channel (column) of the output `X` is an independent pink noise signal.

`X = pinknoise(____,typename)` returns an array of pink noise of data type `typename`. The `typename` input can be either `'single'` or `'double'`. You can combine `typename` with any of the input arguments in the previous syntaxes.

`X = pinknoise(____, 'like', p)` returns an array of pink noise like `p`. You can specify either `typename` or `'like'`, but not both.

Examples

Generate Pink Noise

Generate 100 seconds of pink noise with a sample rate of 44.1 kHz.

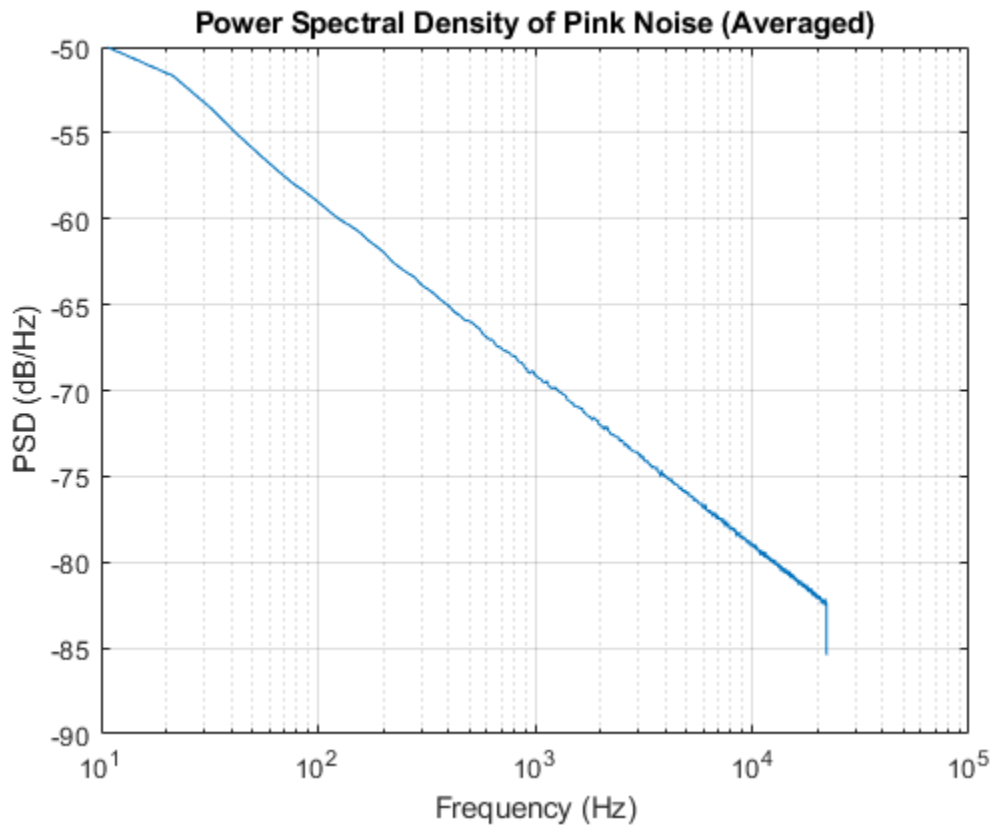
```
fs = 44.1e3;
duration = 100;
```

```
y = pinknoise(duration*fs);
```

Plot the average power spectral density (PSD) of the generated pink noise.

```
[~,freqVec,~,psd] = spectrogram(y,round(0.05*fs),[],[],fs);
meanPSD = mean(psd,2);
```

```
semilogx(freqVec,db(meanPSD,"power"))
xlabel('Frequency (Hz)')
ylabel('PSD (dB/Hz)')
title('Power Spectral Density of Pink Noise (Averaged)')
grid on
```



Amplitude Distribution of Pink Noise

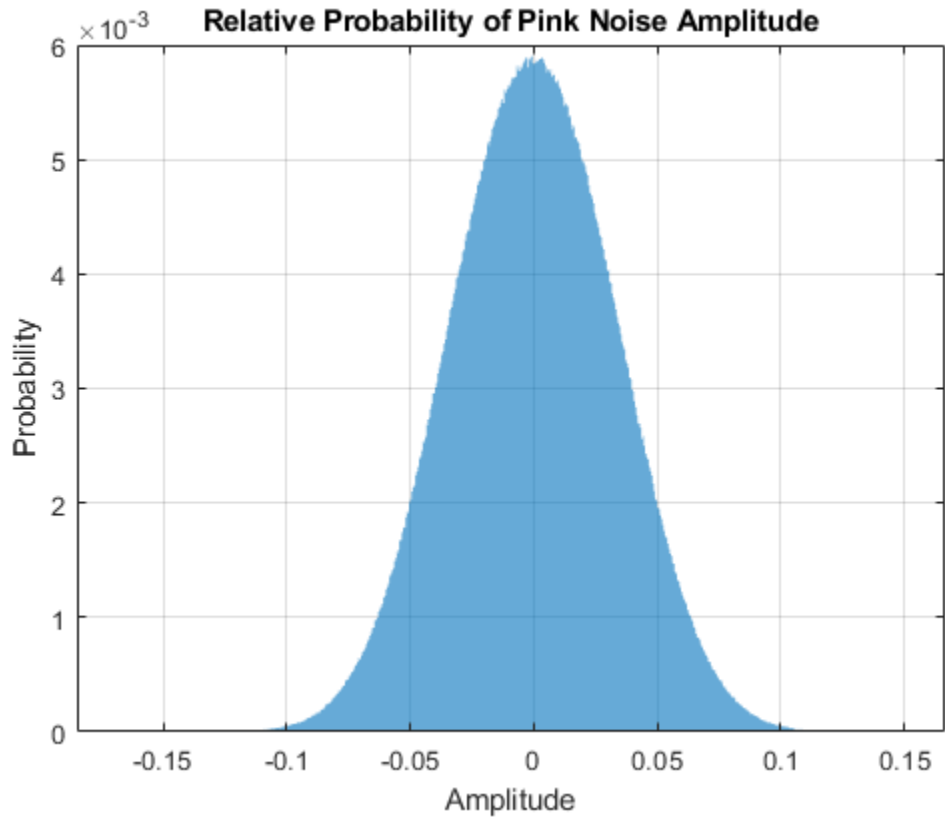
Generate 500 seconds of pink noise with a sample rate of 16 kHz.

```
fs = 16e3;  
duration = 500;
```

```
y = pinknoise(duration*fs);
```

Plot the relative probability of the pink noise amplitude. The amplitude is always bounded between -1 and 1.

```
histogram(y, "Normalization", "probability", "EdgeColor", "none")  
xlabel("Amplitude")  
ylabel("Probability")  
title("Relative Probability of Pink Noise Amplitude")  
grid on
```



Generate Multiple Independent Channels of Pink Noise

Create a 5 second stereo pink noise signal with a 48 kHz sample rate.

```
fs = 48e3;
duration = 5;
numChan = 2;
```

```
pn = pinknoise(duration*fs,numChan);
```

Listen to the stereo pink noise signal.

```
sound(pn, fs)
```

Channels of the pink noise function are generated independently. Note that the off-diagonal correlation coefficients are close to zero (uncorrelated).

```
R = corrcoef(pn(:,1),pn(:,2))
```

```
R = 2x2
```

```
    1.0000    -0.0190
   -0.0190    1.0000
```


Correlated and uncorrelated pink noise have different psychoacoustic effects. When the noise is correlated, the sound is less ambient and more centralized. To listen to correlated pink noise, send a single channel of the pink noise signal to your stereo device. The effect is most pronounced when using headphones.

```
sound([pn(:,1),pn(:,1)],fs)
```

Add Pink Noise to Audio Signal

Read in an audio file.

```
[audioIn,fs] = audioread("MainStreetOne-16-16-mono-12secs.wav");
```

Create a pink noise signal of the same size and data type as audioIn.

```
noise = pinknoise(size(audioIn),'like',audioIn);
```

Add the pink noise to the audio signal and then listen to the first 5 seconds.

```
noisyMainStreet = noise + audioIn;
sound(noisyMainStreet(1:fs*5,:),fs)
```

The pinknoise function generates an approximate -29.5 dB signal level, which is close to the power of the audio signal.

```
noisePower = sum(noise.^2,1)/size(noise,1);
signalPower = sum(audioIn.^2,1)/size(audioIn,1);
snr = 10*log10(signalPower./noisePower)
```

```
snr = 1.9791
```

```
noisePowerdB = 10*log10(noisePower)
```

```
noisePowerdB = -29.6665
```

```
signalPowerdB = 10*log10(signalPower)
```

```
signalPowerdB = -27.6874
```

Mix the input audio with the generated pink noise at an 8 dB SNR.

```
desiredSNR = 8;
scaleFactor = sqrt(signalPower./(noisePower*(10^(desiredSNR/10))));
```

```
noise = noise.*scaleFactor;
```

Verify the resulting SNR is 8 dB and then listen to the first 5 seconds.

```
noisePower = sum(noise.^2,1)/size(noise,1);
snr = 10*log10(signalPower./noisePower)
```

```
snr = 8.0000
```

```
noisyMainStreet = noise + audioIn;
sound(noisyMainStreet(1:fs*5,:),fs)
```

Input Arguments

n — Number of rows of pink noise

nonnegative integer

Number of rows of pink noise, specified as a nonnegative integer.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

sz1, sz2 — Size of each dimension (as separate arguments)

nonnegative integers

Size of each dimension, specified as a nonnegative integer or two separate arguments of nonnegative integers.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

sz — Size of each dimension (as a row vector)

one- or two-element row vector of nonnegative integers

Size of each dimension, specified as a one- or two-element row vector of nonnegative integers. Each element of this vector indicates the size of the corresponding dimension.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

typename — Data type to create

'double' (default) | 'single'

Data type to create, specified as 'double' or 'single'.

Data Types: `char` | `string`

p — Prototype of array to create

numeric array

Prototype of array to create, specified as a numeric array. The generated pink noise is the same data type as `p`.

Data Types: `single` | `double`

Output Arguments

X — Pink noise

column vector | matrix

Pink noise, returned as a column vector or matrix of independent channels.

Data Types: `single` | `double`

Tips

- The concatenation of multiple pink noise vectors does not result in pink noise. For streaming applications, use `dsp.ColoredNoise`.

Algorithms

Pink noise is generated by passing uniformly distributed random numbers through a series of randomly initiated SOS filters. The resulting pink noise amplitude distribution is quasi-Gaussian and bounded between -1 and 1 . The resulting pink noise power spectral density (PSD) is inversely proportional to frequency:

$$S(f) \propto \frac{1}{f}$$

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`dsp.ColoredNoise` | `rng` | `rand`

Introduced in R2019b

stretchAudio

Time-stretch audio

Syntax

```
audioOut = stretchAudio(audioIn,alpha)
audioOut = stretchAudio(audioIn,alpha,Name,Value)
```

Description

`audioOut = stretchAudio(audioIn,alpha)` applies time scale modification (TSM) on the input audio by the TSM factor `alpha`.

`audioOut = stretchAudio(audioIn,alpha,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

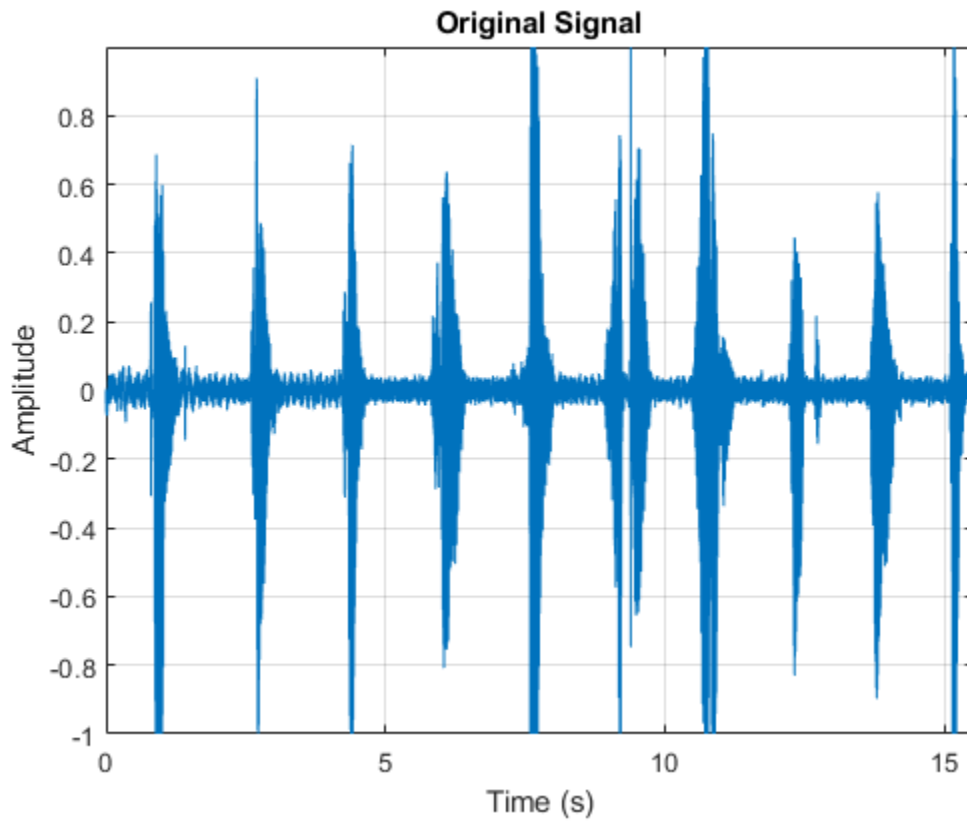
Examples

Apply TSM

Read in an audio signal. Listen to the audio signal and plot it over time.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");

t = (0:size(audioIn,1)-1)/fs;
plot(t,audioIn)
xlabel('Time (s)')
ylabel('Amplitude')
title('Original Signal')
axis tight
grid on
```

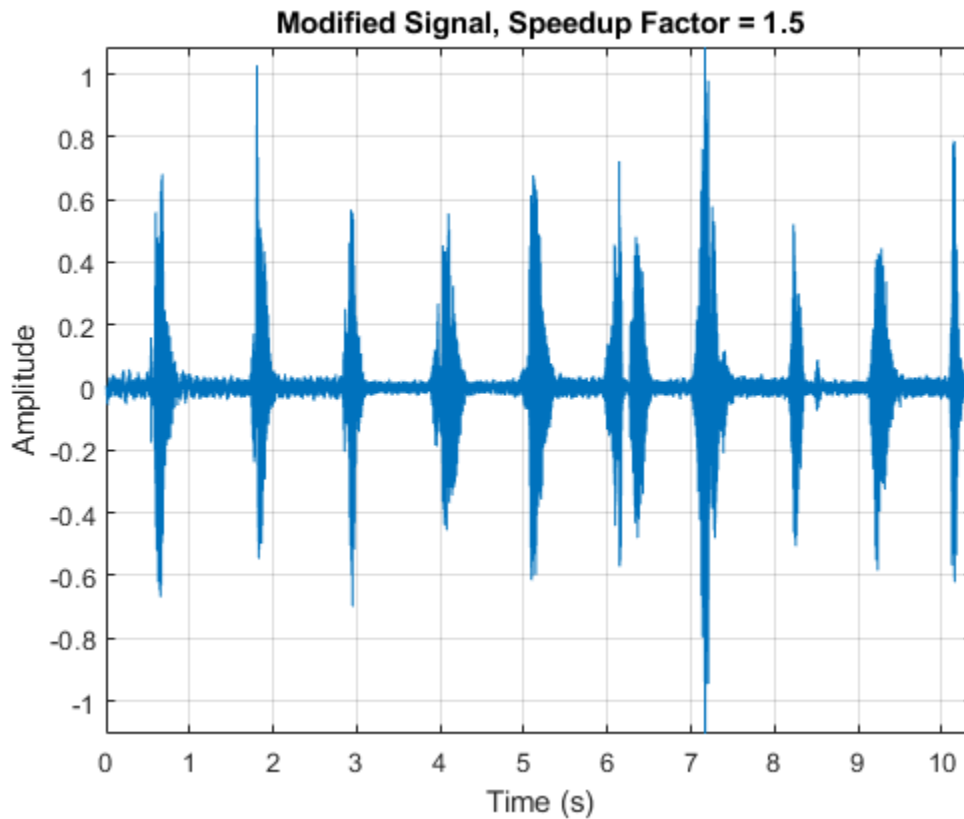


```
sound(audioIn,fs)
```

Use `stretchAudio` to apply a 1.5 speedup factor. Listen to the modified audio signal and plot it over time. The sample rate remains the same, but the duration of the signal has decreased.

```
audioOut = stretchAudio(audioIn,1.5);
```

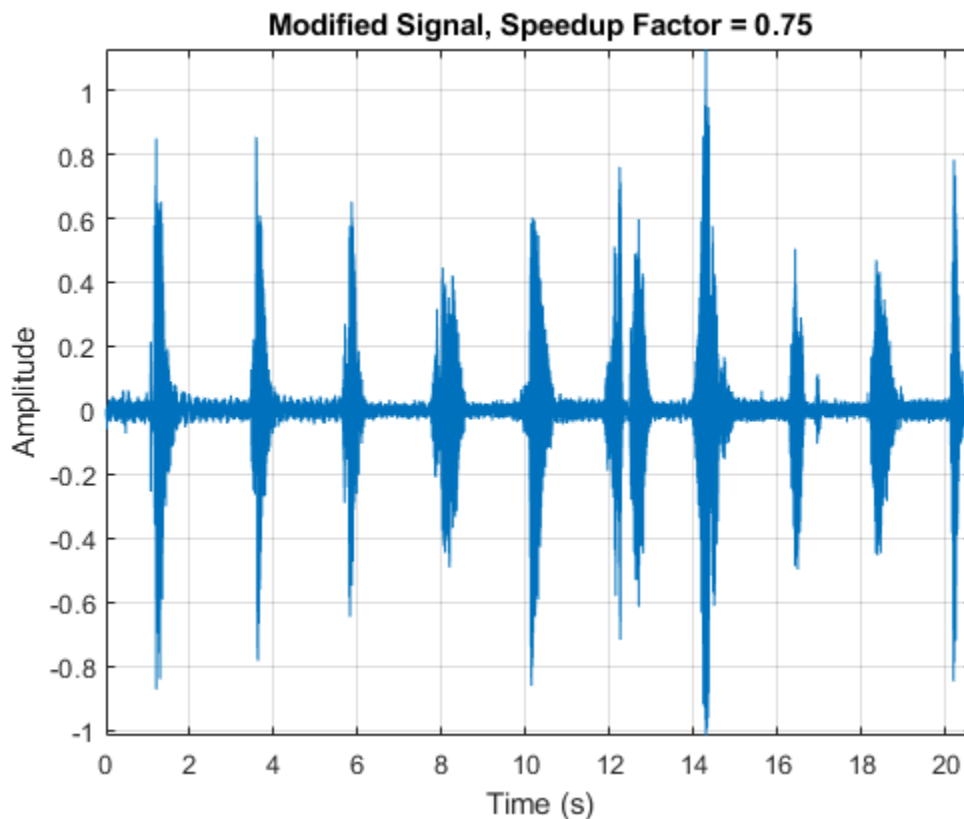
```
t = (0:size(audioOut,1)-1)/fs;  
plot(t,audioOut)  
xlabel('Time (s)')  
ylabel('Amplitude')  
title('Modified Signal, Speedup Factor = 1.5')  
axis tight  
grid on
```



```
sound(audioOut, fs)
```

Slow down the original audio signal by a 0.75 factor. Listen to the modified audio signal and plot it over time. The sample rate remains the same as the original audio, but the duration of the signal has increased.

```
audioOut = stretchAudio(audioIn,0.75);  
  
t = (0:size(audioOut,1)-1)/fs;  
plot(t,audioOut)  
xlabel('Time (s)')  
ylabel('Amplitude')  
title('Modified Signal, Speedup Factor = 0.75')  
axis tight  
grid on
```



```
sound(audioOut, fs)
```

Apply TSM to Frequency-Domain Audio

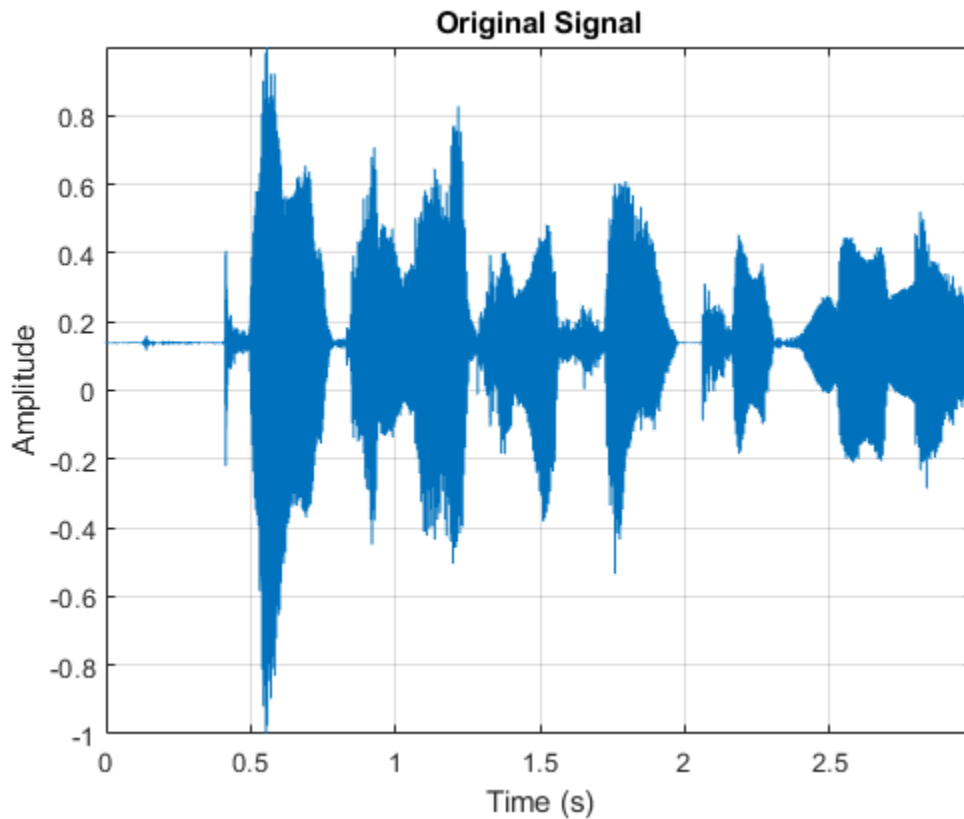
stretchAudio supports TSM on frequency-domain audio when using the default vocoder method. Applying TSM to frequency-domain audio enables you to reuse your STFT computation for multiple TSM factors.

Read in an audio signal. Listen to the audio signal and plot it over time.

```
[audioIn, fs] = audioread('FemaleSpeech-16-8-mono-3secs.wav');
```

```
sound(audioIn, fs)
```

```
t = (0:size(audioIn,1)-1)/fs;
plot(t, audioIn)
xlabel('Time (s)')
ylabel('Amplitude')
title('Original Signal')
axis tight
grid on
```



Convert the audio signal to the frequency domain.

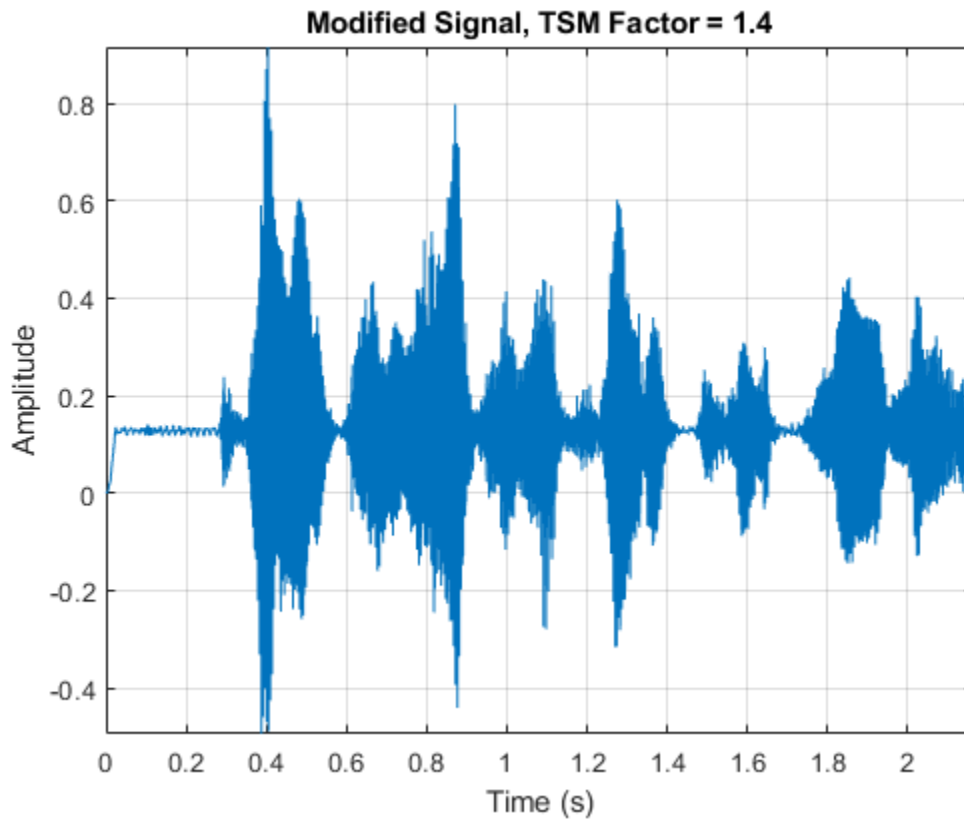
```
win = sqrt(hann(256,'periodic'));
ovrlp = 192;
S = stft(audioIn,'Window',win,'OverlapLength',ovrlp,'Centered',false);
```

Speed up the audio signal by a factor of 1.4. Specify the window and overlap length used to create the frequency-domain representation.

```
alpha = 1.4;
audioOut = stretchAudio(S,alpha,'Window',win,'OverlapLength',ovrlp);
```

```
sound(audioOut,fs)
```

```
t = (0:size(audioOut,1)-1)/fs;
plot(t,audioOut)
xlabel('Time (s)')
ylabel('Amplitude')
title('Modified Signal, TSM Factor = 1.4')
axis tight
grid on
```

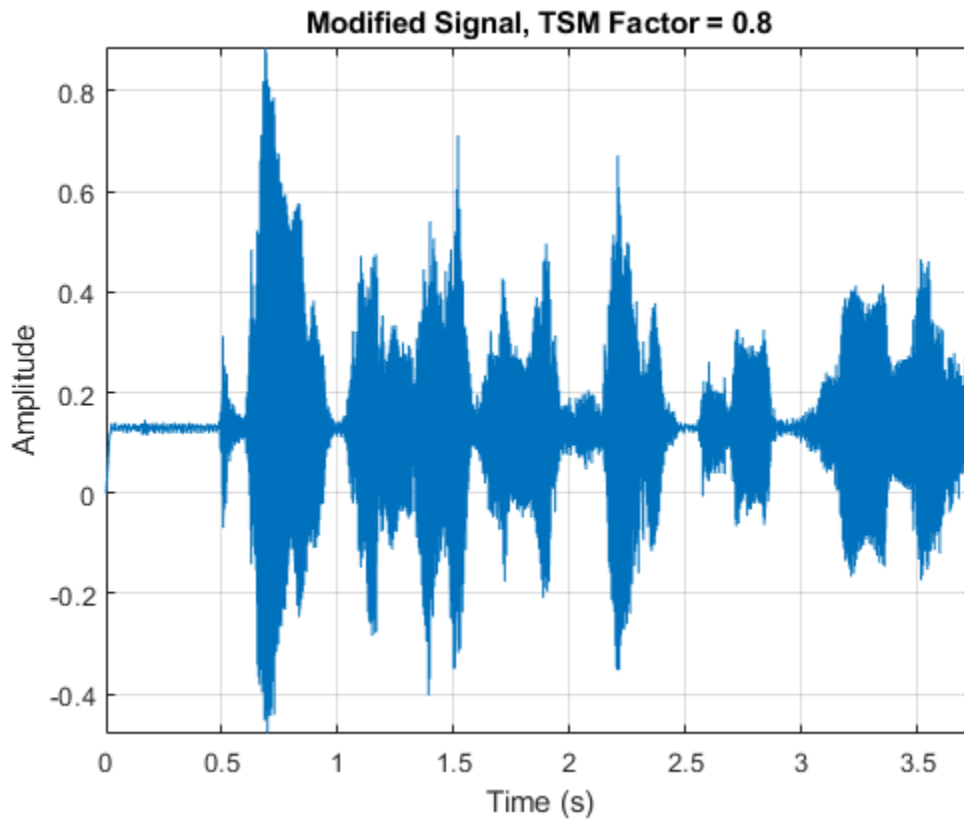



Slow down the audio signal by a factor of 0.8. Specify the window and overlap length used to create the frequency-domain representation.

```
alpha = 0.8;
audioOut = stretchAudio(S,alpha,'Window',win,'OverlapLength',ovrlp);

sound(audioOut,fs)

t = (0:size(audioOut,1)-1)/fs;
plot(t,audioOut)
xlabel('Time (s)')
ylabel('Amplitude')
title('Modified Signal, TSM Factor = 0.8')
axis tight
grid on
```

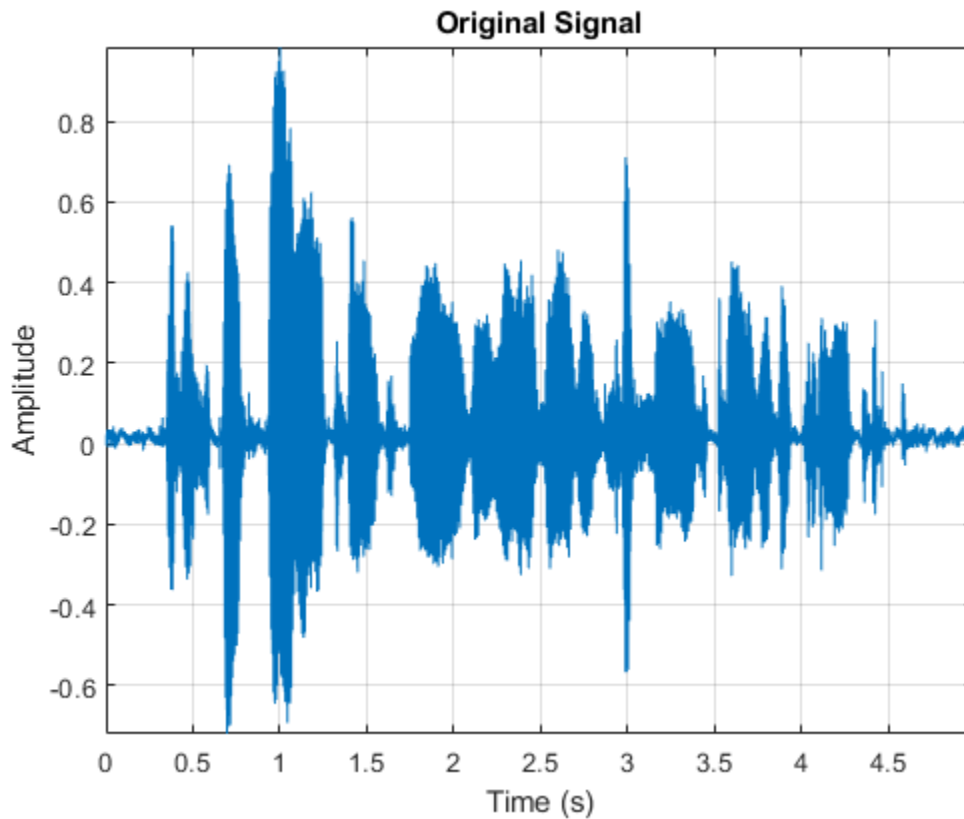


Increase Fidelity Using Phase-Locking

The default TSM method (vocoder) enables you to additionally apply phase-locking to increase the fidelity to the original audio.

Read in an audio signal. Listen to the audio signal and plot it over time.

```
[audioIn,fs] = audioread("SpeechDFT-16-8-mono-5secs.wav");  
  
sound(audioIn,fs)  
  
t = (0:size(audioIn,1)-1)/fs;  
plot(t,audioIn)  
xlabel('Time (s)')  
ylabel('Amplitude')  
title('Original Signal')  
axis tight  
grid on
```



Phase-locking adds a nontrivial computational load to TSM and is not always required. By default, phase-locking is disabled. Apply a speedup factor of 1.8 to the input audio signal. Listen to the audio signal and plot it over time.

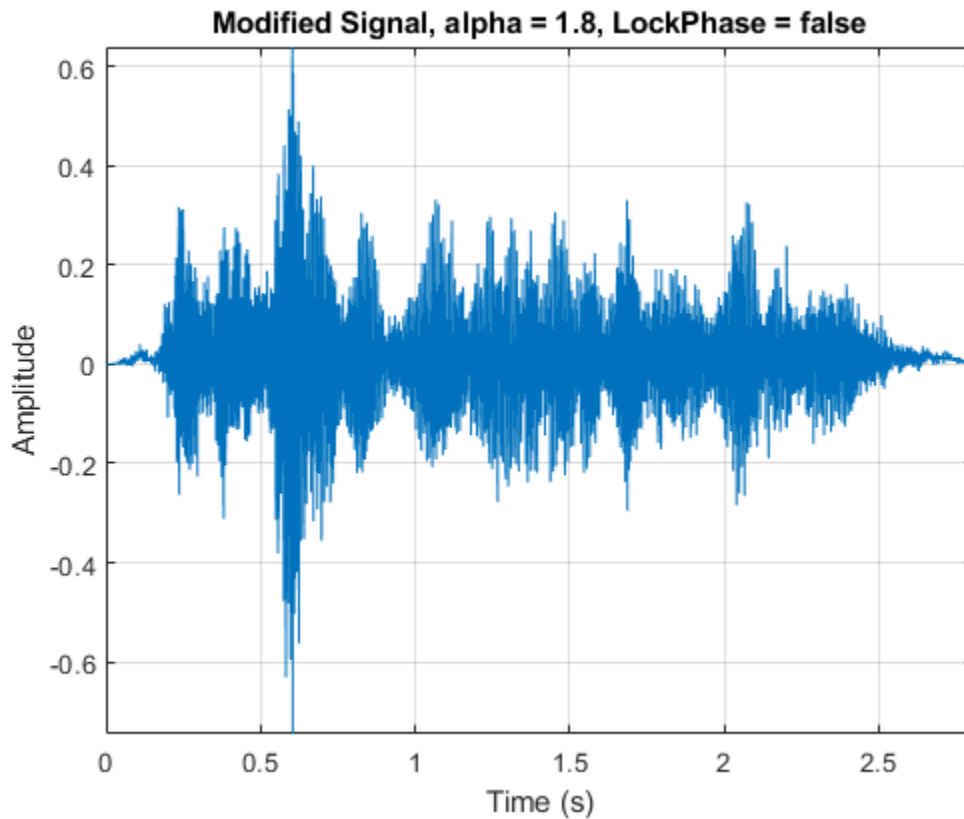
```
alpha = 1.8;

tic
audioOut = stretchAudio(audioIn,alpha);
processingTimeWithoutPhaseLocking = toc

processingTimeWithoutPhaseLocking = 0.0798

sound(audioOut,fs)

t = (0:size(audioOut,1)-1)/fs;
plot(t,audioOut)
xlabel('Time (s)')
ylabel('Amplitude')
title('Modified Signal, alpha = 1.8, LockPhase = false')
axis tight
grid on
```



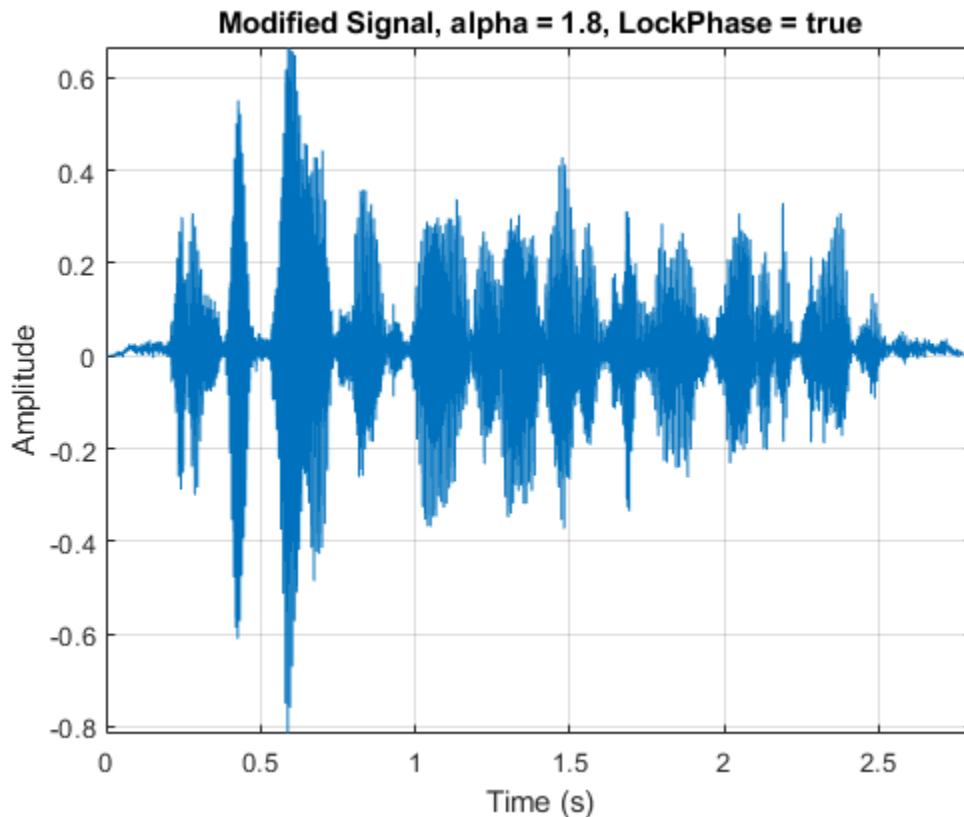
Apply the same 1.8 speedup factor to the input audio signal, this time enabling phase-locking. Listen to the audio signal and plot it over time.

```
tic
audioOut = stretchAudio(audioIn,alpha,"LockPhase",true);
processingTimeWithPhaseLocking = toc

processingTimeWithPhaseLocking = 0.1154

sound(audioOut,fs)

t = (0:size(audioOut,1)-1)/fs;
plot(t,audioOut)
xlabel('Time (s)')
ylabel('Amplitude')
title('Modified Signal, alpha = 1.8, LockPhase = true')
axis tight
grid on
```



Increase Fidelity Using WSOLA Delta

The waveform similarity overlap-add (WSOLA) TSM method enables you to specify the maximum number of samples to search for the best signal alignment. By default, WSOLA delta is the number of samples in the analysis window minus the number of samples overlapped between adjacent analysis windows. Increasing the WSOLA delta increases the computational load but might also increase fidelity.

Read in an audio signal. Listen to the first 10 seconds of the audio signal.

```
[audioIn,fs] = audioread('RockGuitar-16-96-stereo-72secs.flac');
sound(audioIn(1:10*fs,:),fs)
```

Apply a TSM factor of 0.75 to the input audio signal using the WSOLA method. Listen to the first 10 seconds of the resulting audio signal.

```
alpha = 0.75;
tic
audioOut = stretchAudio(audioIn,alpha,"Method","wsola");
processingTimeWithDefaultWSOLADelta = toc

processingTimeWithDefaultWSOLADelta = 19.4403
sound(audioOut(1:10*fs,:),fs)
```

Apply a TSM factor of 0.75 to the input audio signal, this time increasing the WSOLA delta to 1024. Listen to the first 10 seconds of the resulting audio signal.

```
tic
audioOut = stretchAudio(audioIn,alpha,"Method","wsola","WSOLADelta",1024);
processingTimeWithIncreasedWSOLADelta = toc

processingTimeWithIncreasedWSOLADelta = 25.5306

sound(audioOut(1:10*fs,:),fs)
```

Input Arguments

audioIn — Input signal

column vector | matrix | 3-D array

Input signal, specified as a column vector, matrix, or 3-D array. How the function interprets `audioIn` depends on the complexity of `audioIn` and the value of `Method`:

- If `audioIn` is real, `audioIn` is interpreted as a time-domain signal. In this case, `audioIn` must be a column vector or matrix. Columns are interpreted as individual channels.

This syntax applies when `Method` is set to `'vocoder'` or `'wsola'`.

- If `audioIn` is complex, `audioIn` is interpreted as a frequency-domain signal. In this case, `audioIn` must be an L -by- M -by- N array, where L is the FFT length, M is the number of individual spectra, and N is the number of channels.

This syntax only applies when `Method` is set to `'vocoder'`.

Data Types: `single` | `double`
Complex Number Support: Yes

alpha — TSM factor

positive scalar

TSM factor, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'Window', kbdwin(512)`

Method — Method used to time-scale audio

`'vocoder'` (default) | `'wsola'`

Method used to time-scale audio, specified as the comma-separated pair consisting of `'Method'` and `'vocoder'` or `'wsola'`. Set `'Method'` to `'vocoder'` to use the phase vocoder method. Set `'Method'` to `'wsola'` to use the WSOLA method.

If 'Method' is set to 'vocoder', audioIn can be real or complex. If 'Method' is set to 'wsola', audioIn must be real.

Data Types: single | double

Window — Window applied in time domain

sqrt(hann(1024, 'periodic')) (default) | real vector

Window applied in the time domain, specified as the comma-separated pair consisting of 'Window' and a real vector. The number of elements in the vector must be in the range [1, size(audioIn,1)]. The number of elements in the vector must also be greater than OverlapLength.

Note If using stretchAudio with frequency-domain input, you must specify Window as the same window used to transform audioIn to the frequency domain.

Data Types: single | double

OverlapLength — Number of samples overlapped between adjacent windows

round(0.75*numel(Window)) (default) | scalar in the range [0 numel(Window))

Number of samples overlapped between adjacent windows, specified as the comma-separated pair consisting of 'OverlapLength' and an integer in the range [0, numel(Window)).

Note If using stretchAudio with frequency-domain input, you must specify OverlapLength as the same overlap length used to transform audioIn to a time-frequency representation.

Data Types: single | double

LockPhase — Apply identity phase-locking

false (default) | true

Apply identity phase-locking, specified as the comma-separated pair consisting of 'LockPhase' and false or true.

Dependencies

To enable this name-value pair argument, set Method to 'vocoder'.

Data Types: logical

WSOLADelta — Maximum samples used to search for best signal alignment

numel(Window) - OverlapLength (default) | nonnegative scalar

Maximum number of samples used to search for the best signal alignment, specified as the comma-separated pair consisting of 'WSOLADelta' and a nonnegative scalar.

Dependencies

To enable this name-value pair argument, set Method to 'wsola'.

Data Types: single | double

Output Arguments

audioOut — Time-scale modified audio

column vector | matrix

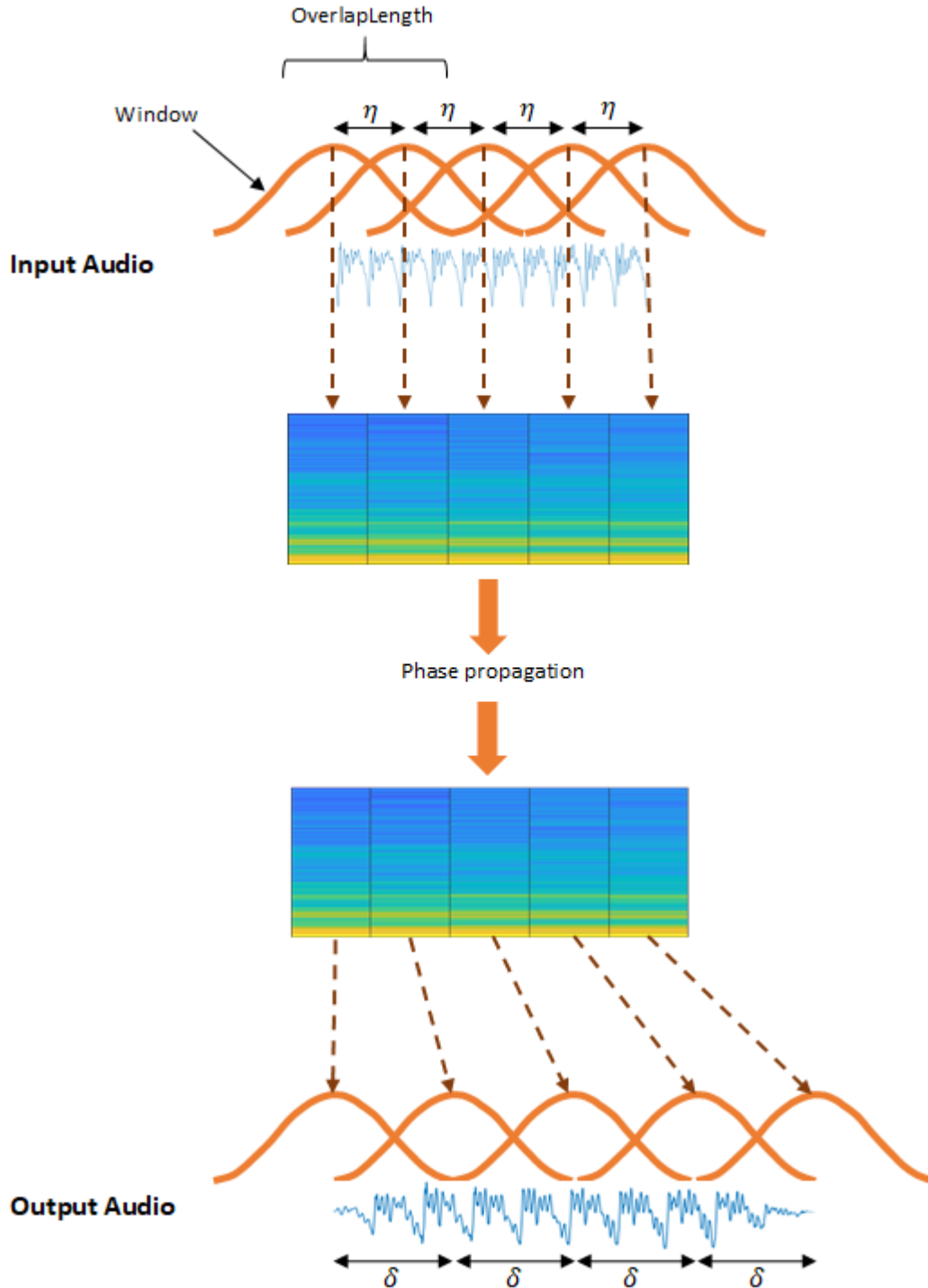
Time-scale modified audio, returned as a column vector or matrix of independent channels.

Algorithms

Phase Vocoder

The phase vocoder algorithm is a frequency-domain approach to TSM [1][2]. The basic steps of the phase vocoder algorithm are:

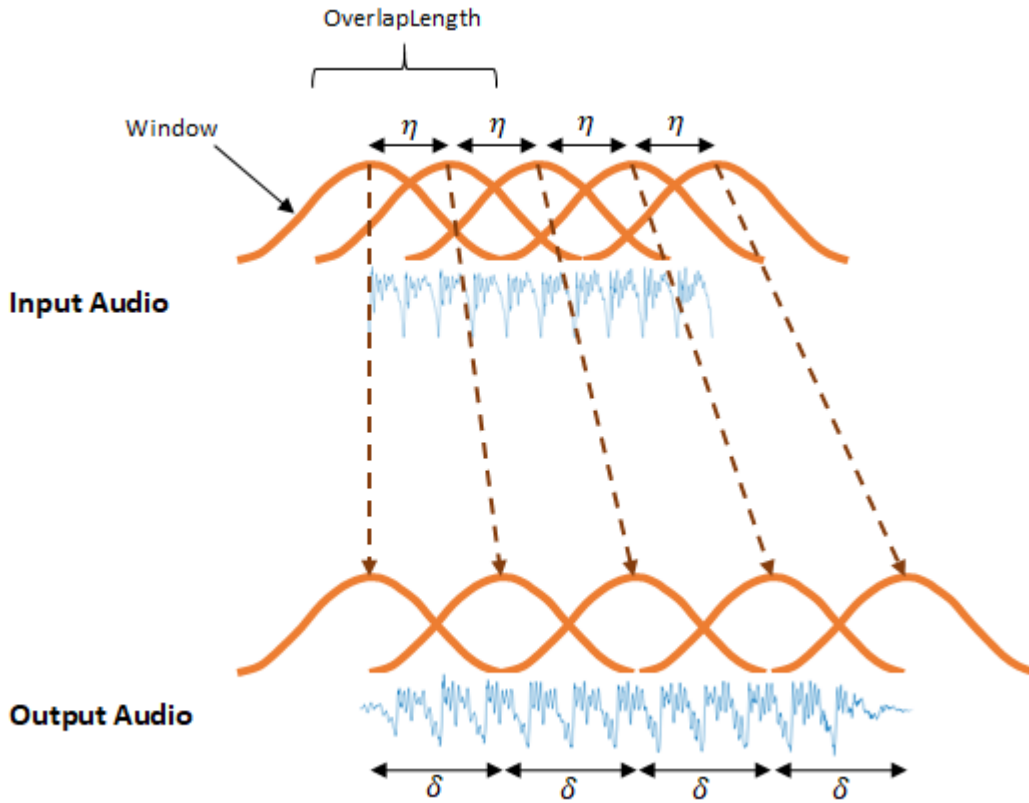
- 1** The algorithm windows a time-domain signal at interval η , where $\eta = \text{numel}(\text{Window}) - \text{OverlapLength}$. The windows are then converted to the frequency domain.
- 2** To preserve horizontal (across time) phase coherence, the algorithm treats each bin as an independent sinusoid whose phase is computed by accumulating the estimates of its instantaneous frequency.
- 3** To preserve vertical (across an individual spectrum) phase coherence, the algorithm locks the phase advance of groups of bins to the phase advance of local peaks. This step only applies if `LockPhase` is set to `true`.
- 4** The algorithm returns the modified spectrogram to the time domain, with windows spaced at intervals of δ , where $\delta \approx \eta/\alpha$. α is the speedup factor specified by the `alpha` input argument.



WSOLA

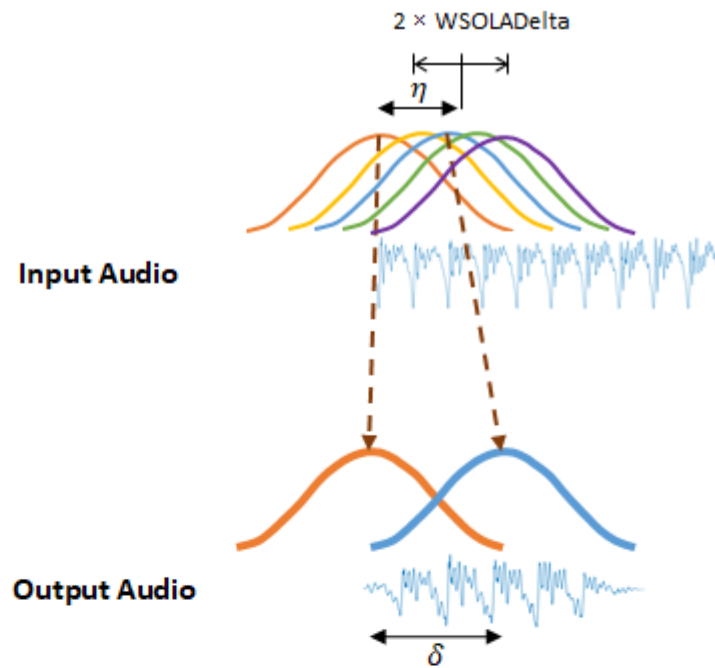
The WSOLA algorithm is a time-domain approach to TSM [1][2]. WSOLA is an extension of the overlap and add (OLA) algorithm. In the OLA algorithm, a time-domain signal is windowed at interval

η , where $\eta = \text{numel}(\text{Window}) - \text{OverlapLength}$. To construct the time-scale modified output audio, the windows are spaced at interval δ , where $\delta \approx \eta/\alpha$. α is the TSM factor specified by the `alpha` input argument.

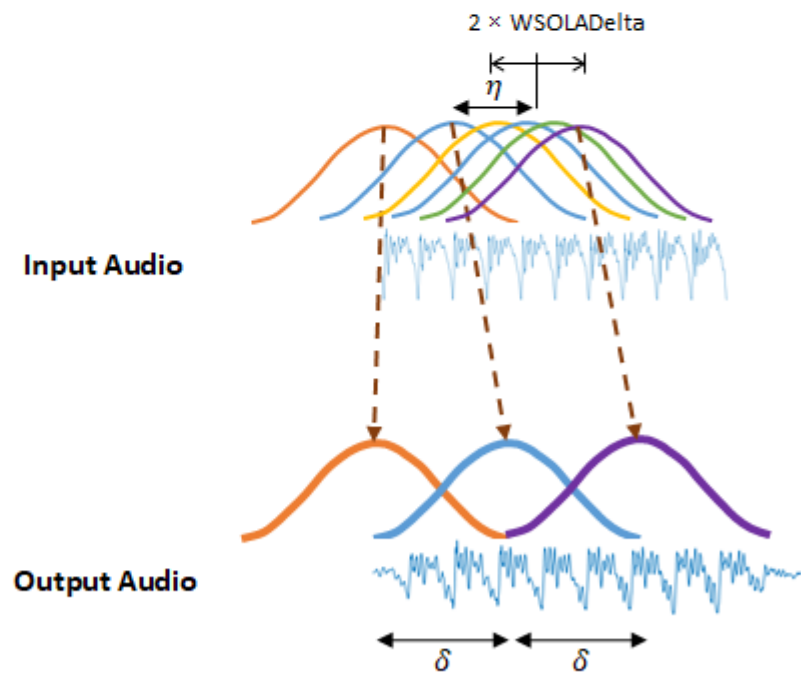


The OLA algorithm does a good job of recreating the magnitude spectra but can introduce phase jumps between windows. The WSOLA algorithm attempts to smooth the phase jumps by searching `WSOLAΔ` samples around the η interval for a window that minimizes phase jumps. The algorithm searches for the best window iteratively, so that each successive window is chosen relative to the previously selected window.

Iteration 1



Iteration 2



⋮

If `WSOLADelta` is set to θ , then the algorithm reduces to OLA.

References

- [1] Driedger, Johnathan, and Meinard Müller. "A Review of Time-Scale Modification of Music Signals." *Applied Sciences*. Vol. 6, Issue 2, 2016.
- [2] Driedger, Johnathan. "Time-Scale Modification Algorithms for Music Audio Signals", Master's thesis, Saarland University, Saarbrücken, Germany, 2011.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

Usage notes and limitations:

- Method must be set to 'vocoder'.
- LockPhase must be set to false.
- Using `gpuArray` (Parallel Computing Toolbox) input with `stretchAudio` is only recommended for a GPU with compute capability 7.0 ("Volta") or above. Other hardware might not offer any performance advantage. To check your GPU compute capability, see `ComputeCapability` in the output from the `gpuDevice` (Parallel Computing Toolbox) function. For more information, see "GPU Support by Release" (Parallel Computing Toolbox).

For an overview of GPU usage in MATLAB, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

`shiftPitch` | `reverberator` | `audioTimeScaler` | `audioDataAugmenter`

Topics

"Time-Frequency Masking for Harmonic-Percussive Source Separation"

Introduced in R2019b

shiftPitch

Shift audio pitch

Syntax

```
audioOut = shiftPitch(audioIn,nsemitones)
audioOut = shiftPitch(audioIn,nsemitones,Name,Value)
```

Description

`audioOut = shiftPitch(audioIn,nsemitones)` shifts the pitch of the audio input by the specified number of semitones, `nsemitones`.

`audioOut = shiftPitch(audioIn,nsemitones,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Examples

Apply Pitch-Shifting to Time-Domain Audio

Read in an audio file and listen to it.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
sound(audioIn,fs)
```

Increase the pitch by 3 semitones and listen to the result.

```
nsemitones = 3;
audioOut = shiftPitch(audioIn,nsemitones);
sound(audioOut,fs)
```

Decrease the pitch of the original audio by 3 semitones and listen to the result.

```
nsemitones = -3;
audioOut = shiftPitch(audioIn,nsemitones);
sound(audioOut,fs)
```

Apply Pitch-Shifting to Frequency-Domain Audio

Read in an audio file and listen to it.


```
[audioIn,fs] = audioread("SpeechDFT-16-8-mono-5secs.wav");
sound(audioIn,fs)
```

Convert the audio signal to a time-frequency representation using `stft`. Use a 512-point `kbdwin` with 75% overlap.

```
win = kbdwin(512);
overlapLength = 0.75* numel(win);
```


```
S = stft(audioIn, ...
         "Window",win, ...
         "OverlapLength",overlapLength, ...
         "Centered",false);
```

Increase the pitch by 8 semitones and listen to the result. Specify the window and overlap length you used to compute the STFT.

```
nsemitones = 8  ;
lockPhase =  ;
audioOut = shiftPitch(S,nsemitones, ...
                    "Window",win, ...
                    "OverlapLength",overlapLength, ...
                    "LockPhase",lockPhase);

sound(audioOut,fs)
```

Decrease the pitch of the original audio by 8 semitones and listen to the result. Specify the window and overlap length you used to compute the STFT.

```
nsemitones = -8  ;
lockPhase =  ;
audioOut = shiftPitch(S,nsemitones, ...
                    "Window",win, ...
                    "OverlapLength",overlapLength, ...
                    "LockPhase",lockPhase);

sound(audioOut,fs)
```

Increase Fidelity Using Phase Locking

Read in an audio file and listen to it.

```
[audioIn,fs] = audioread('FemaleSpeech-16-8-mono-3secs.wav');
sound(audioIn,fs)
```

Increase the pitch by 6 semitones and listen to the result.

```
nsemitones = 6;
lockPhase = false;
audioOut = shiftPitch(audioIn,nsemitones, ...
                    'LockPhase',lockPhase);
sound(audioOut,fs)
```

To increase fidelity, set LockPhase to true. Apply pitch shifting, and listen to the results.


```
lockPhase = true;
audioOut = shiftPitch(audioIn,nsemitones, ...
                    'LockPhase',lockPhase);
sound(audioOut,fs)
```

Increase Fidelity Using Formant Preservation

Read in the first 11.5 seconds of an audio file and listen to it.


```
[audioIn,fs] = audioread('Rainbow-16-8-mono-114secs.wav',[1,8e3*11.5]);
sound(audioIn,fs)
```

Increase the pitch by 4 semitones and apply phase locking. Listen to the results. The resulting audio has a "chipmunk effect" that sounds unnatural.

```
nsemitones = 4  ;
lockPhase =  ;
audioOut = shiftPitch(audioIn,nsemitones, ...
    "LockPhase",lockPhase);

sound(audioOut,fs)
```

To increase fidelity, set PreserveFormants to true. Use the default cepstral order of 30. Listen to the result.

```
cepstralOrder = 30  ;
audioOut = shiftPitch(audioIn,nsemitones, ...
    "LockPhase",lockPhase, ...
    "PreserveFormants",true, ...
    "CepstralOrder",cepstralOrder);

sound(audioOut,fs)
```

Input Arguments

audioIn — Input signal

column vector | matrix | 3-D array

Input signal, specified as a column vector, matrix, or 3-D array. How the function interprets `audioIn` depends on the complexity of `audioIn`:

- If `audioIn` is real, `audioIn` is interpreted as a time-domain signal. In this case, `audioIn` must be a column vector or matrix. Columns are interpreted as individual channels.
- If `audioIn` is complex, `audioIn` is interpreted as a frequency-domain signal. In this case, `audioIn` must be an L -by- M -by- N array, where L is the FFT length, M is the number of individual spectra, and N is the number of channels.

Data Types: `single` | `double`

Complex Number Support: Yes

nsemitones — Number of semitones to shift audio by

real scalar

Number of semitones to shift the audio by, specified as a real scalar.

The range of `nsemitones` depends on the window length (`numel(Window)`) and the overlap length (`OverlapLength`):

$$-12*\log_2(\text{numel}(\text{Window})-\text{OverlapLength}) \leq \text{nsemitones} \leq -12*\log_2((\text{numel}(\text{Window})-\text{OverlapLength})/\text{numel}(\text{Window}))$$

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'Window', kbdwin(512)`

Window — Window applied in time domain

`sqrt(hann(1024, 'periodic'))` (default) | real vector

Window applied in the time domain, specified as the comma-separated pair consisting of `'Window'` and a real vector. The number of elements in the vector must be in the range `[1, size(audioIn,1)]`. The number of elements in the vector must also be greater than `OverlapLength`.

Note If using `shiftPitch` with frequency-domain input, you must specify `Window` as the same window used to transform `audioIn` to the frequency domain.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(0.75*numel(Window))` (default) | scalar in the range `[0, numel(Window))`

Number of samples overlapped between adjacent windows, specified as the comma-separated pair consisting of `'OverlapLength'` and an integer in the range `[0, numel(Window))`.

Note If using `shiftPitch` with frequency-domain input, you must specify `OverlapLength` as the same overlap length used to transform `audioIn` to a time-frequency representation.

Data Types: `single` | `double`

LockPhase — Apply identity phase locking

`false` (default) | `true`

Apply identity phase locking, specified as the comma-separated pair consisting of `'LockPhase'` and `false` or `true`.

Data Types: `logical`

PreserveFormants — Preserve formants

`false` (default) | `true`

Preserves formants, specified as the comma-separated pair consisting of 'PreserveFormants' and true or false. Formant preservation is attempted using spectral envelope estimation with cepstral analysis.

Data Types: logical

CepstralOrder — Cepstral order used for formant preservation

30 (default) | nonnegative integer

Cepstral order used for formant preservation, specified as the comma-separated pair consisting of 'CepstralOrder' and a nonnegative integer.

Dependencies

To enable this name-value pair argument, set PreserveFormants to true.

Data Types: single | double

Output Arguments

audioOut — Pitch-shifted audio

column vector | matrix

Pitch-shifted audio, returned as a column vector or matrix of independent channels.

Algorithms

To apply pitch shifting, `shiftPitch` modifies the time-scale of audio using a phase vocoder and then resamples the modified audio. The time scale modification algorithm is based on [1] and [2] and is implemented as in `stretchAudio`.

After time-scale modification, `shiftPitch` performs sample rate conversion using an interpolation factor equal to the analysis hop length and a decimation factor equal to the synthesis hop length. The interpolation and decimation factors of the resampling stage are selected as follows: The analysis hop length is determined as $\text{analysisHopLength} = \text{numel}(\text{Window}) - \text{OverlapLength}$. The `shiftPitch` function assumes that there are 12 semitones in an octave, so the speedup factor used to stretch the audio is $\text{speedupFactor} = 2^{(-\text{nsemitones}/12)}$. The speedup factor and analysis hop length determine the synthesis hop length for time-scale modification as $\text{synthesisHopLength} = \text{round}((1/\text{SpeedupFactor}) * \text{analysisHopLength})$.

The achievable pitch shift is determined by the window length ($\text{numel}(\text{Window})$) and `OverlapLength`. To see the relationship, note that the equation for speedup factor can be rewritten as: $\text{nsemitones} = -12 * \log_2(\text{speedupFactor})$, and the equation for synthesis hop length can be rewritten as $\text{speedupFactor} = \text{analysisHopLength} / \text{synthesisHopLength}$. Using simple substitution, $\text{nsemitones} = -12 * \log_2(\text{analysisHopLength} / \text{synthesisHopLength})$. The practical range of a synthesis hop length is $[1, \text{numel}(\text{Window})]$. The range of achievable pitch shifts is:

- Max number of semitones lowered: $-12 * \log_2(\text{numel}(\text{Window}) - \text{OverlapLength})$
- Max number of semitones raised: $-12 * \log_2((\text{numel}(\text{Window}) - \text{OverlapLength}) / \text{numel}(\text{Window}))$

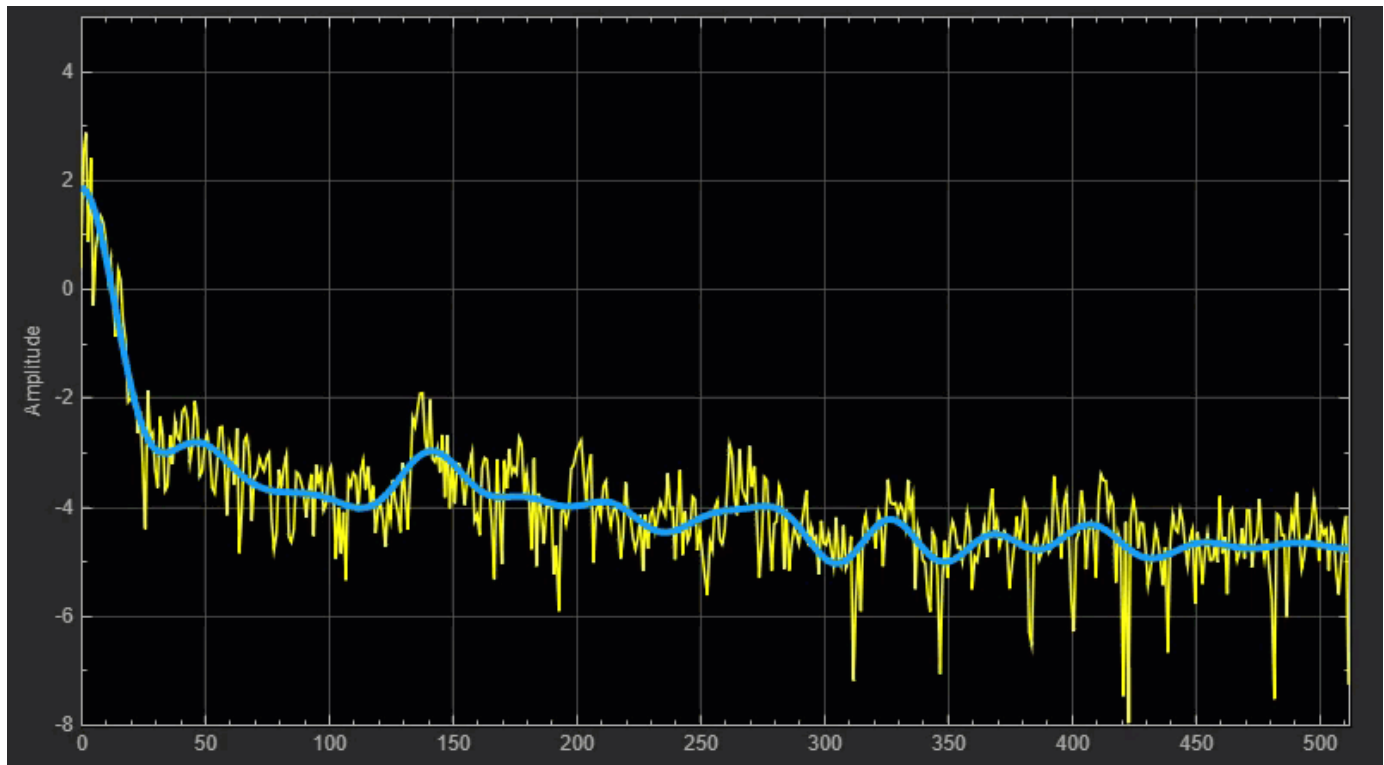
Formant Preservation

Pitch shifting can alter the spectral envelope of the pitch-shifted signal. To diminish this effect, you can set `PreserveFormants` to `true`. If `PreserveFormants` is set to `true`, the algorithm attempts to estimate the spectral envelope using an iterative procedure in the cepstral domain, as described in [3] and [4]. For both the original spectrum, X , and the pitch-shifted spectrum, Y , the algorithm estimates the spectral envelope as follows.

For the first iteration, $EnvX_a$ is set to X . Then, the algorithm repeats these two steps in a loop:

- 1 Lowpass filters the cepstral representation of $EnvX_a$ to get a new estimate, $EnvX_b$. The `CepstralOrder` parameter controls the quefrency bandwidth.
- 2 To update the current best fit, the algorithm takes the element-by-element maximum of the current spectral envelope estimate and the previous spectral envelope estimate:

$$EnvX_a = \max(EnvX_a, EnvX_b).$$



The loop ends if either a maximum number of iterations (`100`) is reached, or if all bins of the estimated log envelope are within a given tolerance of the original log spectrum. The tolerance is set to $\log(10^{(1/20)})$.

Finally, the algorithm scales the spectrum of the pitch-shifted audio by the ratio of estimated envelopes, element-wise:

$$Y = Y \times \left(\frac{EnvX_b}{EnvY_b} \right).$$

References

- [1] Driedger, Johnathan, and Meinard Müller. "A Review of Time-Scale Modification of Music Signals." *Applied Sciences*. Vol. 6, Issue 2, 2016.
- [2] Driedger, Johnathan. "Time-Scale Modification Algorithms for Music Audio Signals." Master's Thesis. Saarland University, Saarbrücken, Germany, 2011.
- [3] Axel Roebel, and Xavier Rodet. "Efficient Spectral Envelope Estimation and its application to pitch shifting and envelope preservation." International Conference on Digital Audio Effects, pp. 30-35. Madrid, Spain, September 2005. hal-01161334
- [4] S. Imai, and Y. Abe. "Spectral envelope extraction by improved cepstral method." *Electron. and Commun. in Japan*. Vol. 62-A, Issue 4, 1997, pp. 10-17.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

Usage notes and limitations:

- `LockPhase` must be set to `false`.
- Using `gpuArray` (Parallel Computing Toolbox) input with `shiftPitch` is only recommended for a GPU with compute capability 7.0 ("Volta") or above. Other hardware might not offer any performance advantage. To check your GPU compute capability, see `ComputeCapability` in the output from the `gpuDevice` (Parallel Computing Toolbox) function. For more information, see "GPU Support by Release" (Parallel Computing Toolbox).

For an overview of GPU usage in MATLAB, see "Run MATLAB Functions on a GPU" (Parallel Computing Toolbox).

See Also

`stretchAudio` | `reverberator` | `audioTimeScaler` | `audioDataAugmenter`

Introduced in R2019b

designAuditoryFilterBank

Design auditory filter bank

Syntax

```
filterBank = designAuditoryFilterBank(fs)
filterBank = designAuditoryFilterBank(fs,Name,Value)
[filterBank,Fc,BW] = designAuditoryFilterBank( ___ )
```

Description

`filterBank = designAuditoryFilterBank(fs)` returns a frequency-domain auditory filter bank, `filterBank`.

`filterBank = designAuditoryFilterBank(fs,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

`[filterBank,Fc,BW] = designAuditoryFilterBank(___)` returns the center frequency and bandwidth of each filter in the filter bank. You can use this output syntax with any of the previous input syntaxes.

Examples

Create Default Auditory Filter Bank

Call `designAuditoryFilterBank` with a specified sample rate to design the default auditory filter bank.

```
fs = 44.1e3;
fb = designAuditoryFilterBank(fs);
```

The default filter bank consists of 32 triangular bandpass filters spaced evenly on the mel scale between 0 and $fs/2$ Hz.

```
numBands = size(fb,1)
```

```
numBands = 32
```

`designAuditoryFilterBank` is intended for frequency-domain filtering. By default, `designAuditoryFilterBank` assumes a 1024-point DFT and returns a half-sided frequency-domain filter bank with 513 points.

```
numPoints = size(fb,2)
```

```
numPoints = 513
```




Design Mel-Based Auditory Filter Bank

Read in audio and convert it to a one-sided power spectrum.

```
[audioIn,fs] = audioread("Laughter-16-8-mono-4secs.wav");

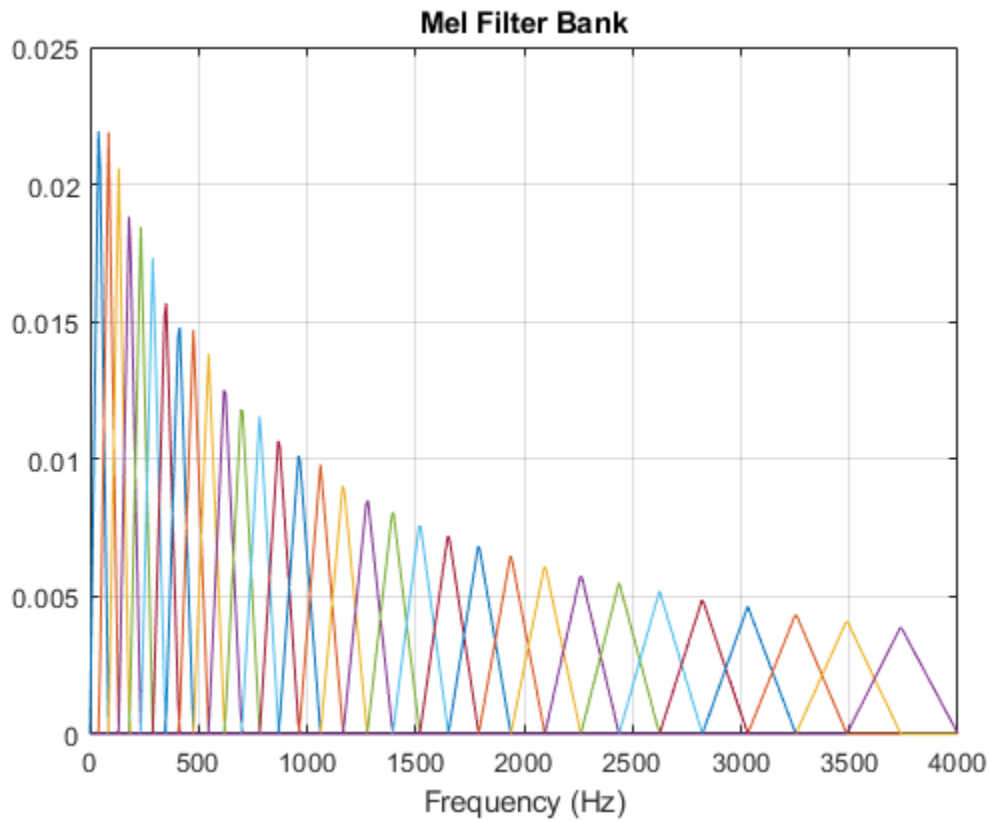
win = hamming(1024,"periodic");
noverlap = 512;
fftLength = 1024;
[S,F,t] = stft(audioIn,fs, ...
    "Window",win, ...
    "OverlapLength",noverlap, ...
    "FFTLength",fftLength, ...
    "FrequencyRange","onesided");
PowerSpectrum = S.*conj(S);
```

Design a mel-based auditory filter bank. Plot the filter bank.

```
numBands = 32  ;
range = [ 0  , 4000  ];
normalization =  ;

[fb,cf] = designAuditoryFilterBank(fs, ...
    "FFTLength",fftLength, ...
    "NumBands",numBands, ...
    "FrequencyRange",range, ...
    "Normalization",normalization);

plot(F,fb.')
grid on
title("Mel Filter Bank")
xlabel("Frequency (Hz)")
```



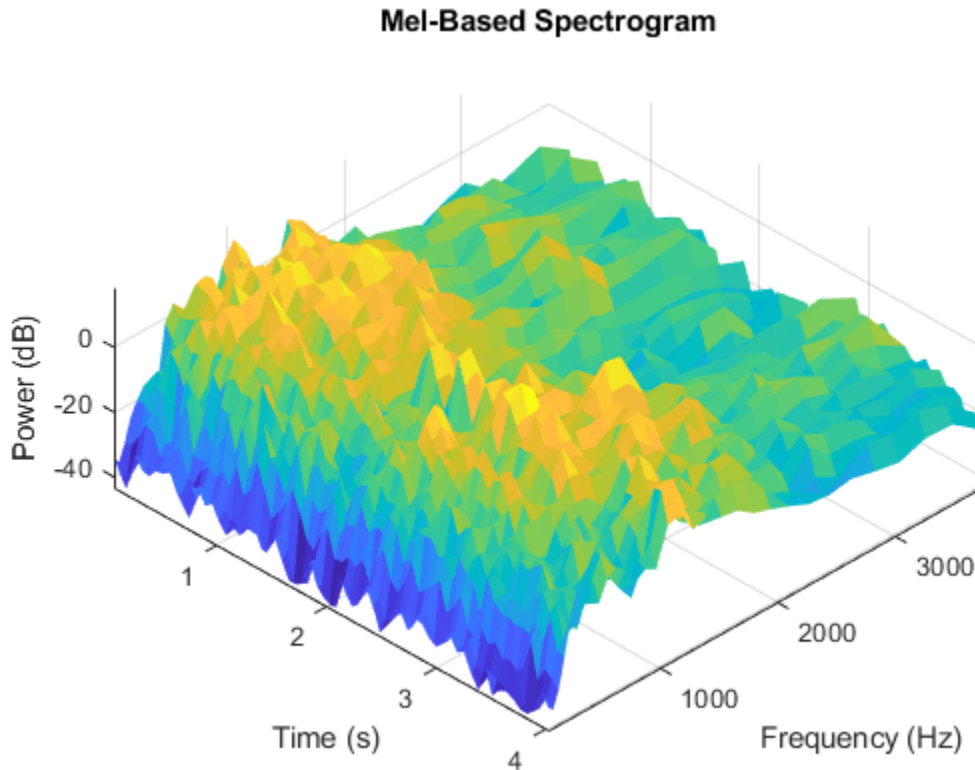
To apply frequency domain filtering, perform a matrix multiplication of the filter bank and the power spectrogram.

```
X = fb*PowerSpectrum;
```

Visualize the power-per-band in dB.

```
XdB = 10*log10(X);
```

```
surf(t,cf,XdB,"EdgeColor","none");  
xlabel("Time (s)")  
ylabel("Frequency (Hz)")  
zlabel("Power (dB)")  
view([45,60])  
title('Mel-Based Spectrogram')  
axis tight
```



Design Bark-Based Auditory Filter Bank

Read in audio and convert it to a one-sided power spectrum.

```
[audioIn,fs] = audioread("RockDrums-44p1-stereo-11secs.mp3");
```

```
win = hann(round(0.03*fs),"periodic");
noverlap = round(0.02*fs);
fftLength = 2048;
```

```
[S,F,t] = stft(audioIn,fs, ...
    "Window",win, ...
    "OverlapLength",noverlap, ...
    "FFTLength",fftLength, ...
    "FrequencyRange","onesided");
PowerSpectrum = S.*conj(S);
```

Design a Bark-based auditory filter bank. Plot the filter bank.

```
numBands = 32  ;
range = [ 0  , 22050  ];
normalization =  ;
```

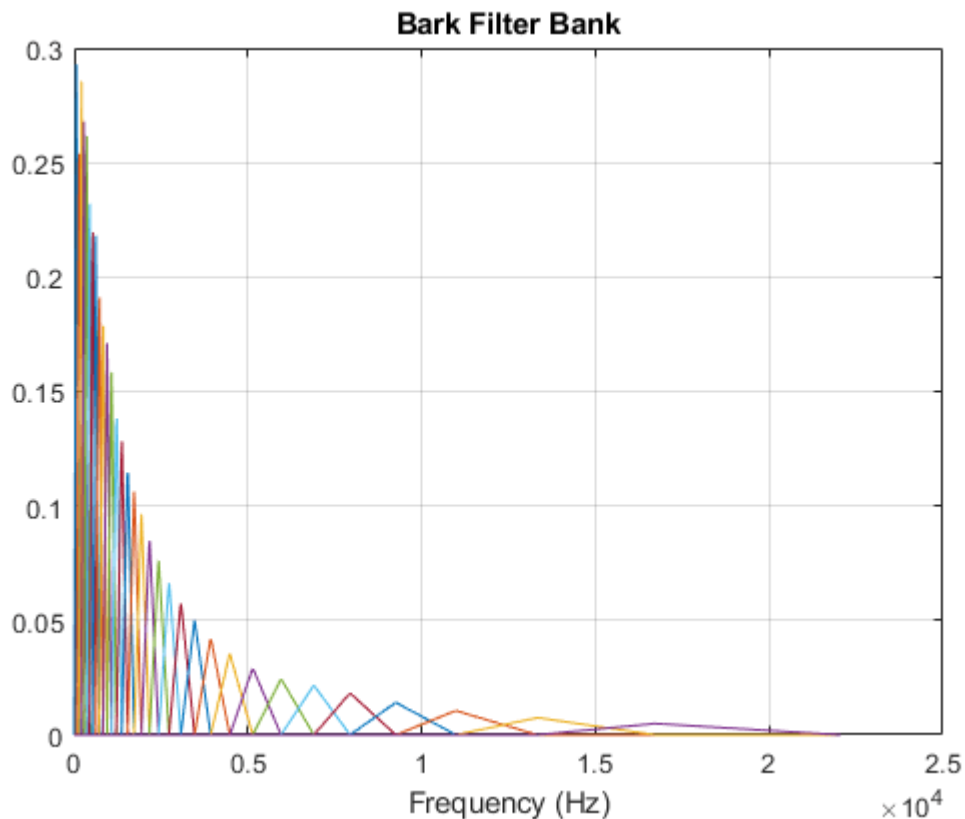
```

designDomain =  ;

[fb,cf] = designAuditoryFilterBank(fs, ...
    "FrequencyScale","bark", ...
    "FFTLength",fftLength, ...
    "NumBands",numBands, ...
    "FrequencyRange",range, ...
    "Normalization",normalization, ...
    "FilterBankDesignDomain",designDomain);

plot(F,fb. ');
grid on
title("Bark Filter Bank")
xlabel("Frequency (Hz)")

```



To apply frequency domain filtering, perform a matrix multiplication of the filter bank and the left and right power spectrograms.

```
X = pagetimes(fb,PowerSpectrum);
```

Visualize the power-per-band in dB.

```

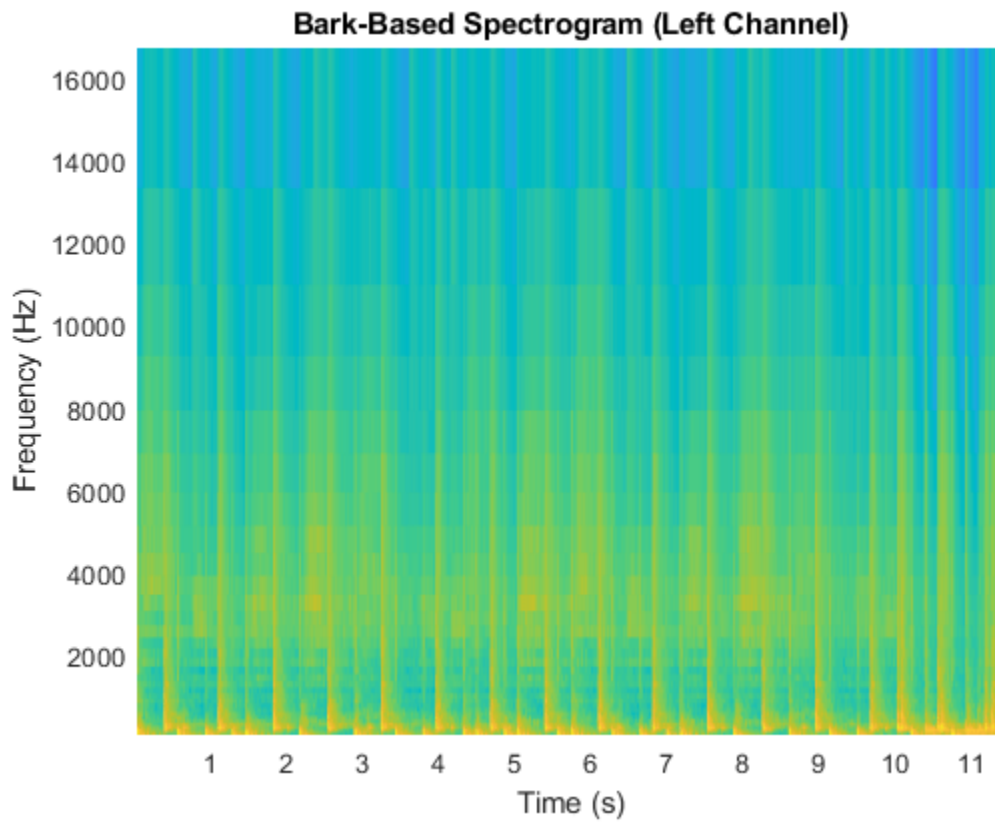
XLdB = 10*log10(X(:,:,1));
XRdB = 10*log10(X(:,:,2));

surf(t,cf,XLdB,"EdgeColor","none");
xlabel("Time (s)")

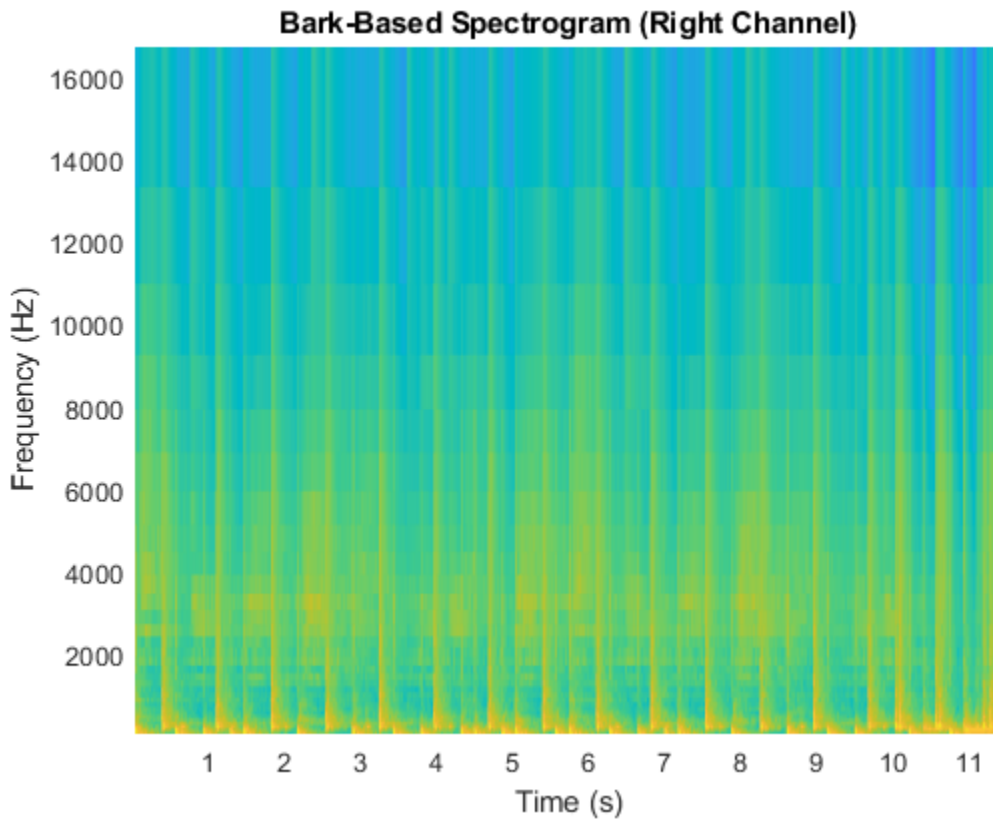
```



```
ylabel("Frequency (Hz)")  
view([0,90])  
title("Bark-Based Spectrogram (Left Channel)")  
axis tight
```



```
surf(t,cf,XRdB,"EdgeColor","none");  
xlabel("Time (s)")  
ylabel("Frequency (Hz)")  
view([0,90])  
title("Bark-Based Spectrogram (Right Channel)")  
axis tight
```



Design ERB-Based Auditory Filter Bank

Read in audio and convert it to a one-sided power spectrum.

```
[audioIn,fs] = audioread("NoisySpeech-16-22p5-mono-5secs.wav");

win = hann(round(0.04*fs),"periodic");
noverlap = round(0.02*fs);
fftLength = 1024;
```

```
[S,F,t] = stft(audioIn,fs, ...
    "Window",win, ...
    "OverlapLength",noverlap, ...
    "FFTLength",fftLength, ...
    "FrequencyRange","onesided");
PowerSpectrum = S.*conj(S);
```

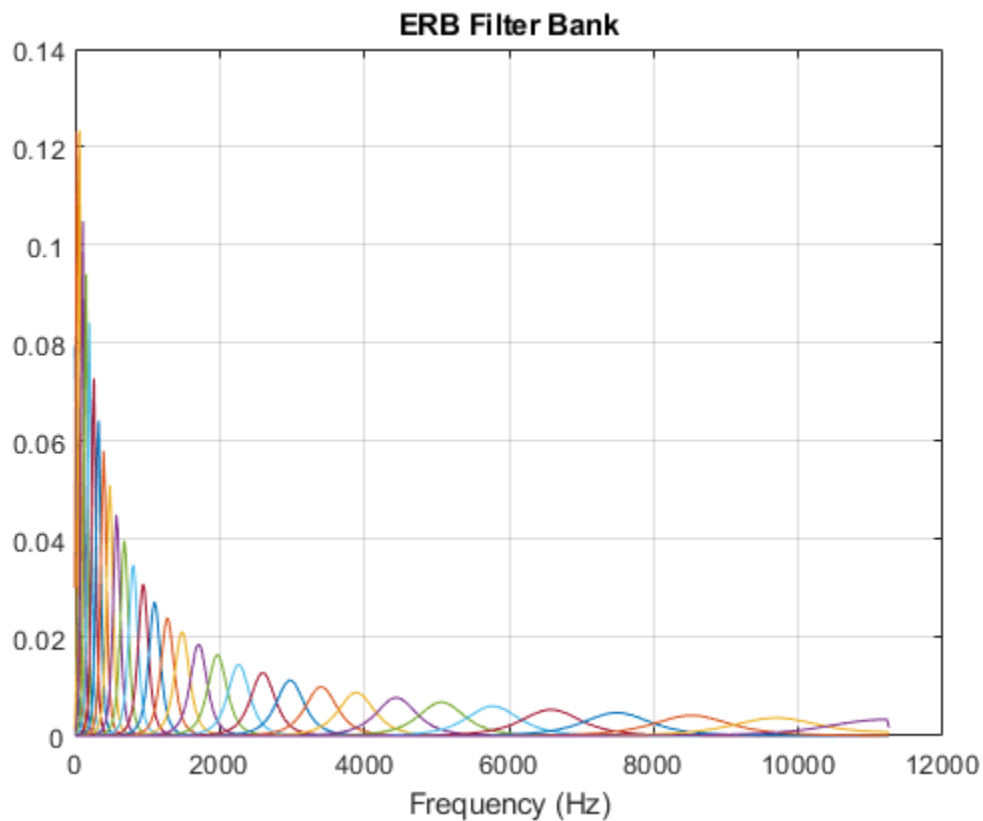
Design an ERB-based auditory filter bank. Plot the filter bank.

```
numBands = 32  ;
range = [  , 11025  ];
normalization =  ;
```

```
[fb,cf] = designAuditoryFilterBank(fs, ...
    "FrequencyScale","erb", ...
    "FFTLength",fftLength, ...
    "NumBands",numBands, ...
    "FrequencyRange",range, ...
    "Normalization",normalization);

plot(F,fb.');
```

```
grid on
title("ERB Filter Bank")
xlabel("Frequency (Hz)")
```

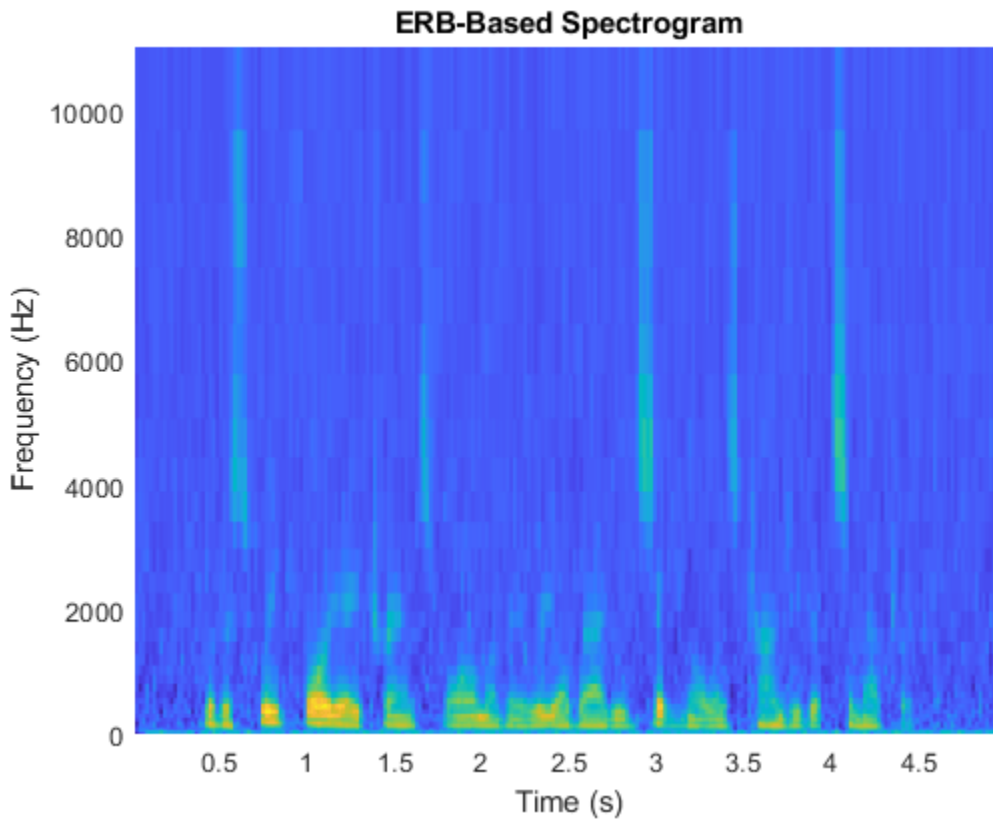


To apply frequency-domain filtering, perform a matrix multiplication of the filter bank and the power spectrogram.

```
X = fb*PowerSpectrum;
```

Visualize the power-per-band in dB.

```
XdB = 10*log10(X);
surf(t,cf,XdB,"EdgeColor","none");
xlabel("Time (s)")
ylabel("Frequency (Hz)")
view([0,90])
title("ERB-Based Spectrogram")
axis tight
```



Input Arguments

fs — Sample rate of filter design (Hz)

positive scalar

Sample rate of filter design in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `"FrequencyScale", "mel"`

FrequencyScale — Frequency scale

`"mel"` (default) | `"bark"` | `"erb"`

Frequency scale used to design the auditory filter bank, specified as the comma-separated pair consisting of `'FrequencyScale'` and `"mel"`, `"bark"`, or `"erb"`.

Data Types: `char` | `string`

FFTLength — Number of DFT points

1024 (default) | positive integer

Number of points used to calculate the DFT, specified as the comma-separated pair consisting of 'FFTLength' and a positive integer.

Data Types: single | double

NumBands — Number of bandpass filters

positive integer

Number of bandpass filters, specified as the comma-separated pair consisting of 'NumBands' and a positive integer. The default number of bandpass filters depends on the FrequencyScale:

- If FrequencyScale is set to "bark" or "mel", then NumBands defaults to 32.
- If FrequencyScale is set to "erb", then NumBands defaults to $\text{ceil}(\text{hz2erb}(\text{FrequencyRange}(2)) - \text{hz2erb}(\text{FrequencyRange}(1)))$.

Data Types: single | double

FrequencyRange — Frequency range over which to design auditory filter bank (Hz)

[0 fs/2] (default) | two-element row vector

Frequency range over which to design auditory filter bank in Hz, specified as the comma-separated pair consisting of 'FrequencyRange' and a two-element row vector of monotonically increasing values in the range [0, fs/2].

Data Types: single | double

Normalization — Normalize filter bank

"bandwidth" (default) | "area" | "none"

Normalization technique used on the weights of the filter bank:

- "bandwidth" -- The weights of each bandpass filter are normalized by the corresponding bandwidth of the filter.
- "area" -- The weights of each bandpass filter are normalized by the corresponding area of the bandpass filter.
- "none" -- The weights of the filters are not normalized.

Data Types: char | string

OneSided — Design one-sided or two-sided filter bank

true (default) | false

Design a one-sided or two-sided filter bank, specified as the comma-separated pair consisting of 'OneSided' and either true or false.

Data Types: logical

FilterBankDesignDomain — Domain in which filter bank is designed

"linear" (default) | "warped"

Domain in which filter bank is designed, specified as the comma-separated pair consisting of 'FilterBankDesignDomain' and either "linear" or "warped". Set the filter bank design domain

to "linear" to design the bandpass filters in the linear (Hz) domain. Set the filter bank design domain to "warped" to design the bandpass filters in the warped (mel or Bark) domain.

Dependencies

This parameter only applies if `FrequencyScale` is set to "mel" (default) or "bark".

Data Types: char | string

Output Arguments**filterBank — Auditory filter bank**

column vector | matrix

Auditory filter bank, returned as an M -by- N matrix, where M is the number of bands (`NumBands`), and N is the number of frequency points of a one-sided spectrum (`ceil(FFTLength/2)`).

Data Types: double

Fc — Center frequencies of bandpass filters (Hz)

row vector

Center frequencies of bandpass filters in Hz, returned as a row vector with `NumBands` elements.

Data Types: double

BW — Bandwidth of bandpass filters (Hz)

row vector

Bandwidth of bandpass filters in Hz, returned as a row vector with `NumBands` elements.

Data Types: double

Algorithms

The mel filter bank is designed as half-overlapped triangles equally spaced on the mel scale. [1]

The Bark filter bank is designed as half-overlapped triangles equally spaced on the Bark scale. [2]

The ERB filter bank is designed as gammatone filters [4] whose center frequencies are equally spaced on the ERB scale. [3]

Compatibility Considerations**designAuditoryFilterBank scaling changed for ERB filter banks**

Behavior changed in R2020b

The half-sided ERB filter bank returned from `designAuditoryFilterBank` is now scaled by 2. This change provides consistent results when applying one-sided or two-sided filtering, without requiring multiplications in the processing loop.

References

- [1] O'Shaughnessy, Douglas. *Speech Communication: Human and Machine*. Reading, MA: Addison-Wesley Publishing Company, 1987.

- [2] Traunmüller, Hartmut. "Analytical Expressions for the Tonotopic Sensory Scale." *Journal of the Acoustical Society of America*. Vol. 88, Issue 1, 1990, pp. 97-100.
- [3] Glasberg, Brian R., and Brian C. J. Moore. "Derivation of Auditory Filter Shapes from Notched-Noise Data." *Hearing Research*. Vol. 47, Issues 1-2, 1990, pp. 103-138.
- [4] Slaney, Malcolm. "An Efficient Implementation of the Patterson-Holdsworth Auditory Filter Bank." Apple Computer Technical Report 35, 1993.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

gammatoneFilterBank | melSpectrogram | hz2mel | hz2bark | hz2erb | erb2hz | bark2hz | mel2hz

Introduced in R2019b

melSpectrogram

Mel spectrogram

Syntax

```
S = melSpectrogram(audioIn,fs)
S = melSpectrogram(audioIn,fs,Name,Value)
[S,F,T] = melSpectrogram( ___ )
melSpectrogram( ___ )
```

Description

`S = melSpectrogram(audioIn,fs)` returns the mel spectrogram of the audio input at sample rate `fs`. The function treats columns of the input as individual channels.

`S = melSpectrogram(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

`[S,F,T] = melSpectrogram(___)` returns the center frequencies of the bands in Hz and the location of each window of data in seconds. The location corresponds to the center of each window. You can use this output syntax with any of the previous input syntaxes.

`melSpectrogram(___)` plots the mel spectrogram on a surface in the current figure.

Examples

Calculate Mel Spectrogram

Use the default settings to calculate the mel spectrogram for an entire audio file. Print the number of bandpass filters in the filter bank and the number of frames in the mel spectrogram.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
S = melSpectrogram(audioIn,fs);
[numBands,numFrames] = size(S);
fprintf("Number of bandpass filters in filterbank: %d\n",numBands)
```

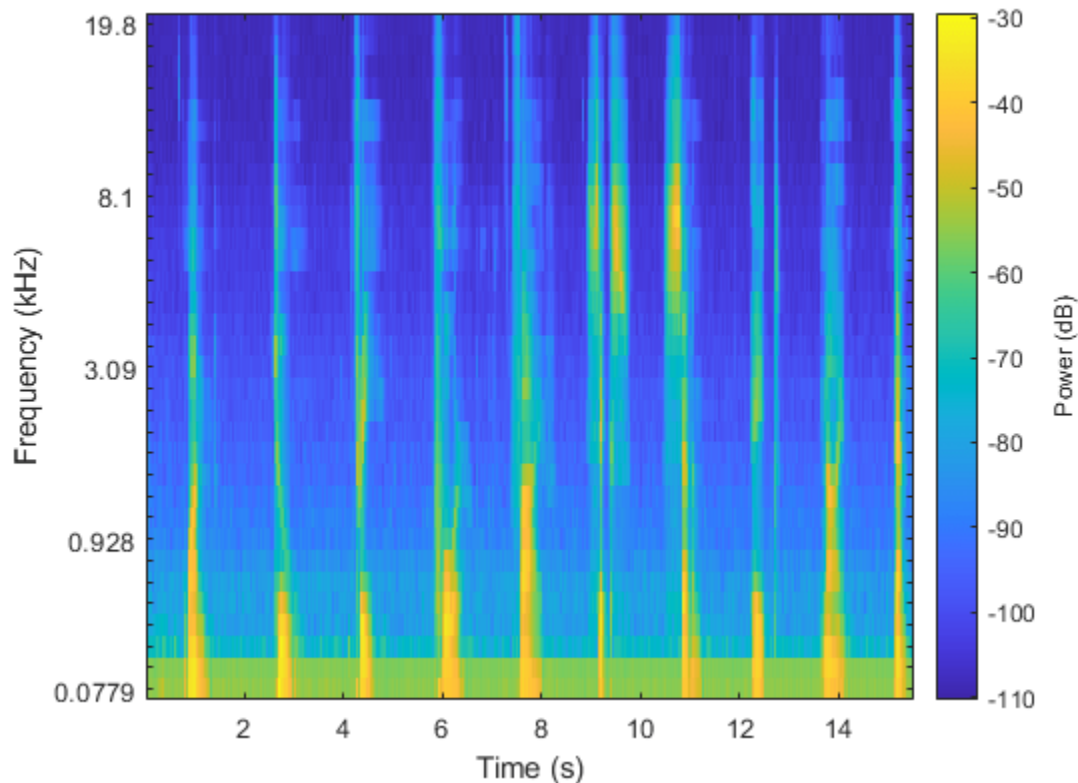
```
Number of bandpass filters in filterbank: 32
```

```
fprintf("Number of frames in spectrogram: %d\n",numFrames)
```

```
Number of frames in spectrogram: 1551
```

Plot the mel spectrogram.

```
melSpectrogram(audioIn,fs)
```

Calculate Mel Spectrums of 2048-Point Windows

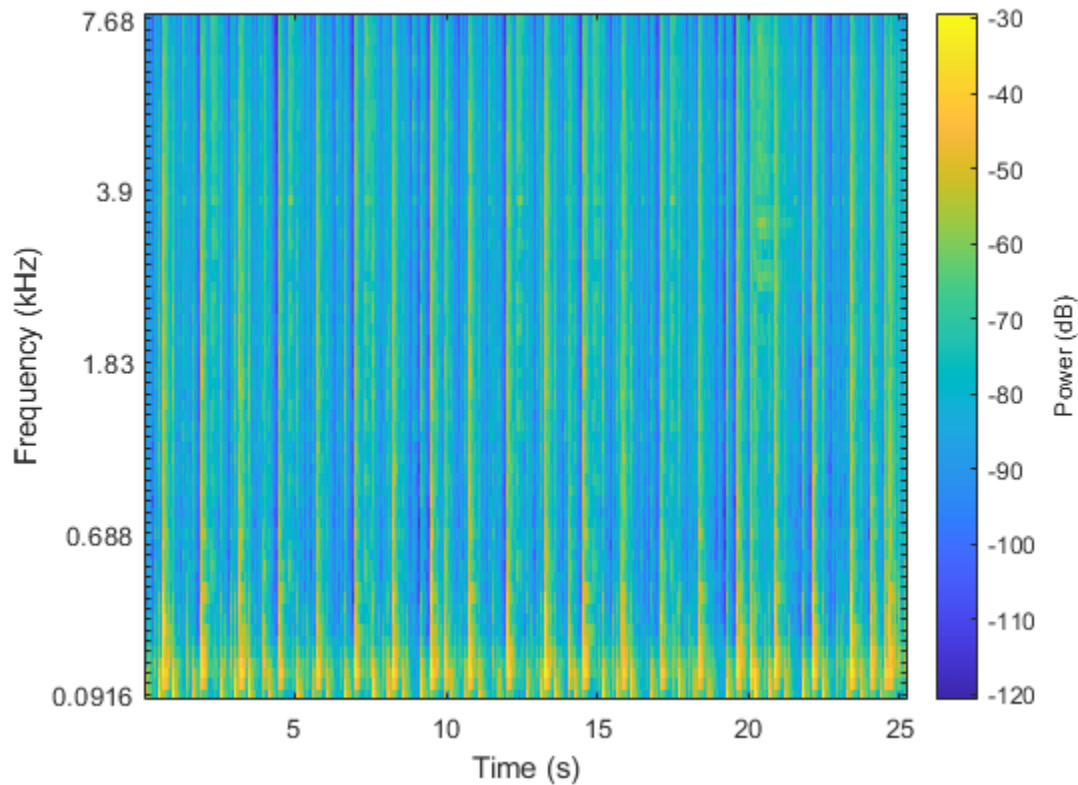
Calculate the mel spectrums of 2048-point periodic Hann windows with 1024-point overlap. Convert to the frequency domain using a 4096-point FFT. Pass the frequency-domain representation through 64 half-overlapped triangular bandpass filters that span the range 62.5 Hz to 8 kHz.

```
[audioIn,fs] = audioread('FunkyDrums-44p1-stereo-25secs.mp3');
```

```
S = melSpectrogram(audioIn,fs, ...
    'Window',hann(2048,'periodic'), ...
    'OverlapLength',1024, ...
    'FFTLength',4096, ...
    'NumBands',64, ...
    'FrequencyRange',[62.5,8e3]);
```

Call `melSpectrogram` again, this time with no output arguments so that you can visualize the mel spectrogram. The input audio is a multichannel signal. If you call `melSpectrogram` with a multichannel input and with no output arguments, only the first channel is plotted.

```
melSpectrogram(audioIn,fs, ...
    'Window',hann(2048,'periodic'), ...
    'OverlapLength',1024, ...
    'FFTLength',4096, ...
    'NumBands',64, ...
    'FrequencyRange',[62.5,8e3])
```

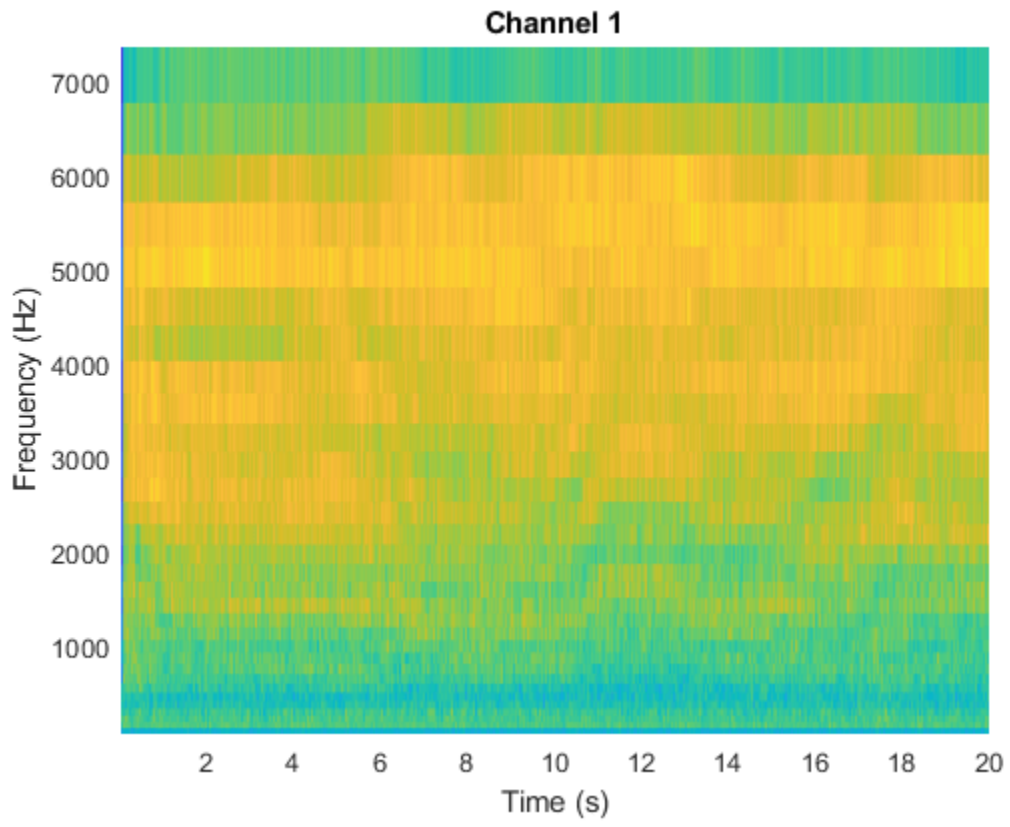


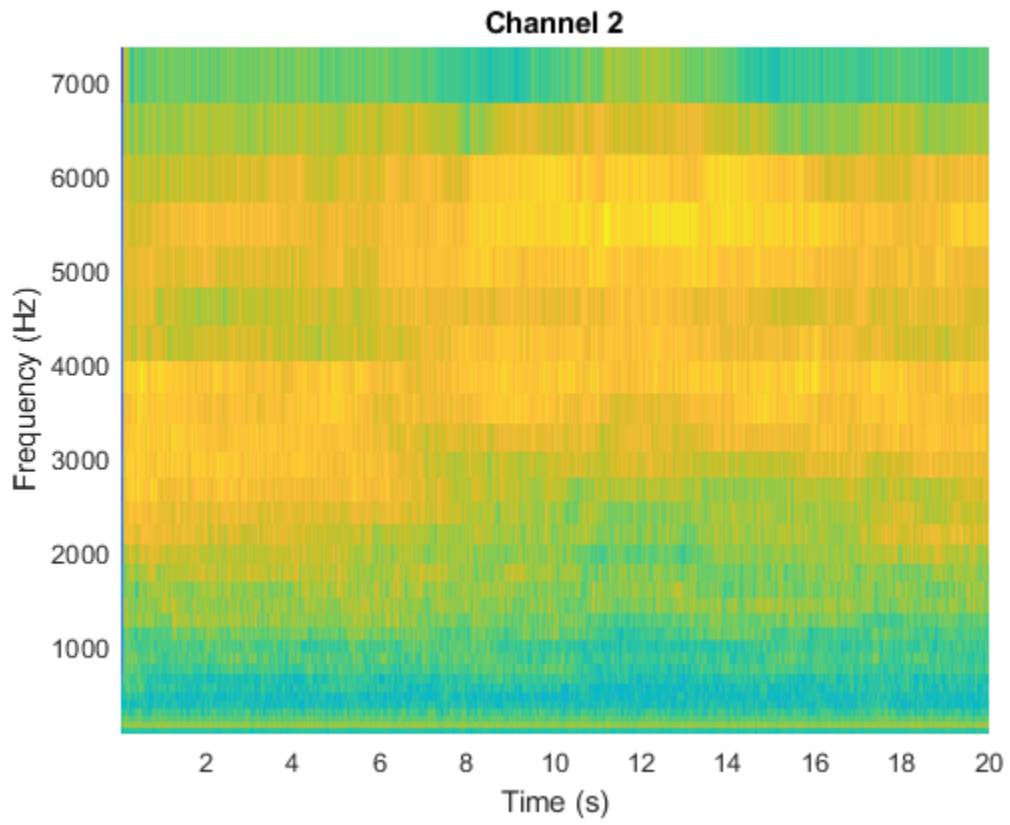
Get Filter Bank Center Frequencies and Analysis Window Time Instants

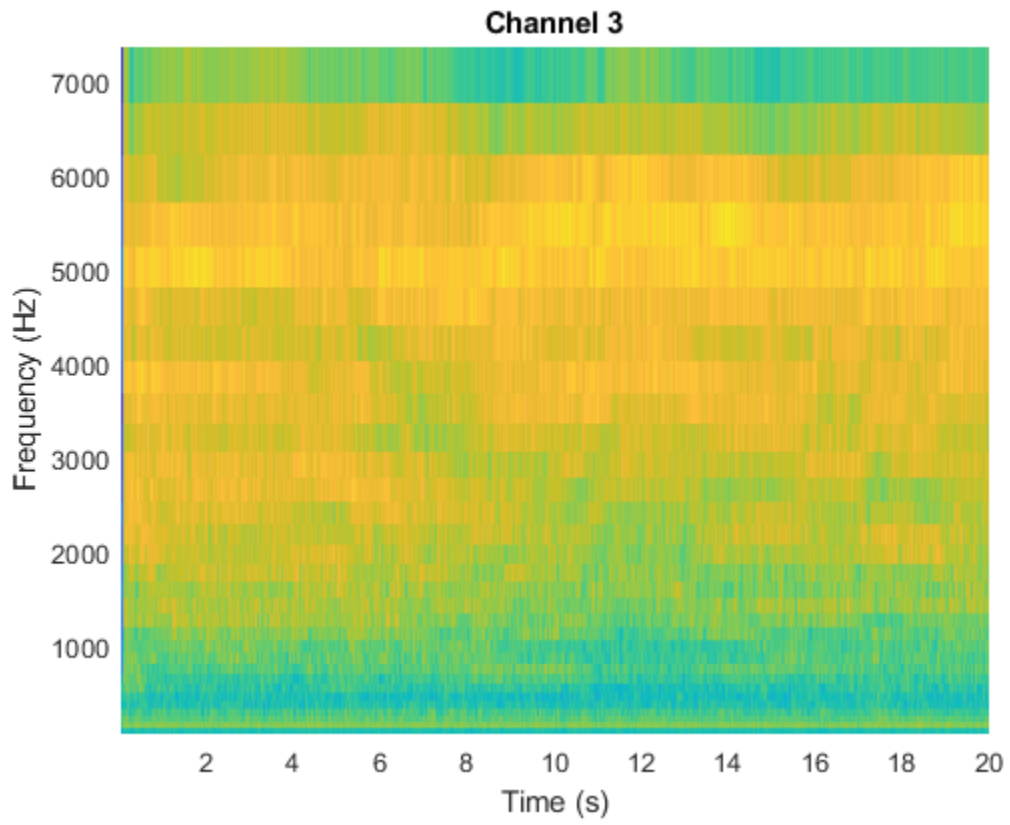
`melSpectrogram` applies a frequency-domain filter bank to audio signals that are windowed in time. You can get the center frequencies of the filters and the time instants corresponding to the analysis windows as the second and third output arguments from `melSpectrogram`.

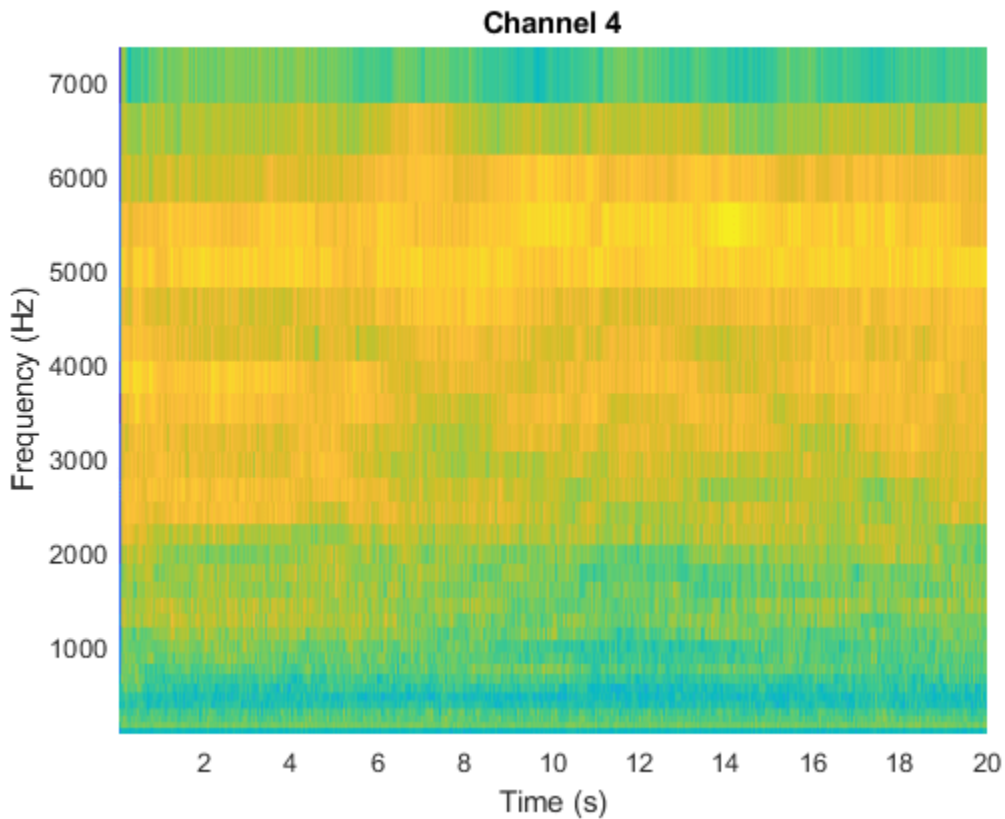
Get the mel spectrogram, filter bank center frequencies, and analysis window time instants of a multichannel audio signal. Use the center frequencies and time instants to plot the mel spectrogram for each channel.

```
[audioIn,fs] = audioread('AudioArray-16-16-4channels-20secs.wav');
[S,cF,t] = melSpectrogram(audioIn,fs);
S = 10*log10(S+eps); % Convert to dB for plotting
for i = 1:size(S,3)
    figure(i)
    surf(t,cF,S(:,:,i),'EdgeColor','none');
    xlabel('Time (s)')
    ylabel('Frequency (Hz)')
    view([0,90])
    title(sprintf('Channel %d',i))
    axis([t(1) t(end) cF(1) cF(end)])
end
```









Input Arguments

audioIn — Audio input

column vector | matrix

Audio input, specified as a column vector or matrix. If specified as a matrix, the function treats columns as independent audio channels.

Data Types: `single` | `double`

fs — Input sample rate (Hz)

positive scalar

Input sample rate in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'WindowLength',1024`

Window — Window applied in time domain

hamming(round(fs*0.3), 'periodic') (default) | vector

Window applied in time domain, specified as the comma-separated pair consisting of 'Window' and a real vector. The number of elements in the vector must be in the range [1, size(audioIn, 1)]. The number of elements in the vector must also be greater than OverlapLength.

Data Types: single | double

OverlapLength — Analysis window overlap length (samples)

round(0.02*fs) (default) | integer in the range [0, (WindowLength - 1)]

Analysis window overlap length in samples, specified as the comma-separated pair consisting of 'OverlapLength' and an integer in the range [0, (WindowLength - 1)].

Data Types: single | double

FFTLength — Number of DFT points

WindowLength (default) | positive integer

Number of points used to calculate the DFT, specified as the comma-separated pair consisting of 'FFTLength' and a positive integer greater than or equal to WindowLength. If unspecified, FFTLength defaults to WindowLength.

Data Types: single | double

NumBands — Number of mel bandpass filters

32 (default) | positive integer

Number of mel bandpass filters, specified as the comma-separated pair consisting of 'NumBands' and a positive integer.

Data Types: single | double

FrequencyRange — Frequency range over which to compute mel spectrogram (Hz)

[0 fs/2] (default) | two-element row vector

Frequency range over which to compute the mel spectrogram in Hz, specified as the comma-separated pair consisting of 'FrequencyRange' and a two-element row vector of monotonically increasing values in the range [0, fs/2].

Data Types: single | double

SpectrumType — Type of mel spectrogram

'power' (default) | 'magnitude'

Type of mel spectrogram, specified as the comma-separated pair consisting of 'SpectrumType' and 'power' or 'magnitude'.

Data Types: char | string

WindowNormalization — Apply window normalization

true (default) | false

Apply window normalization, specified as the comma-separated pair consisting of 'WindowNormalization' and true or false. When WindowNormalization is set to true, the power (or magnitude) in the mel spectrogram is normalized to remove the power (or magnitude) of the time domain Window.

Data Types: char | string

FilterBankNormalization — Type of filter bank normalization

'bandwidth' (default) | 'area' | 'none'

Type of filter bank normalization, specified as the comma-separated pair consisting of 'FilterBankNormalization' and 'bandwidth', 'area', or 'none'.

Data Types: char | string

Output Arguments

S — Mel spectrogram

column vector | matrix | 3-D array

Mel spectrogram, returned as a column vector, matrix, or 3-D array. The dimensions of *S* are *L*-by-*M*-by-*N*, where:

- *L* is the number of frequency bins in each mel spectrum. NumBands and fs determine *L*.
- *M* is the number of frames the audio signal is partitioned into. size(audioIn,1), WindowLength, and OverlapLength determine *M*.
- *N* is the number of channels such that $N = \text{size}(\text{audioIn},2)$.

Trailing singleton dimensions are removed from the output *S*.

Data Types: single | double

F — Center frequencies of mel bandpass filters (Hz)

row vector

Center frequencies of mel bandpass filters in Hz, returned as a row vector with length size(*S*,1).

Data Types: single | double

T — Location of each window of audio (s)

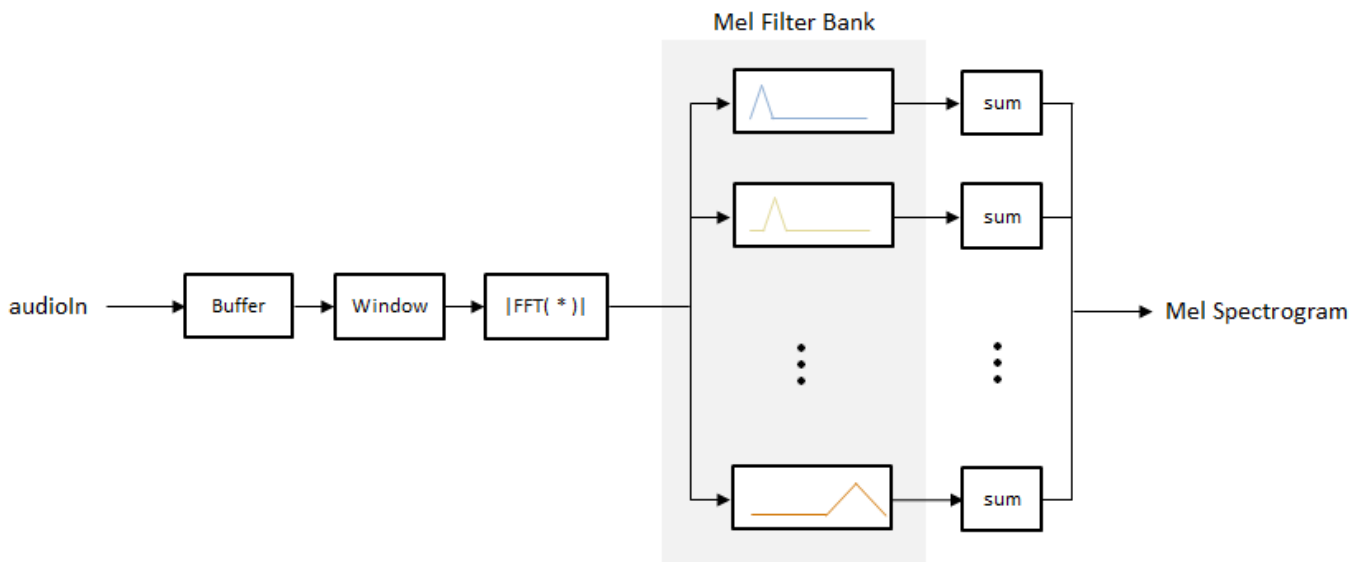
row vector

Location of each analysis window of audio in seconds, returned as a row vector length size(*S*,2). The location corresponds to the center of each window.

Data Types: single | double

Algorithms

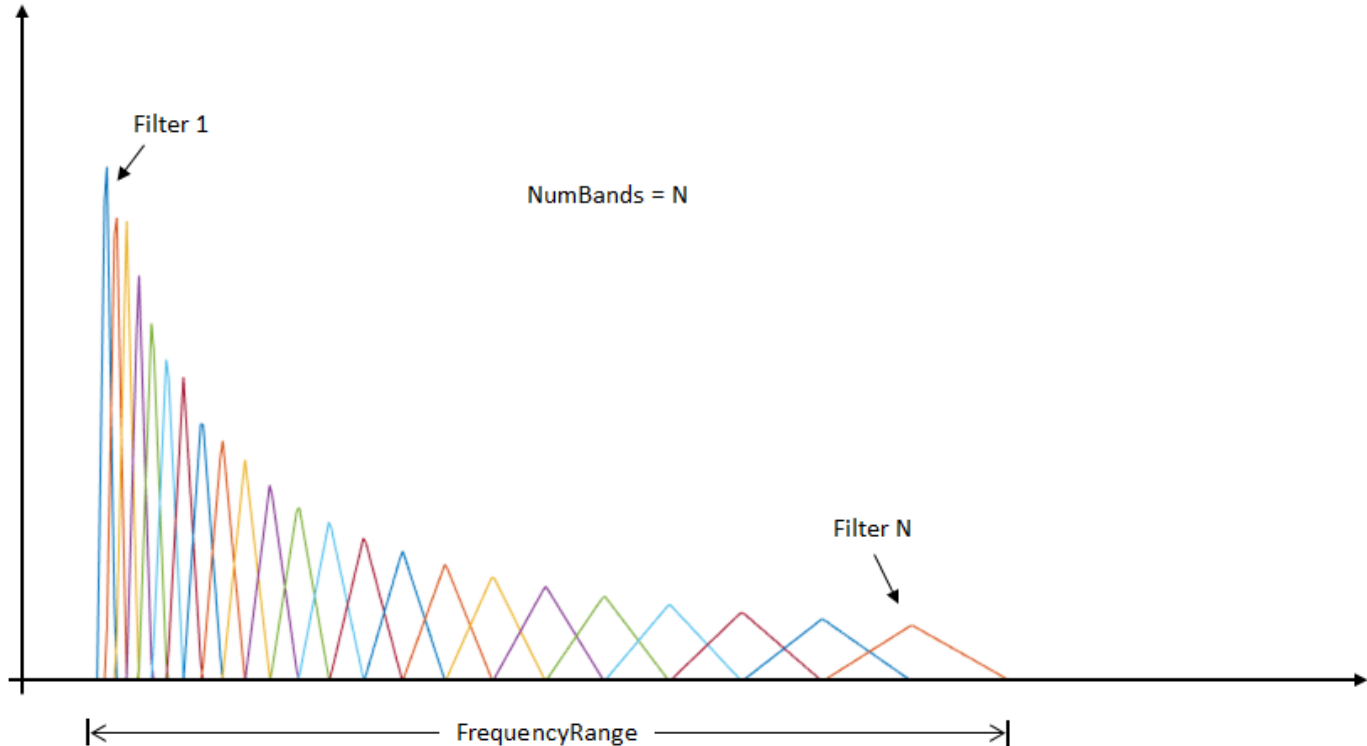
The melSpectrogram function follows the general algorithm to compute a mel spectrogram as described in [1].



In this algorithm, the audio input is first buffered into frames of `numel(Window)` number of samples. The frames are overlapped by `OverlapLength` number of samples. The specified `Window` is applied to each frame, and then the frame is converted to frequency-domain representation with `FFTLenght` number of points. The frequency-domain representation can be either magnitude or power, specified by `SpectrumType`. If `WindowNormalization` is set to `true`, the spectrum is normalized by the window. Each frame of the frequency-domain representation passes through a mel filter bank. The spectral values output from the mel filter bank are summed, and then the channels are concatenated so that each frame is transformed to a `NumBands`-element column vector.

Filter Bank Design

The mel filter bank is designed as half-overlapped triangular filters equally spaced on the mel scale. `NumBands` controls the number of mel bandpass filters. `FrequencyRange` controls the band edges of the first and last filters in the mel filter bank. `FilterBankNormalization` specifies the type of normalization applied to the individual bands.



Compatibility Considerations

WindowLength will be removed in a future release

Behavior change in future release

The `WindowLength` parameter will be removed from the `melSpectrogram` function in a future release. Use the `Window` parameter instead.

In releases prior to R2020b, you could only specify the length of a time-domain window. The window was always designed as a periodic Hamming window. You can replace instances of the code

```
S = melSpectrogram(audioIn, fs, 'WindowLength', 1024);
```

With this code:

```
S = melSpectrogram(audioIn, fs, 'Window', hamming(1024, 'periodic'));
```

References

- [1] Rabiner, Lawrence R., and Ronald W. Schafer. *Theory and Applications of Digital Speech Processing*. Upper Saddle River, NJ: Pearson, 2010.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

[spectrogram](#) | [mfcc](#) | [gtcc](#) | [mdct](#) | [audioFeatureExtractor](#)

Topics

“Speech Command Recognition Using Deep Learning”

Introduced in R2019a

kbdwin

Kaiser-Bessel-derived window

Syntax

```
wdw = kbdwin(N)  
wdw = kbdwin(N,Beta)
```

Description

`wdw = kbdwin(N)` returns an N-point Kaiser-Bessel-derived (KBD) window.

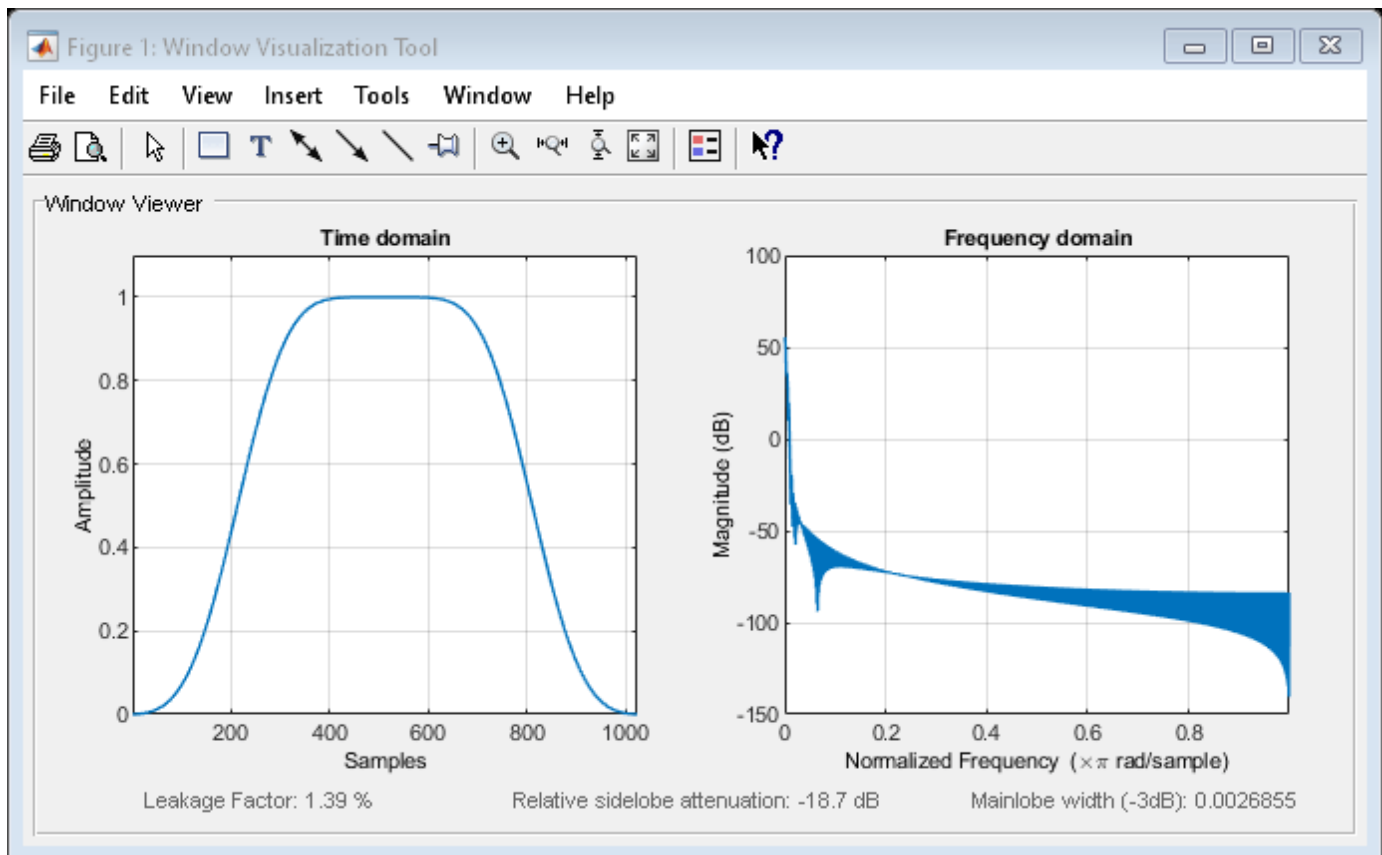
`wdw = kbdwin(N,Beta)` specifies the tuning parameter, `Beta`.

Examples

Create Kaiser-Bessel-Derived Window

Create a 1024-point Kaiser-Bessel-derived (KBD) window. Visualize the KBD window in the time and frequency domains using `wvtool`.

```
wdw = kbdwin(1024);  
wvtool(wdw)
```

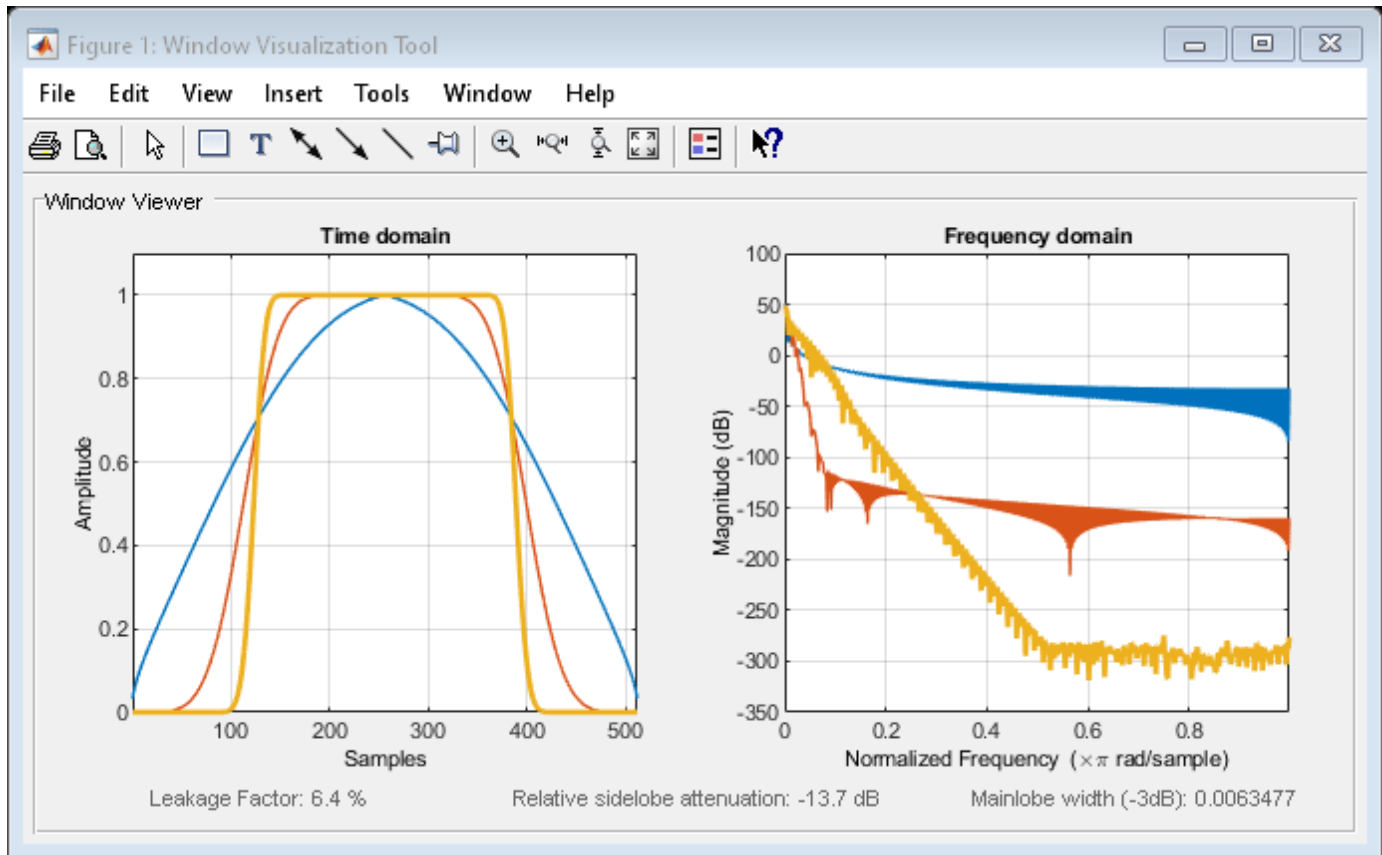


Effect of Tuning Parameter Beta

Create three 512-point KBD windows, with Beta set to 1, 10, and 100. Display the windows for comparison using `wvtool`.

```
N = 512;
beta1 = kbdwin(N,1);
beta10 = kbdwin(N,10);
beta100 = kbdwin(N,100);

wvtool(beta1,beta10,beta100)
```



Input Arguments

N — Number of points in KBD window

even positive integer scalar

Number of points in the KBD window, specified as an even positive integer scalar.

Data Types: single | double

Beta — Tuning parameter

5 (default) | nonnegative real scalar

Tuning parameter, specified as a nonnegative real scalar. If unspecified, Beta defaults to 5.

Data Types: single | double

Output Arguments

wdw — Kaiser-Bessel-derived window

N-point column vector

Kaiser-Bessel-derived window, returned as an N-point column vector.

Algorithms

The coefficients of a Kaiser-Bessel-derived window are computed using the equation:

$$wdw[n] = \begin{cases} \sqrt{\frac{\sum_{i=1}^n w[i]}{\sum_{i=1}^{N/2+1} w[i]}} & \text{if } 1 \leq n < (N/2) \\ \sqrt{\frac{\sum_{i=1}^{N-n} w[i]}{\sum_{i=1}^{N/2+1} w[i]}} & \text{if } (N/2 + 1) \leq n < N \end{cases}$$

where w is a Kaiser window designed using the kaiser function:

```
w = kaiser(N/2+1, Beta*pi)
```

where N is the number of points in the KBD window and $Beta$ is the tuning parameter.

References

- [1] Bosi, Marina, and Richard E. Goldberg. *Introduction to Digital Audio Coding and Standards*. Dordrecht: Kluwer, 2003.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

kaiser | window | mdct

Introduced in R2019a

mdct

Modified discrete cosine transform

Syntax

```
Y = mdct(X,win)
Y = mdct(X,win,Name,Value)
[Y,S,Z] = mdct( ___ )
```

Description

`Y = mdct(X,win)` returns the modified discrete cosine transform (MDCT) of `X`. Before the MDCT is calculated, `X` is buffered into 50% overlapping frames that are each multiplied by the time window `win`. The function treats each column of `X` as an independent channel.

`Y = mdct(X,win,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

`[Y,S,Z] = mdct(___)` returns the modified discrete sine transform (MDST), `S`, and the odd discrete Fourier transform (ODFT), `Z`.

Examples

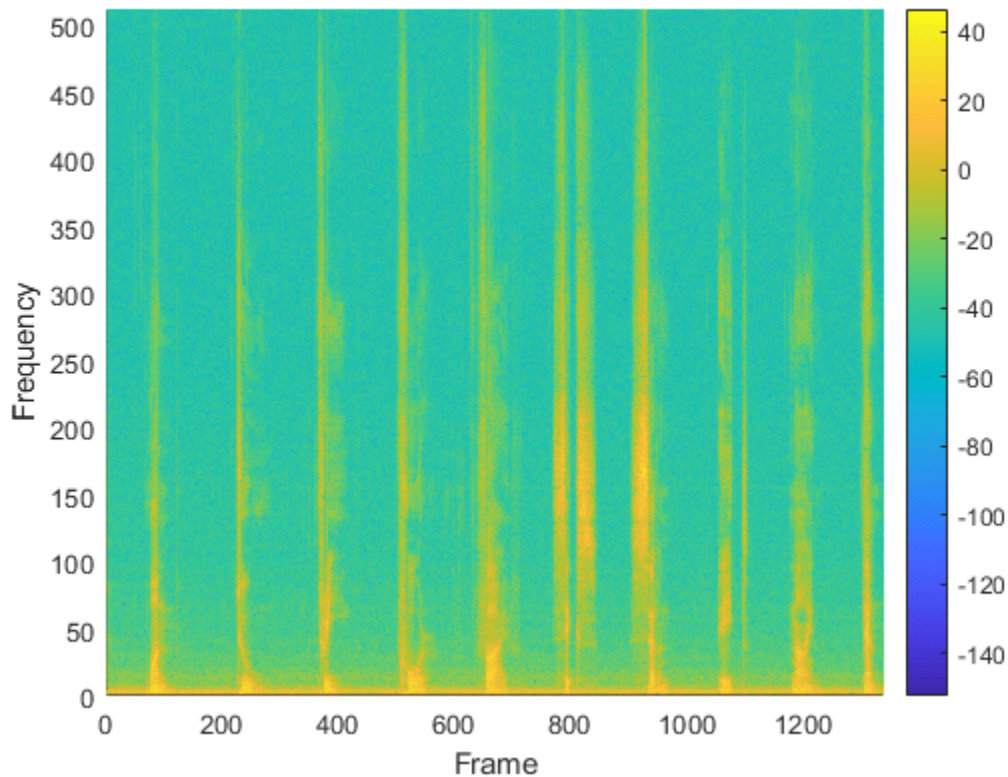
Calculate MDCT

Read in an audio file and then calculate the MDCT using a 1024-point Kaiser-Bessel-derived window.

```
audioIn = audioread('Counting-16-44p1-mono-15secs.wav');
coef = mdct(audioIn,kbdwin(1024));
```

Plot the power of the MDCT coefficients over time.

```
surf(pow2db(coef.^2), 'EdgeColor', 'none');
view([0 90])
xlabel('Frame')
ylabel('Frequency')
axis([0 size(coef,2) 0 size(coef,1)])
colorbar
```

Effect of Input Padding on Perfect Reconstruction

To enable perfect reconstruction, the `mdct` function zero-pads the front and back of the audio input signal. The signal returned from `imdct` removes the zero padding added for perfect reconstruction.

Read in an audio file, create a 2048-point Kaiser-Bessel-derived window, and then clip the audio signal so that its length is a multiple of 2048.

```
[x,fs] = audioread('Click-16-44p1-mono-0.2secs.wav');
win = kbdwin(2048);
```

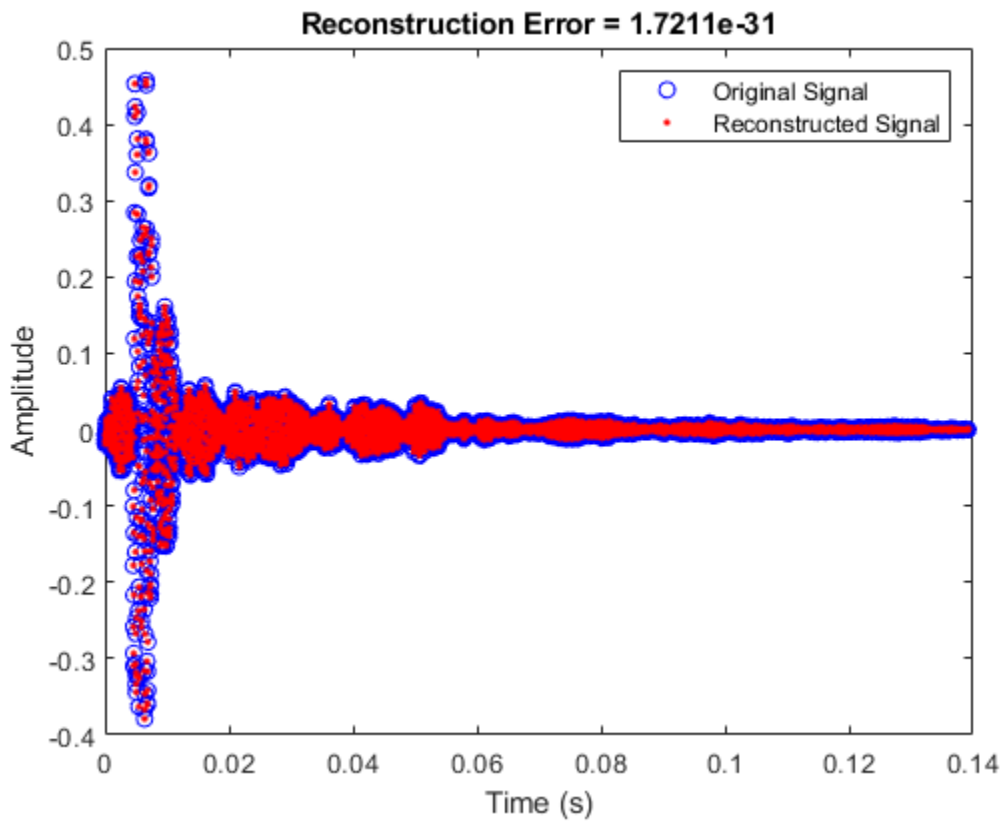
```
xClipped = x(1:end - rem(size(x,1),numel(win)));
```

Convert the signal to the frequency domain, and then reconstruct it back in the time domain. Plot the original and reconstructed signals and display the reconstruction error.

```
C = mdct(xClipped,win);
y = imdct(C,win);
```

```
figure(1)
t = (0:size(xClipped,1)-1)/fs;
plot(t,xClipped,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error = ",num2str(mean((xClipped-y).^2))))
```

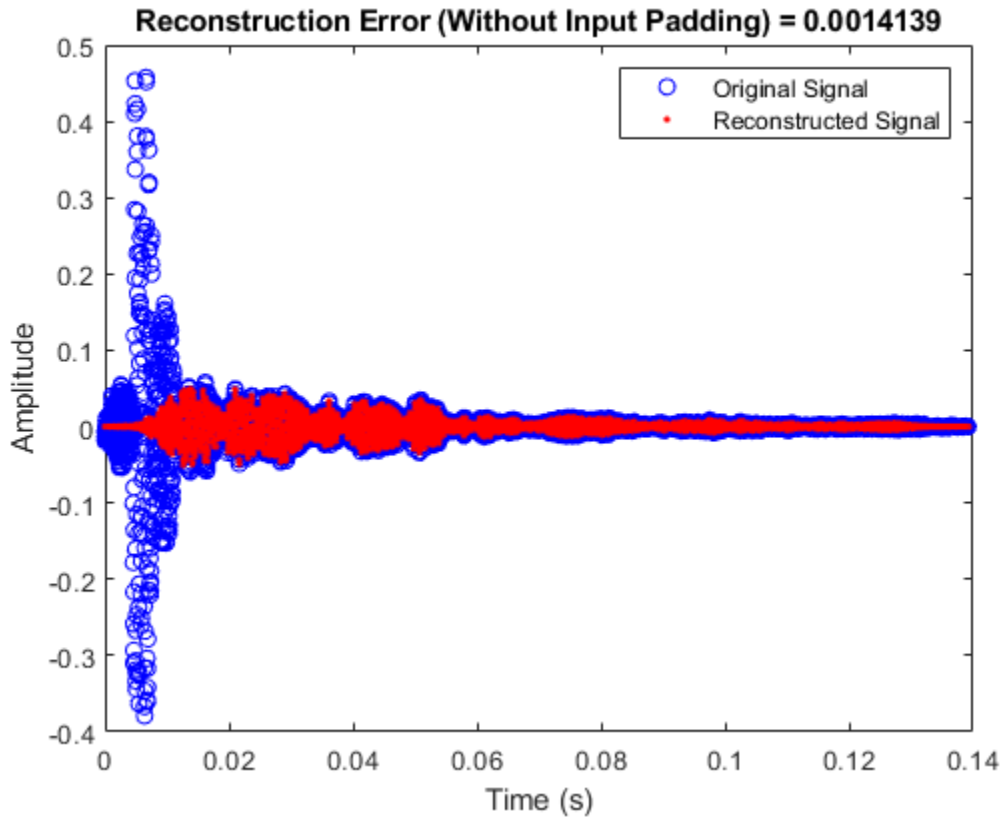
```
xlabel('Time (s)')
ylabel('Amplitude')
```



You can perform the MDCT and IMDCT without input padding using the `PadInput` name-value pair. However, there will be a reconstruction error in the first half-frame and last half-frame of the signal.

```
C = mdct(xClipped,win,'PadInput',false);
y = imdct(C,win,'PadInput',false);
```

```
figure(2)
t = (0:size(xClipped,1)-1)/fs;
plot(t,xClipped,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error (Without Input Padding) = ",num2str(mean((xClipped-y).^2))))
xlabel('Time (s)')
ylabel('Amplitude')
```



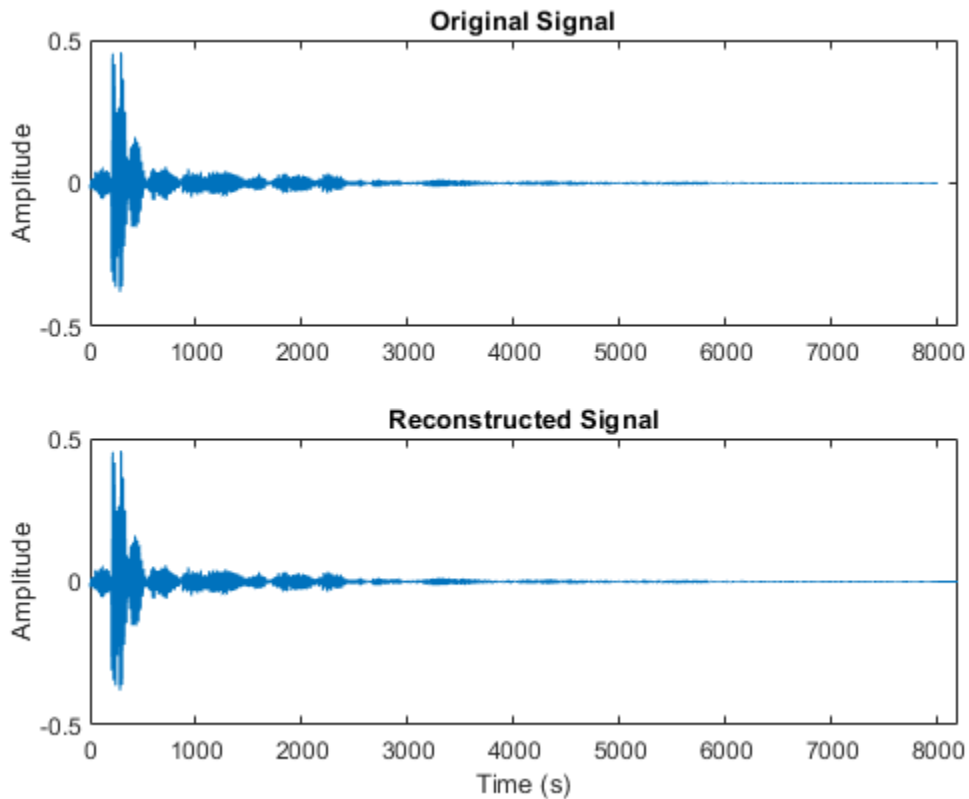
If you specify an input signal to the `mdct` that is not a multiple of the window length, then the input signal is padded with zeros. Pass the original unclipped signal through the transform pair and compare the original signal and the reconstructed signal.

```
C = mdct(x,win);
y = imdct(C,win);
```

```
figure(3)
```

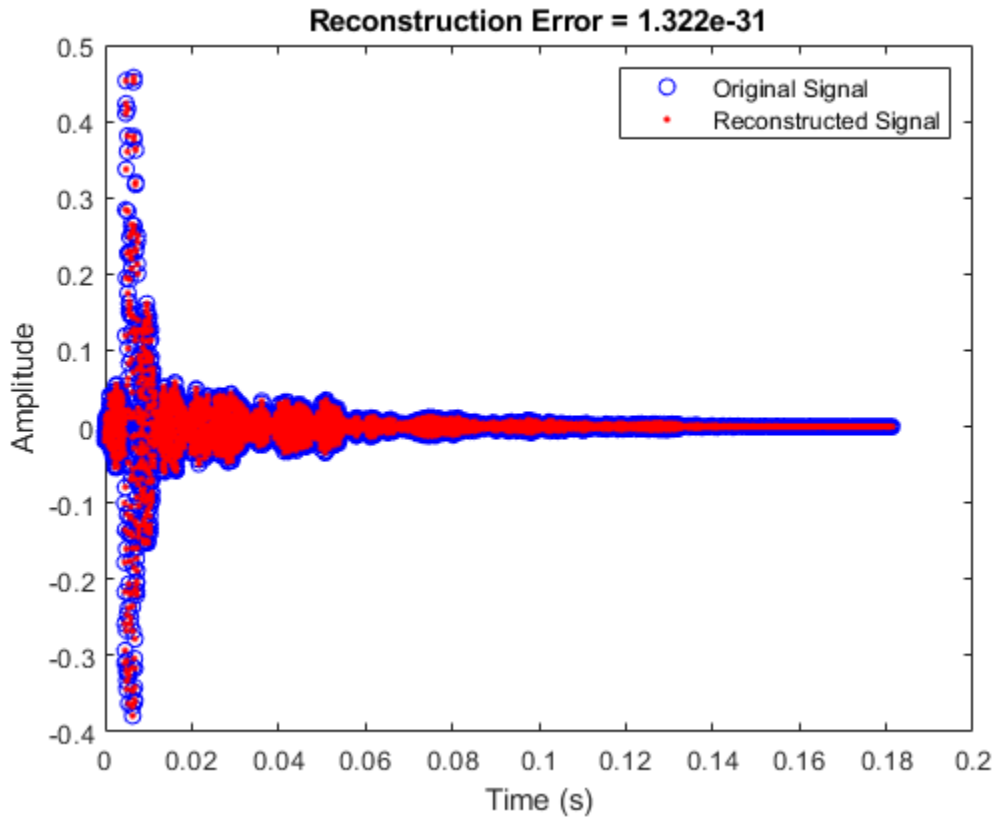
```
subplot(2,1,1)
plot(x)
title('Original Signal')
ylabel('Amplitude')
axis([0,max(size(y,1),size(x,1)),-0.5,0.5])
```

```
subplot(2,1,2)
plot(y)
title('Reconstructed Signal')
xlabel('Time (s)')
ylabel('Amplitude')
axis([0,max(size(y,1),size(x,1)),-0.5,0.5])
```



The reconstructed signal is padded with zeros at the back end. Remove the zero-padding from the reconstructed signal, plot the original and reconstructed signal, and then display the reconstruction error.

```
figure(4)
y = y(1:size(x,1));
t = (0:size(x,1)-1)/fs;
plot(t,x,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error = ",num2str(mean((x-y).^2))))
xlabel('Time (s)')
ylabel('Amplitude')
```



MDCT and IMDCT for Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the reconstructed signal for comparison. Create a `dsp.AsyncBuffer` to buffer the input stream.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');
logger = dsp.SignalSink;
buff = dsp.AsyncBuffer;
```

Create a 512-point Kaiser-Bessel-derived window.

```
N = 512;
win = kbdwin(N);
```

In an audio stream loop:

- 1 Read a frame of data from the file.
- 2 Write the frame of data to the async buffer.
- 3 If half a frame of data is present, read from the buffer and then perform the transform pair. Overlap-add the current output from `imdct` with the previous output, and log the results. Update the memory.

```
mem = zeros(N/2,2); % initialize an empty memory
```

```

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff,audioIn);

    while buff.NumUnreadSamples >= N/2
        x = read(buff,N,N/2);
        C = mdct(x,win,'PadInput',false);
        y = imdct(C,win,'PadInput',false);

        logger(y(1:N/2,:)+mem)
        mem = y(N/2+1:end,:);
    end

end

% Perform the transform pair one last time with a zero-padded final signal.
x = read(buff,N,N/2);
C = mdct(x,win,'PadInput',false);
y = imdct(C,win,'PadInput',false);
logger(y(1:N/2,:)+mem)

reconstructedSignal = logger.Buffer;

```

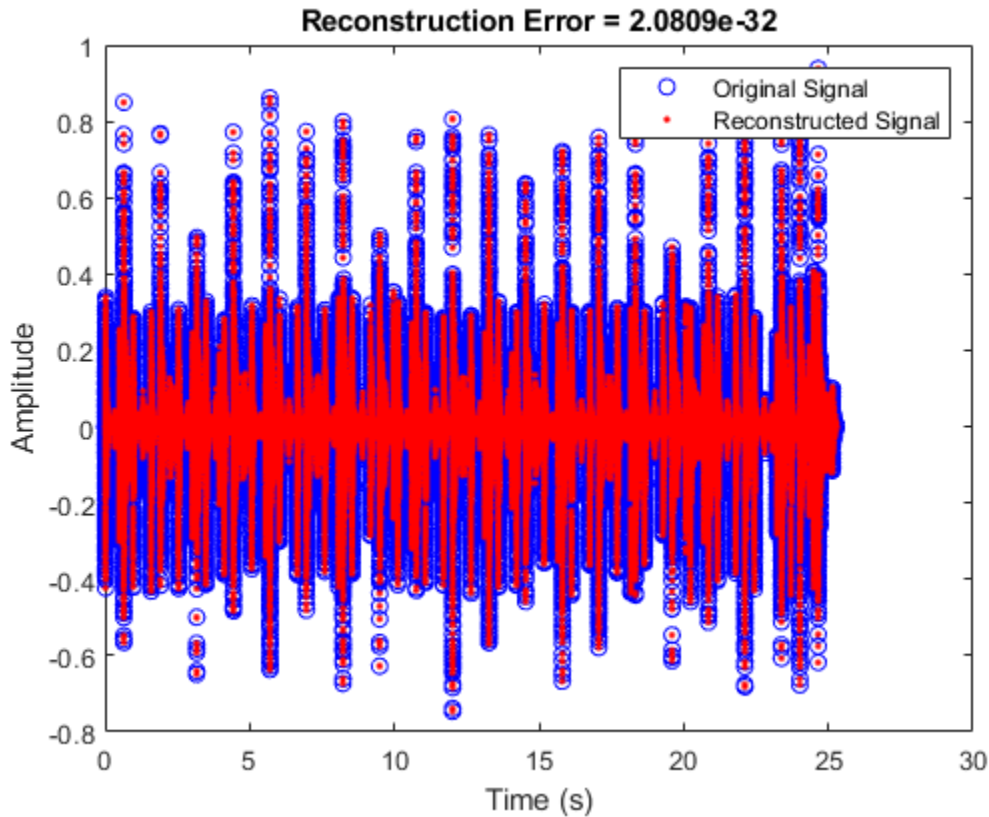
Read in the entire original audio signal. Trim the front and back zero padding from the reconstructed signal for comparison. Plot one channel of the original and reconstructed signals and display the reconstruction error.

```

[originalSignal,fs] = audioread(fileReader.FileName);
signalLength = size(originalSignal,1);
reconstructedSignal = reconstructedSignal((N/2+1):(N/2+1)+signalLength-1,:);

t = (0:size(originalSignal,1)-1)/fs;
plot(t,originalSignal(:,1),'bo',t,reconstructedSignal(:,1),'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error = ", ...
            num2str(mean((originalSignal-reconstructedSignal).^2,'all'))))
xlabel('Time (s)')
ylabel('Amplitude')

```



Input Arguments

X — Input array

column vector | matrix

Input array, specified as a column vector or matrix. If specified as a matrix, the columns are treated as independent audio channels.

Data Types: `single` | `double`

win — Window applied in time domain

even-length vector

Window applied in the time domain, specified as an even-length vector. The transform performed by `mdct` has the same number of points as `win`. To enable perfect reconstruction, use a window that satisfies the Princen-Bradley condition ($w_n^2 + w_{n+N}^2 = 1$), such as a sine window or `kbdwin`.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'PadInput', false

PadInput — Flag to pad input array

true (default) | false

Flag to pad input array, specified as the comma-separated pair consisting of 'PadInput' and true or false. If set to true, zero-padding is added to the input X at both ends to enable perfect reconstruction. The number of zeros at each end is $\text{numel}(\text{win})/2$.

Data Types: logical

Output Arguments

Y — Modified discrete cosine transform

vector | matrix | 3-D array

Modified discrete cosine transform (MDCT), returned as a vector, matrix, or 3-D array. The dimensions of Y are *L*-by-*M*-by-*N*, where:

- *L* -- Number of points in the frequency-domain representation of each frame, equal to $\text{numel}(\text{win})/2$.
- *M* -- Number of frames the input array is partitioned into.
 - If PadInput is set to true, $M = \text{ceil}(2*\text{size}(X,1)/\text{numel}(\text{win}))+1$.
 - If PadInput is set to false, $M = \text{ceil}(2*\text{size}(X,1)/\text{numel}(\text{win}))-1$.
- *N* -- Number of channels, equal to $\text{size}(X,2)$.

Trailing singleton dimensions are removed from the output Y.

Data Types: single | double

S — Modified discrete sine transform

vector | matrix | 3-D array

Modified discrete sine transform (MDST), returned as a vector, matrix, or 3-D array. The dimensions of S are the same as the MDCT output, Y.

Data Types: single | double

Z — Half-sided odd discrete Fourier transform

vector | matrix | 3-D array

Half-sided odd discrete Fourier transform (ODFT), returned as a vector, matrix, or 3-D array of complex numbers. The dimensions of Z are the same as the MDCT output, Y.

To construct the complete (two-sided) ODFT, mirror the half-sided ODFT:

`cat(1,Z,conj(flip(Z,1)))`.

Data Types: single | double

Complex Number Support: Yes

Algorithms

The modified discrete cosine transform is a time-frequency transform. Given an input signal X and window win , the `mdct` function performs the following steps for each independent channel:

- 1 The frame size is the number of elements in the specified window, $N = \text{numel}(\text{win})$. By default, `PadInput` is set to `true`, so the input signal X is padded with $N/2$ zeros on the front and back. If the input signal is not divisible by N , additional padding is added on the back. After padding, the input signal is buffered into 50% overlapped frames.
- 2 Each frame of the buffered and padded input signal is multiplied by the window, win .
- 3 The input is converted into a frequency representation using the modified discrete cosine transform:

$$Y(k) = \sum_{n=0}^{N-1} X(n) \cos\left[\frac{\pi}{(N/2)}\left(n + \frac{(N/2) + 1}{2}\right)\left(k + \frac{1}{2}\right)\right], \quad k = 0, 1, \dots, (N/2) - 1$$

To take advantage of the FFT algorithm, the MDCT is calculated by first calculating the odd DFT:

$$Y_o(k) = \sum_{n=0}^{N-1} X(n) e^{-j\frac{\pi n}{N}(2k+1)}, \quad k = 0, 1, \dots, N-1$$

and then calculating the MDCT:

$$Y(k) = \Re\{Y_o(k)\} \cos\left(\frac{\pi}{N}\left(k + \frac{1}{2}\right)\left(1 + \frac{N}{2}\right)\right), \quad k = 0, 1, \dots, (N/2) - 1$$

If a second argument is requested from the `mdct` function, the modified discrete sine transform (MDST) is also computed and returned:

$$X(k) = \Im\{X_o(k)\} \sin\left(\frac{\pi}{N}\left(k + \frac{1}{2}\right)\left(1 + \frac{N}{2}\right)\right), \quad k = 0, 1, \dots, (N/2) - 1$$

References

- [1] Princen, J., A. Johnson, and A. Bradley. "Subband/Transform Coding Using Filter Bank Designs Based on Time Domain Aliasing Cancellation." *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*. 1987, pp. 2161-2164.
- [2] Princen, J., and A. Bradley. "Analysis/Synthesis Filter Bank Design Based on Time Domain Aliasing Cancellation." *IEEE Transactions on Acoustics, Speech, and Signal Processing*. Vol. 34, Issue 5, 1986, pp. 1153-1161.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`imdct` | `kbdwin` | `spectrogram`

Topics

"Vorbis Decoder"

Introduced in R2019a

imdct

Inverse modified discrete cosine transform

Syntax

```
X = imdct(Y,win)
X = imdct(Y,win,Name,Value)
```

Description

`X = imdct(Y,win)` returns the inverse modified discrete cosine transform (IMDCT) of `Y`, followed by multiplication with time window `win` and overlap-addition of the frames with 50% overlap.

`X = imdct(Y,win,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

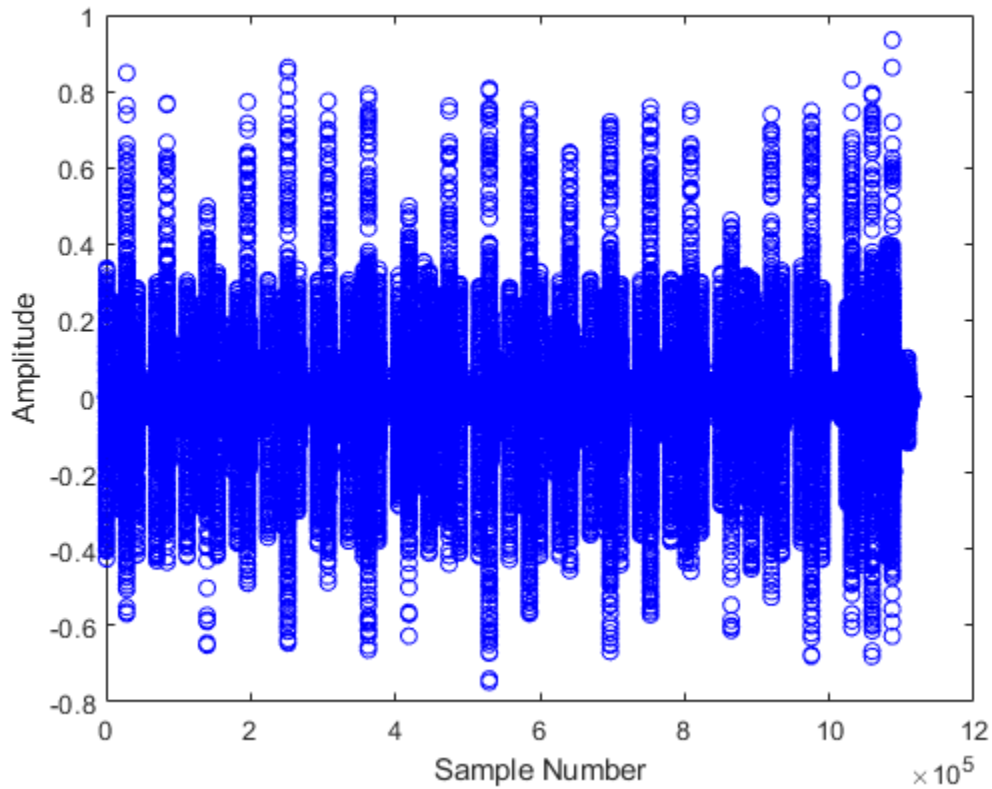
Examples

Calculate IMDCT

Read in an audio file, convert it to mono, and then plot it.

```
audioIn = audioread('FunkyDrums-44p1-stereo-25secs.mp3');
audioIn = mean(audioIn,2);

figure(1)
plot(audioIn,'bo')
ylabel('Amplitude')
xlabel('Sample Number')
```



Calculate the MDCT using a 4096-point sine window. Plot the power of the MDCT coefficients over time.

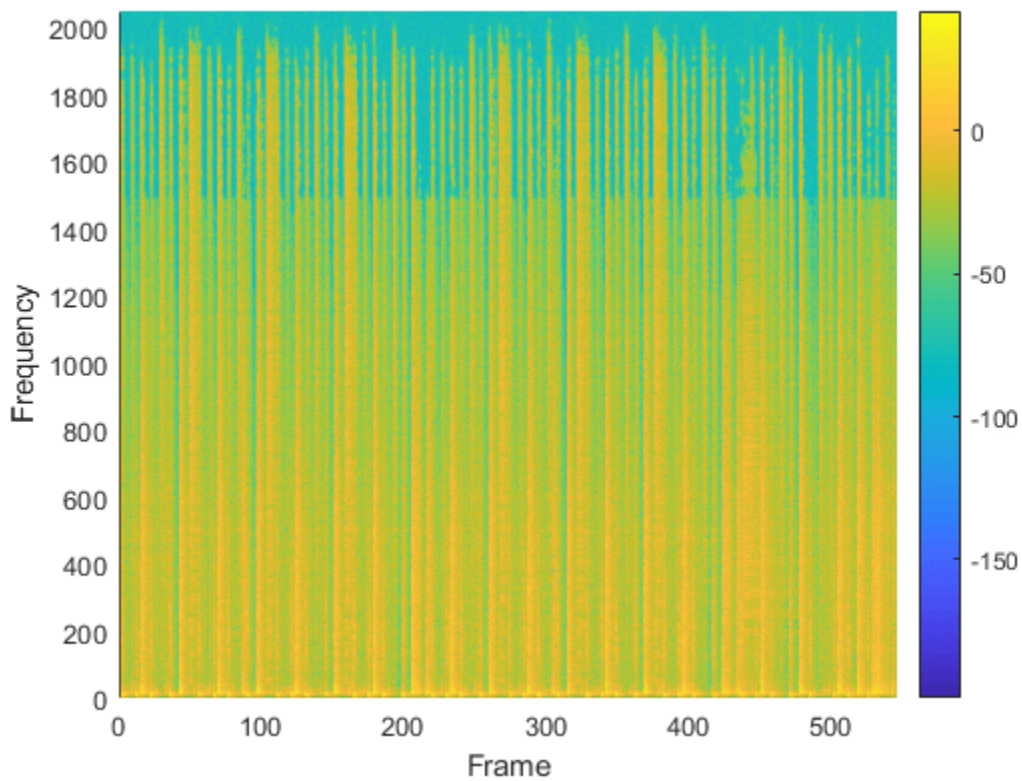
```

N = 4096;
wdw = sin(pi*((1:N)-0.5)/N);

C = mdct(audioIn,wdw);

figure(2)
surf(pow2db(C.*conj(C)), 'EdgeColor', 'none');
view([0 90])
xlabel('Frame')
ylabel('Frequency')
axis([0 size(C,2) 0 size(C,1)])
colorbar

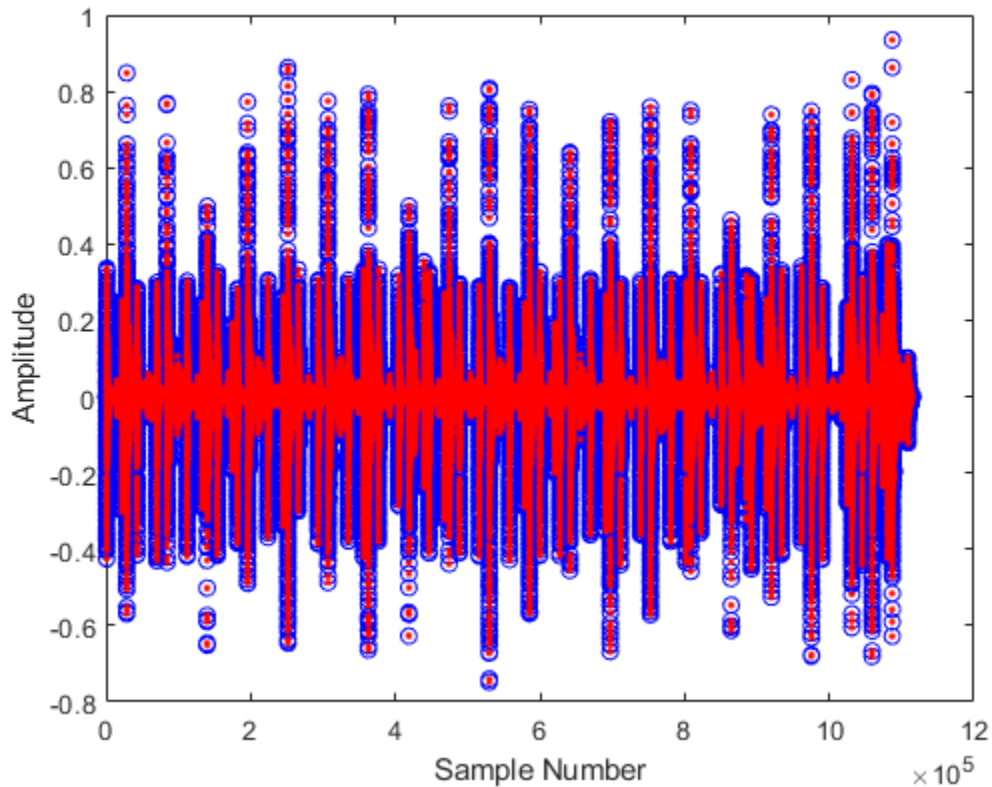
```



Transform the representation back to the time domain. Verify the perfect reconstruction property by computing the mean squared error. Plot the reconstructed signal over the original signal.

```
audioReconstructed = imdct(C,wdw);  
err = mean((audioIn-audioReconstructed(1:size(audioIn,1),:)).^2)  
  
err = 9.5889e-31
```

```
figure(1)  
hold on  
plot(audioReconstructed,'r.')  
ylabel('Amplitude')  
xlabel('Sample Number')
```



Effect of Input Padding on Perfect Reconstruction

To enable perfect reconstruction, the `mdct` function zero-pads the front and back of the audio input signal. The signal returned from `imdct` removes the zero padding added for perfect reconstruction.

Read in an audio file, create a 2048-point Kaiser-Bessel-derived window, and then clip the audio signal so that its length is a multiple of 2048.

```
[x,fs] = audioread('Click-16-44p1-mono-0.2secs.wav');
win = kbdwin(2048);
```

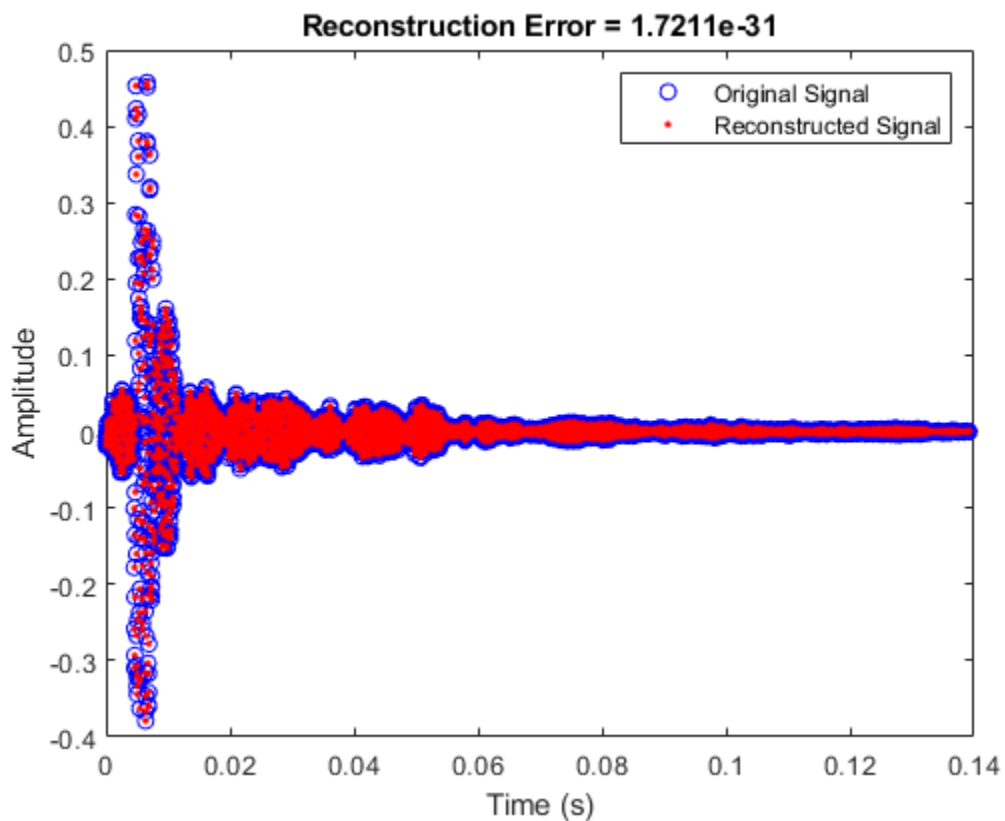
```
xClipped = x(1:end - rem(size(x,1),numel(win)));
```

Convert the signal to the frequency domain, and then reconstruct it back in the time domain. Plot the original and reconstructed signals and display the reconstruction error.

```
C = mdct(xClipped,win);
y = imdct(C,win);
```

```
figure(1)
t = (0:size(xClipped,1)-1)/fs;
plot(t,xClipped,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error = ",num2str(mean((xClipped-y).^2))))
```

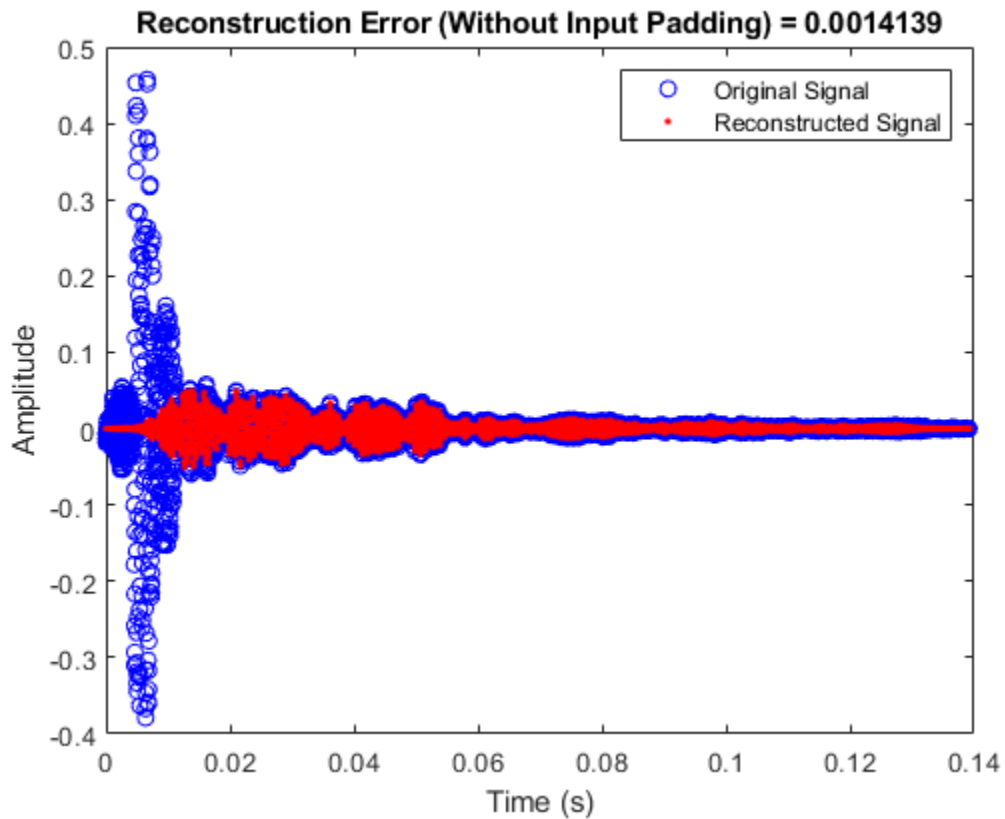
```
xlabel('Time (s)')
ylabel('Amplitude')
```



You can perform the MDCT and IMDCT without input padding using the `PadInput` name-value pair. However, there will be a reconstruction error in the first half-frame and last half-frame of the signal.

```
C = mdct(xClipped,win,'PadInput',false);
y = imdct(C,win,'PadInput',false);
```

```
figure(2)
t = (0:size(xClipped,1)-1)/fs;
plot(t,xClipped,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error (Without Input Padding) = ",num2str(mean((xClipped-y).^2))))
xlabel('Time (s)')
ylabel('Amplitude')
```



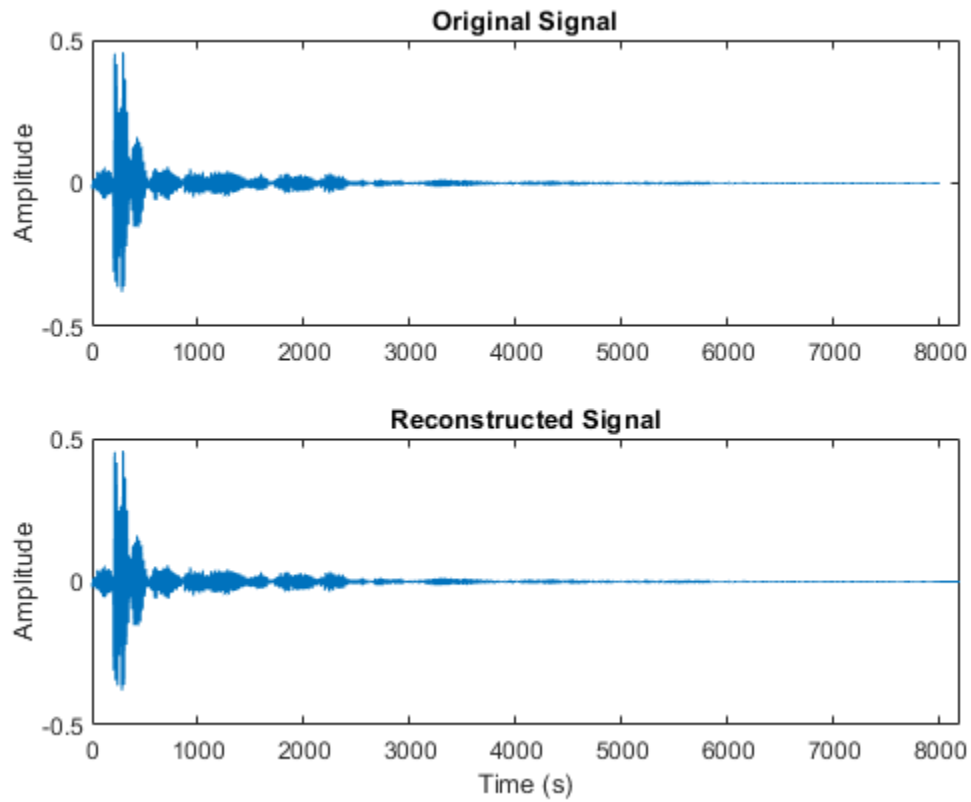
If you specify an input signal to the `mdct` that is not a multiple of the window length, then the input signal is padded with zeros. Pass the original unclipped signal through the transform pair and compare the original signal and the reconstructed signal.

```
C = mdct(x,win);
y = imdct(C,win);
```

```
figure(3)
```

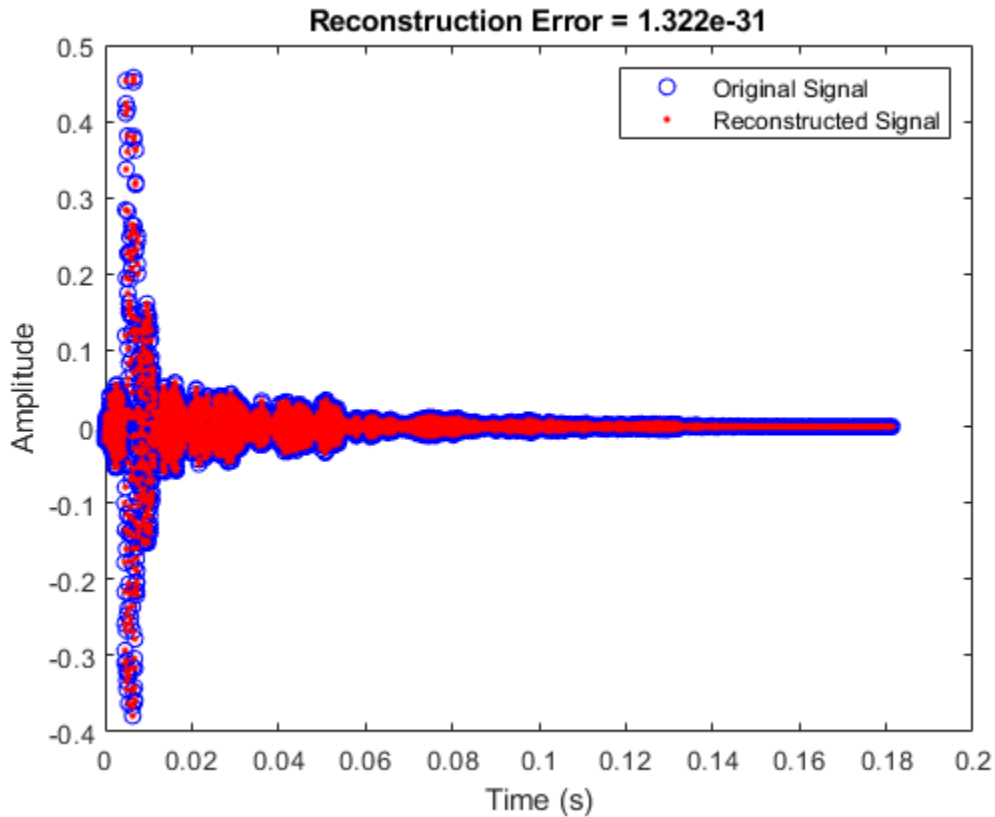
```
subplot(2,1,1)
plot(x)
title('Original Signal')
ylabel('Amplitude')
axis([0,max(size(y,1),size(x,1)),-0.5,0.5])
```

```
subplot(2,1,2)
plot(y)
title('Reconstructed Signal')
xlabel('Time (s)')
ylabel('Amplitude')
axis([0,max(size(y,1),size(x,1)),-0.5,0.5])
```

The reconstructed signal is padded with zeros at the back end. Remove the zero-padding from the reconstructed signal, plot the original and reconstructed signal, and then display the reconstruction error.

```
figure(4)
y = y(1:size(x,1));
t = (0:size(x,1)-1)/fs;
plot(t,x,'bo',t,y,'r.')
legend('Original Signal','Reconstructed Signal')
title(strcat("Reconstruction Error = ",num2str(mean((x-y).^2))))
xlabel('Time (s)')
ylabel('Amplitude')
```



MDCT and IMDCT for Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the reconstructed signal for comparison. Create a `dsp.AsyncBuffer` to buffer the input stream.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');
logger = dsp.SignalSink;
buff = dsp.AsyncBuffer;
```

Create a 512-point Kaiser-Bessel-derived window.

```
N = 512;
win = kbdwin(N);
```

In an audio stream loop:

- 1 Read a frame of data from the file.
- 2 Write the frame of data to the async buffer.
- 3 If half a frame of data is present, read from the buffer and then perform the transform pair. Overlap-add the current output from `imdct` with the previous output, and log the results. Update the memory.

```
mem = zeros(N/2,2); % initialize an empty memory
```

```

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff, audioIn);

    while buff.NumUnreadSamples >= N/2
        x = read(buff, N, N/2);
        C = mdct(x, win, 'PadInput', false);
        y = imdct(C, win, 'PadInput', false);

        logger(y(1:N/2, :) + mem)
        mem = y(N/2+1:end, :);
    end

end

% Perform the transform pair one last time with a zero-padded final signal.
x = read(buff, N, N/2);
C = mdct(x, win, 'PadInput', false);
y = imdct(C, win, 'PadInput', false);
logger(y(1:N/2, :) + mem)

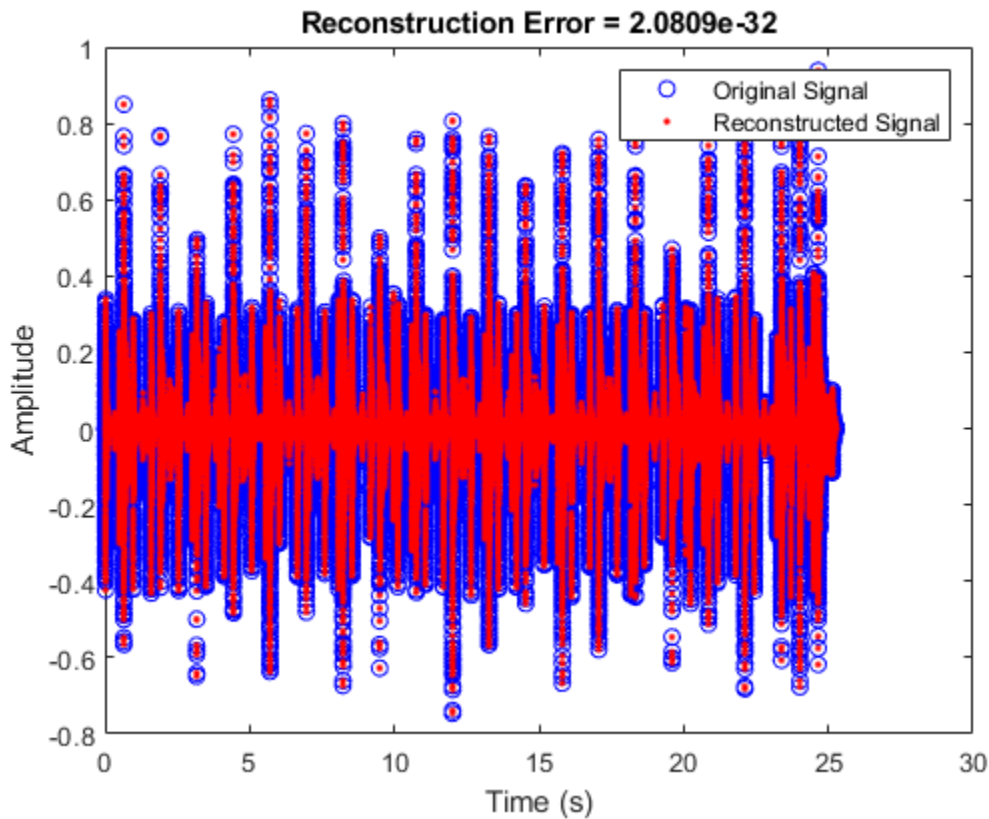
reconstructedSignal = logger.Buffer;

Read in the entire original audio signal. Trim the front and back zero padding from the reconstructed
signal for comparison. Plot one channel of the original and reconstructed signals and display the
reconstruction error.

[originalSignal, fs] = audioread(fileReader.FileName);
signalLength = size(originalSignal, 1);
reconstructedSignal = reconstructedSignal((N/2+1):(N/2+1)+signalLength-1, :);

t = (0:size(originalSignal, 1)-1)/fs;
plot(t, originalSignal(:, 1), 'bo', t, reconstructedSignal(:, 1), 'r.')
legend('Original Signal', 'Reconstructed Signal')
title(strcat("Reconstruction Error = ", ...
    num2str(mean((originalSignal - reconstructedSignal).^2, 'all'))))
xlabel('Time (s)')
ylabel('Amplitude')

```



Input Arguments

Y — Modified discrete cosine transform

vector | matrix | 3-D array

Modified discrete cosine transform (MDCT), specified as a vector, matrix, or 3-D array. The dimensions of *Y* are interpreted as output from the `mdct` function. If *Y* is an *L*-by-*M*-by-*N* array, the dimensions are interpreted as:

- *L* -- Number of points in the frequency-domain representation of each frame. *L* must be half the number of points in the window, `win`.
- *M* -- Number of frames.
- *N* -- Number of channels.

Data Types: `single` | `double`

win — Window applied in time domain

vector

Window applied in the time domain, specified as vector. The length of `win` must be twice the number of rows of *Y*: `numel(win)==2*size(Y,1)`. To enable perfect reconstruction, use the same window used in the forward transformation `mdct`.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `'PadInput', false`

PadInput — Flag if input was padded

`true` (default) | `false`

Flag if input to the forward `mdct` was padded. If set to `true`, the output is truncated at both ends to remove the zero-padding that the forward `mdct` added.

Data Types: `logical`

Output Arguments

X — Inverse modified discrete cosine transform

column vector | matrix

Inverse modified discrete cosine transform (IMDCT) of input array `Y`, returned as a column vector or matrix of independent channels.

Data Types: `single` | `double`

Algorithms

The inverse modified discrete cosine transform is a time-frequency transform. Given a frequency domain input signal `Y` and window `win`, the `imdct` function performs the follows steps for each independent channel:

- 1 Each frame of the input is converted into a time-domain representation:

$$X(n) = \sum_{k=0}^{\frac{N}{2}-1} Y(k) \cos \left[\frac{\pi}{(N/2)} \left(n + \frac{(N/2)+1}{2} \right) \left(k + \frac{1}{2} \right) \right], \quad n = 0, 1, \dots, N-1$$

where N is the number of elements in `win`.

- 2 Each frame of the time-domain signal is multiplied by the window, `win`.
- 3 The frames are overlap-added with 50% overlap to construct a contiguous time-domain signal. If `PadInput` is set to `true`, the `imdct` function assumes the original input signal in the forward transform (`mdct`) was padded with $N/2$ zeros on the front and back and removes the padding. By default, `PadInput` is set to `true`.

References

- [1] Princen, J., A. Johnson, and A. Bradley. "Subband/Transform Coding Using Filter Bank Designs Based on Time Domain Aliasing Cancellation." *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*. 1987, pp. 2161-2164.

- [2] Princen, J., and A. Bradley. "Analysis/Synthesis Filter Bank Design Based on Time Domain Aliasing Cancellation." *IEEE Transactions on Acoustics, Speech, and Signal Processing*. Vol. 34, Issue 5, 1986, pp. 1153-1161.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

mdct | kbdwin | spectrogram

Topics

"Vorbis Decoder"

Introduced in R2019a

harmonicRatio

Harmonic ratio

Syntax

```
hr = harmonicRatio(audioIn,fs)
hr = harmonicRatio(audioIn,fs,Name=Value)
harmonicRatio( ___ )
```

Description

`hr = harmonicRatio(audioIn,fs)` returns the harmonic ratio of the signal, `audioIn`, over time. Columns of the input are treated as individual channels.

`hr = harmonicRatio(audioIn,fs,Name=Value)` specifies options using one or more name-value arguments.

Example: `hr = harmonicRatio(audioIn,fs,Window=rectwin(round(fs*0.1)),OverlapLength=round(fs*0.05))` returns the harmonic ratio for the audio input signal sampled at `fs` Hz. The harmonic ratio is calculated for 100 ms rectangular windows with 50 ms overlap.

`harmonicRatio(___)` with no output arguments plots the harmonic ratio against time. You can specify an input combination from any of the previous syntaxes.

Examples

Calculate Harmonic Ratio

Read in an audio file and calculate the harmonic ratio using default parameters.

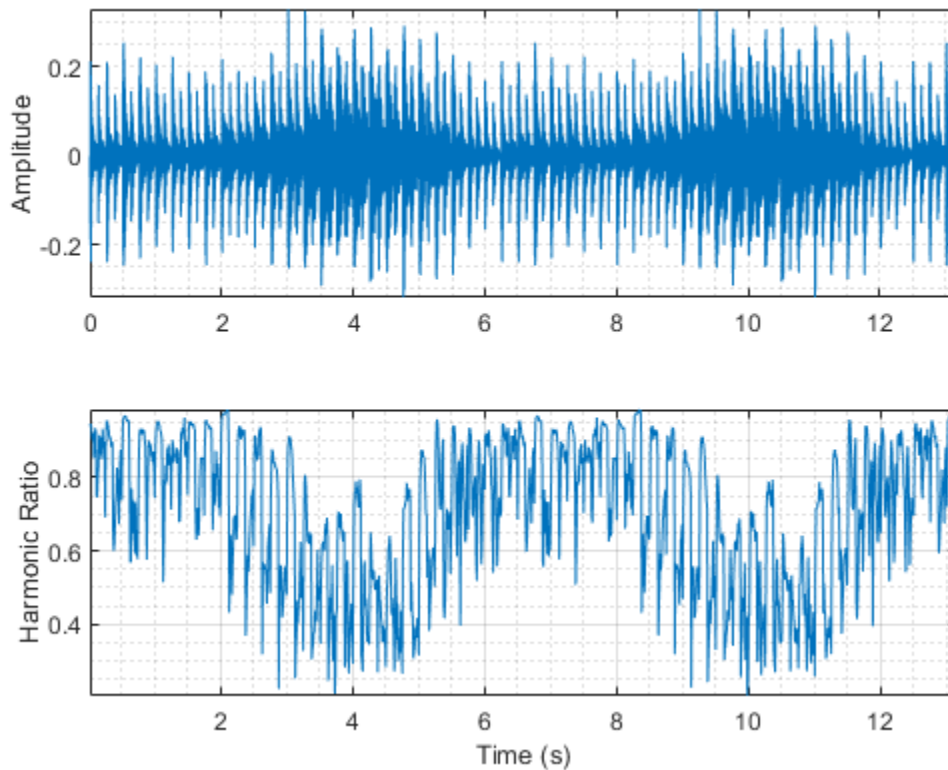
```
[audioIn,fs] = audioread("RandomOscThree-24-96-stereo-13secs.aif");
audioInMono = mean(audioIn,2);

hr = harmonicRatio(audioInMono,fs);
```

Plot the amplitude and the harmonic ratio of the signal against time.

```
t = (0:length(audioInMono)-1)/fs;
subplot(2,1,1)
plot(t,audioInMono)
ylabel("Amplitude")
grid minor
axis tight

subplot(2,1,2)
harmonicRatio(audioInMono,fs)
```



Specify Nondefault Parameters

Read in an audio file.

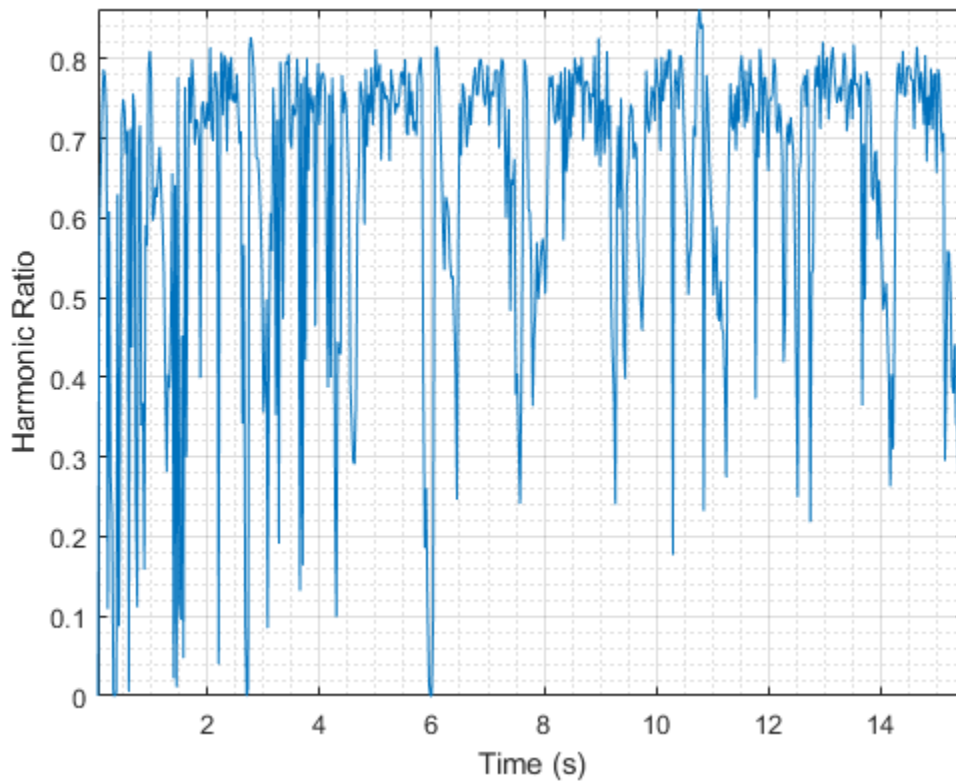
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the harmonic ratio of the audio file using 50 ms Hann windows with 25 ms overlap.

```
hr = harmonicRatio(audioIn,fs, ...
    Window=hann(round(fs.*0.05),"periodic"), ...
    OverlapLength=round(fs.*0.025));
```

Plot the harmonic ratio.

```
harmonicRatio(audioIn,fs, ...
    Window=hann(round(fs.*0.05),"periodic"), ...
    OverlapLength=round(fs.*0.025))
```

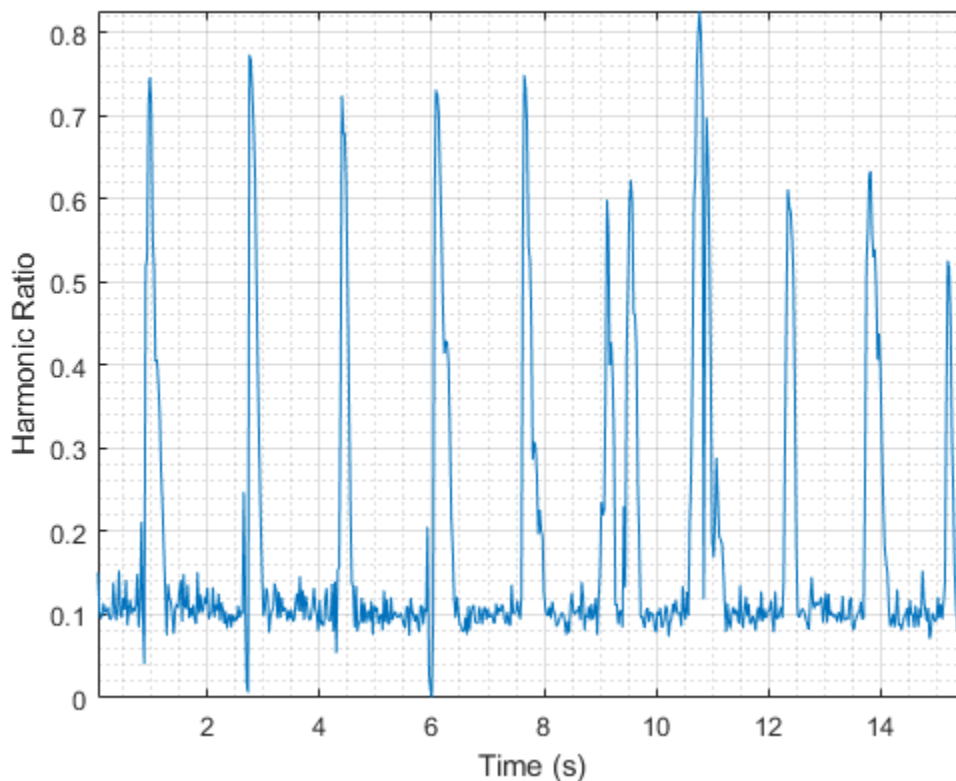



The harmonic ratio indicates the ratio of energy in the harmonic portion of audio to the total energy of the audio. Because the audio signal in this example has regions of near silence, where the total energy is very low, the harmonic ratio does a poor job discriminating between regions of speech and regions of silence. Add white noise to the audio signal and then calculate the harmonic ratio.

```
audioIn = audioIn + 0.1*randn(size(audioIn));
hr = harmonicRatio(audioIn,fs, ...
    Window=hann(round(fs.*0.05),"periodic"), ...
    OverlapLength=round(fs.*0.025));
```

Plot the new harmonic ratio of the audio signal combined with white noise.

```
harmonicRatio(audioIn,fs, ...
    Window=hann(round(fs.*0.05),"periodic"), ...
    OverlapLength=round(fs.*0.025))
```



Calculate Harmonic Ratio of Streaming Audio

Create a `dsp.AudioFileReader` object to read in stereo audio data frame-by-frame. Create a `dsp.SignalSink` object to log the harmonic ratio calculation.

```
fileReader = dsp.AudioFileReader('Random0scThree-24-96-stereo-13secs.aif');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the harmonic ratio for each channel of the frame of audio.
- 3 Log the harmonic ratio for later plotting.

To calculate the harmonic ratio for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame, 'periodic');
while ~isDone(fileReader)
    audioIn = fileReader();

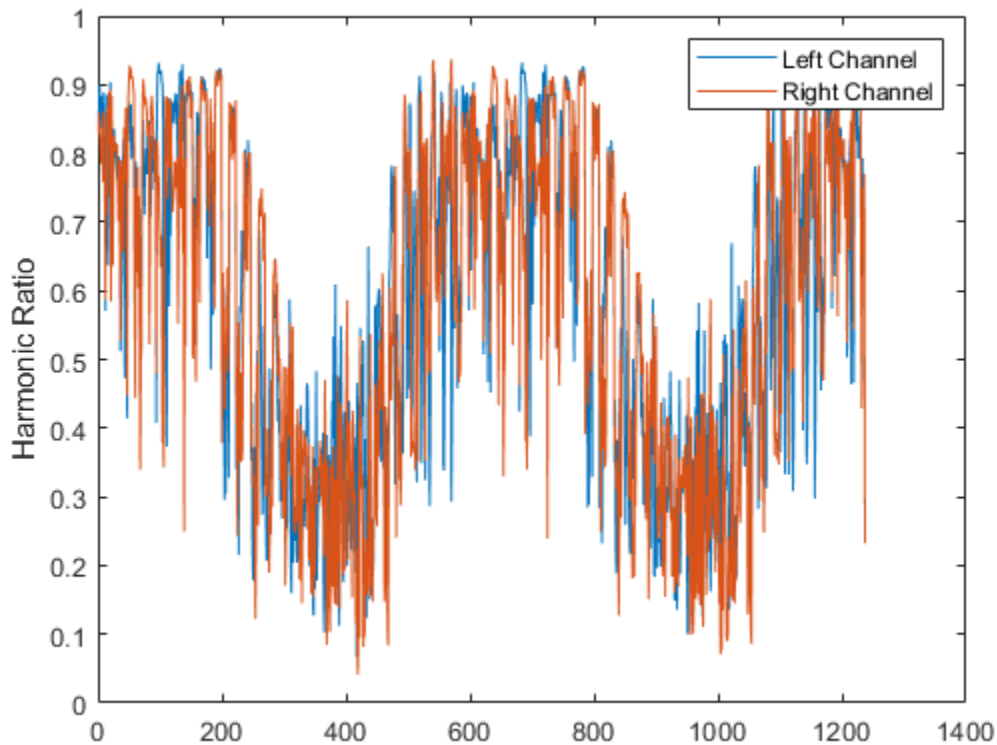
    hr = harmonicRatio(audioIn, fileReader.SampleRate, ...
        'Window', win, ...
        'OverlapLength', 0);
```

```

    logger(hr)
end

plot(logger.Buffer)
ylabel('Harmonic Ratio')
legend('Left Channel', 'Right Channel')

```



If the input to your audio stream loop has a variable samples-per-frame, an inconsistent samples-per-frame with the analysis window size of `harmonicRatio`, or if you want to calculate the harmonic ratio of overlapped data, use `dsp.AsyncBuffer`.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```

buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)

```

Calculate the harmonic ratio using 50 ms frames with a 25 ms overlap.

```

fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame);

```

```
while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff,audioIn);

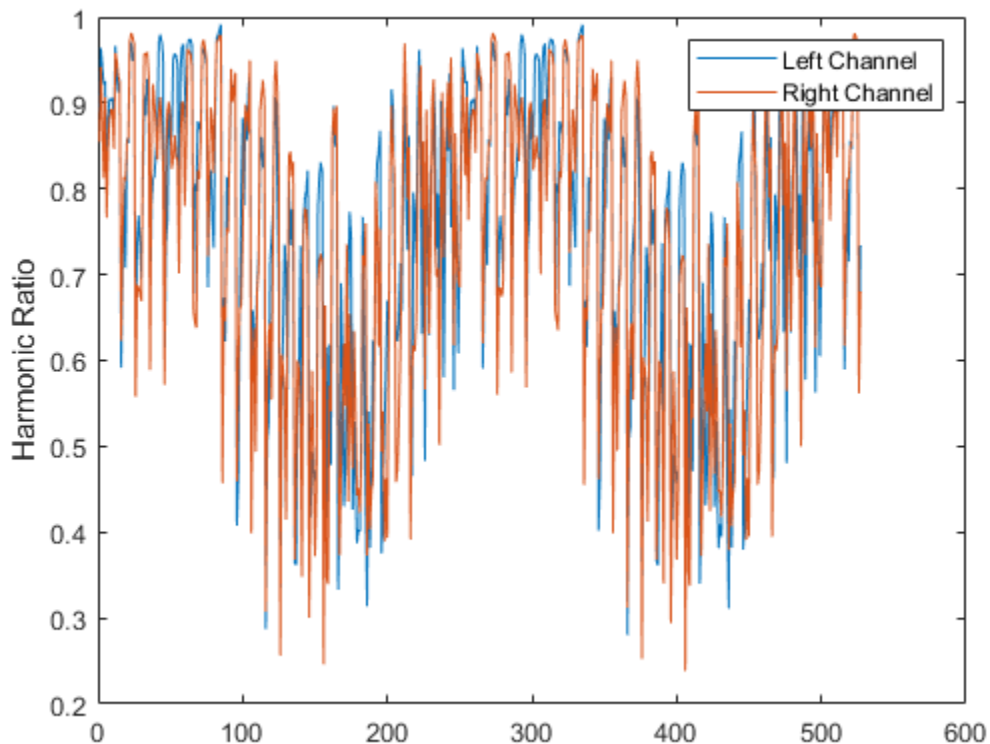
    while buff.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);

        hr = harmonicRatio(audioBuffered,fs, ...
                           'Window',win, ...
                           'OverlapLength',0);

        logger(hr)
    end
end
release(fileReader)
```

Plot the logged data.

```
plot(logger.Buffer)
ylabel('Harmonic Ratio')
legend('Left Channel','Right Channel')
```



Harmonic Ratio of Tones and White Noise

The harmonic ratio measures the amount of energy in the tonal part of the signal compared to the amount of energy in the total signal.

Harmonic Ratio of Pure Tone

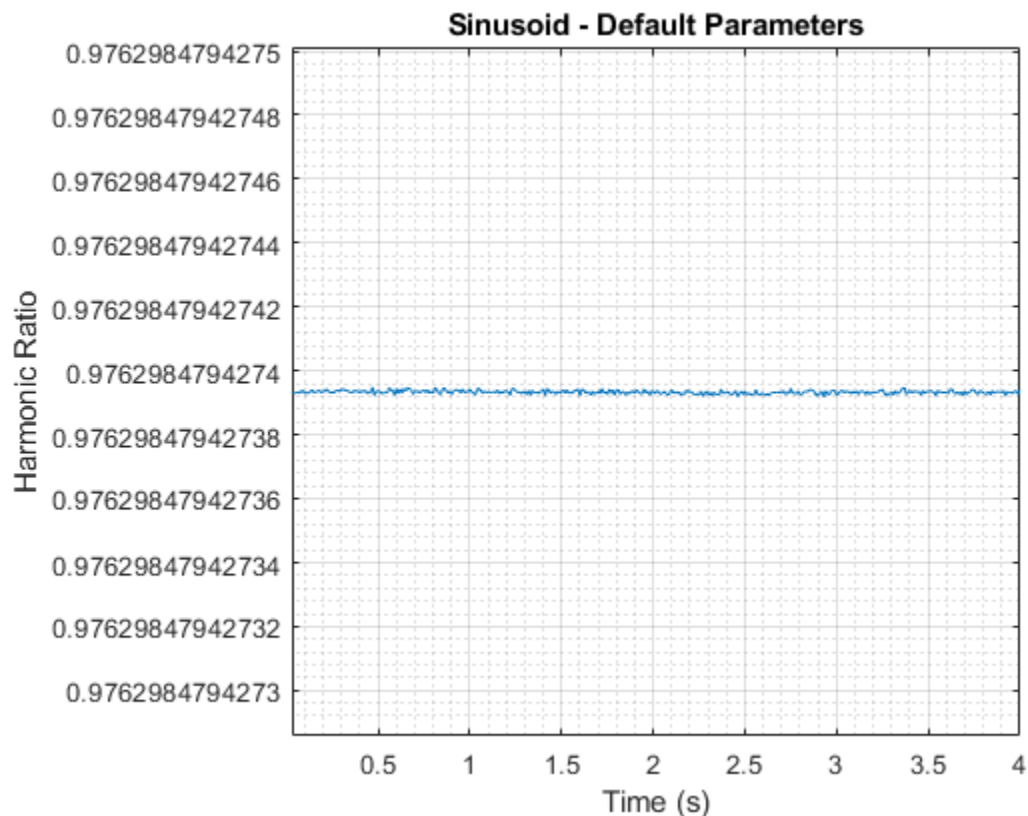
Create a pure tone and then calculate the harmonic ratio using default parameters. By default, the harmonic ratio is calculated for 30 ms Hamming windows with 10 ms hops. Plot the results. The harmonic ratio is near 1, which is the theoretical maximum.

```
fs = 48e3;
osc = audioOscillator(Frequency=500, SamplesPerFrame=192e3, SampleRate=fs);
sinewave = osc();
```

```
hr = harmonicRatio(sinewave, fs);
```

Plot the harmonic ratio against time. The harmonic ratio is near 1, which is the theoretical maximum.

```
harmonicRatio(sinewave, fs)
title("Sinusoid - Default Parameters")
```



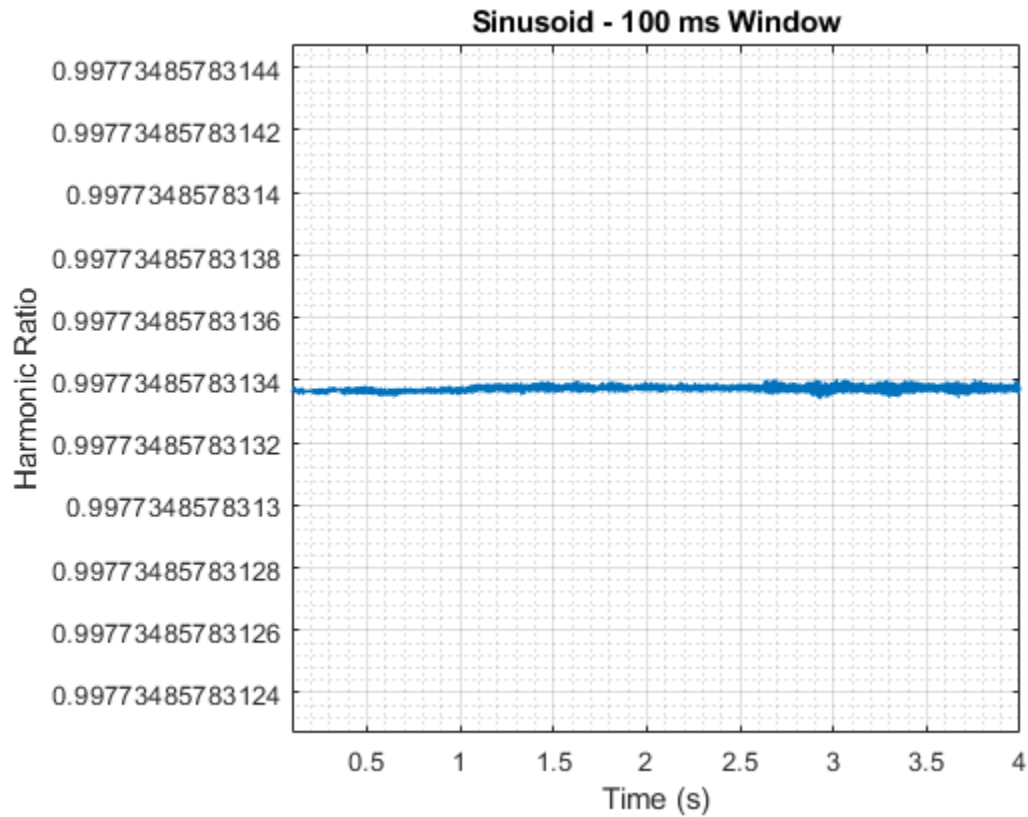
The short-time analysis required for windowing lowers the harmonic ratio from the theoretical value of 1. To diminish the effect of windowing, you can increase the window size. Use a 100 ms Hamming window and a 10 ms hop.

```
win = hamming(round(fs*0.1), "periodic");
overlap = round(fs*0.099);
```

```
hr = harmonicRatio(sinewave, fs, Window=win, OverlapLength=overlap);
```

Plot the harmonic ratio and observe that it is closer to one than when using the default window length.

```
harmonicRatio(sinewave, fs, Window=win, OverlapLength=overlap)
title("Sinusoid - 100 ms Window")
```



Harmonic Ratio of White Noise

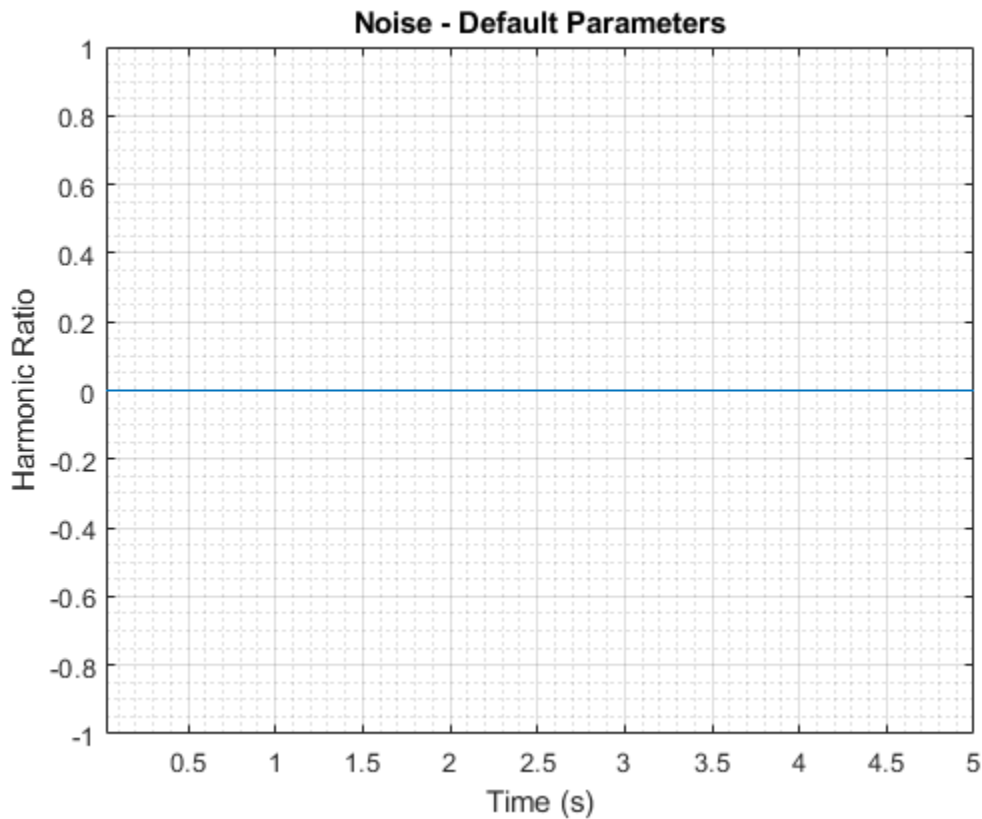
Create 5 seconds of white noise and then calculate the harmonic ratio using default parameters. By default, the harmonic ratio is calculated for 30 ms Hamming windows with 10 ms hops.

```
fs = 48e3;
noise = rand(fs*5,1);
```

```
hr = harmonicRatio(noise, fs);
```

Plot the results. The harmonic ratio is 0.

```
harmonicRatio(noise, fs)
title("Noise - Default Parameters")
```



Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If specified as a matrix, `harmonicRatio` treats the columns of the matrix as individual audio channels.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`hamming(round(fs*0.03), "periodic")` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(\text{audioIn}, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(fs*0.02)` (default) | nonnegative integer scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

Output Arguments**hr — Harmonic ratio**

scalar | vector | matrix

Harmonic ratio, returned as a scalar, vector, or matrix. Each row of `hr` corresponds to the harmonic ratio of a window of `audioIn`. The harmonic ratio is returned with values in the range $[0, 1]$. A value of 0 represents low harmonicity, and a value of 1 represents high harmonicity.

Data Types: `single` | `double`

Algorithms

The harmonic ratio is calculated as described in [1]. The following algorithm is applied independently to each window of audio data. The normalized autocorrelation of the signal is determined as:

$$\Gamma(m) = \frac{\sum_{n=1}^N s(n)s(n-m)}{\sqrt{\sum_{n=1}^N s(n)^2 \sum_{n=0}^N s(n-m)^2}} \text{ for } (1 \leq m \leq M)$$

where

- s is a single frame of audio data with N elements.
- M is the maximum lag in the calculation. The maximum lag is 40 ms, which corresponds to a minimum fundamental frequency of 25 Hz.

A first estimate of the harmonic ratio is determined as the maximum of the normalized autocorrelation, within a given range:

$$\beta HR = \max_{M_0 \leq m \leq M} \{\Gamma(m)\}$$

where M_0 is the lower edge of the search range, determined as the first zero crossing of the normalized autocorrelation.

Finally, the harmonic ratio estimate is improved using parabolic interpolation, as described in [2].

References

- [1] Kim, Hyoung-Gook, Nicholas Moreau, and Thomas Sikora. *MPEG-7 Audio and Beyond: Audio Content Indexing and Retrieval*. John Wiley & Sons, 2005.
- [2] Quadratic Interpolation of Spectral Peaks. Accessed October 11, 2018. https://ccrma.stanford.edu/~jos/sasp/Quadratic_Interpolation_Spectral_Peaks.html

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`pitch` | `spectralCentroid` | `voiceActivityDetector`

Introduced in R2019a

gtcc

Extract gammatone cepstral coefficients, log-energy, delta, and delta-delta

Syntax

```
coeffs = gtcc(audioIn,fs)
coeffs = gtcc( ____,Name=Value)
[coeffs,delta,deltaDelta,loc] = gtcc( ____ )
gtcc( ____ )
```

Description

`coeffs = gtcc(audioIn,fs)` returns the gammatone cepstral coefficients (GTCCs) for the audio input, sampled at a frequency of `fs` Hz.

`coeffs = gtcc(____,Name=Value)` specifies options using one or more name-value arguments.

`[coeffs,delta,deltaDelta,loc] = gtcc(____)` also returns the delta, delta-delta, and location in samples corresponding to each window of data. You can specify an input combination from any of the previous syntaxes.

`gtcc(____)` with no output arguments plots the gammatone cepstral coefficients. Before plotting, the coefficients are normalized to have mean 0 and standard deviation 1.

- If the input is in the time domain, the coefficients are plotted against time.
- If the input is in the frequency domain, the coefficients are plotted against frame number.
- If the log-energy is extracted, then it is also plotted.

Examples

Extract GTCC from Audio Signal

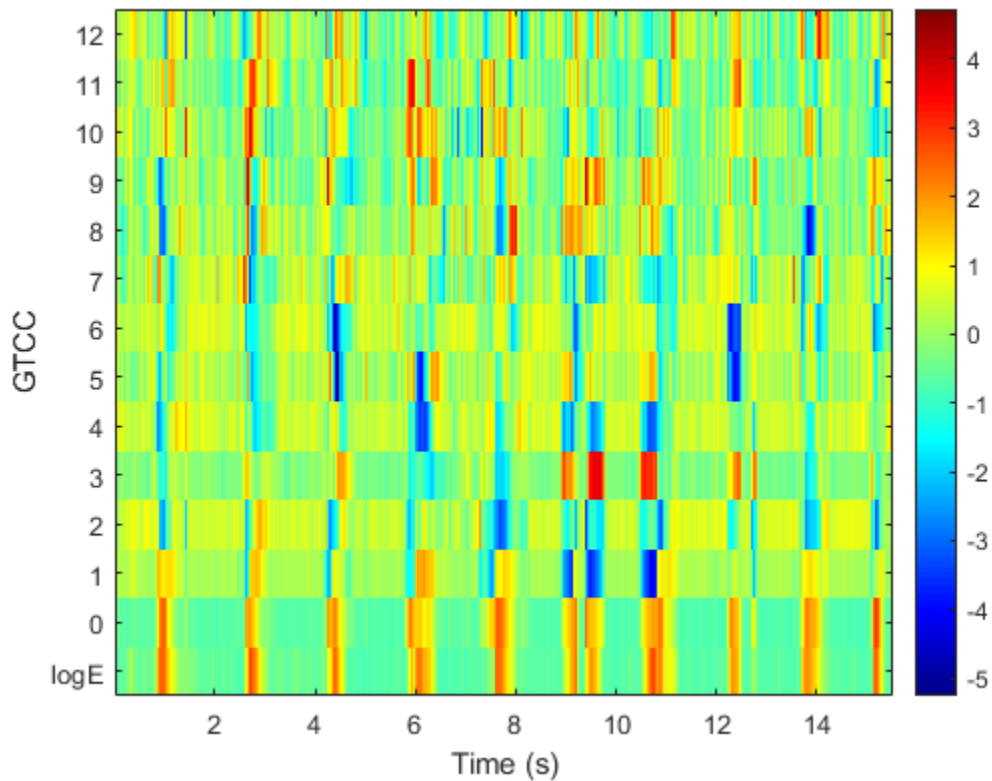
Get the gammatone cepstral coefficients for an audio file using default settings.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[coeffs,~,~,loc] = gtcc(audioIn,fs);
```

Plot the normalized coefficients.

```
gtcc(audioIn,fs)
```



Specify Nondefault Parameters

Read in an audio file.

```
[audioIn,fs] = audioread("Turbine-16-44p1-mono-22secs.wav");
```

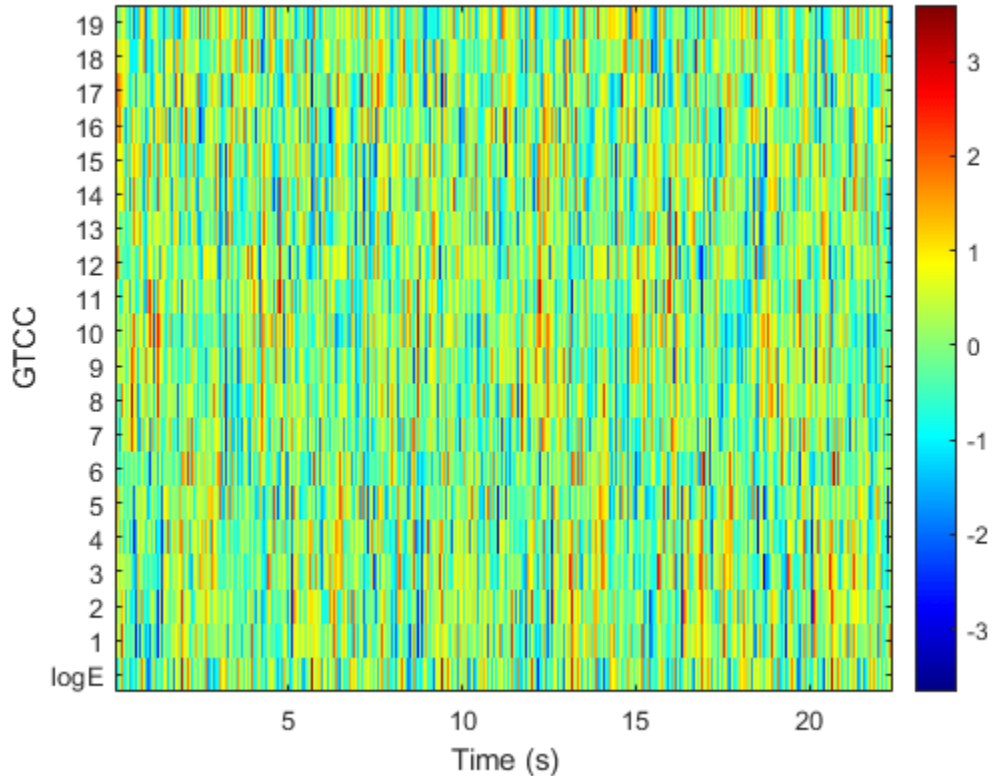
Calculate 20 GTCCs using filters equally spaced on the ERB scale between `hz2erb(62.5)` and `hz2erb(12000)`. Calculate the coefficients using 50 ms periodic Hann windows with 25 ms overlap. Replace the 0th coefficient with the log-energy. Use time-domain filtering.

```
[coeffs,~,~,loc] = gtcc(audioIn,fs, ...
    NumCoeffs=20, ...
    FrequencyRange=[62.5,12000], ...
    Window=hann(round(0.05*fs),"periodic"), ...
    OverlapLength=round(0.025*fs), ...
    LogEnergy="replace", ...
    FilterDomain="time");
```

Plot the normalized coefficients.

```
gtcc(audioIn,fs, ...
    NumCoeffs=20, ...
    FrequencyRange=[62.5,12000], ...
    Window=hann(round(0.05*fs),"periodic"), ...
    OverlapLength=round(0.025*fs), ...
```

```
LogEnergy="replace", ...
FilterDomain="time")
```



Extract GTCC from Frequency-Domain Audio

Read in an audio file and convert it to a frequency representation.

```
[audioIn,fs] = audioread("Rainbow-16-8-mono-114secs.wav");

win = hann(1024,"periodic");
S = stft(audioIn,"Window",win,"OverlapLength",512,"Centered",false);
```

To extract the gammatone cepstral coefficients, call `gtcc` with the frequency-domain audio. Ignore the log-energy.

```
coeffs = gtcc(S,fs,"LogEnergy","Ignore");
```

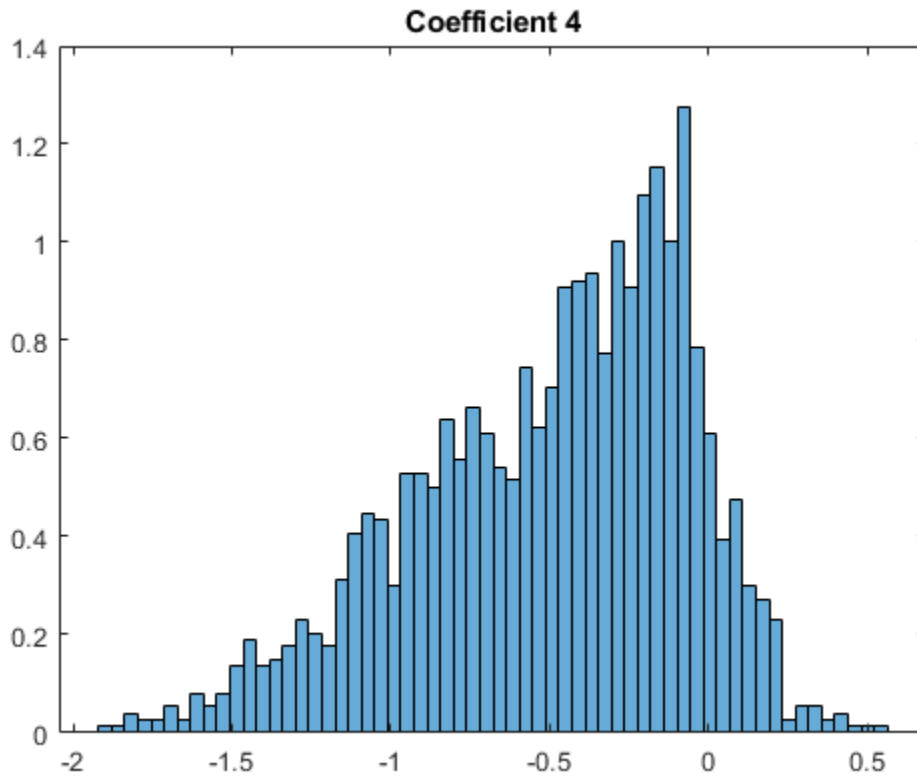
In many applications, GTCC observations are converted to summary statistics for use in classification tasks. Plot a probability density function for one of the gammatone cepstral coefficients to observe its distributions.

```
nbins = 60;
coefficientToAnalyze = ;
```

```

histogram(coeffs(:,coefficientToAnalyze+1),nbins,'Normalization','pdf')
title(sprintf("Coefficient %d",coefficientToAnalyze))

```



Input Arguments

audioIn — Input signal

vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array.

If `FilterDomain` is set to "frequency" (default), then `audioIn` can be real or complex.

- If `audioIn` is real, it is interpreted as a time-domain signal and must be a column vector or a matrix. Columns of the matrix are treated as independent audio channels.
- If `audioIn` is complex, it is interpreted as a frequency-domain signal. In this case, `audioIn` must be an L -by- M -by- N array, where L is the number of DFT points, M is the number of individual spectra, and N is the number of individual channels.

If `FilterDomain` is set to "time", then `audioIn` must be a real column vector or matrix. Columns of the matrix are treated as independent audio channels.

Data Types: single | double

Complex Number Support: Yes

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`**Name-Value Arguments**

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `coeffs = gtcc(audioIn,fs,LogEnergy="replace")` returns gammatone cepstral coefficients for the audio input signal sampled at `fs` Hz. For each analysis window, the first coefficient in the `coeffs` vector is replaced with the log energy of the input signal.

Window — Window applied in time domain`hamming(round(0.03*fs),"periodic")` (default) | vector

Window applied in time domain, specified as a real vector. The number of elements in the vector must be in the range `[1, size(audioIn,1)]`. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`**OverlapLength — Number of samples overlapped between adjacent windows**`round(0.02*fs)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range `[0, numel(Window)]`. If unspecified, `OverlapLength` defaults to `round(0.02*fs)`.

Data Types: `single` | `double`**NumCoeffs — Number of coefficients returned**`13` (default) | positive scalar integer

Number of coefficients returned for each window of data, specified as an integer in the range `[2, v]`. `v` is the number of valid passbands. If unspecified, `NumCoeffs` defaults to 13.

The number of valid passbands is defined as the number of ERB steps (ERB_N) in the frequency range of the filter bank. The frequency range of the filter bank is specified by `FrequencyRange`.

Data Types: `single` | `double`**FilterDomain — Domain in which to apply filtering**`"frequency"` (default) | `"time"`

Domain in which to apply filtering, specified as `"frequency"` or `"time"`. If unspecified, `FilterDomain` defaults to `"frequency"`.

Data Types: `string` | `char`**FrequencyRange — Frequency range of gammatone filter bank (Hz)**`[50 fs/2]` (default) | two-element row vector

Frequency range of gammatone filter bank in Hz, specified as a two-element row vector of increasing values in the range $[0, fs/2]$. If unspecified, `FrequencyRange` defaults to $[50, fs/2]$

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the discrete Fourier transform (DFT) of windowed input samples. The FFT length must be greater than or equal to the number of elements in the `Window`.

Data Types: `single` | `double`

Rectification — Type of nonlinear rectification

`'log'` (default) | `'cubic-root'`

Type of nonlinear rectification applied prior to the discrete cosine transform, specified as `'log'` or `'cubic-root'`.

Data Types: `char` | `string`

DeltaWindowLength — Number of coefficients used to calculate delta and delta-delta

9 (default) | odd integer greater than two

Number of coefficients used to calculate the delta and the delta-delta values, specified as an odd integer greater than two. If unspecified, `DeltaWindowLength` defaults to 9.

Deltas are computed using the `audioDelta` function.

Data Types: `single` | `double`

LogEnergy — Log energy usage

`"append"` (default) | `"replace"` | `"ignore"`

Log energy usage, specified as `"append"`, `"replace"`, or `"ignore"`. If unspecified, `LogEnergy` defaults to `"append"`.

- `"append"` -- The function prepends the log energy to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$.
- `"replace"` -- The function replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is `NumCoeffs`.
- `"ignore"` -- The function does not calculate or return the log energy.

Data Types: `char` | `string`

Output Arguments

coeffs — Gammatone cepstral coefficients

`matrix` | `array`

Gammatone cepstral coefficients, returned as an L -by- M matrix or an L -by- M -by- N array, where:

- L -- Number of analysis windows the audio signal is partitioned into. The input size, `Window`, and `OverlapLength` control this dimension: $L = \text{floor}((\text{size}(\text{audioIn}, 1) - \text{numel}(\text{Window})) / (\text{numel}(\text{Window}) - \text{OverlapLength}) + 1)$.

- *M* -- Number of coefficients returned per frame. This value is determined by `NumCoeffs` and `LogEnergy`.

When `LogEnergy` is set to:

- "append" -- The function prepends the log energy value to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$.
 - "replace" -- The function replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is `NumCoeffs`.
 - "ignore" -- The function does not calculate or return the log energy. The length of the coefficients vector is `NumCoeffs`.
- *N* -- Number of input channels (columns). This value is `size(audioIn,2)`.

Data Types: `single` | `double`

delta — Change in coefficients

matrix | array

Change in coefficients from one analysis window to another, returned as an *L*-by-*M* matrix or an *L*-by-*M*-by-*N* array. The `delta` array is the same size and data type as the `coeffs` array. See `coeffs` for the definitions of *L*, *M*, and *N*.

Data Types: `single` | `double`

deltaDelta — Change in delta values

matrix | array

Change in `delta` values, returned as an *L*-by-*M* matrix or an *L*-by-*M*-by-*N* array. The `deltaDelta` array is the same size and data type as the `coeffs` and `delta` arrays. See `coeffs` for the definitions of *L*, *M*, and *N*.

Data Types: `single` | `double`

loc — Location of the last sample in each analysis window

column vector

Location of last sample in each analysis window, returned as a column vector with the same number of rows as `coeffs`.

Data Types: `single` | `double`

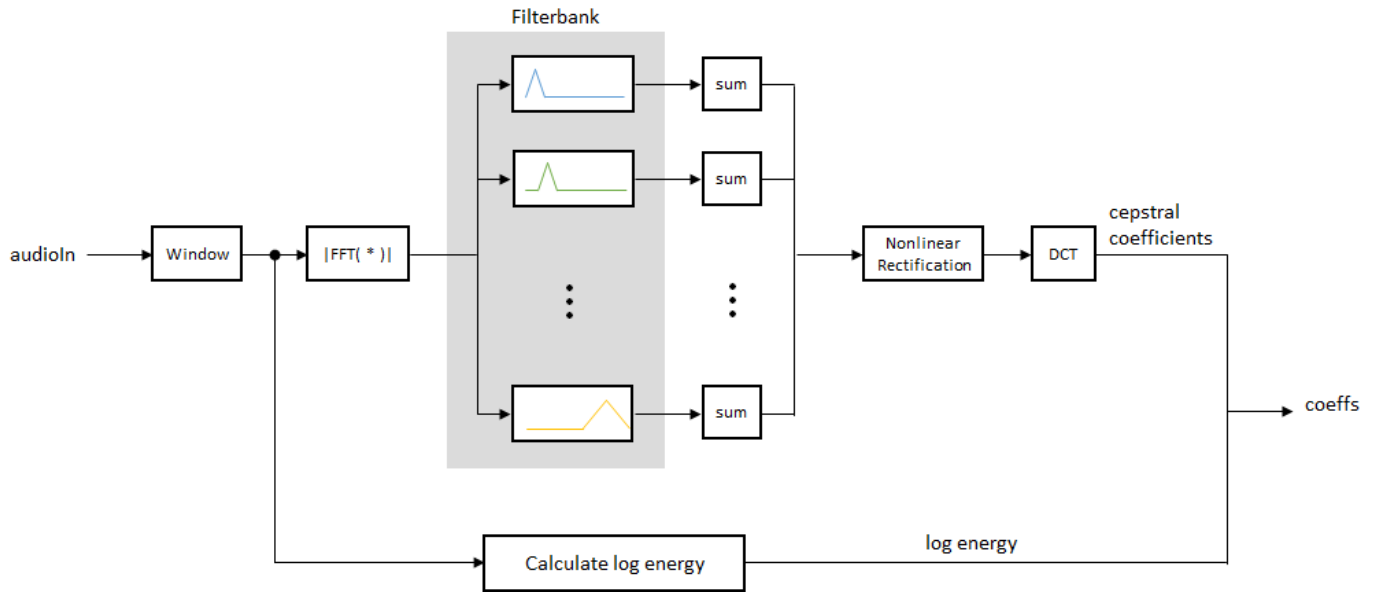
Algorithms

The `gtcc` function splits the entire data into overlapping segments. The length of each analysis window is determined by `Window`. The length of overlap between analysis windows is determined by `OverlapLength`. The algorithm to determine the gammatone cepstral coefficients depends on the filter domain, specified by `FilterDomain`. The default filter domain is `frequency`.

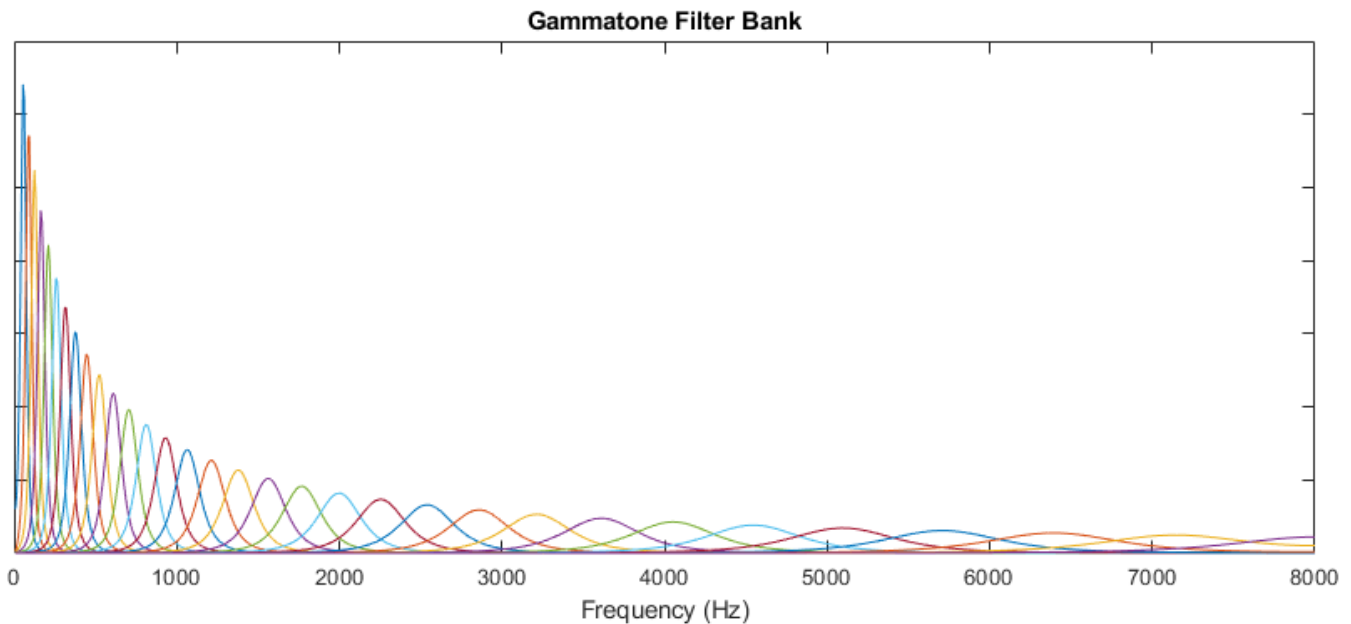
Frequency-Domain Filtering

Gammatone cepstrum coefficients are popular features extracted from speech signals for use in recognition tasks. In the source-filter model of speech, cepstral coefficients are understood to represent the filter (vocal tract). The vocal tract frequency response is relatively smooth, whereas the source of voiced speech can be modeled as an impulse train. As a result, the vocal tract can be estimated by the spectral envelope of a speech segment.

The motivating idea of gammatone cepstral coefficients is to compress information about the vocal tract (smoothed spectrum) into a small number of coefficients based on an understanding of the cochlea. Although there is no hard standard for calculating the coefficients, the basic steps are outlined by the diagram.



The default gammatone filter bank is composed of gammatone filters spaced linearly on the ERB scale between 50 and 8000 Hz. The filter bank is designed by `designAuditoryFilterBank`.



The information contained in the zeroth gammatone cepstral coefficient is often augmented with or replaced by the log energy. The log energy calculation depends on the input domain.

If the input is a time-domain signal, the log energy is computed using the following equation:

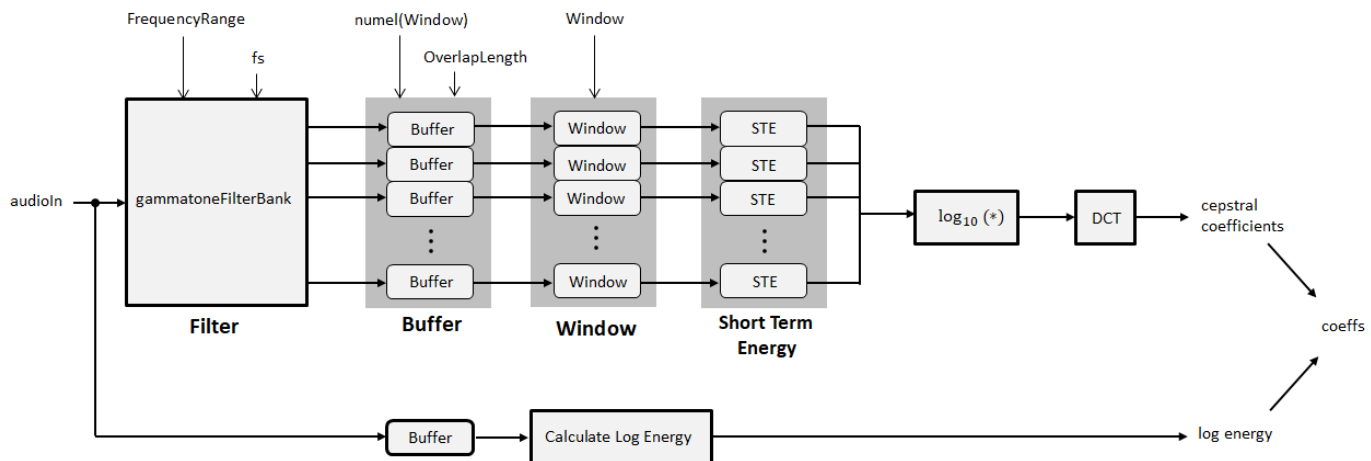
$$\log E = \log(\text{sum}(x^2))$$

If the input is a frequency-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(|x|^2)/\text{FFTLengh})$$

Time-Domain Filtering

If `FilterDomain` is specified as "time", the `gtcc` function uses the `gammatoneFilterBank` to apply time-domain filtering. The basic steps of the `gtcc` algorithm are outlined by the diagram.



The `FrequencyRange` and sample rate (`fs`) parameters are set on the filter bank using the name-value pairs input to the `gtcc` function. The number of filters in the gammatone filter bank is defined as $\text{hz2erb}(\text{FrequencyRange}(2)) - \text{hz2erb}(\text{FrequencyRange}(1))$. This roughly corresponds to placing a gammatone filter every 0.9 mm in the cochlea.

The output from the gammatone filter bank is a multichannel signal. Each channel output from the gammatone filter bank is buffered into overlapped analysis windows, as specified by the `Window` and `OverlapLength` parameters. The energy for each analysis window of data is calculated. The STE of the channels are concatenated. The concatenated signal is then passed through a logarithm function and transformed to the cepstral domain using a discrete cosine transform (DCT).

The log-energy is calculated on the original audio signal using the same buffering scheme applied to the gammatone filter bank output.

Compatibility Considerations

Delta and delta-delta computation

Behavior changed in R2020b

The delta and delta-delta calculations are now computed using the `audioDelta` function, which has a different startup behavior than the previous algorithm. The default value of the `DeltaWindowLength` parameter has changed from 2 to 9. A delta window length of 2 is no longer supported.

WindowLength will be removed in a future release

Behavior change in future release

The `WindowLength` parameter will be removed from the `gtcc` function in a future release. Use the `Window` parameter instead.

In releases prior to R2020b, you could only specify the length of a time-domain window. The window was always designed as a periodic Hamming window. You can replace instances of the code

```
coeffs = gtcc(audioIn,fs,WindowLength=1024);
```

With this code:

```
coeffs = gtcc(audioIn,fs,Window=hamming(1024,"periodic"));
```

References

- [1] Shao, Yang, Zhaozhang Jin, Deliang Wang, and Soundararajan Srinivasan. "An Auditory-Based Feature for Robust Speech Recognition." *IEEE International Conference on Acoustics, Speech and Signal Processing*. 2009.
- [2] Valero, X., and F. Alias. "Gammatone Cepstral Coefficients: Biologically Inspired Features for Non-Speech Audio Classification." *IEEE Transactions on Multimedia*. Vol. 14, Issue 6, 2012, pp. 1684-1689.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

[mfcc](#) | [audioDelta](#) | [cepstralCoefficients](#) | [audioFeatureExtractor](#) | [detectSpeech](#) | [Cepstral Feature Extractor](#)

Topics

"Speech Emotion Recognition"

Introduced in R2019a

spectralSpread

Spectral spread for audio signals and auditory spectrograms

Syntax

```
spread = spectralSpread(x,f)
spread = spectralSpread(x,f,Name=Value)
[spread,centroid] = spectralSpread( ___ )
spectralSpread( ___ )
```

Description

`spread = spectralSpread(x,f)` returns the spectral spread of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`spread = spectralSpread(x,f,Name=Value)` specifies options using one or more name-value arguments.

`[spread,centroid] = spectralSpread(___)` returns the spectral centroid. You can specify an input combination from any of the previous syntaxes.

`spectralSpread(___)` with no output arguments plots the spectral spread.

- If the input is in the time domain, the spectral spread is plotted against time.
- If the input is in the frequency domain, the spectral spread is plotted against frame number.

Examples

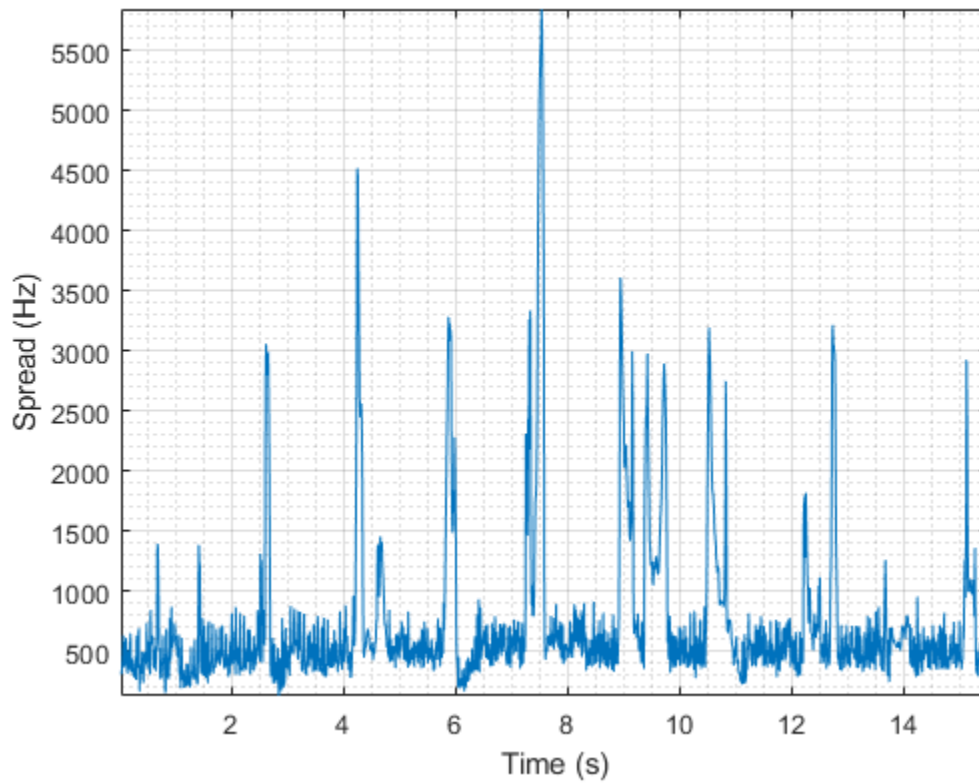
Spectral Spread of Time-Domain Audio

Read in an audio file, calculate the spread using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
spread = spectralSpread(audioIn,fs);
```

Plot the spectral spread against time.

```
spectralSpread(audioIn,fs)
```



Spectral Spread of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the spread of the mel spectrums over time.

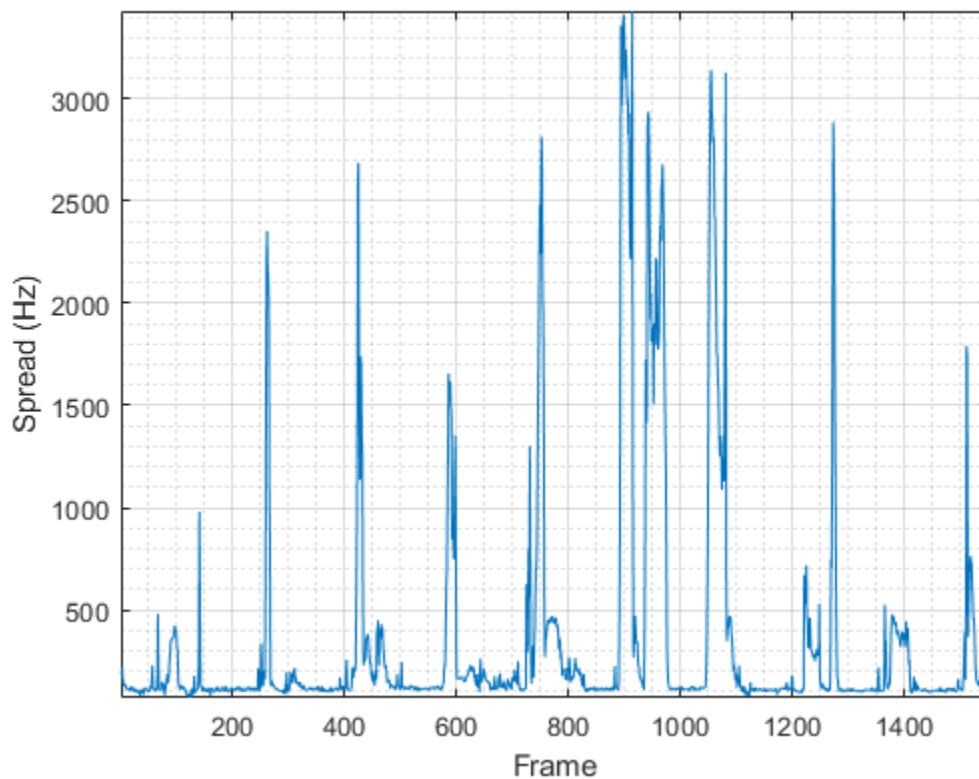
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[s,cf,t] = melSpectrogram(audioIn,fs);
```

```
spread = spectralSpread(s,cf);
```

Plot spectral spread against the frame number.

```
spectralSpread(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

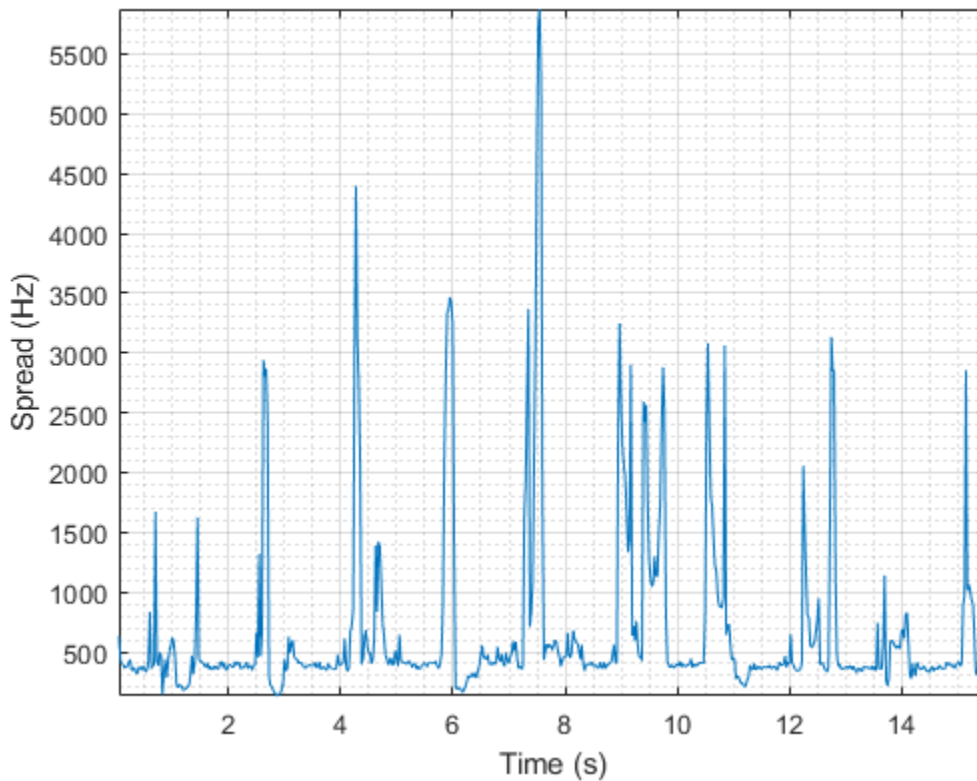
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the spread of the power spectrum over time. Calculate the spread for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the spread calculation.

```
spread = spectralSpread(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral spread.

```
spectralSpread(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```



Calculate Spectral Spread of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral spread calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

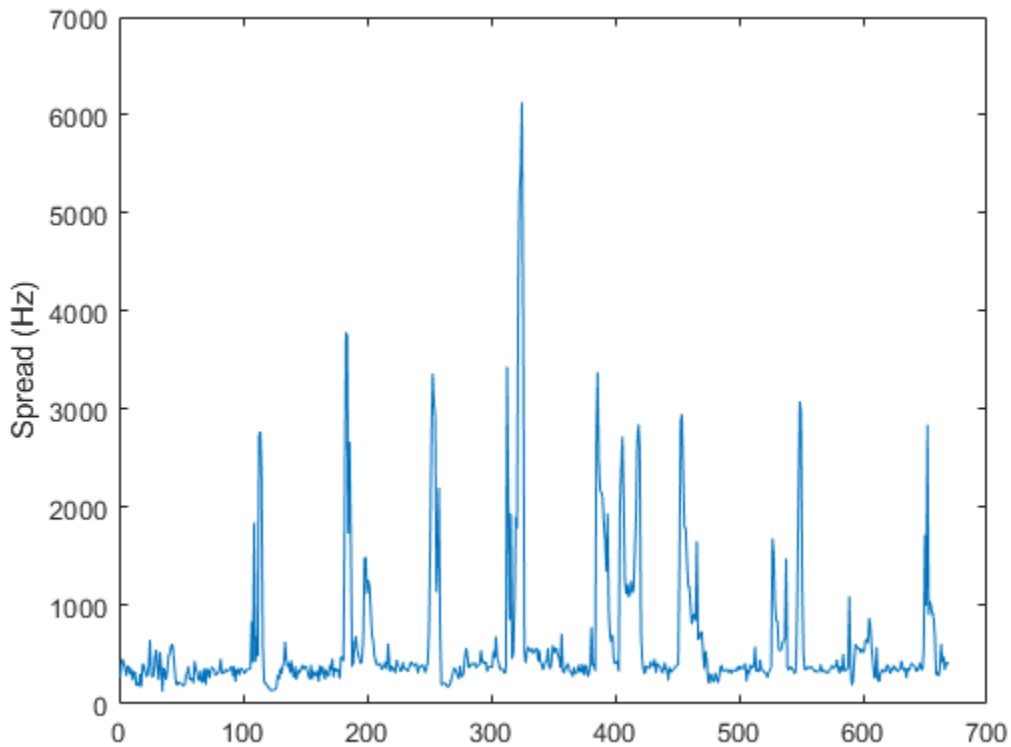
- 1 Read in a frame of audio data.
- 2 Calculate the spectral spread for the frame of audio.
- 3 Log the spectral spread for later plotting.

To calculate the spectral spread for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    spread = spectralSpread(audioIn,fileReader.SampleRate, ...
        'Window',win, ...
        'OverlapLength',0);
    logger(spread)
```

```
end
```

```
plot(logger.Buffer)  
ylabel('Spread (Hz)')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralSpread`.
- You want to calculate the spectral spread for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

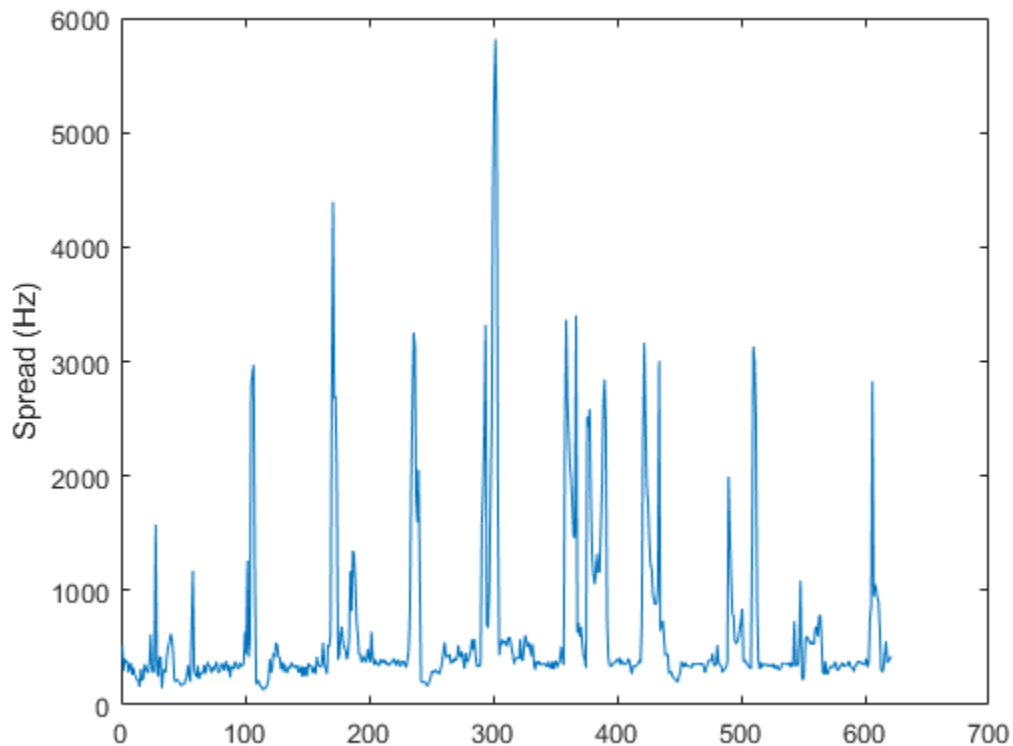
```
buff = dsp.AsyncBuffer;  
reset(logger)  
release(fileReader)
```

Specify that the spectral spread is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;  
  
samplesPerFrame = round(fs*0.05);  
samplesOverlap = round(fs*0.025);  
  
samplesPerHop = samplesPerFrame - samplesOverlap;
```



```
win = hamming(samplesPerFrame);  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buff,audioIn);  
  
    while buff.NumUnreadSamples >= samplesPerHop  
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);  
  
        spread = spectralSpread(audioBuffered,fs, ...  
                                'Window',win, ...  
                                'OverlapLength',0);  
  
        logger(spread)  
    end  
end  
release(fileReader)  
  
Plot the logged data.  
  
plot(logger.Buffer)  
ylabel('Spread (Hz)')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral spread is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral spread is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

spread — Spectral spread (Hz)

`scalar` | `vector` | `matrix`

Spectral spread in Hz, returned as a scalar, vector, or matrix. Each row of `centroid` corresponds to the spectral spread of a window of `x`. Each column of `spread` corresponds to an independent channel.

centroid — Spectral centroid (Hz)

`scalar` | `vector` | `matrix`

Spectral centroid in Hz, returned as a scalar, vector, or matrix. Each row of `centroid` corresponds to the spectral centroid of a window of `x`. Each column of `centroid` corresponds to an independent channel.

Algorithms

The spectral spread is calculated as described in [1]:

$$\text{spread} = \sqrt{\frac{\sum_{k=b_1}^{b_2} (f_k - \mu_1)^2 s_k}{\sum_{k=b_1}^{b_2} s_k}}$$

where

- f_k is the frequency in Hz corresponding to bin k .
- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral spread.
- μ_1 is the spectral centroid, calculated as described by the `spectralCentroid` function.

References

- [1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralCentroid` | `spectralSkewness` | `spectralKurtosis`

Topics

"Spectral Descriptors"

Introduced in R2019a

spectralSlope

Spectral slope for audio signals and auditory spectrograms

Syntax

```
slope = spectralSlope(x,f)
slope = spectralSlope(x,f,Name=Value)
spectralSlope( ___ )
```

Description

`slope = spectralSlope(x,f)` returns the spectral slope of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`slope = spectralSlope(x,f,Name=Value)` specifies options using one or more name-value arguments.

`spectralSlope(___)` with no output arguments plots the spectral slope. You can specify an input combination from any of the previous syntaxes.

- If the input is in the time domain, the spectral slope is plotted against time.
- If the input is in the frequency domain, the spectral slope is plotted against frame number.

Examples

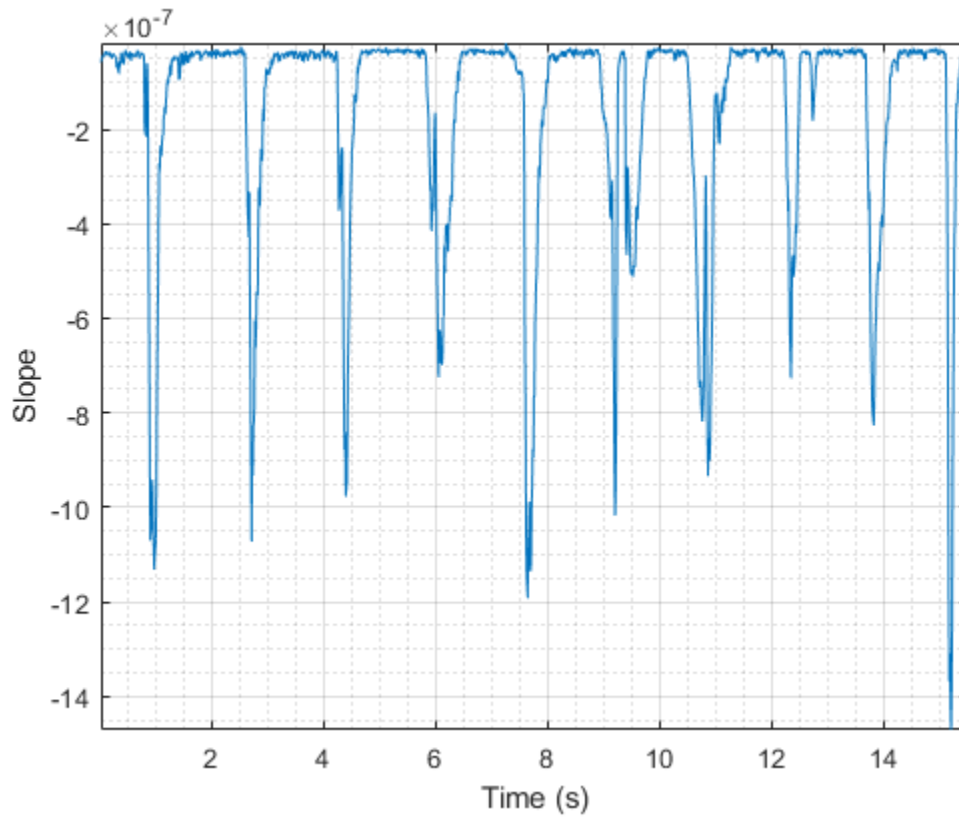
Spectral Slope of Time-Domain Audio

Read in an audio file, calculate the slope using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
slope = spectralSlope(audioIn,fs);
```

Plot the spectral slope against time.

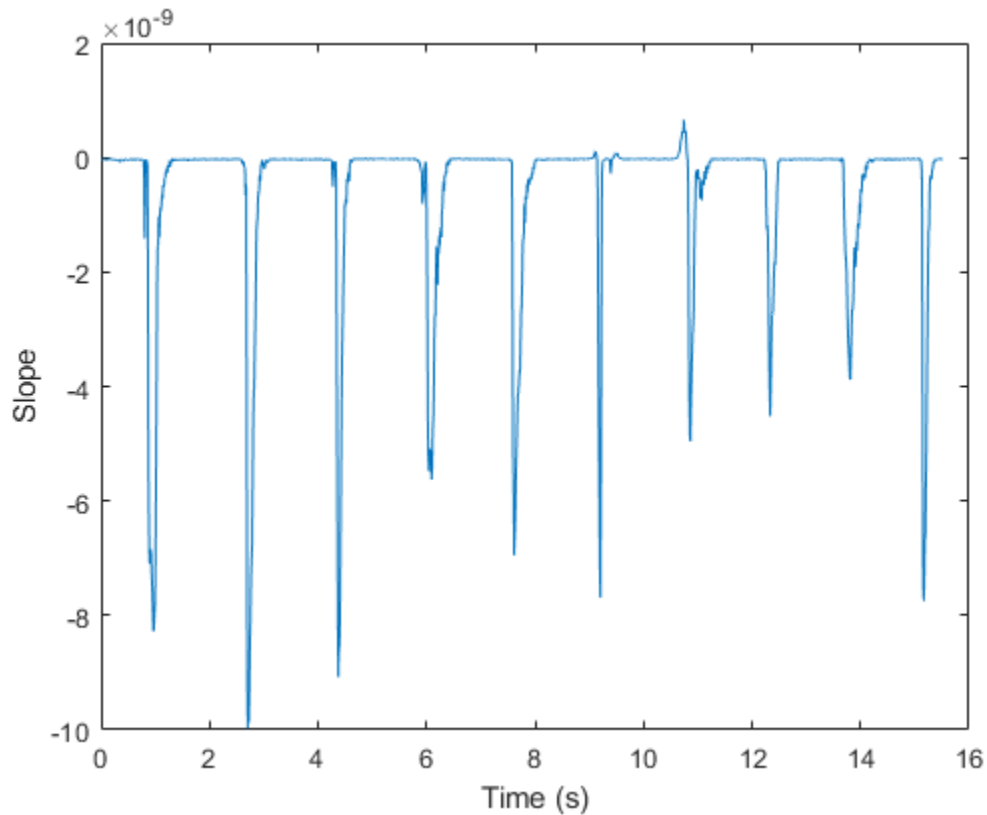
```
spectralSlope(audioIn,fs)
```



Spectral Slope of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the slope of the mel spectrogram over time. Plot the results.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');  
[s,cf,t] = melSpectrogram(audioIn,fs);  
slope = spectralSlope(s,cf);  
plot(t,slope)  
xlabel('Time (s)')  
ylabel('Slope')
```



Specify Nondefault Parameters

Read in an audio file.

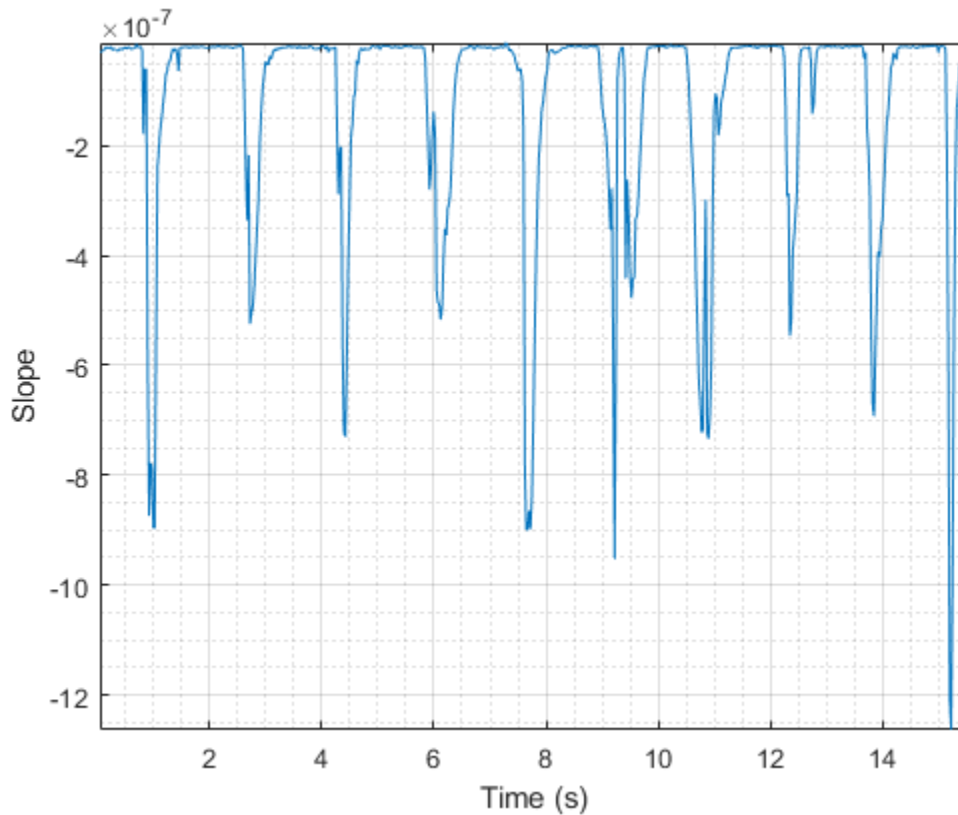
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the slope of the magnitude spectrum over time. Calculate the slope for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the slope calculation.

```
slope = spectralSlope(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral slope against time.

```
spectralSlope(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```



Calculate Spectral Slope of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral slope calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral slope for the frame of audio.
- 3 Log the spectral slope for later plotting.

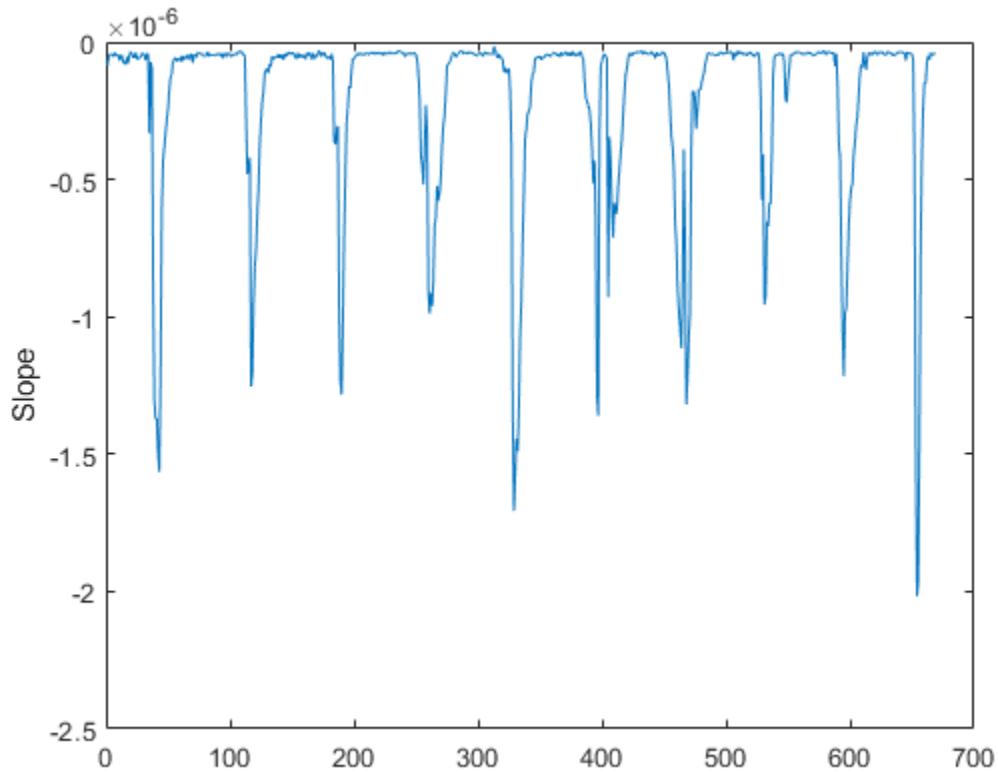
To calculate the spectral slope for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    slope = spectralSlope(audioIn,fileReader.SampleRate, ...
                        'Window',win, ...
                        'OverlapLength',0);
    logger(slope)
```



```
end
```

```
plot(logger.Buffer)
ylabel('Slope')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralSlope`.
- You want to calculate the spectral slope for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral slope is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

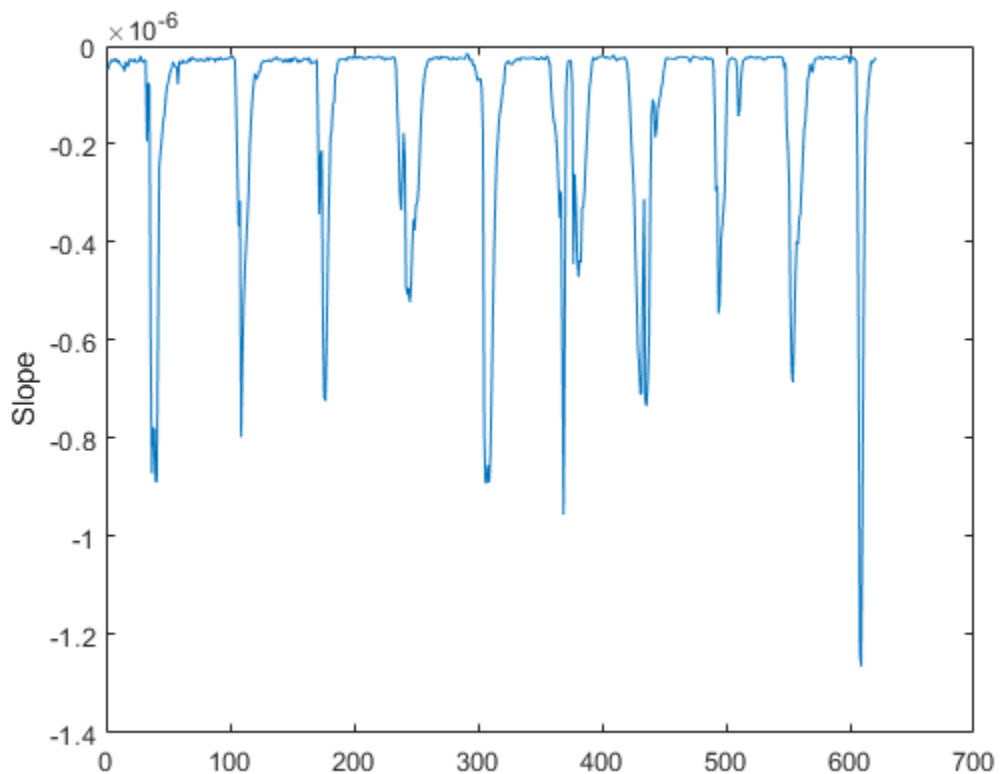
samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;
```

```
win = hamming(samplesPerFrame);  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buff,audioIn);  
  
    while buff.NumUnreadSamples >= samplesPerHop  
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);  
  
        slope = spectralSlope(audioBuffered,fs, ...  
                               'Window',win, ...  
                               'OverlapLength',0);  
  
        logger(slope)  
    end  
end  
release(fileReader)
```

Plot the logged data.

```
plot(logger.Buffer)  
ylabel('Slope')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets **x** depends on the shape of **f**.

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets **x** depends on the shape of **f**:

- If **f** is a scalar, **x** is interpreted as a time-domain signal, and **f** is interpreted as the sample rate. In this case, **x** must be a real vector or matrix. If **x** is specified as a matrix, the columns are interpreted as individual channels.
- If **f** is a vector, **x** is interpreted as a frequency-domain signal, and **f** is interpreted as the frequencies, in Hz, corresponding to the rows of **x**. In this case, **x** must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of **f**, M is the number of individual spectra, and N is the number of channels.
- The number of rows of **x**, L , must be equal to the number of elements of **f**.

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if **x** is a time-domain signal. If **x** is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"magnitude"` (default) | `"power"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral slope is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral slope is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

slope — Spectral slope

`scalar` | `vector` | `matrix`

Spectral slope in Hz, returned as a scalar, vector, or matrix. Each row of `slope` corresponds to the spectral slope of a window of `x`. Each column of `slope` corresponds to an independent channel.

Algorithms

The spectral slope is calculated as described in [1]:

$$\text{slope} = \frac{\sum_{k=b_1}^{b_2} (f_k - \mu_f)(s_k - \mu_s)}{\sum_{k=b_1}^{b_2} (f_k - \mu_f)^2}$$

where

- f_k is the frequency in Hz corresponding to bin k .
- μ_f is the mean frequency.
- s_k is the spectral value at bin k .
- μ_s is the mean spectral value.

- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral slope.

References

- [1] Lerch, Alexander. *An Introduction to Audio Content Analysis Applications in Signal Processing and Music Informatics*. Piscataway, NJ: IEEE Press, 2012.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

spectralCrest | spectralDecrease

Topics

“Spectral Descriptors”

Introduced in R2019a

spectralSkewness

Spectral skewness for audio signals and auditory spectrograms

Syntax

```
skewness = spectralSkewness(x,f)
skewness = spectralSkewness(x,f,Name=Value)
[skewness,spread,centroid] = spectralSkewness( ___ )
spectralSkewness( ___ )
```

Description

`skewness = spectralSkewness(x,f)` returns the spectral skewness of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`skewness = spectralSkewness(x,f,Name=Value)` specifies options using one or more name-value arguments.

`[skewness,spread,centroid] = spectralSkewness(___)` returns the spectral spread and spectral centroid. You can specify an input combination from any of the previous syntaxes.

`spectralSkewness(___)` with no output arguments plots the spectral skewness.

- If the input is in the time domain, the spectral skewness is plotted against time.
- If the input is in the frequency domain, the spectral skewness is plotted against frame number.

Examples

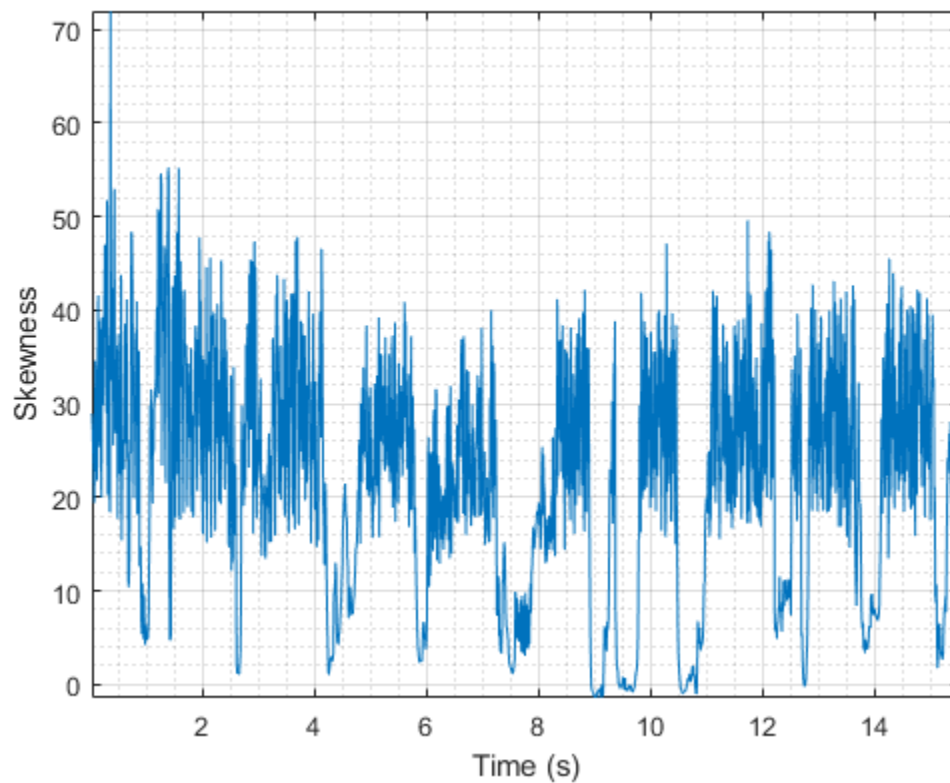
Spectral Skewness of Time-Domain Audio

Read in an audio file, calculate the skewness using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
skewness = spectralSkewness(audioIn,fs);
```

Plot the spectral skewness against time.

```
spectralSkewness(audioIn,fs)
```



Spectral Skewness of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the skewness of the mel spectrogram over time.

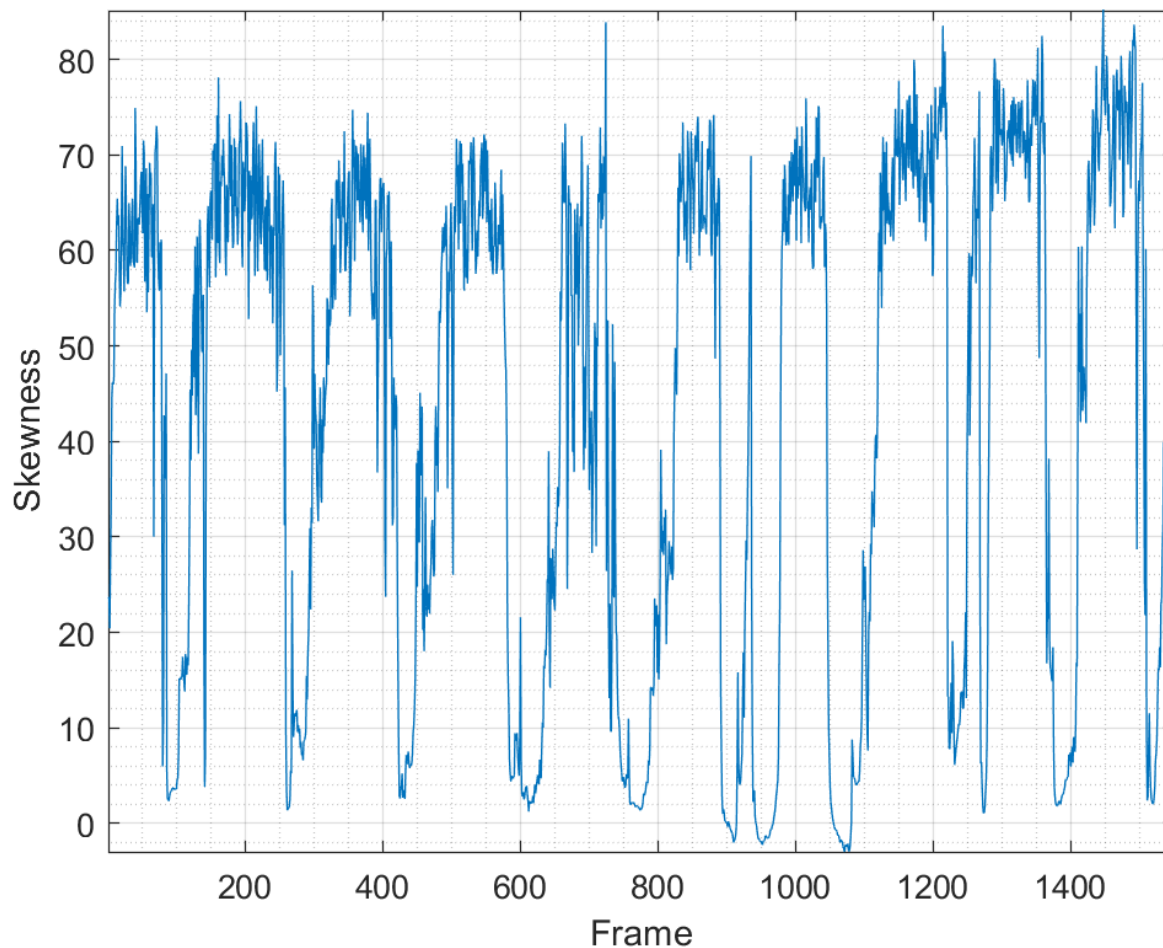
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[s,cf,t] = melSpectrogram(audioIn,fs);
```

```
skewness = spectralSkewness(s,cf);
```

Plot the spectral skewness against the frame number.

```
spectralSkewness(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the skewness of the power spectrum over time. Calculate the skewness for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the skewness calculation.

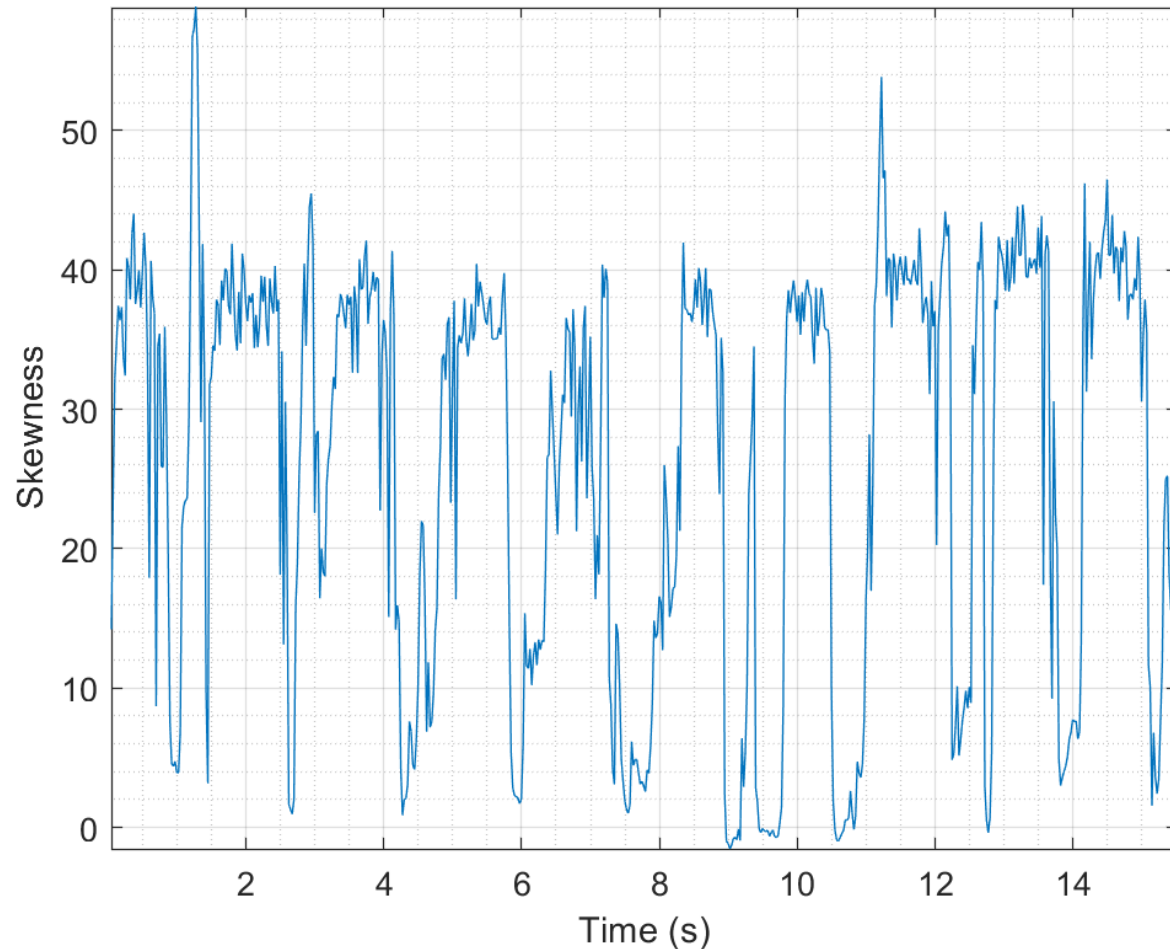
```
skewness = spectralSkewness(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral skewness.

```
spectralSkewness(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
```



```
OverlapLength=round(0.025*fs), ...
Range=[62.5, fs/2])
```



Calculate Spectral Skewness of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral skewness calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

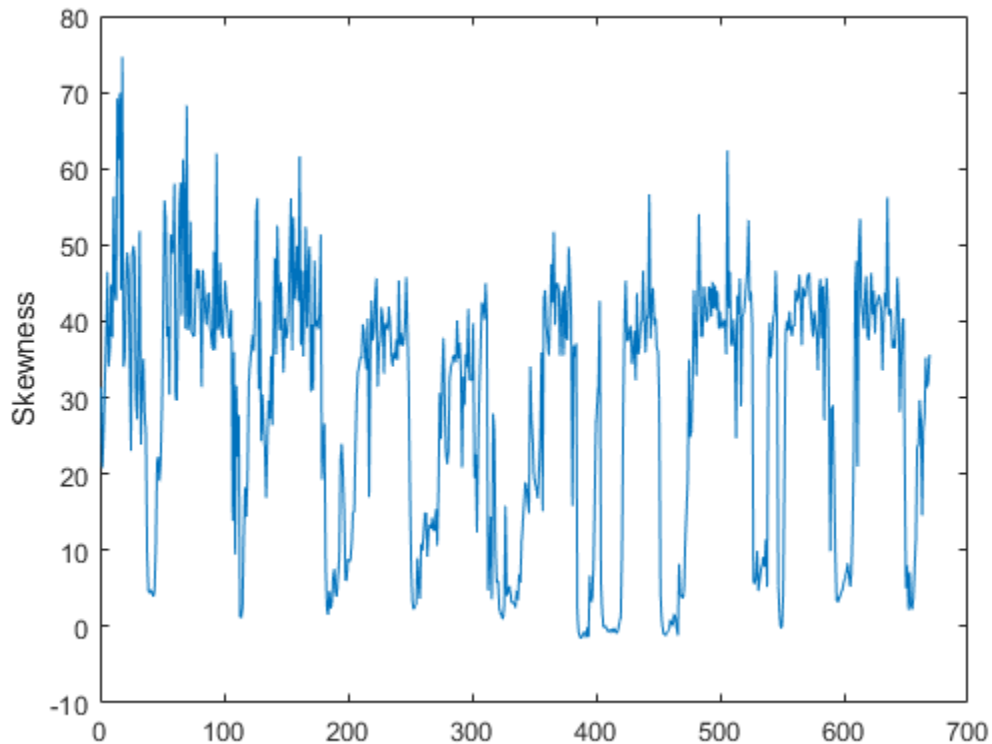
- 1 Read in a frame of audio data.
- 2 Calculate the spectral skewness for the frame of audio.
- 3 Log the spectral skewness for later plotting.

To calculate the spectral skewness for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    skewness = spectralSkewness(audioIn,fileReader.SampleRate, ...
                               'Window',win, ...
                               'OverlapLength',0);

    logger(skewness)
end

plot(logger.Buffer)
ylabel('Skewness')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralSkewness`.
- You want to calculate the spectral skewness for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral skewness is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame);

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff, audioIn);

    while buff.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(buff, samplesPerFrame, samplesOverlap);

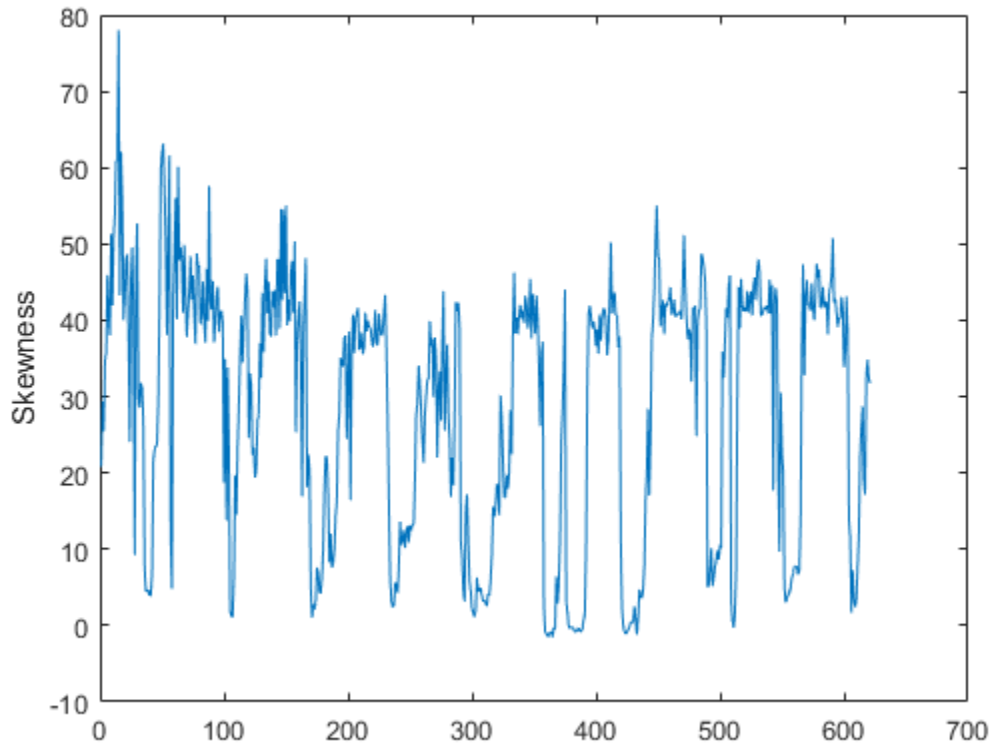
        skewness = spectralSkewness(audioBuffered, fs, ...
                                   'Window', win, ...
                                   'OverlapLength', 0);

        logger(skewness)
    end
end

release(fileReader)

Plot the logged data.

plot(logger.Buffer)
ylabel('Skewness')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.

- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range $[0, f/2]$.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- "power" -- The spectral skewness is calculated for the one-sided power spectrum.
- "magnitude" -- The spectral skewness is calculated for the one-sided magnitude spectrum.

Data Types: char | string

Output Arguments

skewness — Spectral skewness

scalar | vector | matrix

Spectral skewness, returned as a scalar, vector, or matrix. Each row of `skewness` corresponds to the spectral skewness of a window of `x`. Each column of `skewness` corresponds to an independent channel.

spread — Spectral spread

scalar | vector | matrix

Spectral spread, returned as a scalar, vector, or matrix. Each row of `spread` corresponds to the spectral spread of a window of `x`. Each column of `spread` corresponds to an independent channel.

centroid — Spectral centroid (Hz)

scalar | vector | matrix

Spectral centroid in Hz, returned as a scalar, vector, or matrix. Each row of `centroid` corresponds to the spectral centroid of a window of `x`. Each column of `centroid` corresponds to an independent channel.

Algorithms

The spectral skewness is calculated as described in [1]:

$$\text{skewness} = \frac{\sum_{k=b_1}^{b_2} (f_k - \mu_1)^3 s_k}{(\mu_2)^3 \sum_{k=b_1}^{b_2} s_k}$$

where

- f_k is the frequency in Hz corresponding to bin k .
- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral skewness.
- μ_1 is the spectral centroid, calculated as described by the `spectralCentroid` function.
- μ_2 is the spectral spread, calculated as described by the `spectralSpread` function.

References

- [1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

[spectralCentroid](#) | [spectralSpread](#) | [spectralKurtosis](#)

Topics

“Spectral Descriptors”

Introduced in R2019a

spectralRolloffPoint

Spectral rolloff point for audio signals and auditory spectrograms

Syntax

```
rolloffPoint = spectralRolloffPoint(x,f)
rolloffPoint = spectralRolloffPoint(x,f,Name=Value)
spectralRolloffPoint( ___ )
```

Description

`rolloffPoint = spectralRolloffPoint(x,f)` returns the spectral rolloff point of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`rolloffPoint = spectralRolloffPoint(x,f,Name=Value)` specifies options using one or more name-value arguments.

`spectralRolloffPoint(___)` with no output arguments plots the spectral rolloff point. You can specify an input combination from any of the previous syntaxes.

- If the input is in the time domain, the spectral rolloff point is plotted against time.
- If the input is in the frequency domain, the spectral rolloff point is plotted against frame number.

Examples

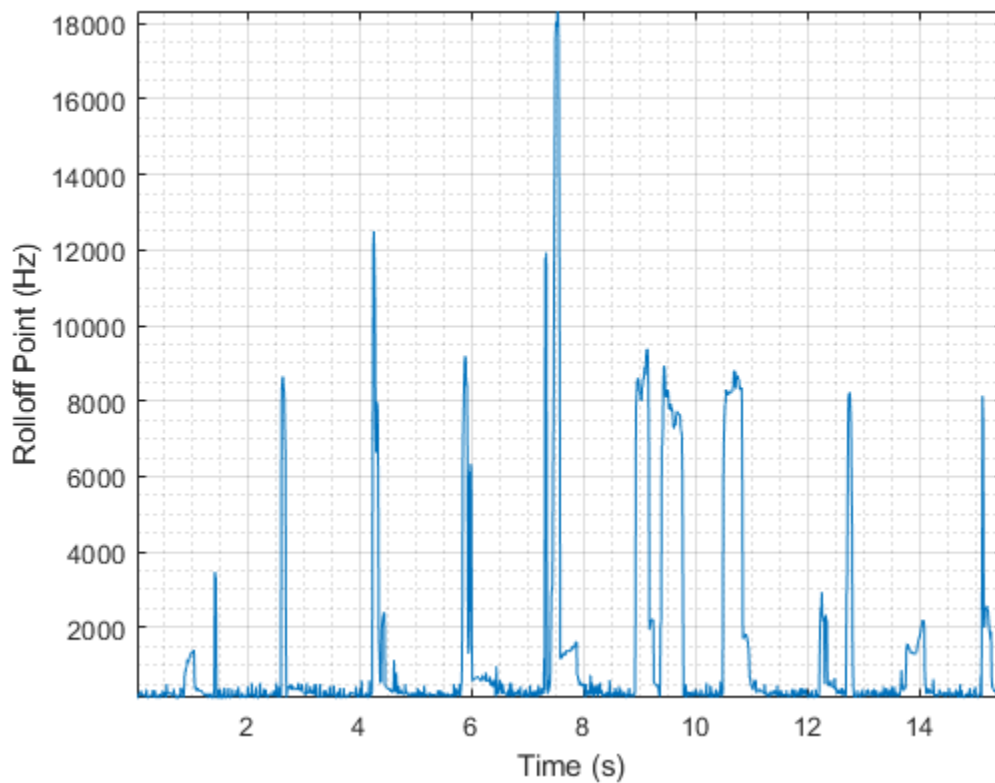
Spectral Rolloff Point of Time-Domain Audio

Read in an audio file. Calculate the rolloff point using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
rolloffPoint = spectralRolloffPoint(audioIn,fs);
```

Plot the spectral rolloff point against time.

```
spectralRolloffPoint(audioIn,fs)
```

Spectral Rolloff Point of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the rolloff point of the mel spectrogram over time.

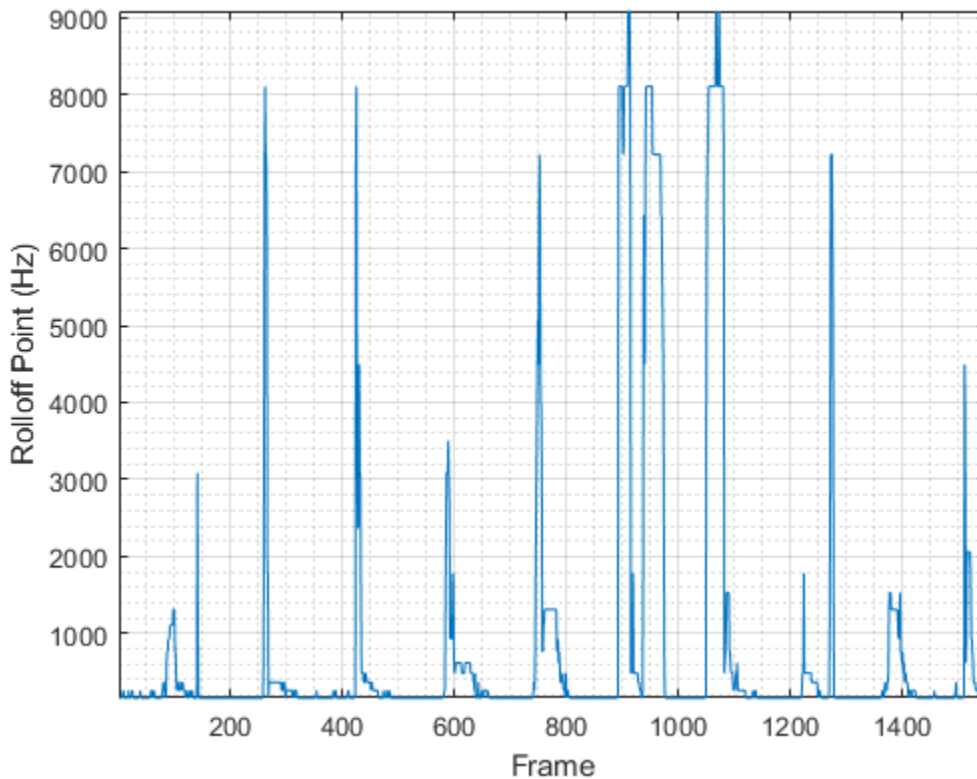
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[s,cf,t] = melSpectrogram(audioIn,fs);
```

```
rolloffPoint = spectralRolloffPoint(s,cf);
```

Plot the spectral rolloff point against the frame number.

```
spectralRolloffPoint(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

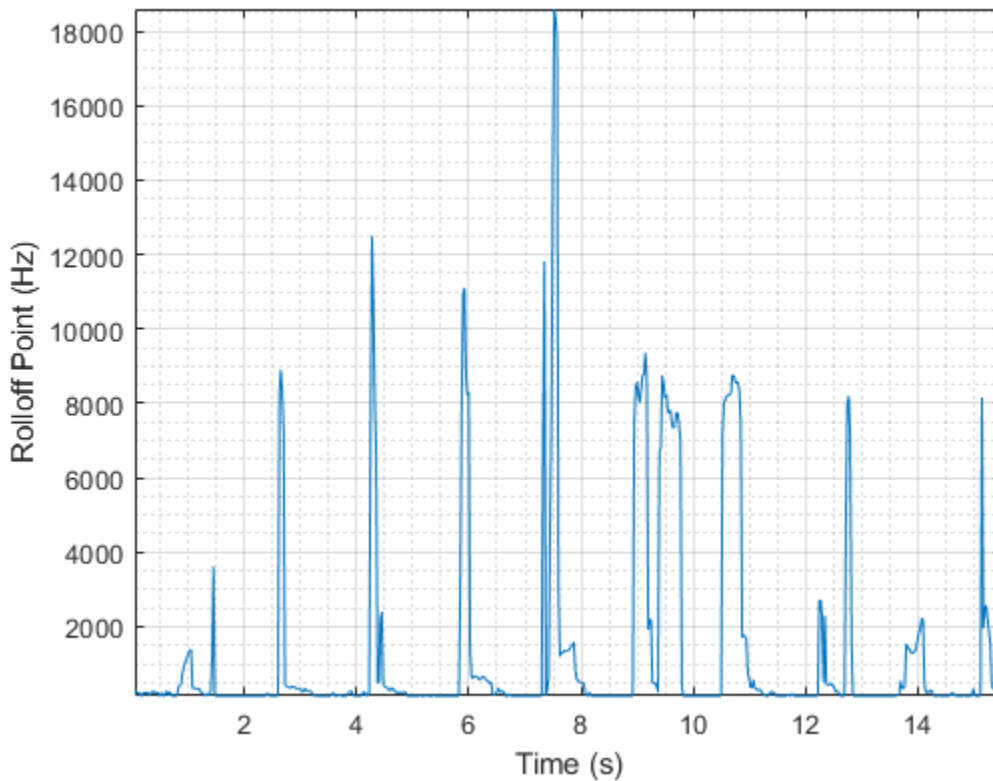
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the rolloff point of the power spectrum over time. Calculate the rolloff point for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $f_s/2$ for the rolloff point calculation.

```
rolloffPoint = spectralRolloffPoint(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral rolloff point against time.

```
spectralRolloffPoint(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2])
```



Calculate Spectral Rolloff Point of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral rolloff point calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral rolloff point for the frame of audio.
- 3 Log the spectral rolloff point for later plotting.

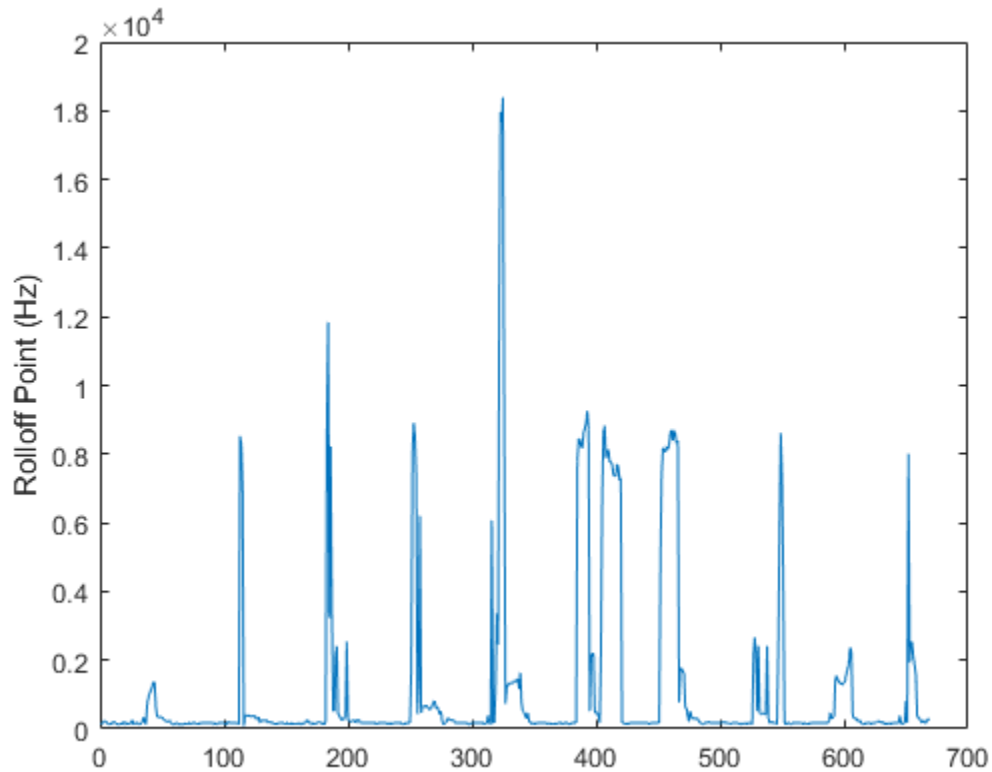
To calculate the spectral rolloff point for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    rolloffPoint = spectralRolloffPoint(audioIn,fileReader.SampleRate, ...
                                      'Window',win, ...
                                      'OverlapLength',0);

    logger(rolloffPoint)
```

```
end
```

```
plot(logger.Buffer)
ylabel('Rolloff Point (Hz)')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralRolloffPoint`.
- You want to calculate the spectral rolloff point for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral rolloff point is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;
```

```

win = hamming(samplesPerFrame);

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff,audioIn);

    while buff.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);

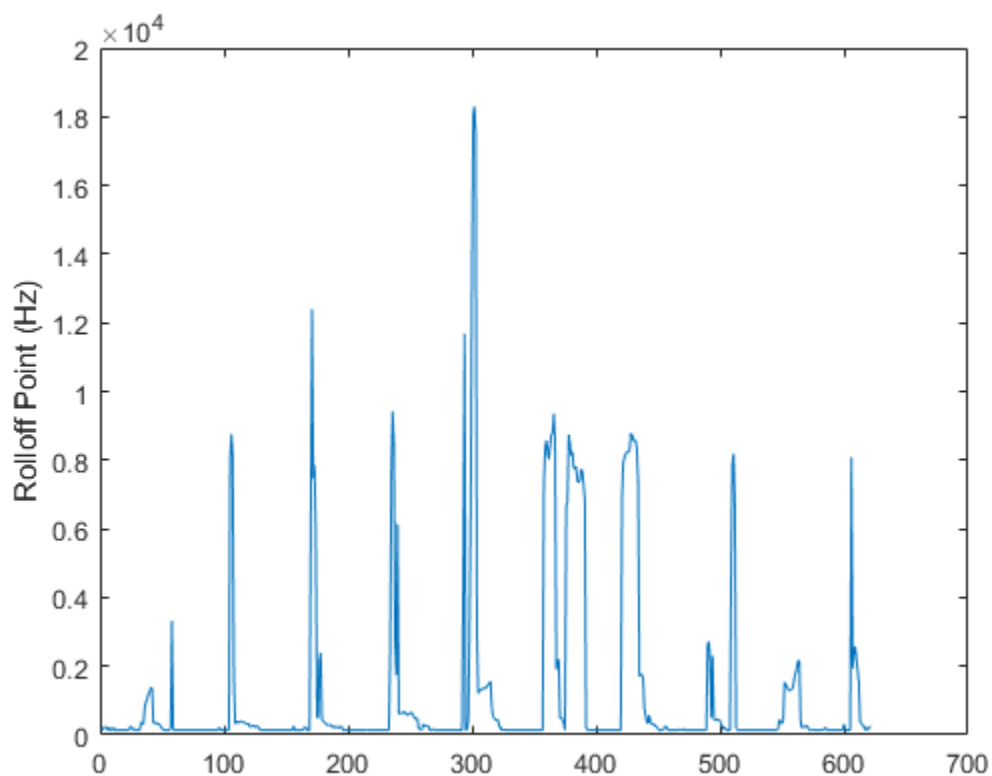
        rolloffPoint = spectralRolloffPoint(audioBuffered,fs, ...
            'Window',win, ...
            'OverlapLength',0);

        logger(rolloffPoint)
    end
end
release(fileReader)

Plot the logged data.

plot(logger.Buffer)
ylabel('Rolloff Point (Hz)')

```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Threshold — Threshold of rolloff point

0.95 (default) | scalar in the range (0,1)

Threshold of rolloff point, specified as a scalar between zero and one, exclusive.

Data Types: `single` | `double`

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range `[0, size(Window,1))`.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral rolloff point is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral rolloff point is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

rolloffPoint — Spectral rolloff point (Hz)

scalar | vector | matrix

Spectral rolloff point in Hz, returned as a scalar, vector, or matrix. Each row of `rolloffPoint` corresponds to the spectral rolloff point of a window of `x`. Each column of `rolloffPoint` corresponds to an independent channel.

Algorithms

The spectral rolloff point is calculated as described in [1]:

$$\text{rolloffPoint} = i$$

such that

$$\sum_{k=b_1}^i s_k = K \sum_{k=b_1}^{b_2} s_k$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral spread.
- κ is the percentage of total energy contained between b_1 and i . You can set κ using `Threshold`.

References

- [1] Scheirer, E., and M. Slaney, "Construction and Evaluation of a Robust Multifeature Speech/Music Discriminator," *IEEE International Conference on Acoustics, Speech, and Signal Processing*. Volume 2, 1997, pp. 1221-1224.

Extended Capabilities

C/C++ Code Generation

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GPU Arrays

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See Also

`spectralSpread` | `spectralSkewness` | `spectralKurtosis`

Topics

"Spectral Descriptors"

Introduced in R2019a

spectralKurtosis

Spectral kurtosis for audio signals and auditory spectrograms

Syntax

```
kurtosis = spectralKurtosis(x,f)
kurtosis = spectralKurtosis(x,f,Name=Value)
[kurtosis,spread,centroid] = spectralKurtosis( ___ )
spectralKurtosis( ___ )
```

Description

`kurtosis = spectralKurtosis(x,f)` returns the spectral kurtosis of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`kurtosis = spectralKurtosis(x,f,Name=Value)` specifies options using one or more name-value arguments.

`[kurtosis,spread,centroid] = spectralKurtosis(___)` returns the spectral spread and spectral centroid. You can specify an input combination from any of the previous syntaxes.

`spectralKurtosis(___)` with no output arguments plots the spectral kurtosis.

- If the input is in the time domain, the spectral kurtosis is plotted against time.
- If the input is in the frequency domain, the spectral kurtosis is plotted against frame number.

Examples

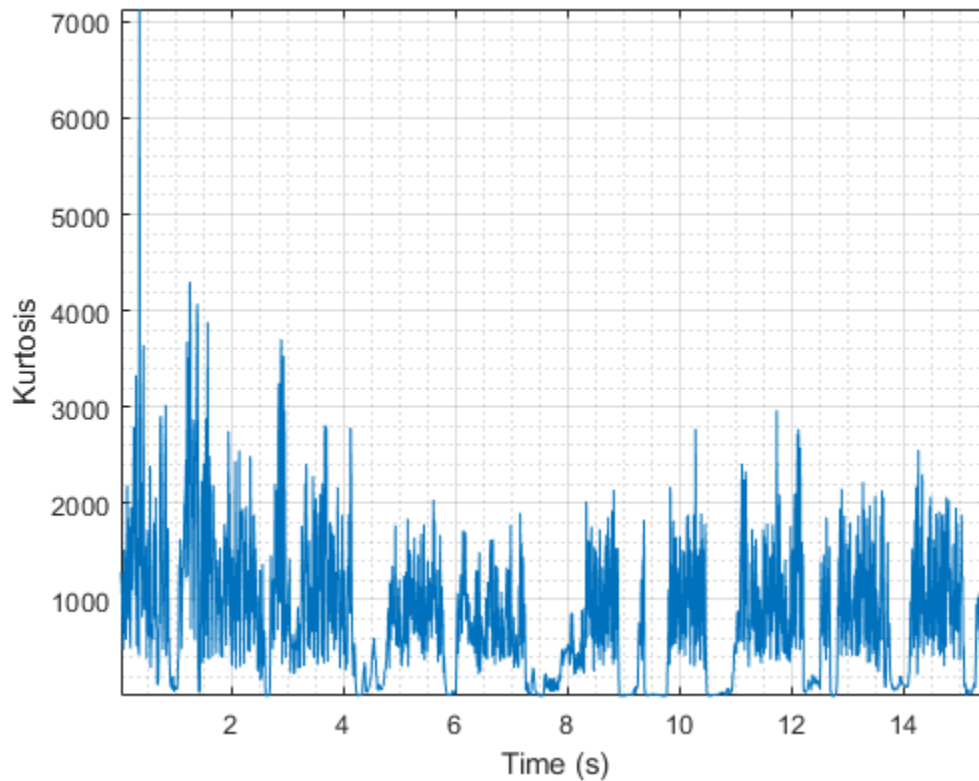
Spectral Kurtosis of Time-Domain Audio

Read in an audio file and calculate the kurtosis using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
kurtosis = spectralKurtosis(audioIn,fs);
```

Plot the spectral kurtosis against time.

```
spectralKurtosis(audioIn,fs)
```



Spectral Kurtosis of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the kurtosis of the mel spectrogram over time.

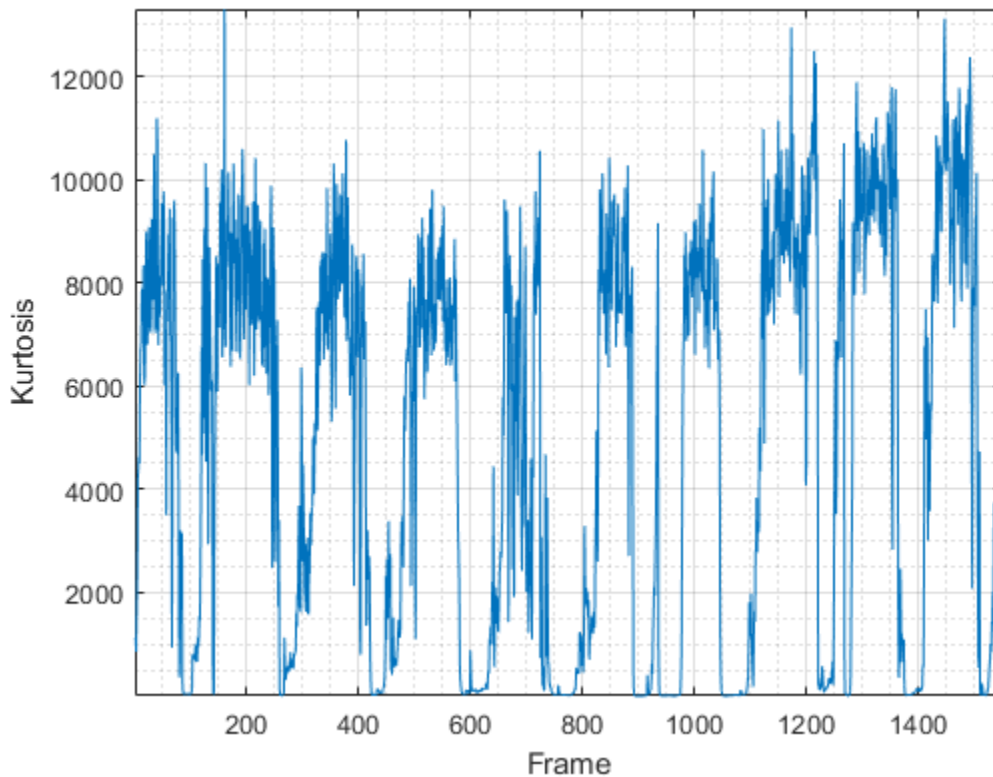
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[s,cf,t] = melSpectrogram(audioIn,fs);
```

```
kurtosis = spectralKurtosis(s,cf);
```

Plot the spectral kurtosis against the frame number.

```
spectralKurtosis(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

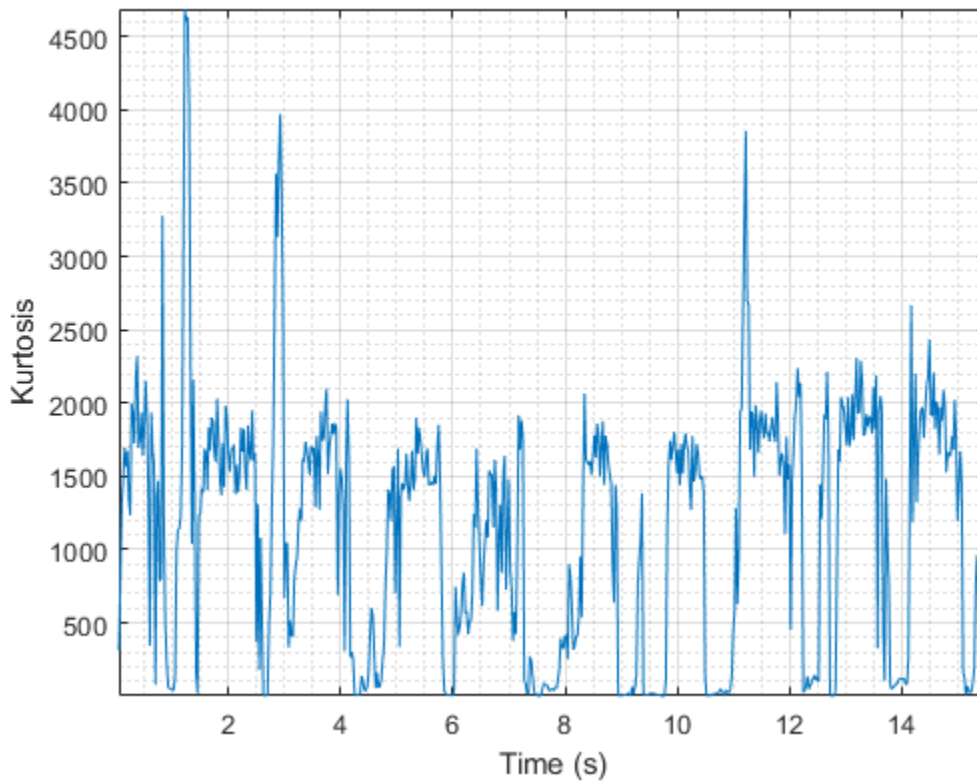
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the kurtosis of the power spectrum over time. Calculate the kurtosis for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the kurtosis calculation.

```
kurtosis = spectralKurtosis(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral kurtosis.

```
spectralKurtosis(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2])
```



Calculate Spectral Kurtosis of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral kurtosis calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral kurtosis for the frame of audio.
- 3 Log the spectral kurtosis for later plotting.

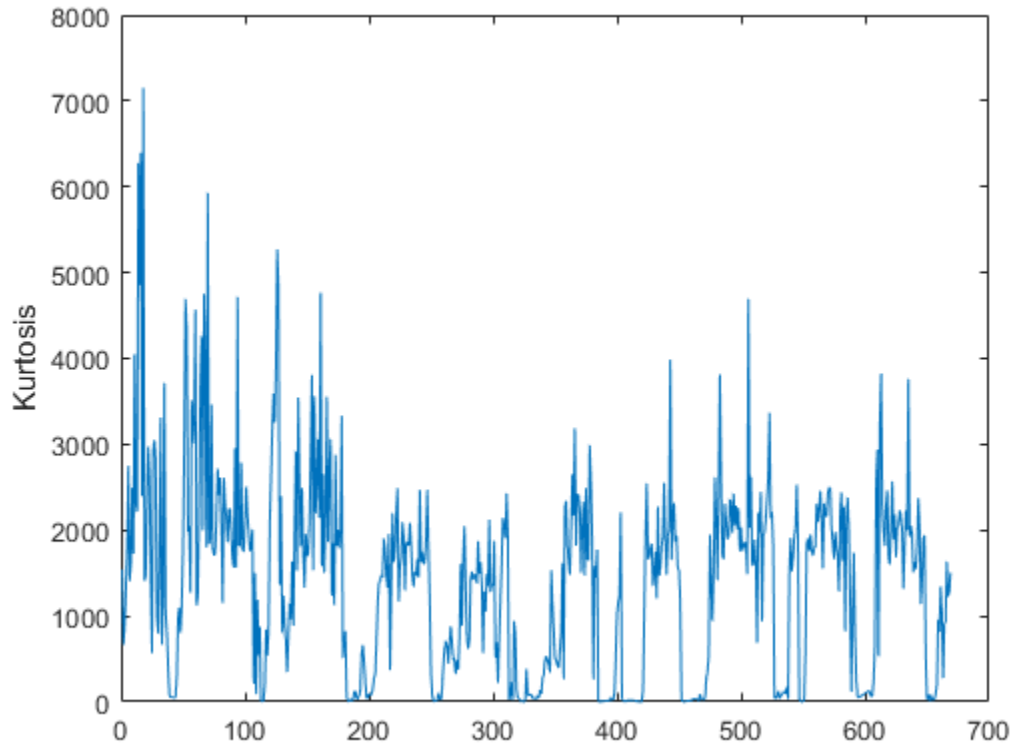
To calculate the spectral kurtosis for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    kurtosis = spectralKurtosis(audioIn,fileReader.SampleRate, ...
                              'Window',win, ...
                              'OverlapLength',0);

    logger(kurtosis)
```

```
end
```

```
plot(logger.Buffer)
ylabel('Kurtosis')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralKurtosis`.
- You want to calculate the spectral kurtosis for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

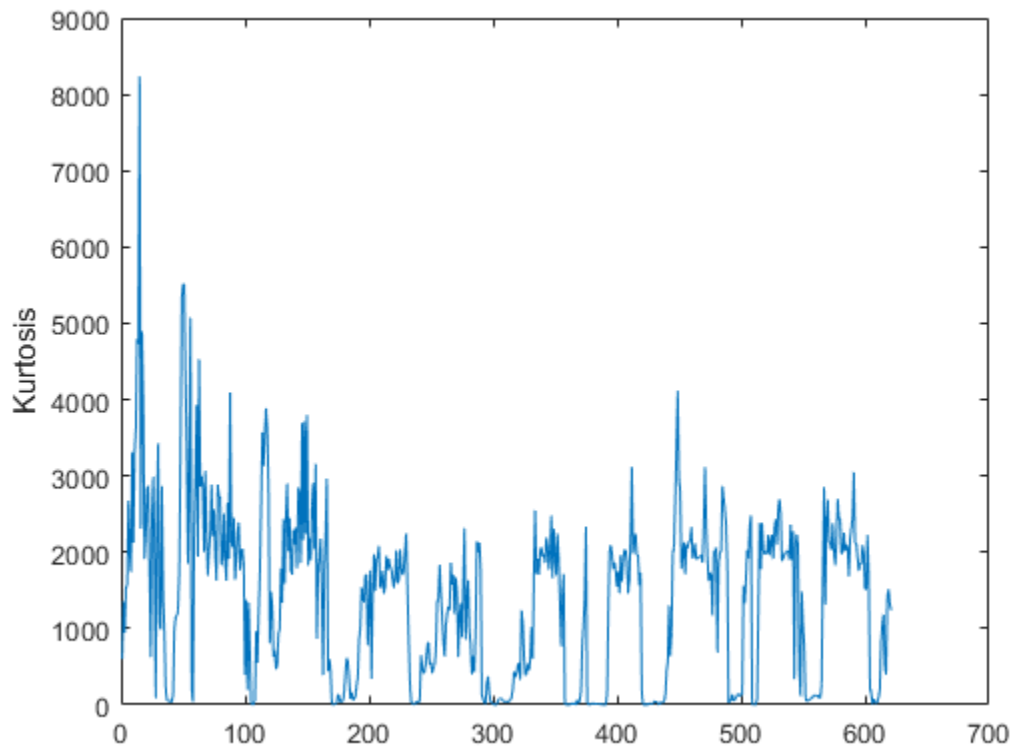
Specify that the spectral kurtosis is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;
```

```
win = hamming(samplesPerFrame);  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buff,audioIn);  
  
    while buff.NumUnreadSamples >= samplesPerHop  
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);  
  
        kurtosis = spectralKurtosis(audioBuffered,fs, ...  
                                   'Window',win, ...  
                                   'OverlapLength',0);  
  
        logger(kurtosis)  
    end  
end  
release(fileReader)  
  
Plot the logged data.  
  
plot(logger.Buffer)  
ylabel('Kurtosis')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral kurtosis is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral kurtosis is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

kurtosis — Spectral kurtosis

`scalar` | `vector` | `matrix`

Spectral kurtosis, returned as a scalar, vector, or matrix. Each row of `kurtosis` corresponds to the spectral kurtosis of a window of `x`. Each column of `kurtosis` corresponds to an independent channel.

spread — Spectral spread

`scalar` | `vector` | `matrix`

Spectral spread, returned as a scalar, vector, or matrix. Each row of `spread` corresponds to the spectral spread of a window of `x`. Each column of `spread` corresponds to an independent channel.

centroid — Spectral centroid (Hz)

`scalar` | `vector` | `matrix`

Spectral centroid in Hz, returned as a scalar, vector, or matrix. Each row of `centroid` corresponds to the spectral centroid of a window of `x`. Each column of `centroid` corresponds to an independent channel.

Algorithms

The spectral kurtosis is calculated as described in [1]:

$$\text{kurtosis} = \frac{\sum_{k=b_1}^{b_2} (f_k - \mu_1)^4 s_k}{(\mu_2)^4 \sum_{k=b_1}^{b_2} s_k}$$

where

- f_k is the frequency in Hz corresponding to bin k .
- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral skewness.
- μ_1 is the spectral centroid, calculated as described by the `spectralCentroid` function.
- μ_2 is the spectral spread, calculated as described by the `spectralSpread` function.

References

- [1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralCentroid` | `spectralSpread` | `spectralSkewness`

Topics

"Spectral Descriptors"

Introduced in R2019a

spectralFlux

Spectral flux for audio signals and auditory spectrograms

Syntax

```
flux = spectralFlux(x,f)
flux = spectralFlux(x,f,initialCondition)
flux = spectralFlux( ___,Name=Value)
[flux,finalCondition] = spectralFlux( ___ )
spectralFlux( ___ )
```

Description

`flux = spectralFlux(x,f)` returns the spectral flux of the signal, `x`, over time. Spectral flux is a measure of the variability of the spectrum over time. How the function interprets `x` depends on the shape of `f`.

`flux = spectralFlux(x,f,initialCondition)` specifies the previous spectral state. This syntax is supported only for frequency-domain inputs.

`flux = spectralFlux(___,Name=Value)` specifies options using one or more name-value arguments.

For example, `flux = spectralFlux(x,f, NormType=1)` calculates spectral flux using norm type 1.

`[flux,finalCondition] = spectralFlux(___)` also returns the final spectral state. You can specify an input combination from any of the previous syntaxes.

`spectralFlux(___)` with no output arguments plots the spectral flux.

- If the input is in the time domain, the spectral flux is plotted against time.
- If the input is in the frequency domain, the spectral flux is plotted against frame number.

Examples

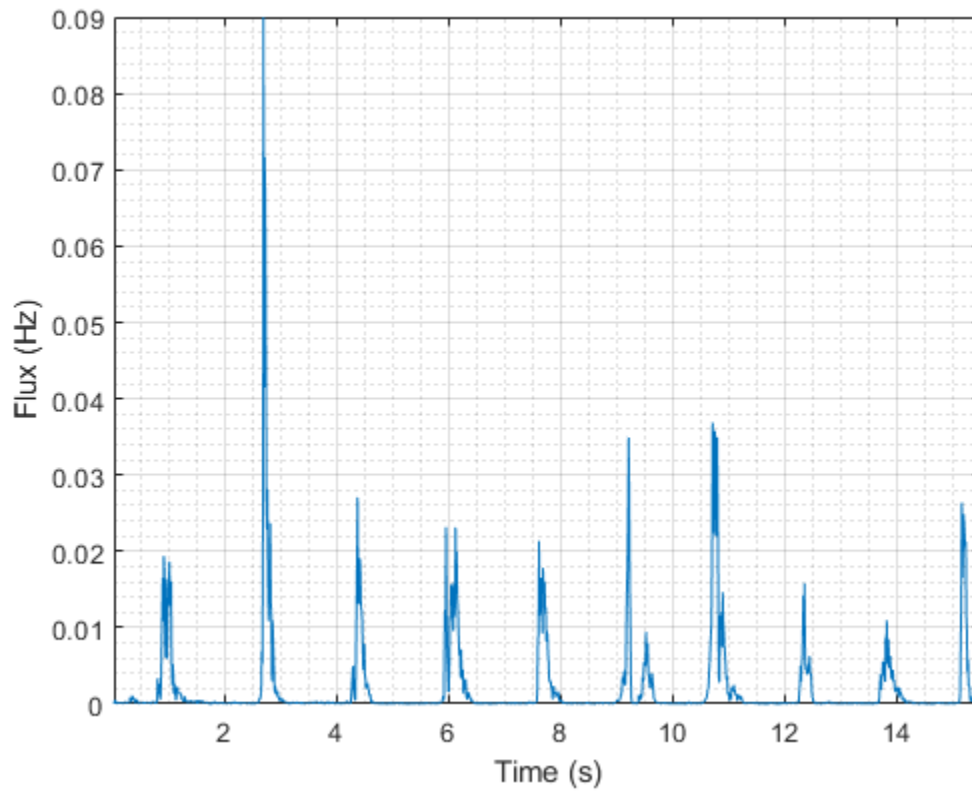
Spectral Flux of Time-Domain Audio

Read in an audio file and calculate the flux using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
flux = spectralFlux(audioIn,fs);
```

Plot the spectral flux against time.

```
spectralFlux(audioIn,fs)
```



Spectral Flux of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function. Calculate the flux of the mel spectrogram over time.

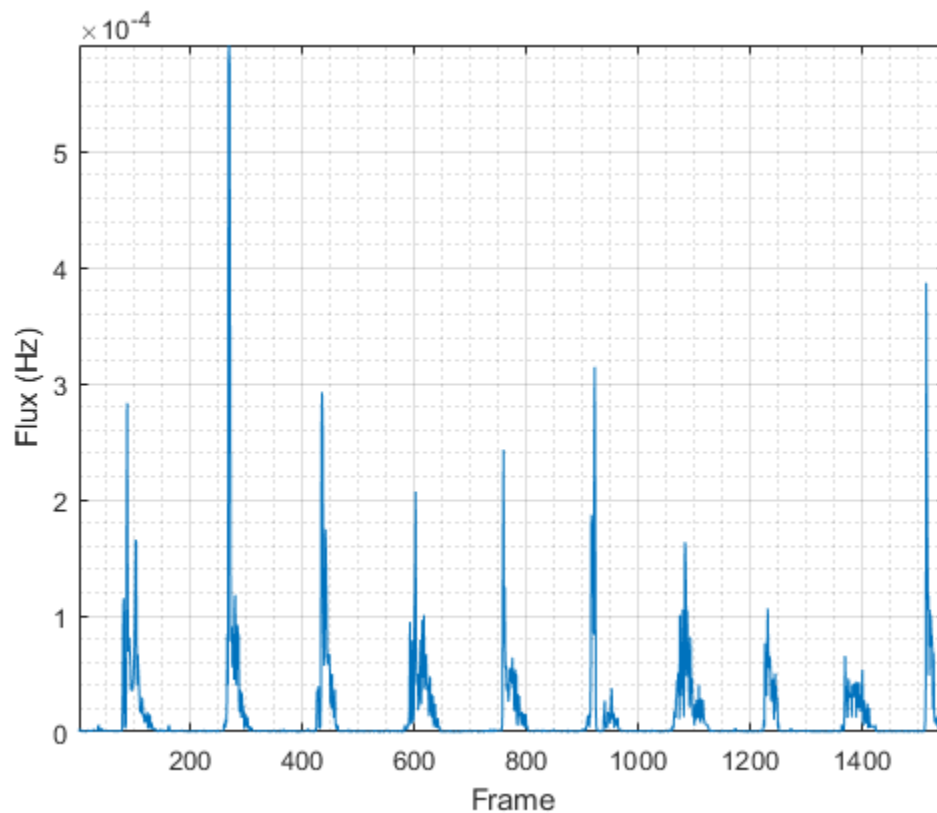
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

```
[s,cf,t] = melSpectrogram(audioIn,fs);
```

```
flux = spectralFlux(s,cf);
```

Plot the spectral flux against the frame number.

```
spectralFlux(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

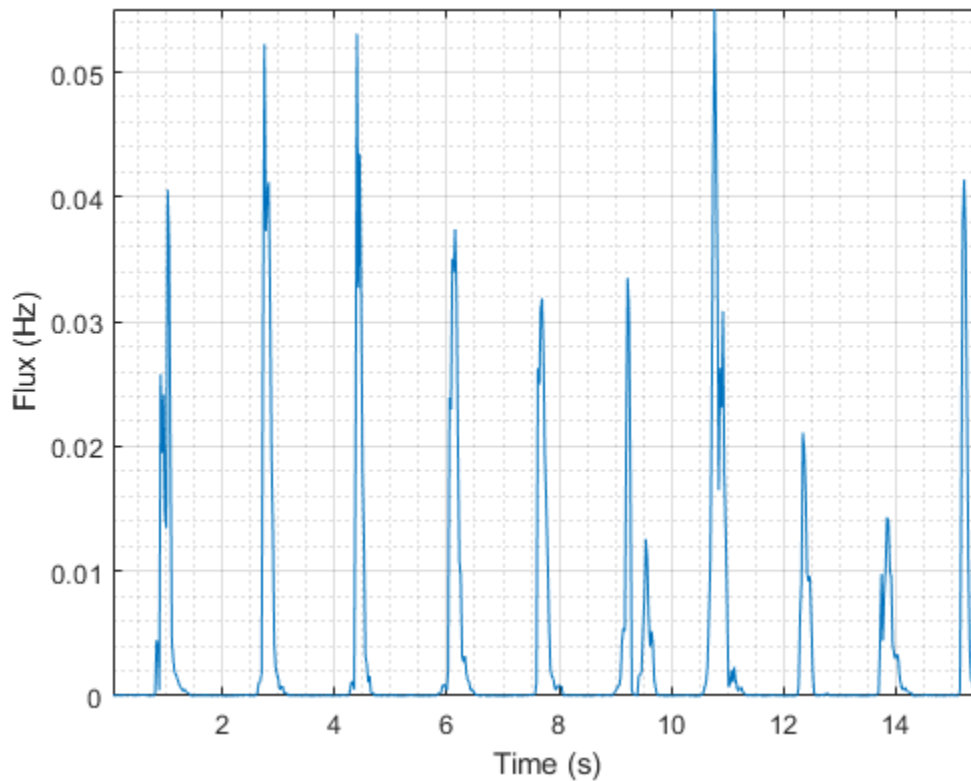
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the flux of the power spectrum over time. Calculate the flux for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the flux calculation.

```
flux = spectralFlux(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral flux.

```
spectralFlux(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2])
```



Calculate Spectral Flux of Streaming Audio

Spectral flux measures the change in consecutive spectra. To calculate spectral flux of streaming audio, you can pass the state in and out of the function.

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.AsyncBuffer` object to buffer the audio input into overlapped frames. Create a second `dsp.AsyncBuffer` object to log the spectral flux calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
inputBuffer = dsp.AsyncBuffer;
logger = dsp.AsyncBuffer;
```

In an audio stream loop:

- 1 Read in a frame of audio data from your source.
- 2 Write the audio data to the input buffer.
- 3 If a hop of data is available from the buffer, read a frame of data with overlap.
- 4 Calculate the one-sided magnitude short time Fourier transform.
- 5 Calculate the spectral flux.
- 6 Log the spectral flux for later plotting.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame, 'periodic');

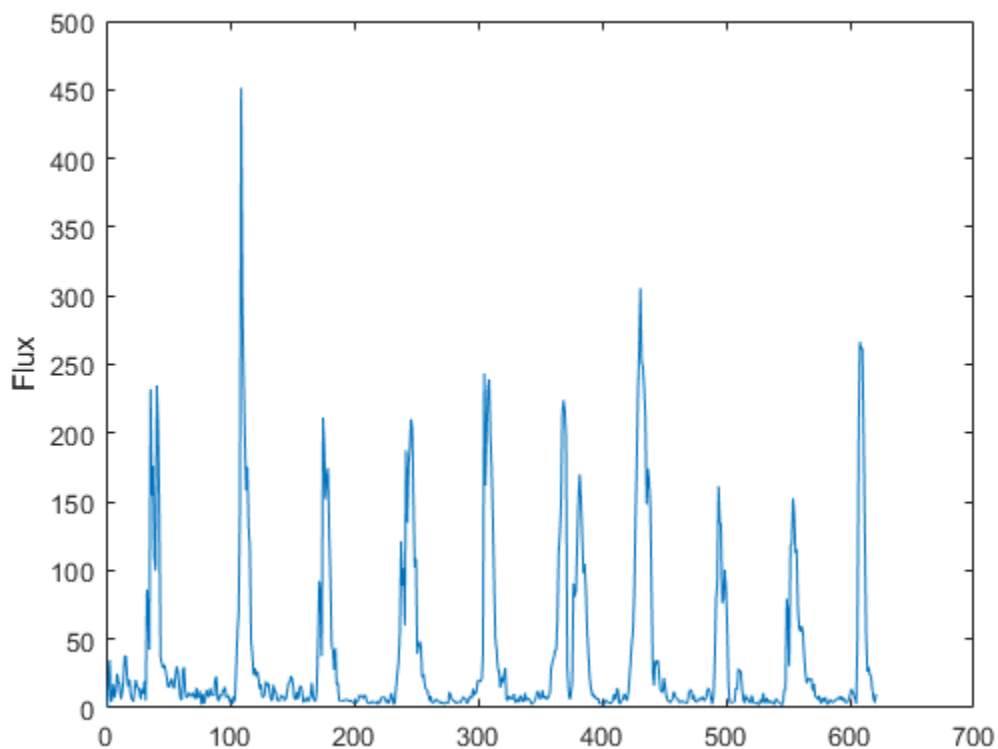
Sprev = [];
while ~isDone(fileReader)
    audioIn = fileReader();
    write(inputBuffer, audioIn);

    while inputBuffer.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(inputBuffer, samplesPerFrame, samplesOverlap);
        [S, f] = stft(audioBuffered, fs, "Window", win, "OverlapLength", samplesOverlap, "FrequencyRange");
        [flux, Sprev] = spectralFlux(abs(S), f, Sprev);
        write(logger, flux);
    end

end
release(fileReader)

Plot the logged data.

plot(read(logger))
ylabel('Flux')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.

Data Types: `single` | `double`

initialCondition — Previous spectral state

`[]` (default) | matrix

Previous spectral state, specified as an L -by- N matrix, where:

- L is the number of bins in the one-sided spectral representation, equal to `numel(f)`.
- N is the number of channels of audio data, equal to `size(x,3)`.

If `initialCondition` is unspecified, or specified as an empty, `spectralFlux` considers the first spectrum as repeating. That is, the first `flux` output is zero.

Dependencies

This input argument is only valid if the input, x , is a frequency-domain representation of audio. The `spectralFlux` function interprets the domain of the input x based on the size of f .

Data Types: `single` | `double`

Name-Value Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

NormType — Norm type

2 (default) | 1

Norm type used to calculate flux, specified as 2 or 1.

Data Types: `single` | `double`

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, the following name-value arguments are ignored.

Window — Window applied in time domain`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range $[0, f/2]$.

Data Types: `single` | `double`

SpectrumType — Spectrum type`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral flux is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral flux is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

flux — Spectral flux (Hz)

scalar | vector | matrix

Spectral flux in Hz, returned as a scalar, vector, or matrix. Each row of `flux` corresponds to the spectral flux of a window of `x`. Each column of `flux` corresponds to an independent channel.

finalCondition — Final spectral state

matrix

Final spectral state, returned as an L -by- N matrix, where:

- L is the number of bins in the one-sided spectral representation, equal to `numel(f)`.
- N is the number of channels of audio data, equal to `size(x,3)`.

Dependencies

This output argument is only valid if the input, `x`, is a frequency-domain representation of audio. The `spectralFlux` function interprets the domain of the input `x` based on the size of `f`.

Algorithms

The spectral flux is calculated as described in [1]:

$$\text{flux}(t) = \left(\sum_{k=b_1}^{b_2} |s_k(t) - s_k(t-1)|^P \right)^{1/P}$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral flux.
- P is the norm type. You can specify the norm type using `NormType`.

References

- [1] Scheirer, E., and M. Slaney. "Construction and Evaluation of a Robust Multifeature Speech/Music Discriminator." *IEEE International Conference on Acoustics, Speech, and Signal Processing*. Volume 2, 1997, pp. 1221-1224.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralCentroid` | `integratedLoudness` | `splMeter` | `acousticFluctuation`

Topics

“Spectral Descriptors”

Introduced in R2019a

spectralFlatness

Spectral flatness for audio signals and auditory spectrograms

Syntax

```
flatness = spectralFlatness(x,f)
flatness = spectralFlatness(x,f,Name=Value)
[flatness,arithmeticMean,geometricMean] = spectralFlatness( ___ )
spectralFlatness( ___ )
```

Description

`flatness = spectralFlatness(x,f)` returns the spectral flatness of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`flatness = spectralFlatness(x,f,Name=Value)` specifies options using one or more name-value arguments.

`[flatness,arithmeticMean,geometricMean] = spectralFlatness(___)` returns the spectral arithmetic mean and spectral geometric mean. You can specify an input combination from any of the previous syntaxes.

`spectralFlatness(___)` with no output arguments plots the spectral flatness.

- If the input is in the time domain, the spectral flatness is plotted against time.
- If the input is in the frequency domain, the spectral flatness is plotted against frame number.

Examples

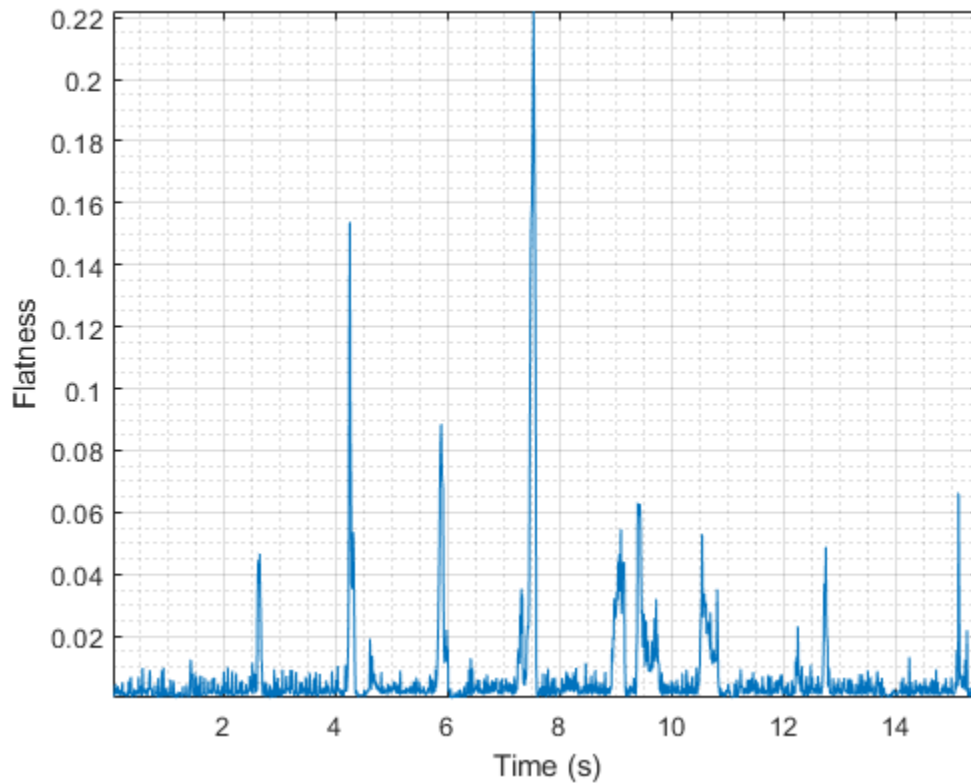
Spectral Flatness of Time-Domain Audio

Read in an audio file and calculate the flatness using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
flatness = spectralFlatness(audioIn,fs);
```

Plot the spectral flatness against time.

```
spectralFlatness(audioIn,fs)
```



Spectral Flatness of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function.

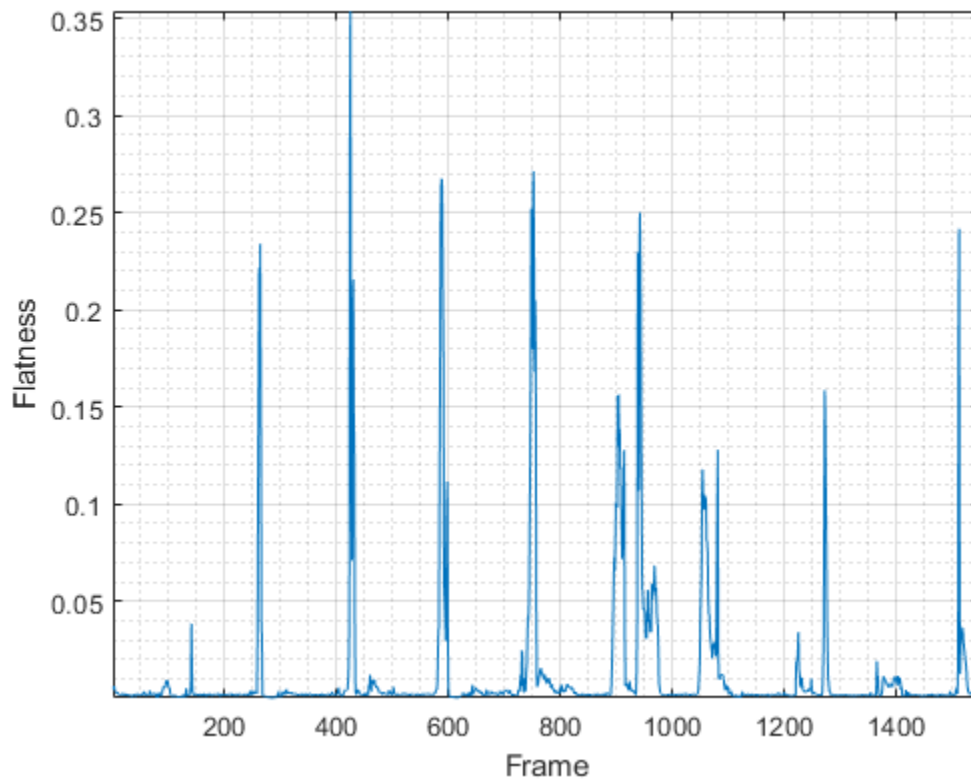
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");  
[s,cf,t] = melSpectrogram(audioIn,fs);
```

Calculate the flatness of the mel spectrogram over time.

```
flatness = spectralFlatness(s,cf);
```

Plot the spectral flatness against the frame number.

```
spectralFlatness(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

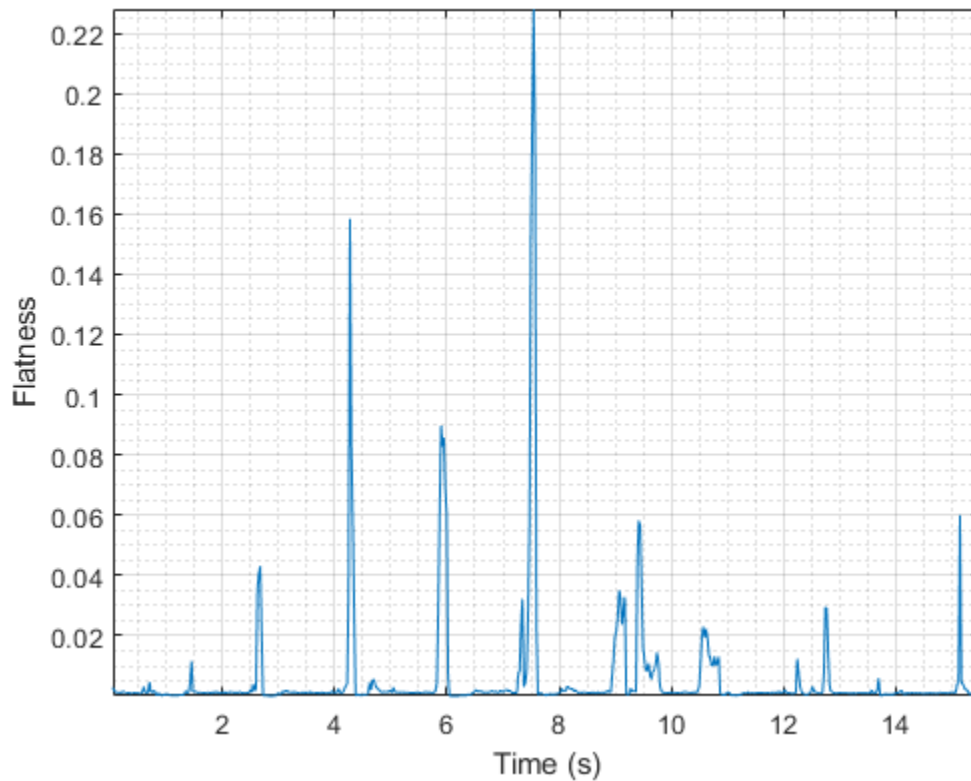
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the flatness of the power spectrum over time. Calculate the flatness for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the flatness calculation.

```
flatness = spectralFlatness(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral flatness.

```
spectralFlatness(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```



Calculate Spectral Flatness of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral flatness calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral flatness for the frame of audio.
- 3 Log the spectral flatness for later plotting.

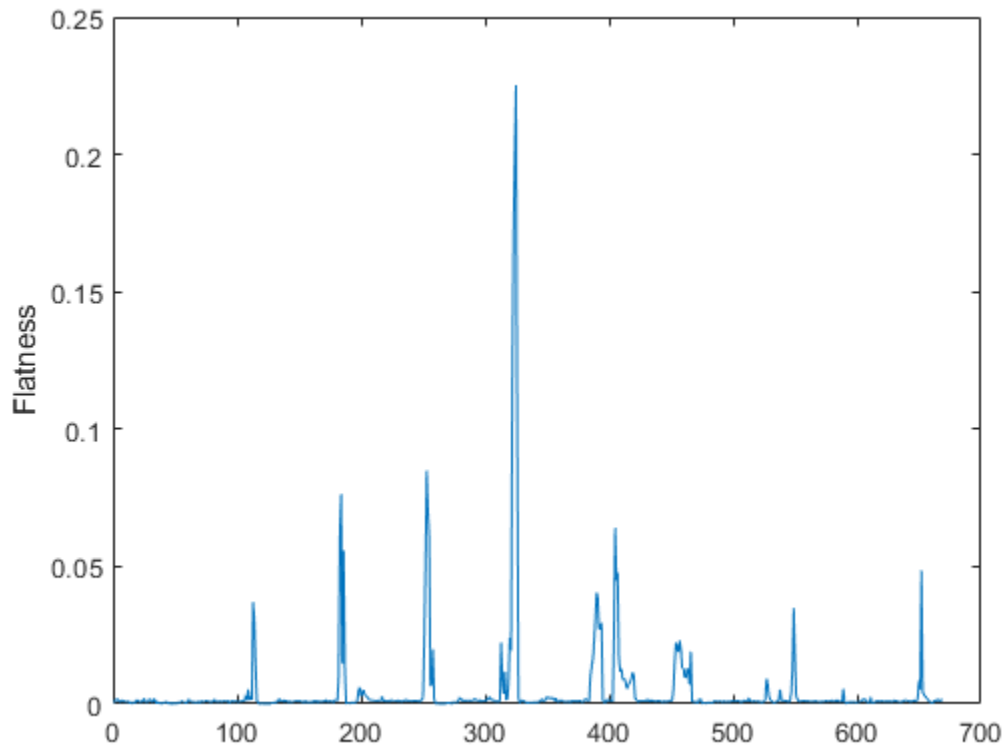
To calculate the spectral flatness for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
win = hamming(fileReader.SamplesPerFrame);
while ~isDone(fileReader)
    audioIn = fileReader();
    flatness = spectralFlatness(audioIn,fileReader.SampleRate, ...
                              'Window',win, ...
                              'OverlapLength',0);

    logger(flatness)
```

```
end
```

```
plot(logger.Buffer)
ylabel('Flatness')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralFlatness`.
- You want to calculate the spectral flatness for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral flatness is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

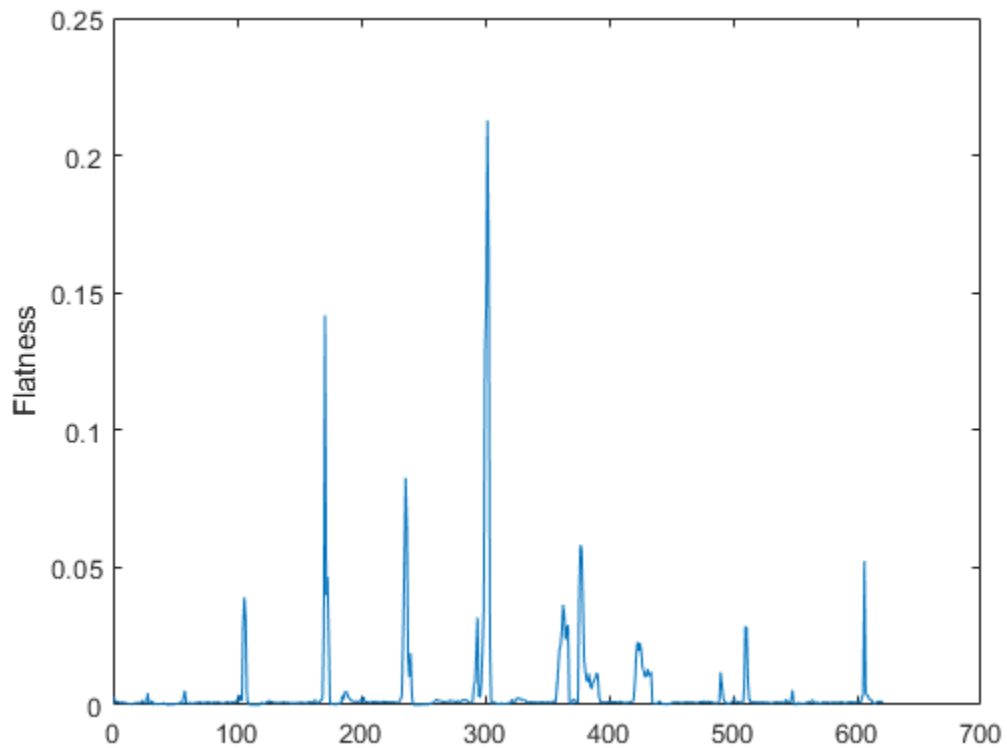
samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;
```

```
win = hamming(samplesPerFrame);  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buff,audioIn);  
  
    while buff.NumUnreadSamples >= samplesPerHop  
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);  
  
        flatness = spectralFlatness(audioBuffered,fs, ...  
                                   'Window',win, ...  
                                   'OverlapLength',0);  
  
        logger(flatness)  
    end  
end  
release(fileReader)
```

Plot the logged data.

```
plot(logger.Buffer)  
ylabel('Flatness')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral flatness is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral flatness is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

flatness — Spectral flatness

`scalar` | `vector` | `matrix`

Spectral flatness, returned as a scalar, vector, or matrix. Each row of `flatness` corresponds to the spectral flatness of a window of `x`. Each column of `flatness` corresponds to an independent channel.

arithmeticMean — Spectral arithmetic mean

`scalar` | `vector` | `matrix`

Spectral arithmetic mean, returned as a scalar, vector, or matrix. Each row of `arithmeticMean` corresponds to the arithmetic mean of the spectrum of a window of `x`. Each column of `arithmeticMean` corresponds to an independent channel.

geometricMean — Spectral geometric mean

`scalar` | `vector` | `matrix`

Spectral geometric mean, returned as a scalar, vector, or matrix. Each row of `geometricMean` corresponds to the geometric mean of the spectrum of a window of `x`. Each column of `geometricMean` corresponds to an independent channel.

Algorithms

The spectral flatness is calculated as described in [1]:

$$\text{flatness} = \frac{\left(\prod_{k=b_1}^{b_2} s_k \right)^{\frac{1}{b_2-b_1}}}{\frac{1}{b_2-b_1} \sum_{k=b_1}^{b_2} s_k}$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral spread.

References

- [1] Johnston, J. D. "Transform Coding of Audio Signals Using Perceptual Noise Criteria." *IEEE Journal on Selected Areas in Communications*. Vol. 6, Number 2, 1988, pp. 314-323.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

spectralCrest

Topics

"Spectral Descriptors"

Introduced in R2019a

spectralEntropy

Spectral entropy for audio signals and auditory spectrograms

Syntax

```
entropy = spectralEntropy(x,f)
entropy = spectralEntropy(x,f,Name=Value)
spectralEntropy( ___ )
```

Description

`entropy = spectralEntropy(x,f)` returns the spectral entropy of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`entropy = spectralEntropy(x,f,Name=Value)` specifies options using one or more name-value arguments.

`spectralEntropy(___)` with no output arguments plots the spectral entropy. You can specify an input combination from any of the previous syntaxes.

- If the input is in the time domain, the spectral entropy is plotted against time.
- If the input is in the frequency domain, the spectral entropy is plotted against frame number.

Examples

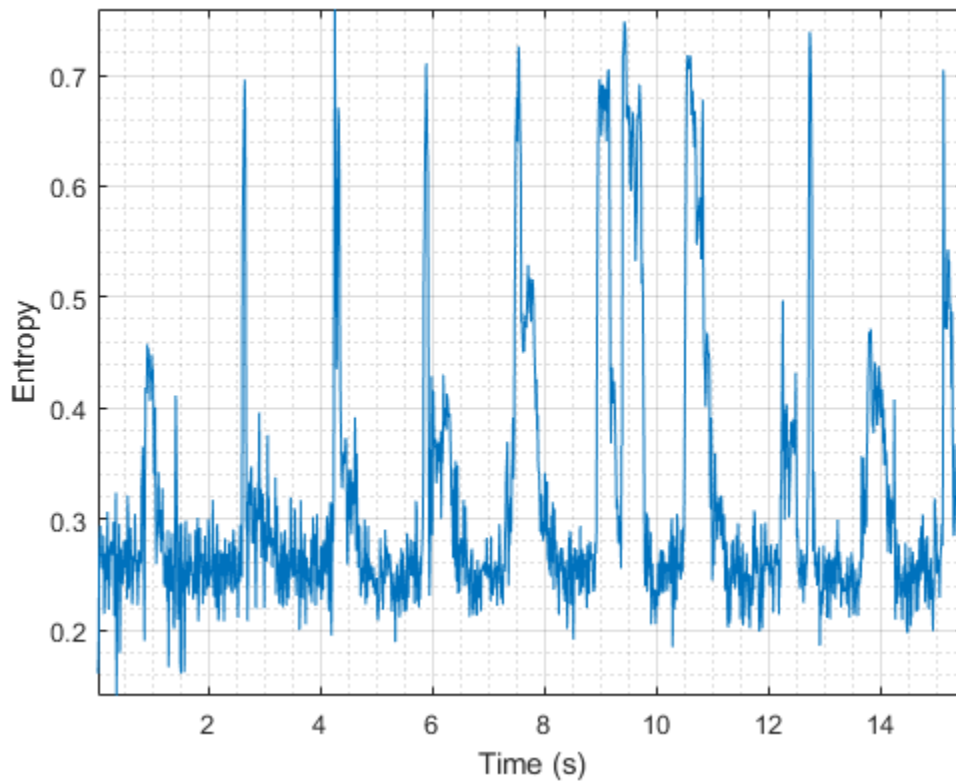
Spectral Entropy of Time-Domain Audio

Read in an audio file and calculate the entropy using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
entropy = spectralEntropy(audioIn,fs);
```

Plot the spectral entropy against time

```
spectralEntropy(audioIn,fs)
```



Spectral Entropy of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function.

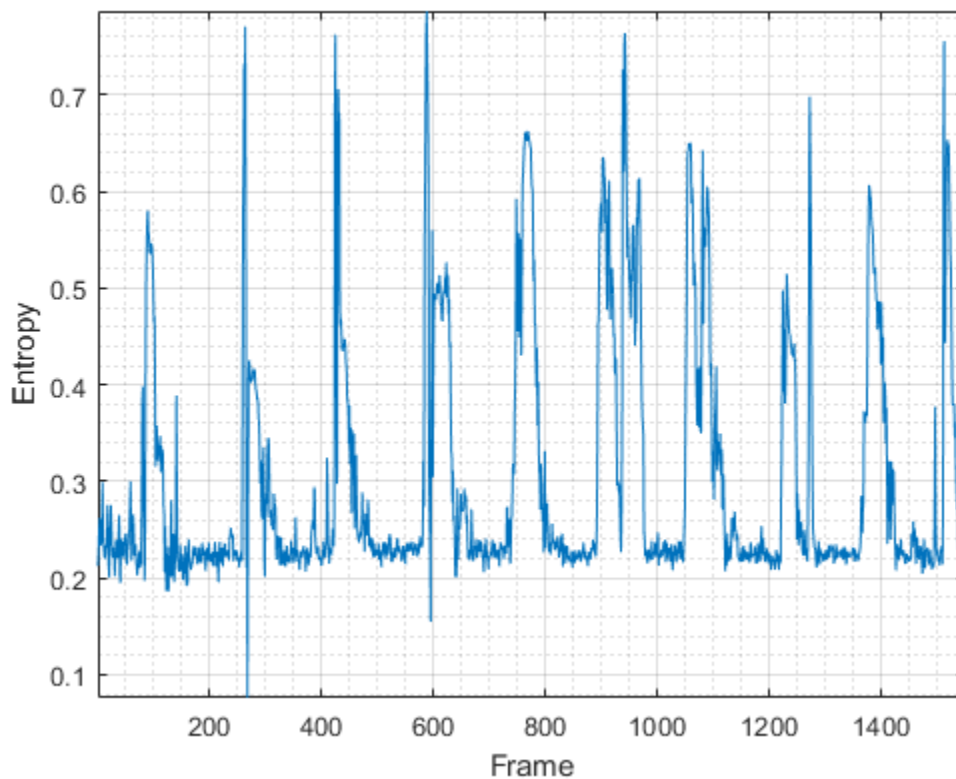
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");  
[s,cf,t] = melSpectrogram(audioIn,fs);
```

Calculate the entropy of the mel spectrogram over time.

```
entropy = spectralEntropy(s,cf);
```

Plot the spectral entropy against the frame number.

```
spectralEntropy(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

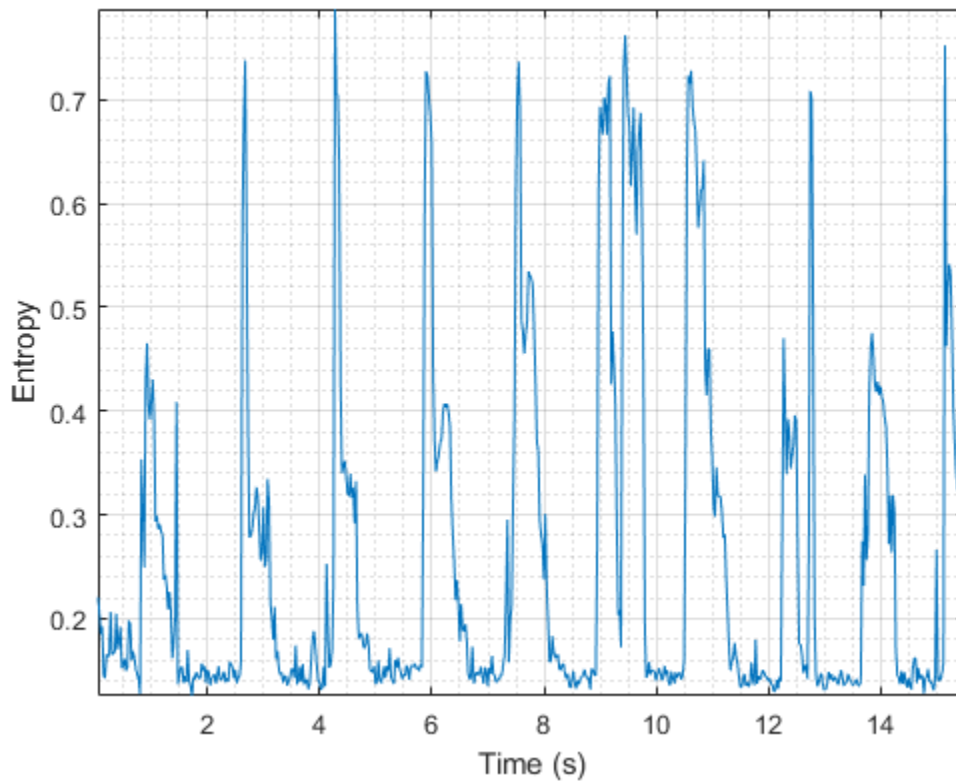
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the entropy of the power spectrum over time. Calculate the entropy for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the entropy calculation.

```
entropy = spectralEntropy(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5, fs/2]);
```

Plot the spectral entropy against time.

```
spectralEntropy(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5, fs/2])
```



Calculate Spectral Entropy of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral entropy calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

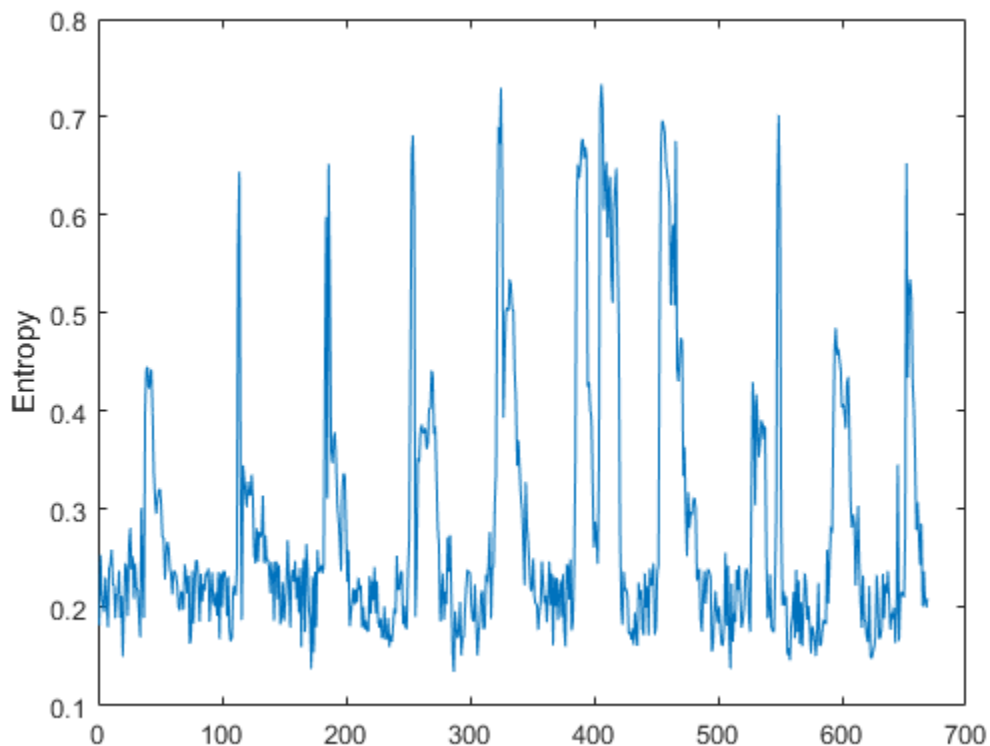
In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral entropy for the frame of audio.
- 3 Log the spectral entropy for later plotting.

To calculate the spectral entropy for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    entropy = spectralEntropy(audioIn,fileReader.SampleRate, ...
                             'Window',hamming(size(audioIn,1)), ...
                             'OverlapLength',0);
    logger(entropy)
end
```

```
plot(logger.Buffer)
ylabel('Entropy')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralEntropy`.
- You want to calculate the spectral entropy for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral entropy is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame);
```



```

while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff,audioIn);

    while buff.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);

        entropy = spectralEntropy(audioBuffered,fs, ...
            'Window',win, ...
            'OverlapLength',0);

        logger(entropy)
    end
end
release(fileReader)

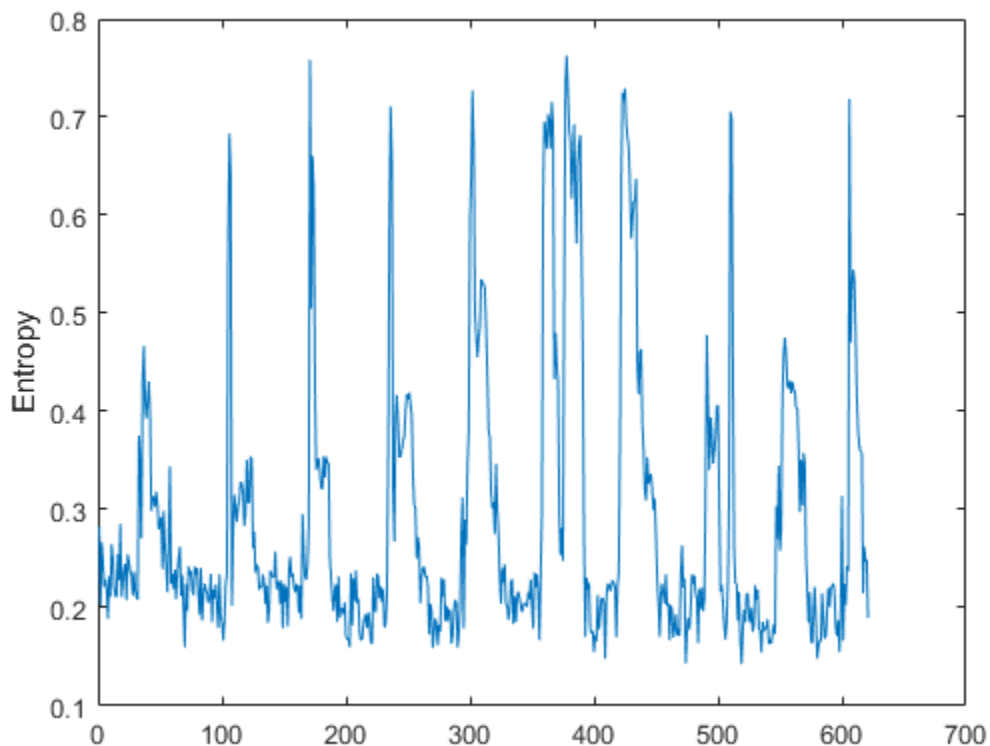
```

Plot the logged data.

```

plot(logger.Buffer)
ylabel('Entropy')

```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

`scalar` | `vector`

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | `vector`

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral entropy is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral entropy is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

entropy — Spectral entropy

`scalar` | `vector` | `matrix`

Spectral entropy, returned as a scalar, vector, or matrix. Each row of `entropy` corresponds to the spectral entropy of a window of `x`. Each column of `entropy` corresponds to an independent channel.

Algorithms

The spectral entropy is calculated as described in [1]:

$$\text{entropy} = \frac{- \sum_{k=b_1}^{b_2} s_k \log(s_k)}{\log(b_2 - b_1)}$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral entropy.

References

- [1] Misra, H., S. Iqbal, H. Bourlard, and H. Hermansky. "Spectral Entropy Based Feature for Robust ASR." *2004 IEEE International Conference on Acoustics, Speech, and Signal Processing*.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralSpread` | `spectralSkewness` | `spectralKurtosis`

Topics

“Spectral Descriptors”

Introduced in R2019a

spectralDecrease

Spectral decrease for audio signals and auditory spectrograms

Syntax

```
decrease = spectralDecrease(x, f)
decrease = spectralDecrease(x, f, Name=Value)
spectralDecrease( ___ )
```

Description

`decrease = spectralDecrease(x, f)` returns the spectral decrease of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`decrease = spectralDecrease(x, f, Name=Value)` specifies options using one or more name-value arguments.

`spectralDecrease(___)` with no output arguments plots the spectral decrease. You can specify an input combination from any of the previous syntaxes.

- If the input is in the time domain, the spectral decrease is plotted against time.
- If the input is in the frequency domain, the spectral decrease is plotted against frame number.

Examples

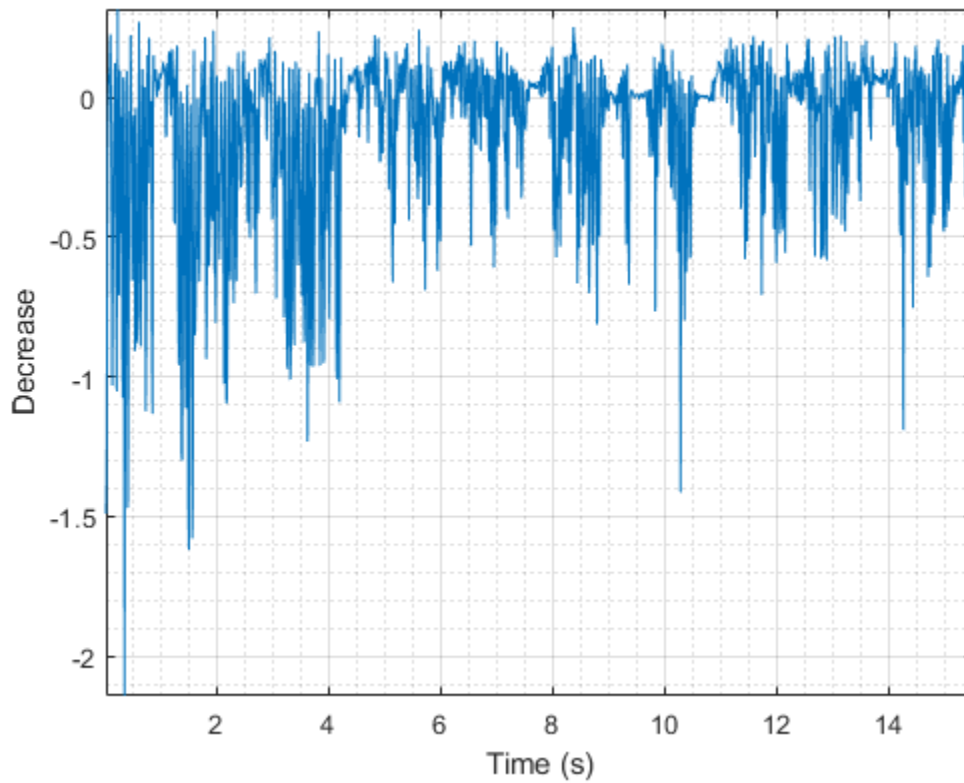
Spectral Decrease of Time-Domain Audio

Read in an audio file and calculate the decrease using default parameters.

```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
decrease = spectralDecrease(audioIn, fs);
```

Plot the spectral decrease against time.

```
spectralDecrease(audioIn, fs)
```



Spectral Decrease of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function.

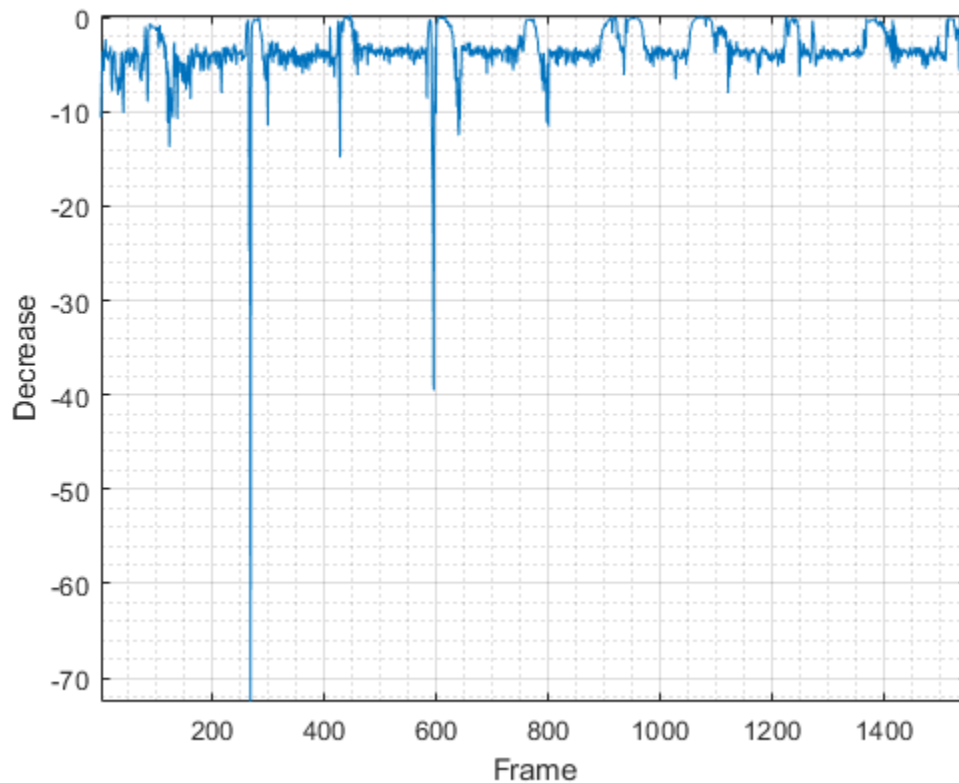
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");  
[s,cf] = melSpectrogram(audioIn,fs);
```

Calculate the decrease of the mel spectrogram over time.

```
decrease = spectralDecrease(s,cf);
```

Plot the spectral decrease against the frame number.

```
spectralDecrease(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

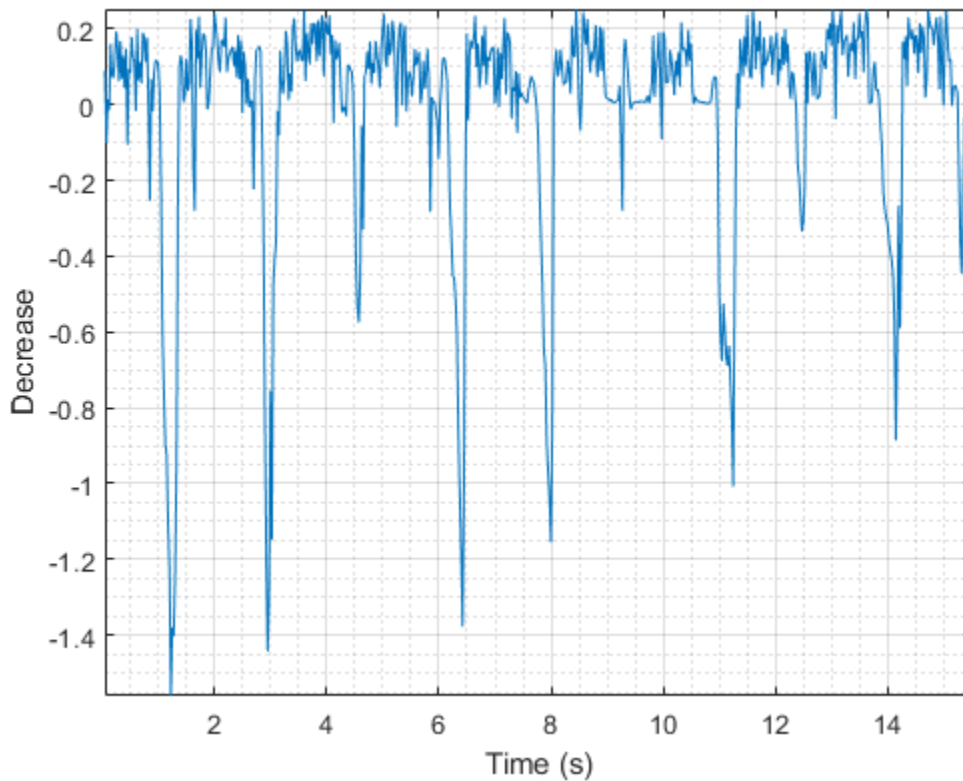
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the decrease of the magnitude spectrum over time. Calculate the decrease for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $f_s/2$ for the decrease calculation.

```
decrease = spectralDecrease(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the spectral decrease.

```
spectralDecrease(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2])
```



Calculate Spectral Decrease of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral decrease calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

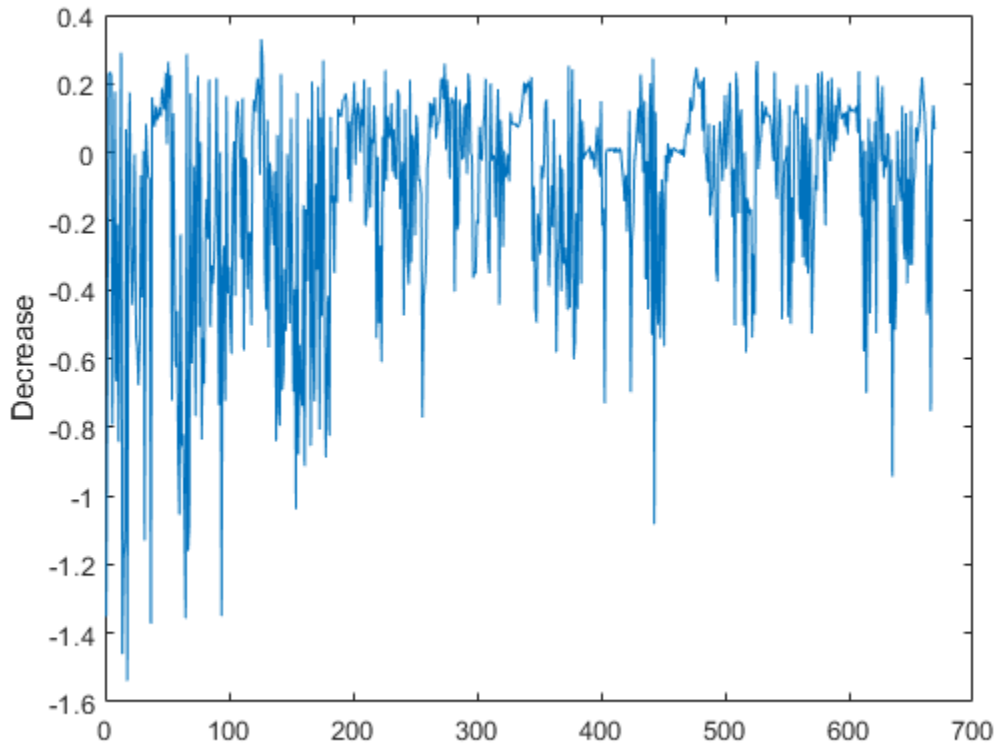
- 1 Read in a frame of audio data.
- 2 Calculate the spectral decrease for the frame of audio.
- 3 Log the spectral decrease for later plotting.

To calculate the spectral decrease for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero. Plot the logged data.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    decrease = spectralDecrease(audioIn,fileReader.SampleRate, ...
                               'Window',hamming(size(audioIn,1)), ...
                               'OverlapLength',0);
    logger(decrease)
end
```



```
plot(logger.Buffer)
ylabel('Decrease')
```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralDecrease`.
- You want to calculate the spectral decrease for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```
buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)
```

Specify that the spectral decrease is calculated for 50 ms frames with a 25 ms overlap.

```
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame);
```

```
while ~isDone(fileReader)
    audioIn = fileReader();
    write(buff,audioIn);

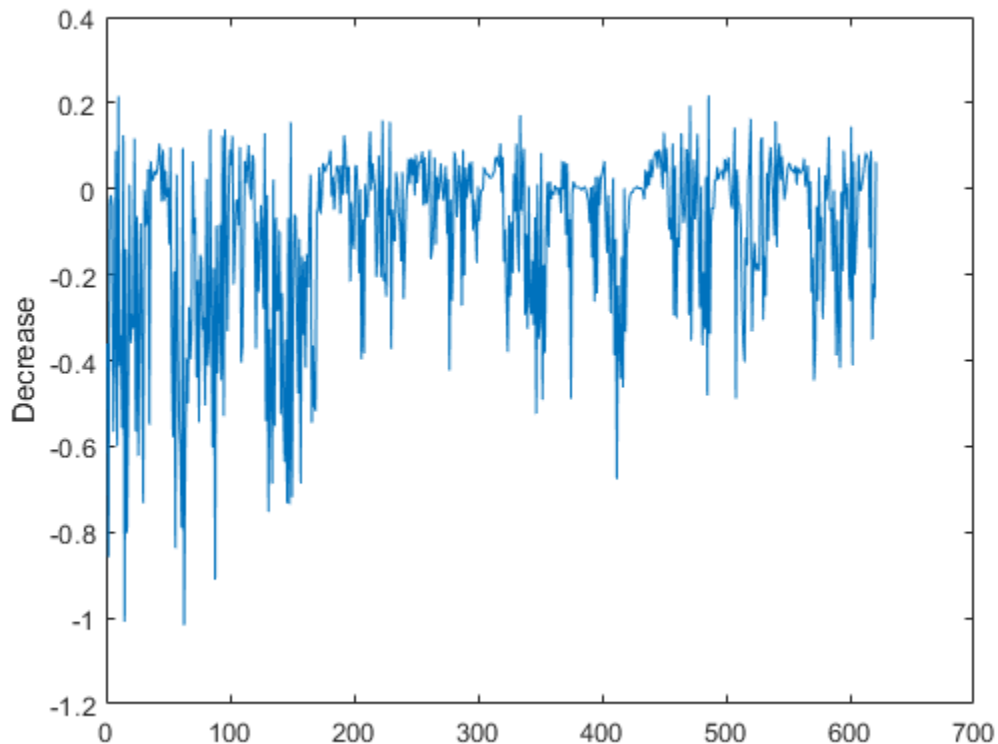
    while buff.NumUnreadSamples >= samplesPerHop
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);

        decrease = spectralDecrease(audioBuffered,fs, ...
                                   'Window',win, ...
                                   'OverlapLength',0);

        logger(decrease)
    end
end
release(fileReader)
```

Plot the logged data.

```
plot(logger.Buffer)
ylabel('Decrease')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

`scalar` | `vector`

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | `vector`

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"magnitude"` (default) | `"power"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral decrease is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral decrease is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

decrease — Spectral decrease

`scalar` | `vector` | `matrix`

Spectral decrease in Hz, returned as a scalar, vector, or matrix. Each row of `decrease` corresponds to the spectral centroid of a window of `x`. Each column of `decrease` corresponds to an independent channel.

Algorithms

The spectral decrease is calculated as described in [1]:

$$\text{decrease} = \frac{\sum_{k=b_1+1}^{b_2} \frac{s_k - s_{b_1}}{k-1}}{\sum_{k=b_1+1}^{b_2} s_k}$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral decrease.

References

- [1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralCrest` | `spectralSlope`

Topics

“Spectral Descriptors”

Introduced in R2019a

spectralCrest

Spectral crest for audio signals and auditory spectrograms

Syntax

```
crest = spectralCrest(x,f)
crest = spectralCrest(x,f,Name=Value)
[crest,spectralPeak,spectralMean] = spectralCrest( ___ )
spectralCrest( ___ )
```

Description

`crest = spectralCrest(x,f)` returns the spectral crest of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`crest = spectralCrest(x,f,Name=Value)` specifies options using one or more name-value arguments.

`[crest,spectralPeak,spectralMean] = spectralCrest(___)` returns the spectral peak and spectral mean. You can specify an input combination from any of the previous syntaxes.

`spectralCrest(___)` with no output arguments plots the spectral crest.

- If the input is in the time domain, the spectral crest is plotted against time.
- If the input is in the frequency domain, the spectral crest is plotted against frame number.

Examples

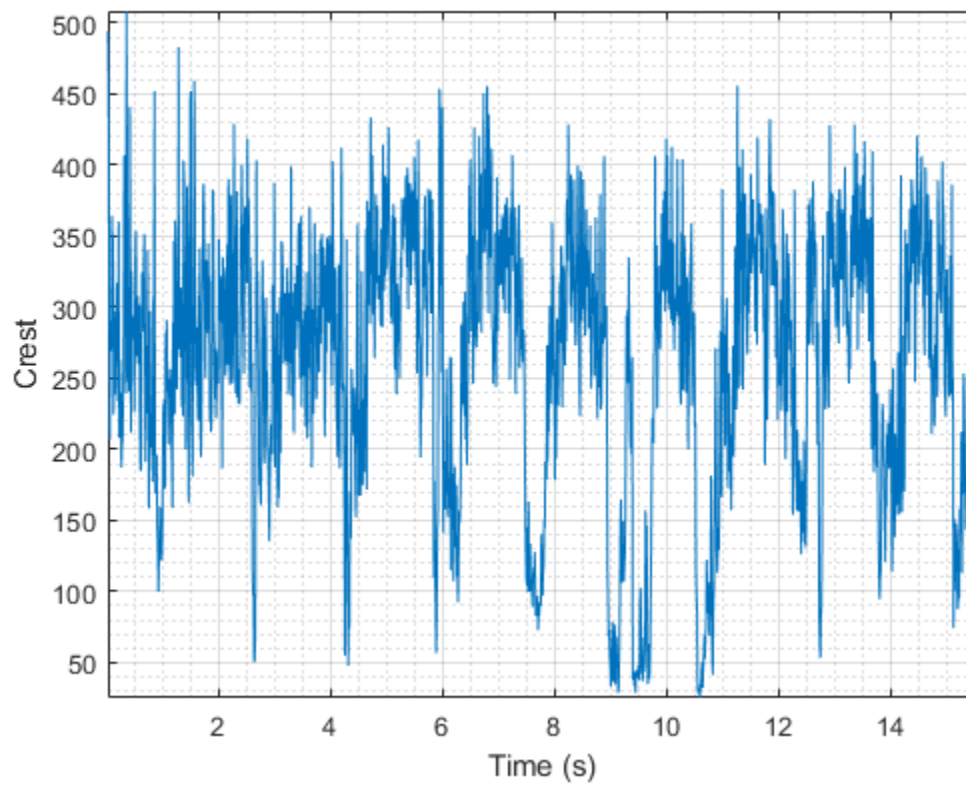
Spectral Crest of Time-Domain Audio

Read in an audio file and calculate the crest using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
crest = spectralCrest(audioIn,fs);
```

Plot the spectral crest against time.

```
spectralCrest(audioIn,fs)
```



Spectral Crest of Frequency-Domain Audio Data

Read in an audio file and then calculate the mel spectrogram using the `melSpectrogram` function.

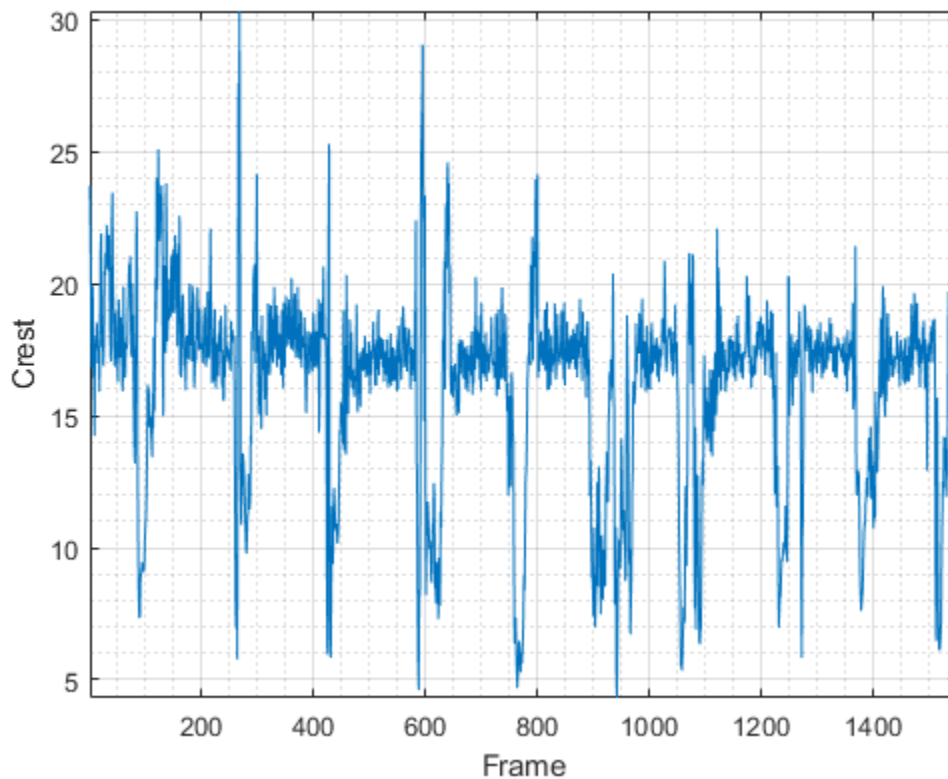
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");  
[s,cf] = melSpectrogram(audioIn,fs);
```

Calculate the crest of the mel spectrogram over time.

```
crest = spectralCrest(s,cf);
```

Plot the spectral crest against the frame number.

```
spectralCrest(s,cf)
```



Specify Nondefault Parameters

Read in an audio file.

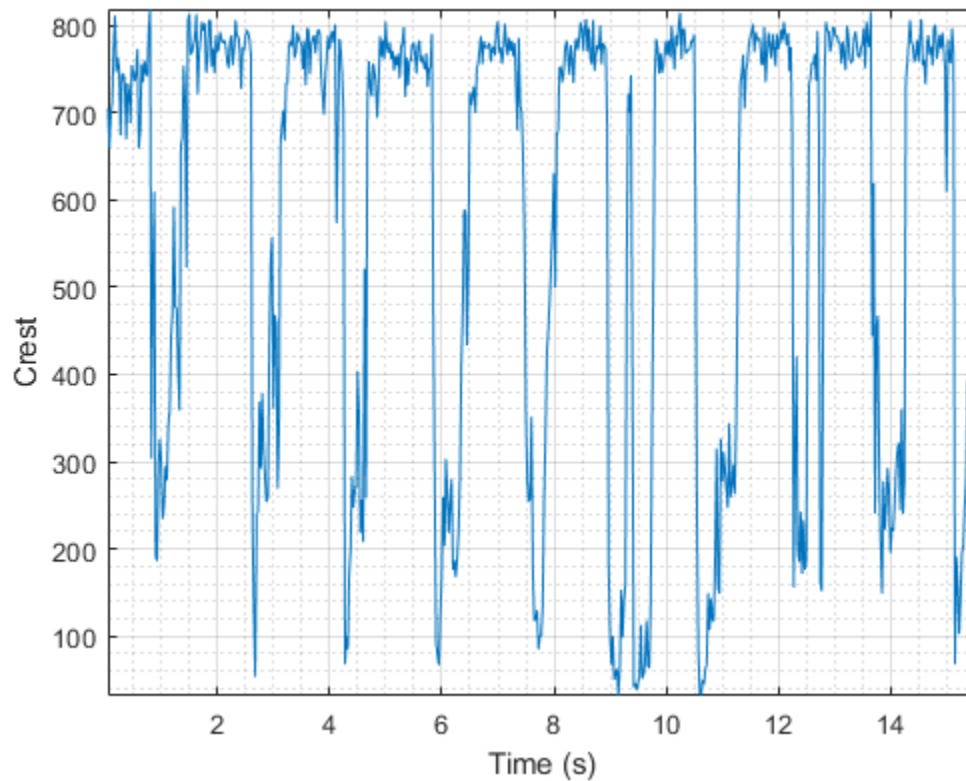
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the crest of the power spectrum over time. Calculate the crest for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the crest calculation.

```
crest = spectralCrest(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2]);
```

Plot the crest against time.

```
spectralCrest(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5,fs/2])
```

Calculate Spectral Crest of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral crest calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral crest for the frame of audio.
- 3 Log the spectral crest for later plotting.

To calculate the spectral crest for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero.

Plot the logged data.

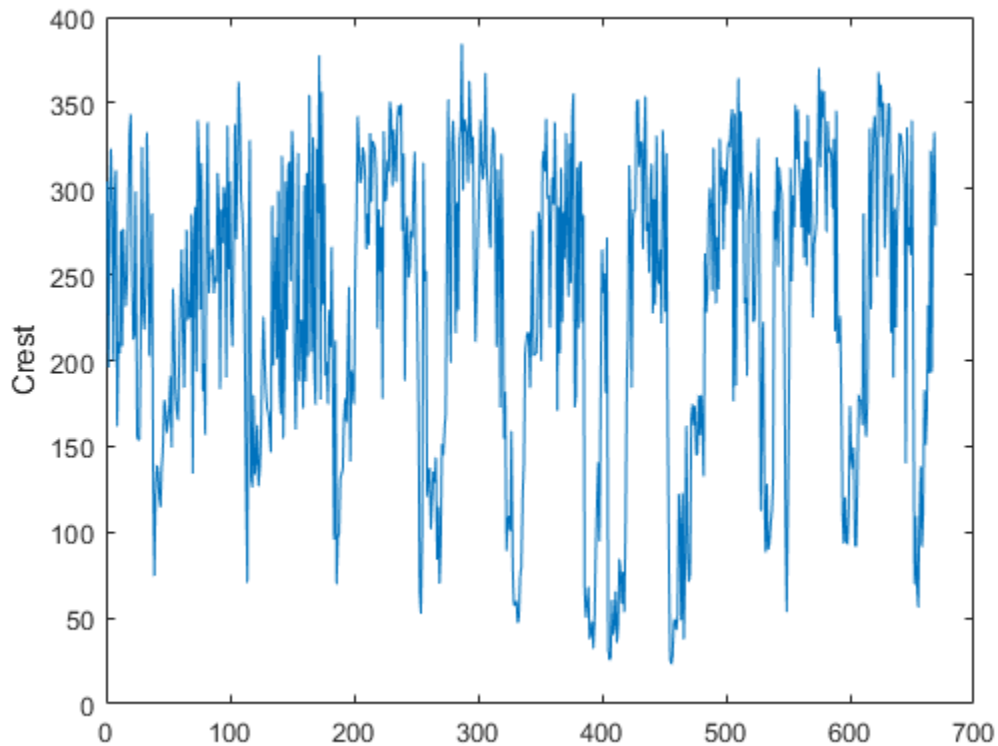
```
while ~isDone(fileReader)
    audioIn = fileReader();
    crest = spectralCrest(audioIn,fileReader.SampleRate, ...
        'Window',hamming(size(audioIn,1)), ...
        'OverlapLength',0);
```

```

    logger(crest)
end

plot(logger.Buffer)
ylabel('Crest')

```



Use `dsp.AsyncBuffer` if

- The input to your audio stream loop has a variable samples-per-frame.
- The input to your audio stream loop has an inconsistent samples-per-frame with the analysis window of `spectralCrest`.
- You want to calculate the spectral crest for overlapped data.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```

buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)

```

Specify that the spectral crest is calculated for 50 ms frames with a 25 ms overlap.

```

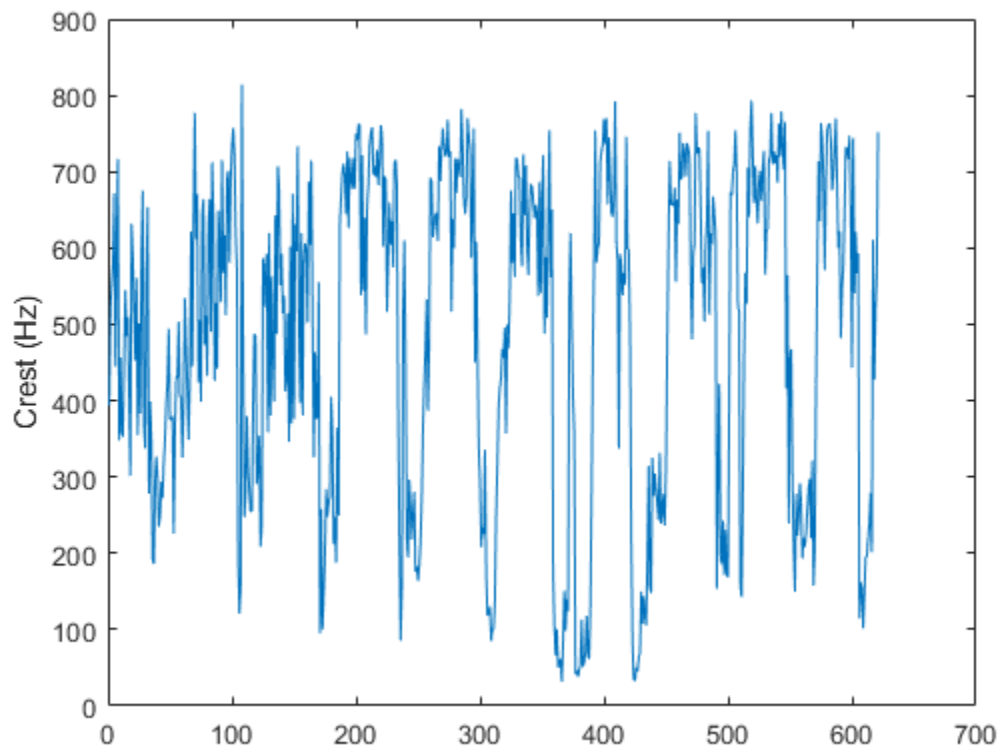
fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

```

```
win = hamming(samplesPerFrame);  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buff,audioIn);  
  
    while buff.NumUnreadSamples >= samplesPerHop  
        audioBuffered = read(buff,samplesPerFrame,samplesOverlap);  
  
        crest = spectralCrest(audioBuffered,fs, ...  
                               'Window',win, ...  
                               'OverlapLength',0);  
  
        logger(crest)  
    end  
end  
release(fileReader)  
  
Plot the logged data.  
  
plot(logger.Buffer)  
ylabel('Crest (Hz)')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

scalar | vector

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | vector

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | non-negative scalar

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral crest is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral crest is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

crest — Spectral crest

`scalar` | `vector` | `matrix`

Spectral crest, returned as a scalar, vector, or matrix. Each row of `crest` corresponds to the spectral crest of a window of `x`. Each column of `crest` corresponds to an independent channel.

spectralPeak — Spectral peak

`scalar` | `vector` | `matrix`

Spectral peak, returned as a scalar, vector, or matrix. Each row of `spectralPeak` corresponds to the spectral crest of a window of `x`. Each column of `spectralPeak` corresponds to an independent channel.

spectralMean — Spectral mean

`scalar` | `vector` | `matrix`

Spectral mean, returned as a scalar, vector, or matrix. Each row of `spectralMean` corresponds to the spectral crest of a window of `x`. Each column of `spectralMean` corresponds to an independent channel.

Algorithms

The spectral crest is calculated as described in [1]:

$$\text{crest} = \frac{\max(s_k \in [b_1, b_2])}{\frac{1}{b_2 - b_1} \sum_{k=b_1}^{b_2} s_k}$$

where

- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral crest.

References

[1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

`spectralSpread` | `spectralFlatness` | `spectralSkewness`

Topics

"Spectral Descriptors"

Introduced in R2019a

spectralCentroid

Spectral centroid for audio signals and auditory spectrograms

Syntax

```
centroid = spectralCentroid(x,f)
centroid = spectralCentroid(x,f,Name=Value)
spectralCentroid( ___ )
```

Description

`centroid = spectralCentroid(x,f)` returns the spectral centroid of the signal, `x`, over time. How the function interprets `x` depends on the shape of `f`.

`centroid = spectralCentroid(x,f,Name=Value)` specifies options using one or more name-value arguments.

`spectralCentroid(___)` with no output arguments plots the spectral centroid. You can specify an input combination from any of the previous syntaxes.

- If the input is in the time domain, the spectral centroid is plotted against time.
- If the input is in the frequency domain, the spectral centroid is plotted against frame number.

Examples

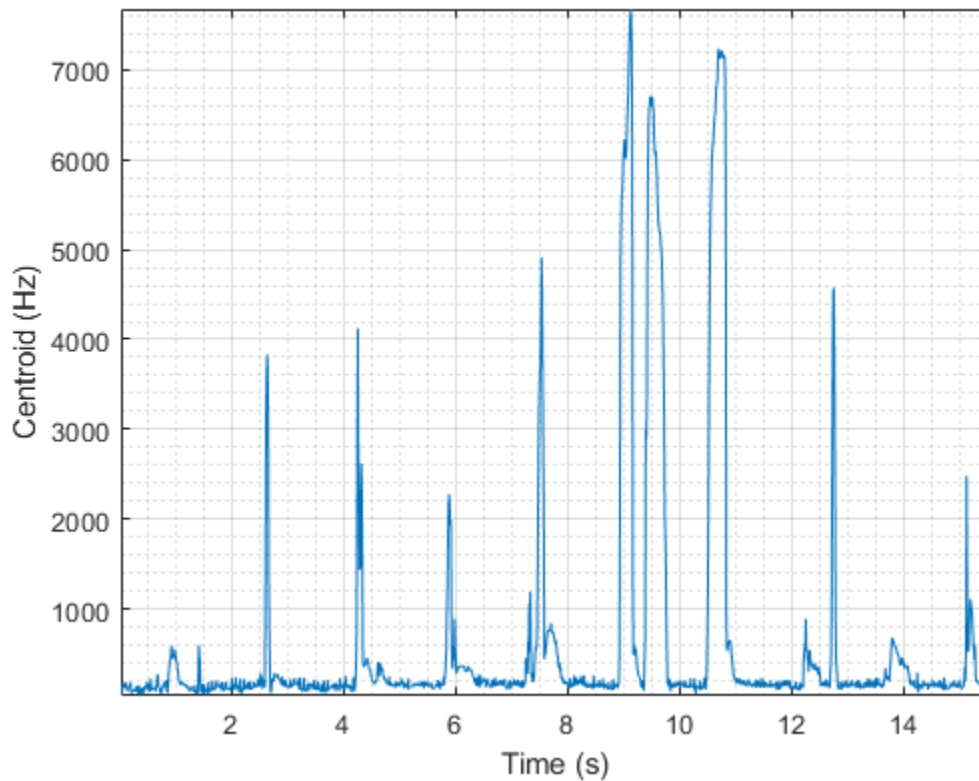
Spectral Centroid of Time-Domain Audio

Read in an audio file and calculate the centroid using default parameters.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
centroid = spectralCentroid(audioIn,fs);
```

Plot the centroid against time.

```
spectralCentroid(audioIn,fs);
```



Spectral Centroid of Frequency-Domain Audio Data

Read in an audio file and then buffer the signal into 30 ms frames with 20 ms overlap. Calculate the octave power spectrum using the `p octave` function.

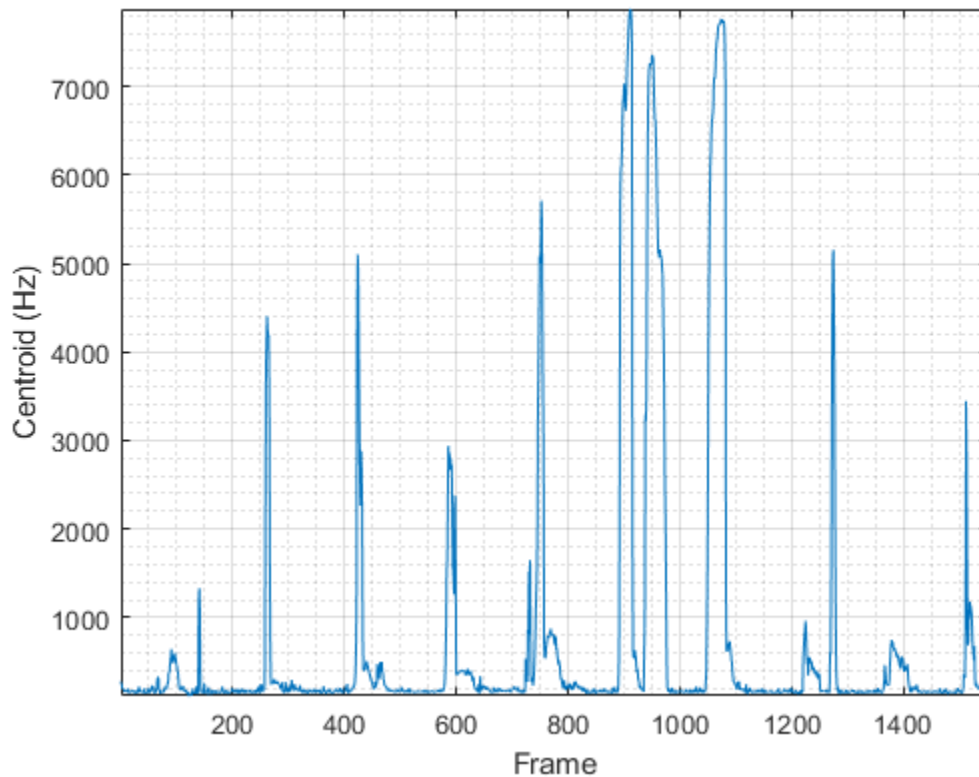
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
audioBuffered = buffer(audioIn,round(fs*0.03),round(fs*0.02),"nodelay");
[p,cf] = p octave(audioBuffered,fs);
```

Calculate the centroid of the octave power spectrum over time.

```
centroid = spectralCentroid(p,cf);
```

Plot the centroid against the frame number.

```
spectralCentroid(p,cf)
```

Specify Nondefault Parameters

Read in an audio file.

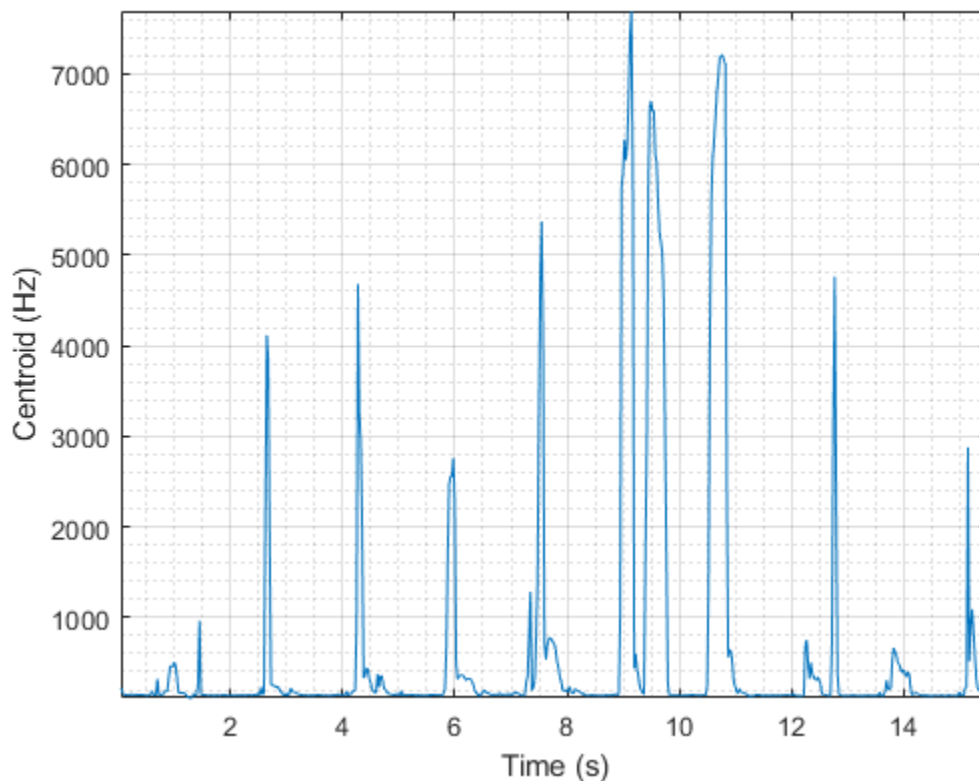
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Calculate the centroid of the power spectrum over time. Calculate the centroid for 50 ms Hamming windows of data with 25 ms overlap. Use the range from 62.5 Hz to $fs/2$ for the centroid calculation.

```
centroid = spectralCentroid(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5, fs/2]);
```

Plot the centroid against time.

```
spectralCentroid(audioIn,fs, ...
    Window=hamming(round(0.05*fs)), ...
    OverlapLength=round(0.025*fs), ...
    Range=[62.5, fs/2])
```



Calculate Spectral Centroid of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create a `dsp.SignalSink` to log the spectral centroid calculation.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
logger = dsp.SignalSink;
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Calculate the spectral centroid for the frame of audio.
- 3 Log the spectral centroid for later plotting.

To calculate the spectral centroid for only a given input frame, specify a window with the same number of samples as the input, and set the overlap length to zero.

Plot the logged data.

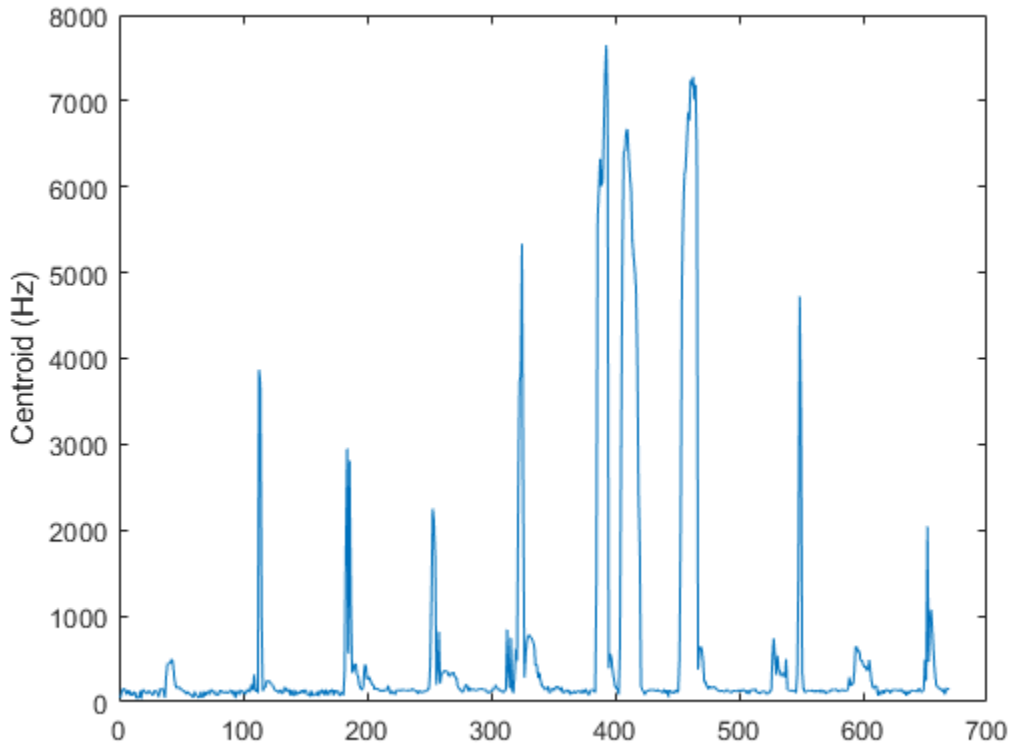
```
while ~isDone(fileReader)
    audioIn = fileReader();
    centroid = spectralCentroid(audioIn,fileReader.SampleRate, ...
                               'Window',hamming(size(audioIn,1)), ...
                               'OverlapLength',0);
```

```

    logger(centroid)
end

plot(logger.Buffer)
ylabel('Centroid (Hz)')

```



If the input to your audio stream loop has a variable samples-per-frame, an inconsistent samples-per-frame with the analysis window size of `spectralCentroid`, or if you want to calculate the spectral centroid for overlapped data, use `dsp.AsyncBuffer`.

Create a `dsp.AsyncBuffer` object, reset the logger, and release the file reader.

```

buff = dsp.AsyncBuffer;
reset(logger)
release(fileReader)

```

Specify that the spectral centroid is calculated for 50 ms frames with a 25 ms overlap.

```

fs = fileReader.SampleRate;

samplesPerFrame = round(fs*0.05);
samplesOverlap = round(fs*0.025);

samplesPerHop = samplesPerFrame - samplesOverlap;

win = hamming(samplesPerFrame);

while ~isDone(fileReader)

```

```
audioIn = fileReader();
write(buff, audioIn);

while buff.NumUnreadSamples >= samplesPerHop
    audioBuffered = read(buff, samplesPerFrame, samplesOverlap);

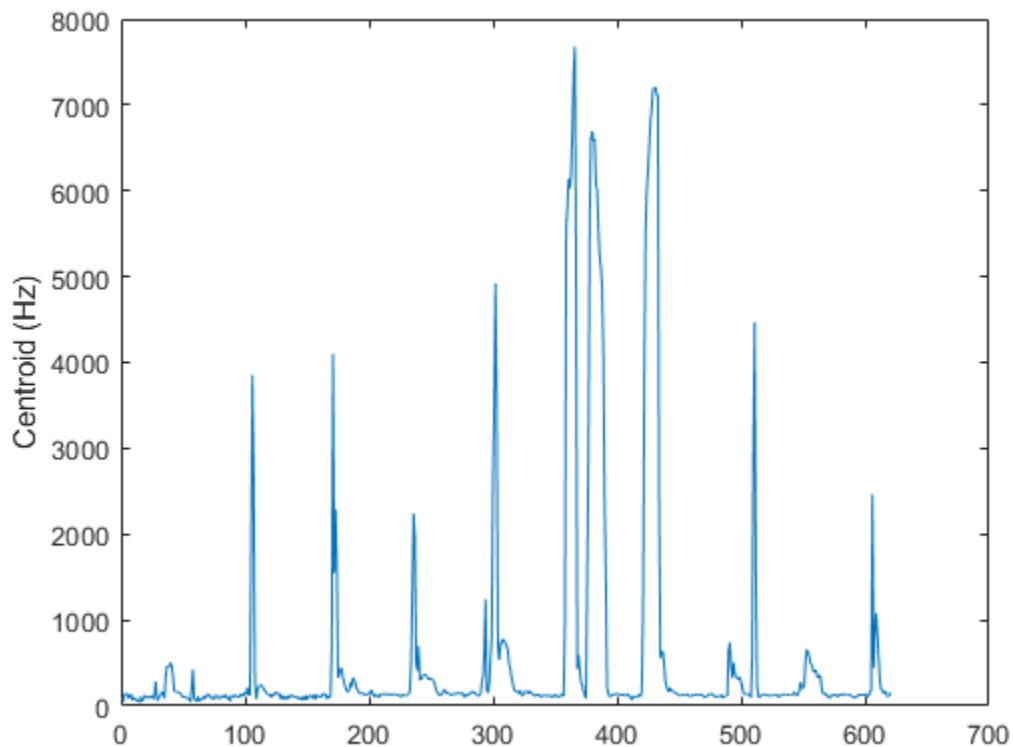
    centroid = spectralCentroid(audioBuffered, fs, ...
                                'Window', win, ...
                                'OverlapLength', 0);

    logger(centroid)
end

end
release(fileReader)
```

Plot the logged data.

```
plot(logger.Buffer)
ylabel('Centroid (Hz)')
```



Input Arguments

x — Input signal

column vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array. How the function interprets x depends on the shape of f .

Data Types: `single` | `double`

f — Sample rate or frequency vector (Hz)

`scalar` | `vector`

Sample rate or frequency vector in Hz, specified as a scalar or vector, respectively. How the function interprets x depends on the shape of f :

- If f is a scalar, x is interpreted as a time-domain signal, and f is interpreted as the sample rate. In this case, x must be a real vector or matrix. If x is specified as a matrix, the columns are interpreted as individual channels.
- If f is a vector, x is interpreted as a frequency-domain signal, and f is interpreted as the frequencies, in Hz, corresponding to the rows of x . In this case, x must be a real L -by- M -by- N array, where L is the number of spectral values at given frequencies of f , M is the number of individual spectra, and N is the number of channels.
- The number of rows of x , L , must be equal to the number of elements of f .

Data Types: `single` | `double`

Name-Value Arguments

Note The following name-value arguments apply if x is a time-domain signal. If x is a frequency-domain signal, name-value arguments are ignored.

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `Window=hamming(256)`

Window — Window applied in time domain

`rectwin(round(f*0.03))` (default) | `vector`

Window applied in the time domain, specified as a real vector. The number of elements in the vector must be in the range $[1, \text{size}(x, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapped between adjacent windows

`round(f*0.02)` (default) | `non-negative scalar`

Number of samples overlapped between adjacent windows, specified as an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

FFTLength — Number of bins in DFT

`numel(Window)` (default) | `positive scalar integer`

Number of bins used to calculate the DFT of windowed input samples, specified as a positive scalar integer. If unspecified, `FFTLength` defaults to the number of elements in the `Window`.

Data Types: `single` | `double`

Range — Frequency range (Hz)

`[0, f/2]` (default) | two-element row vector

Frequency range in Hz, specified as a two-element row vector of increasing real values in the range `[0, f/2]`.

Data Types: `single` | `double`

SpectrumType — Spectrum type

`"power"` (default) | `"magnitude"`

Spectrum type, specified as `"power"` or `"magnitude"`:

- `"power"` -- The spectral centroid is calculated for the one-sided power spectrum.
- `"magnitude"` -- The spectral centroid is calculated for the one-sided magnitude spectrum.

Data Types: `char` | `string`

Output Arguments

centroid — Spectral centroid (Hz)

scalar | vector | matrix

Spectral centroid in Hz, returned as a scalar, vector, or matrix. Each row of `centroid` corresponds to the spectral centroid of a window of `x`. Each column of `centroid` corresponds to an independent channel.

Algorithms

The spectral centroid is calculated as described in [1]:

$$\text{centroid} = \frac{\sum_{k=b_1}^{b_2} f_k s_k}{\sum_{k=b_1}^{b_2} s_k}$$

where

- f_k is the frequency in Hz corresponding to bin k .
- s_k is the spectral value at bin k .
- b_1 and b_2 are the band edges, in bins, over which to calculate the spectral centroid.

References

- [1] Peeters, G. "A Large Set of Audio Features for Sound Description (Similarity and Classification) in the CUIDADO Project." Technical Report; IRCAM: Paris, France, 2004.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

[spectralSkewness](#) | [spectralKurtosis](#) | [spectralSpread](#)

Topics

“Spectral Descriptors”

Introduced in R2019a

hz2mel

Convert from hertz to mel scale

Syntax

```
mel = hz2mel(hz)
```

Description

`mel = hz2mel(hz)` converts values in hertz to values on the mel frequency scale.

Examples

Convert Between Mel Scale and Hz

Set two bounding frequencies in Hz and then convert them to the mel scale.

```
b = hz2mel([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the mel scale.

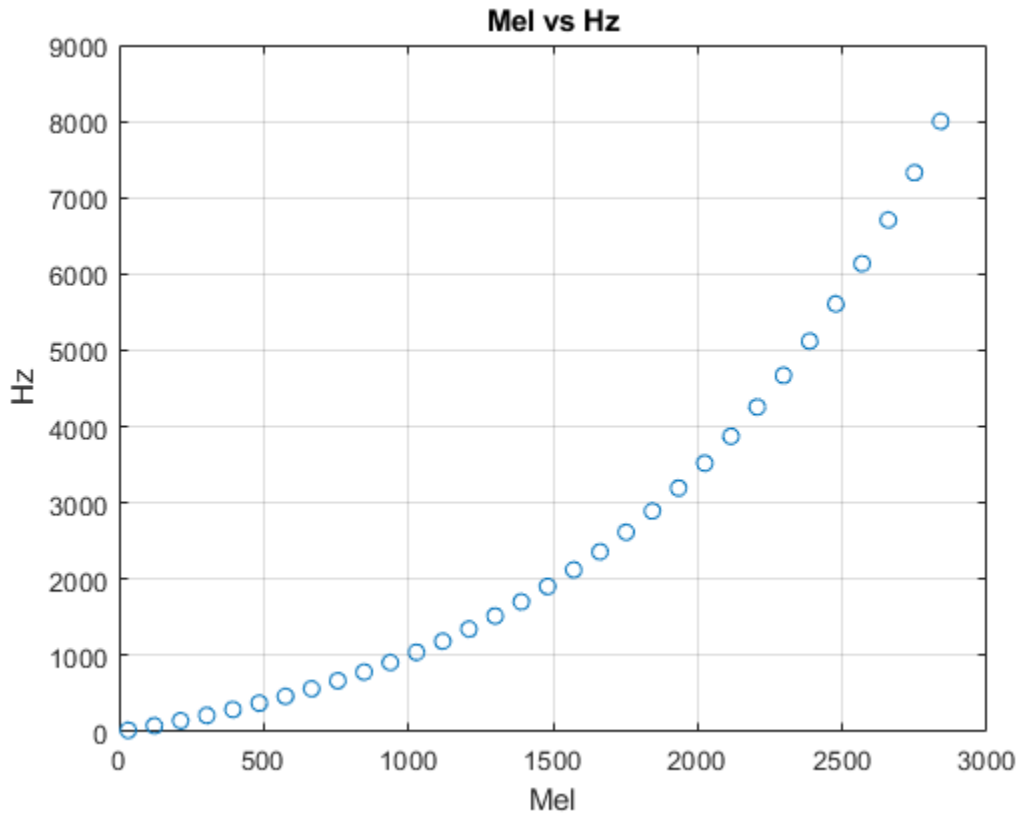
```
melVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = mel2hz(melVect);
```

Plot the two vectors for comparison. As mel values increase linearly, Hz values increase exponentially.

```
plot(melVect,hzVect,'o')  
title('Mel vs Hz')  
xlabel('Mel')  
ylabel('Hz')  
grid on
```

Input Arguments

hz — Input frequency in Hz

scalar | vector | matrix | multidimensional array

Input frequency in Hz, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: single | double

Output Arguments

mel — Output frequency on mel scale

scalar | vector | matrix | multidimensional array

Output frequency on the mel scale, returned as a scalar, vector, matrix, or multidimensional array the same size as hz.

Data Types: single | double

Algorithms

The frequency conversion from Hz to the mel scale uses the following formula:

$$mel = 2595 \log_{10} \left(1 + \frac{hz}{700} \right)$$

References

[1] O'Shaghnessy, Douglas. *Speech Communication: Human and Machine*. Reading, MA: Addison-Wesley Publishing Company, 1987.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

mel2hz | hz2erb | erb2hz | hz2bark | bark2hz

Introduced in R2019a

hz2bark

Convert from hertz to Bark scale

Syntax

```
bark = hz2bark(hz)
```

Description

`bark = hz2bark(hz)` converts values in hertz to values on the Bark frequency scale.

Examples

Convert Between Bark Scale and Hz

Set two bounding frequencies in Hz and then convert them to the Bark scale.

```
b = hz2bark([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the Bark scale.

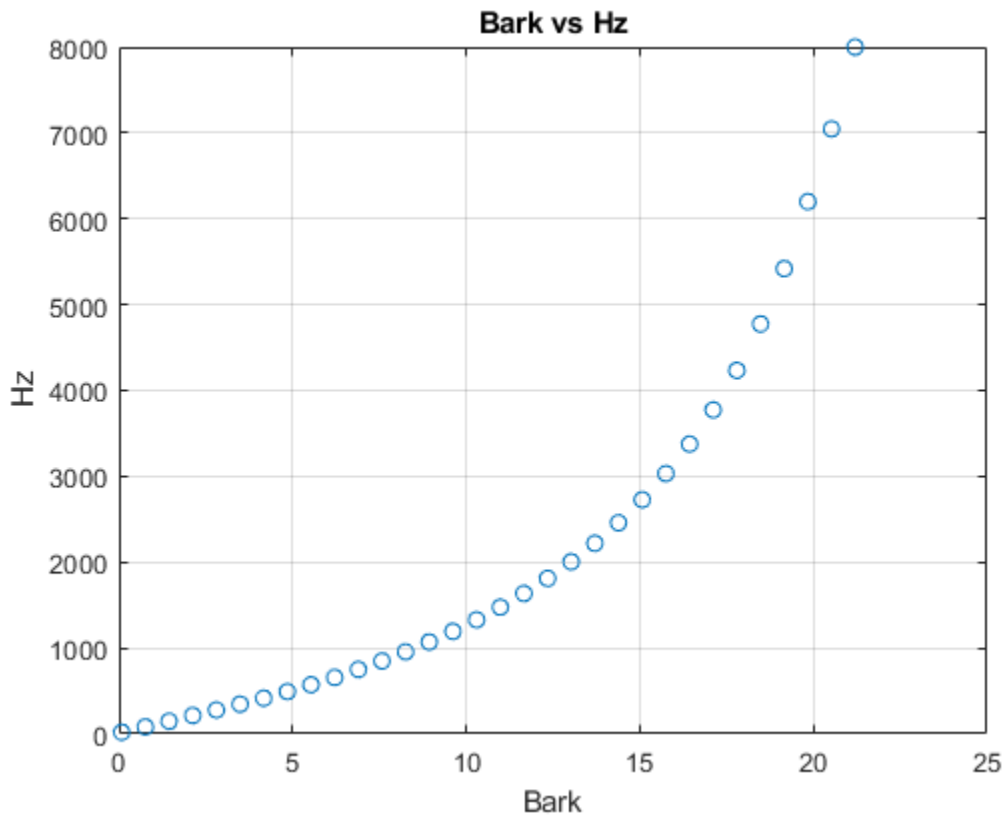
```
barkVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = bark2hz(barkVect);
```

Plot the two vectors for comparison. As Bark values increase linearly, Hz values increase exponentially.

```
plot(barkVect,hzVect,'o')
title('Bark vs Hz')
xlabel('Bark')
ylabel('Hz')
grid on
```



Input Arguments

hz — Input frequency in Hz

scalar | vector | matrix | multidimensional array

Input frequency in Hz, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: single | double

Output Arguments

bark — Output frequency on Bark scale

scalar | vector | matrix | multidimensional array

Output frequency on the Bark scale, returned as a scalar, vector, matrix, or multidimensional array the same size as hz.

Data Types: single | double

Algorithms

The frequency conversion from Hz to the Bark scale uses the following formula:

$$bark = \frac{(26.81)(hz)}{1960 + hz} - 0.53$$

$$if: bark < 2 \rightarrow bark = bark + (0.15)(2 - bark)$$

$$if: bark > 20.1 \rightarrow bark = bark + (0.22)(bark - 20.1)$$

The Bark value correction occurs after the conversion from Hz to the Bark scale.

References

- [1] Traunmüller, Hartmut. "Analytical Expressions for the Tonotopic Sensory Scale." *Journal of the Acoustical Society of America*. Vol. 88, Issue 1, 1990, pp. 97-100.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

bark2hz | hz2mel | mel2hz | hz2erb | erb2hz

Introduced in R2019a

hz2erb

Convert from hertz to equivalent rectangular bandwidth (ERB) scale

Syntax

```
erb = hz2erb(hz)
```

Description

`erb = hz2erb(hz)` converts values in hertz to values on the ERB frequency scale.

Examples

Convert Between ERB Scale and Hz

Set two bounding frequencies in Hz and then convert them to the ERB scale.

```
b = hz2erb([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the ERB scale.

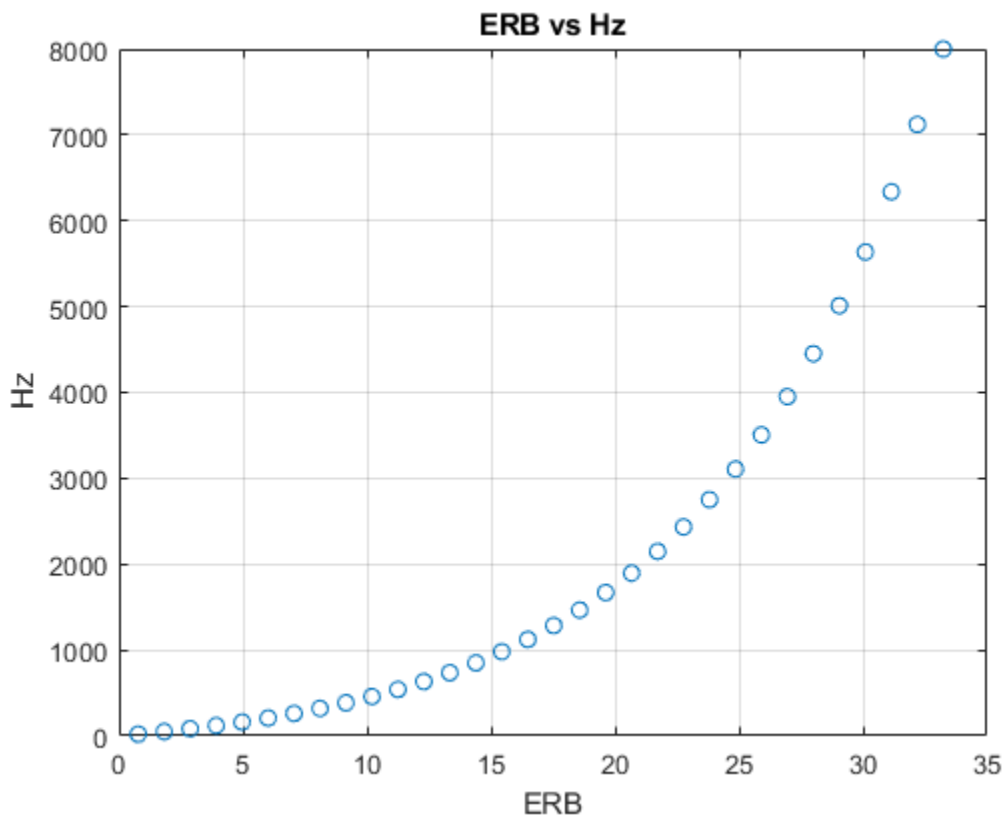
```
erbVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = erb2hz(erbVect);
```

Plot the two vectors for comparison. As ERB values increase linearly, Hz values increase exponentially.

```
plot(erbVect,hzVect,'o')
title('ERB vs Hz')
xlabel('ERB')
ylabel('Hz')
grid on
```



Input Arguments

hz — Input frequency in Hz

scalar | vector | matrix | multidimensional array

Input frequency in Hz, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: single | double

Output Arguments

erb — Output frequency on ERB scale

scalar | vector | matrix | multidimensional array

Output frequency on the ERB scale, returned as a scalar, vector, matrix, or multidimensional array the same size as hz.

Data Types: single | double

Algorithms

The frequency conversion from Hz to the ERB scale uses the following formula:

$$erb = A \log_{10}(1 + hz(0.00437))$$

where

$$A = \frac{1000 \log_e(10)}{(24.7)(4.37)}$$

References

- [1] Glasberg, Brian R., and Brian C. J. Moore. "Derivation of Auditory Filter Shapes from Notched-Noise Data." *Hearing Research*. Vol. 47, Issues 1-2, 1990, pp. 103-138.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

erb2hz | hz2mel | mel2hz | hz2bark | bark2hz

Introduced in R2019a

mel2hz

Convert from mel scale to hertz

Syntax

```
hz = mel2hz(mel)
```

Description

`hz = mel2hz(mel)` converts values on the mel frequency scale to values in hertz.

Examples

Convert Between Mel Scale and Hz

Set two bounding frequencies in Hz and then convert them to the mel scale.

```
b = hz2mel([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the mel scale.

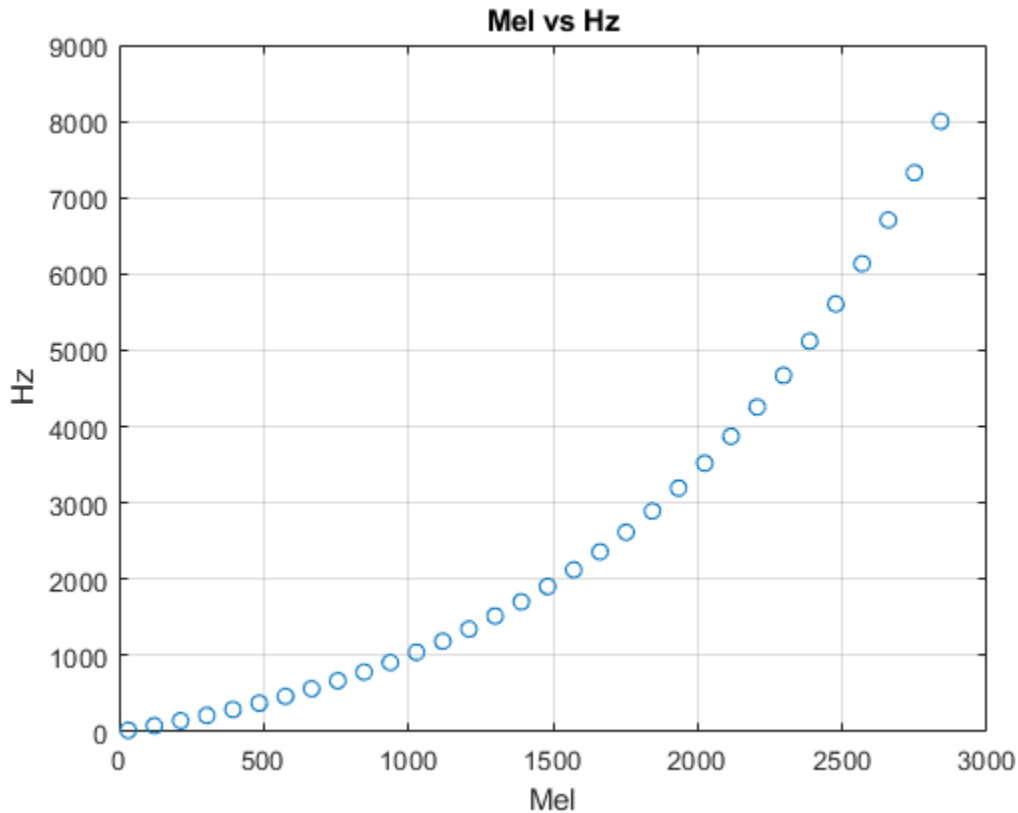
```
melVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = mel2hz(melVect);
```

Plot the two vectors for comparison. As mel values increase linearly, Hz values increase exponentially.

```
plot(melVect,hzVect,'o')
title('Mel vs Hz')
xlabel('Mel')
ylabel('Hz')
grid on
```



Input Arguments

mel — Input frequency on mel scale

scalar | vector | matrix | multidimensional array

Input frequency on the mel scale, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: single | double

Output Arguments

hz — Output frequency in Hz

scalar | vector | matrix | multidimensional array

Output frequency in Hz, returned as a scalar, vector, matrix, or multidimensional array the same size as `mel`.

Data Types: single | double

Algorithms

The frequency conversion from the mel scale to Hz uses the following formula:

$$hz = 700 \left(10^{\frac{mel}{2595}} - 1 \right)$$

References

- [1] O'Shaughnessy, Douglas. *Speech Communication: Human and Machine*. Reading, MA: Addison-Wesley Publishing Company, 1987.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

hz2mel | hz2erb | erb2hz | hz2bark | bark2hz

Introduced in R2019a

bark2hz

Convert from Bark scale to hertz

Syntax

```
hz = bark2hz(bark)
```

Description

`hz = bark2hz(bark)` converts values on the Bark frequency scale to values in hertz.

Examples

Convert Between Bark Scale and Hz

Set two bounding frequencies in Hz and then convert them to the Bark scale.

```
b = hz2bark([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the Bark scale.

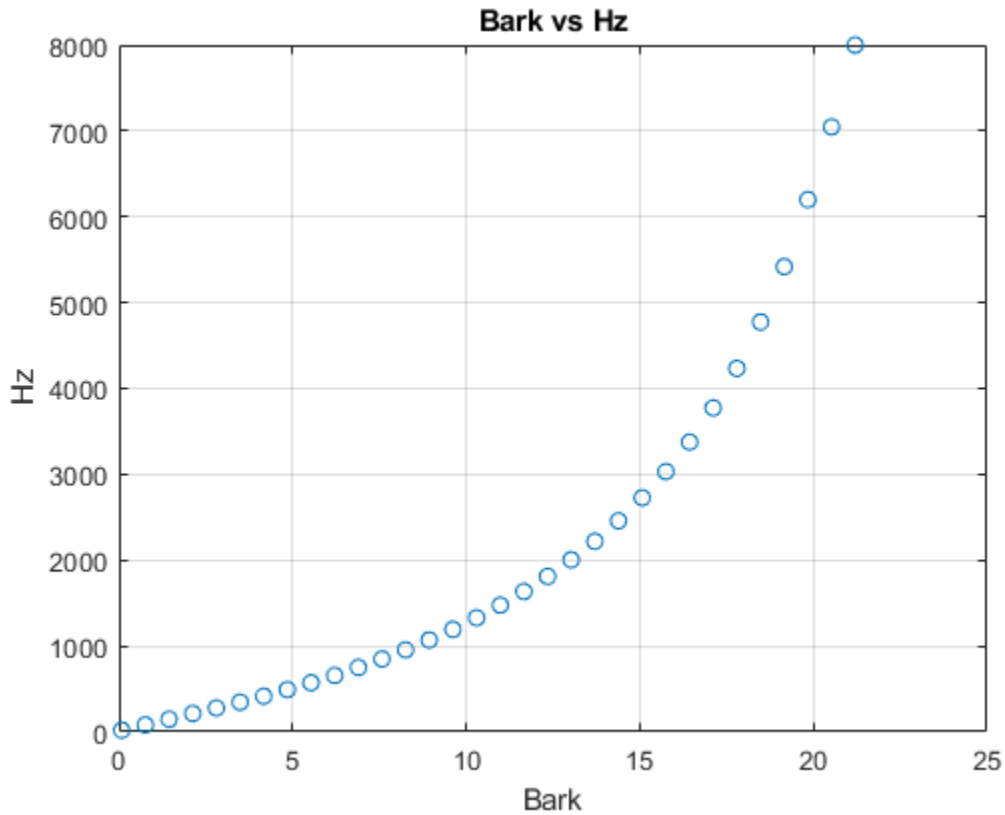
```
barkVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = bark2hz(barkVect);
```

Plot the two vectors for comparison. As Bark values increase linearly, Hz values increase exponentially.

```
plot(barkVect,hzVect,'o')
title('Bark vs Hz')
xlabel('Bark')
ylabel('Hz')
grid on
```



Input Arguments

bark — Input frequency on Bark scale

scalar | vector | matrix | multidimensional array

Input frequency on the Bark scale, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: single | double

Output Arguments

hz — Output frequency in Hz

scalar | vector | matrix | multidimensional array

Output frequency in Hz, returned as a scalar, vector, matrix, or multidimensional array the same size as bark.

Data Types: single | double

Algorithms

The frequency conversion from the Bark scale to Hz uses the following formula:

$$\text{if: } \text{bark} < 2 \rightarrow \text{bark} = \frac{(\text{bark} - 0.3)}{0.85}$$

$$\text{if: } \text{bark} > 20.1 \rightarrow \text{bark} = \frac{(\text{bark} + 4.422)}{1.22}$$

$$\text{hz} = 1960 \left(\frac{\text{bark} + 0.53}{26.28 - \text{bark}} \right)$$

The Bark value correction occurs before the conversion from the Bark scale to Hz.

References

- [1] Traunmüller, Hartmut. "Analytical Expressions for the Tonotopic Sensory Scale." *Journal of the Acoustical Society of America*. Vol. 88, Issue 1, 1990, pp. 97-100.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

hz2bark | hz2mel | mel2hz | hz2erb | erb2hz

Introduced in R2019a

erb2hz

Convert from equivalent rectangular bandwidth (ERB) scale to hertz

Syntax

```
hz = erb2hz(erb)
```

Description

`hz = erb2hz(erb)` converts values on the ERB frequency scale to values in hertz.

Examples

Convert Between ERB Scale and Hz

Set two bounding frequencies in Hz and then convert them to the ERB scale.

```
b = hz2erb([20,8000]);
```

Generate a row vector of 32 values uniformly spaced on the ERB scale.

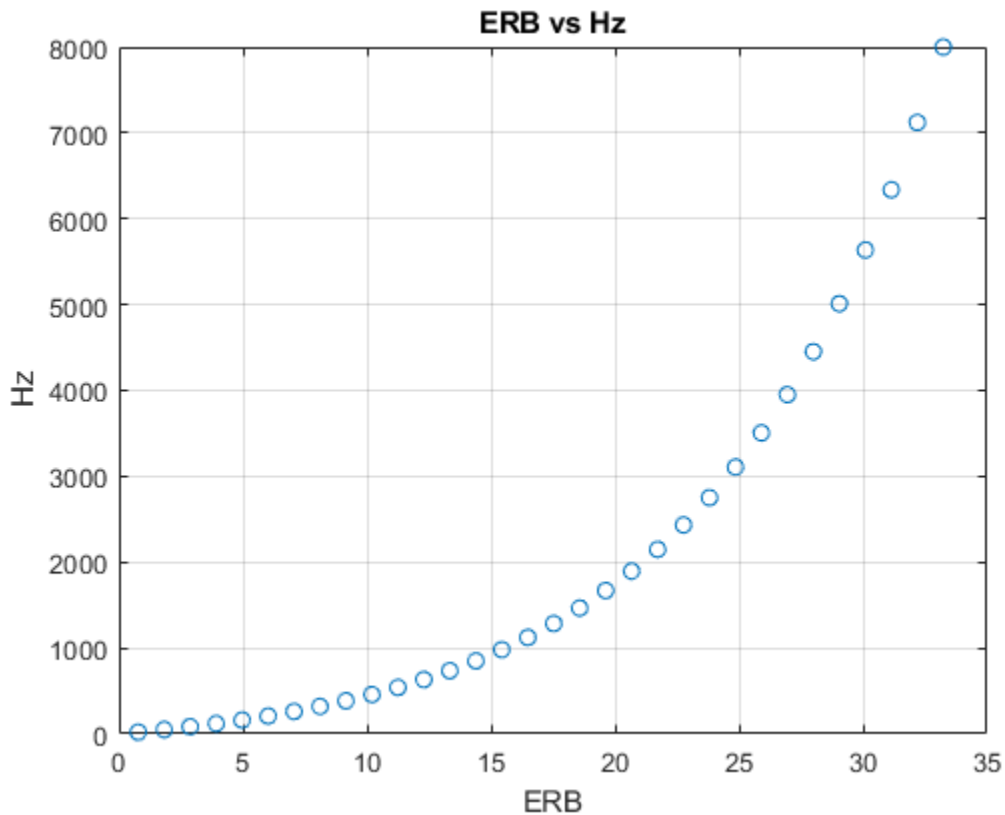
```
erbVect = linspace(b(1),b(2),32);
```

Convert the row vector of values into equivalent frequencies in Hz.

```
hzVect = erb2hz(erbVect);
```

Plot the two vectors for comparison. As ERB values increase linearly, Hz values increase exponentially.

```
plot(erbVect,hzVect,'o')
title('ERB vs Hz')
xlabel('ERB')
ylabel('Hz')
grid on
```



Input Arguments

erb — Input frequency on ERB scale

scalar | vector | matrix | multidimensional array

Input frequency on the equivalent rectangular band (ERB) scale, specified as a scalar, vector, matrix, or multidimensional array.

Data Types: `single` | `double`

Output Arguments

hz — Output frequency in Hz

scalar | vector | matrix | multidimensional array

Output frequency in Hz, returned as a scalar, vector, matrix, or multidimensional array the same size as `erb`.

Data Types: `single` | `double`

Algorithms

The frequency conversion from the ERB scale to Hz uses the following formula:

$$hz = \frac{10^{\frac{erb}{A}} - 1}{0.00437}$$

where

$$A = \frac{1000 \log_e(10)}{(24.7)(4.37)}$$

References

- [1] Glasberg, Brian R., and Brian C. J. Moore. "Derivation of Auditory Filter Shapes from Notched-Noise Data." *Hearing Research*. Vol. 47, Issues 1-2, 1990, pp. 103-138.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

hz2erb | hz2mel | mel2hz | hz2bark | bark2hz

Introduced in R2019a

mls

Maximum length sequence

Syntax

```
excitation = mls  
excitation = mls(L)  
excitation = mls(L,Name,Value)
```

Description

`excitation = mls` returns an excitation signal generated using the maximum length sequence (MLS) technique. This type of sequence is a pseudo-random binary sequence.

`excitation = mls(L)` specifies the output length `L` of the excitation signal.

`excitation = mls(L,Name,Value)` specifies options using one or more `Name,Value` pair arguments, in addition to the input arguments in the previous syntaxes.

Examples

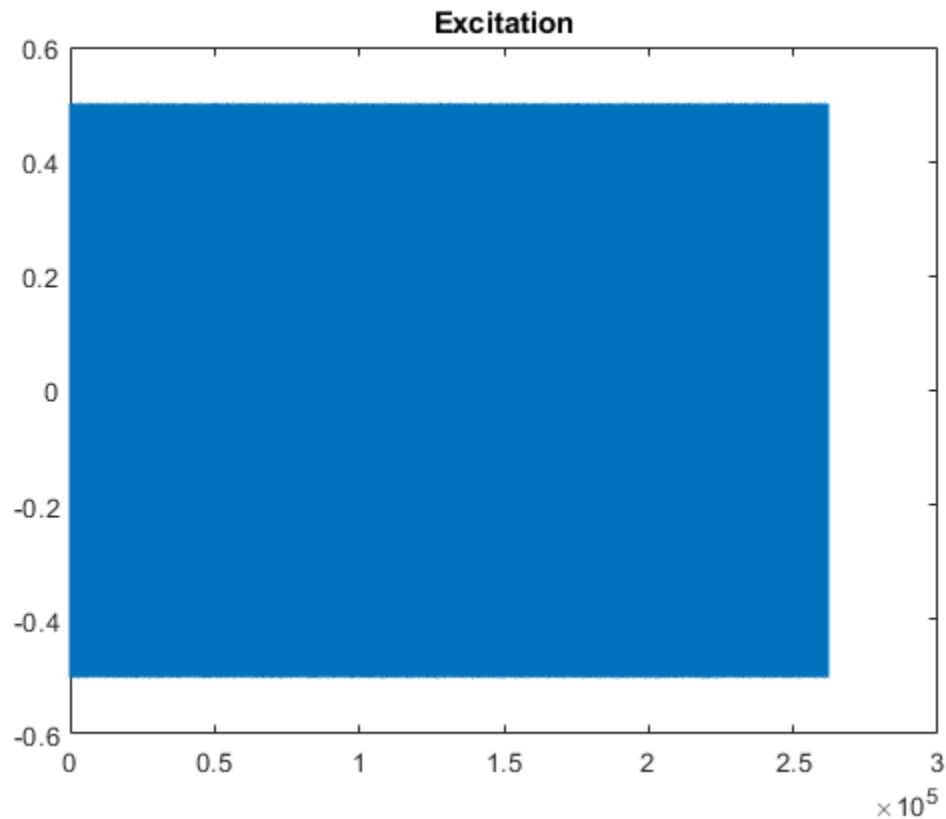
Estimate Impulse Response Using MLS Excitation

Use `audioread` to read in an impulse response recording. Create a `dsp.FrequencyDomainFIRFilter` object to perform frequency domain filtering using the known impulse response.

```
[irKnown,fs] = audioread('ChurchImpulseResponse-16-44p1-mono-5secs.wav');  
systemModel = dsp.FrequencyDomainFIRFilter(irKnown);
```

Create an MLS excitation signal by using the `mls` function. The MLS excitation signal must be longer than the impulse response. Note that the length of the MLS excitation is extended to the next power of two minus one.

```
excitation = mls(numel(irKnown)+1);  
  
plot(excitation)  
title('Excitation')
```



Replicate the excitation signal four times to measure the average of three measurements. The recording of the first MLS sequence does include all the impulse response information, so `impzest` discards it as a warmup run. Pad the excitation signal with zeros to account for the filter latency.

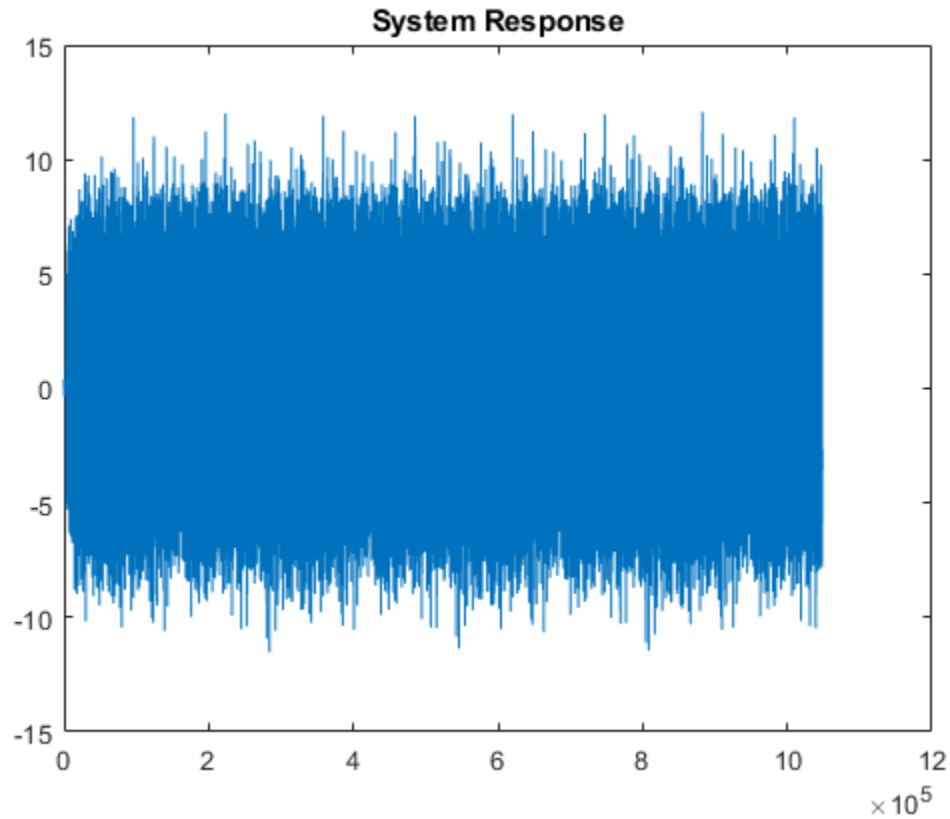
```
numRuns = 4;
excrep = repmat(excitation,numRuns,1);
excrep = [excrep;zeros(numel(irKnown)+1,1)];
```

Pass the excitation signal through the known filter and then add noise to model a real-word recording (system response). Cut the delay introduced at the beginning by the filter.

```
rec = systemModel(excrep);
rec = rec + 0.1*randn(size(rec));

rec = rec(numel(irKnown)+2:end,:);

plot(rec)
title('System Response')
```



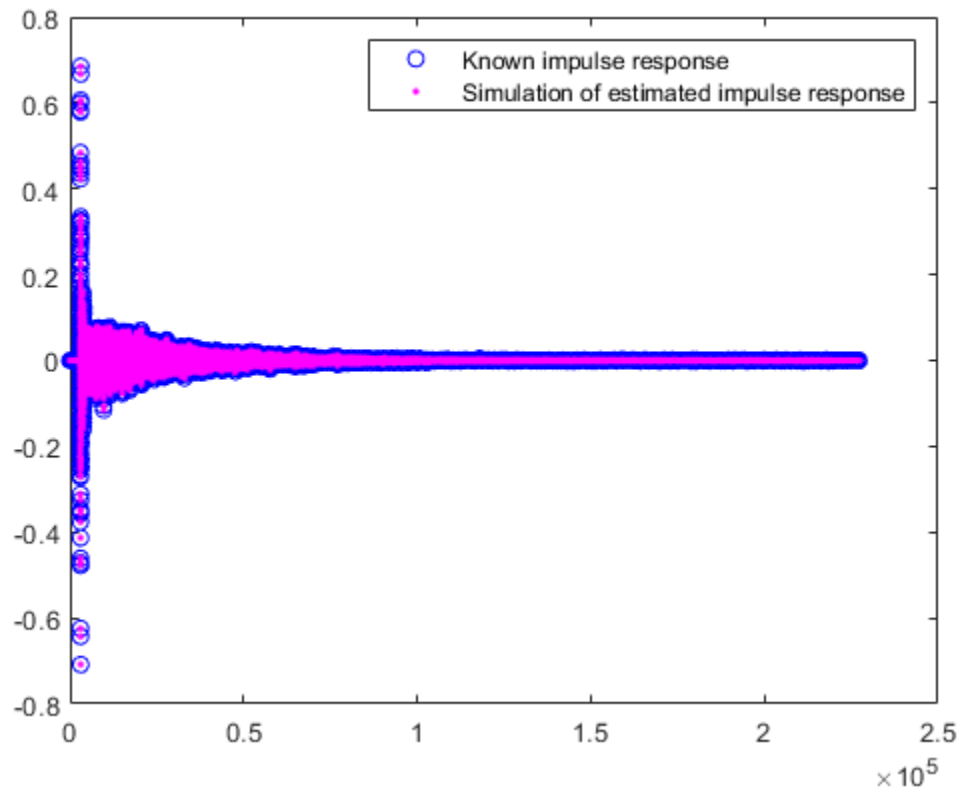
In a real-world scenario, the MLS sequence is played back in the system under test while recording. The recording would be cut so that it begins at the moment the MLS sequence is picked-up and truncated to last the duration of the repeated sequence.

Pass the excitation signal and the system response to the `impzest` function to estimate the impulse response. Plot the known impulse response and the simulation of the estimated impulse response for comparison.

```
irEstimate = impzest(excitation,rec);

samples = 1:numel(irKnown);
plot(samples,irEstimate(samples),'bo', ...
      samples,irKnown(samples),'m.')

legend('Known impulse response','Simulation of estimated impulse response')
```



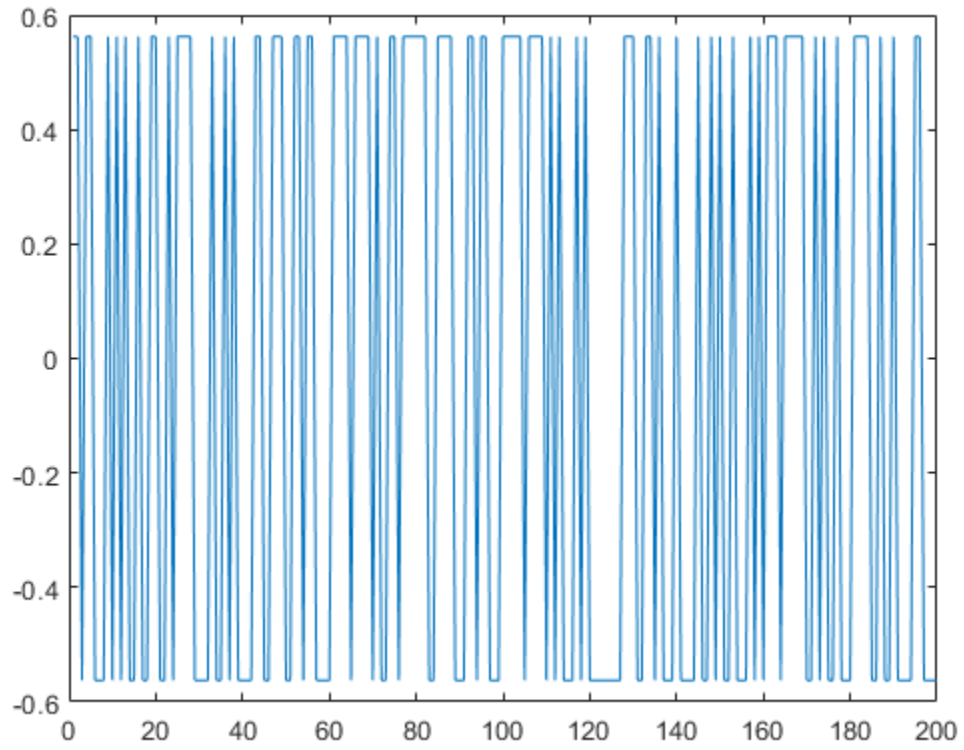
Generate MLS Signal

Generate an MLS signal that is $2^{14}-1$ samples long and has a level of -5 dB.

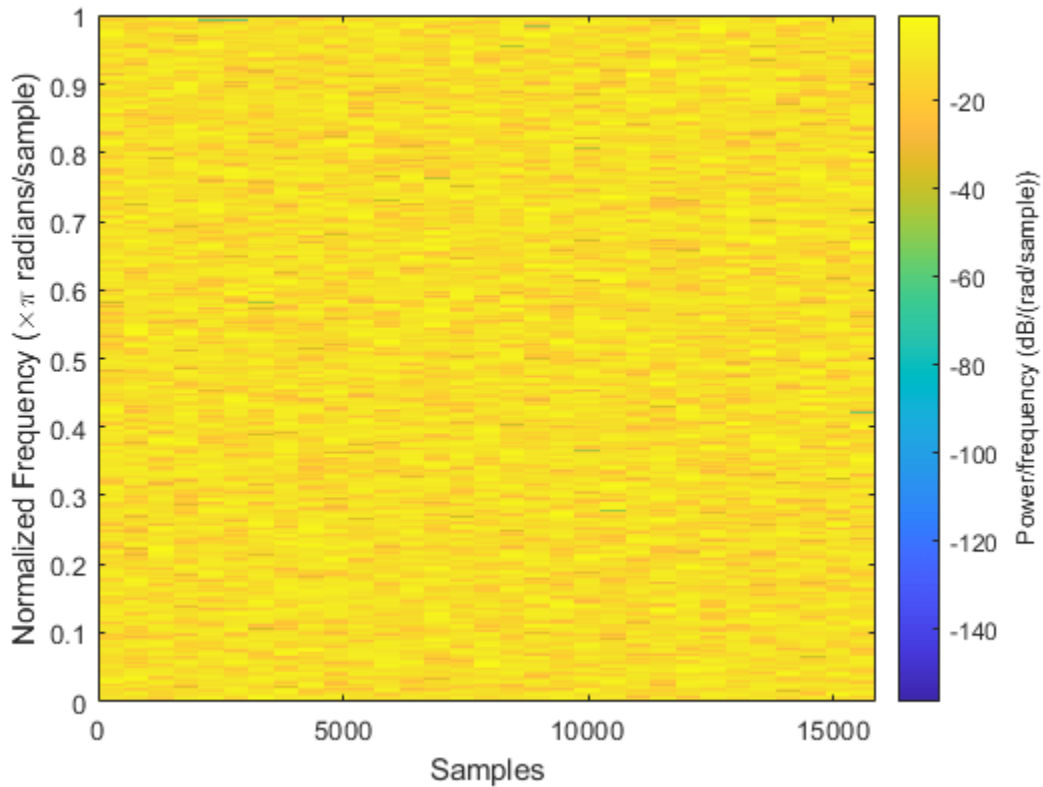
```
L = 2^14-1;  
level = -5;  
excitation = mls(L, 'ExcitationLevel', level);
```

Visualize the excitation in time and time-frequency. For the time-domain plot, plot only the first 200 samples for visibility. The pattern is constant.

```
plot(excitation(1:200))
```



```
spectrogram(excitation,512,0,1024,'yaxis')
```



Input Arguments

L – Length of excitation signal

32767 (default) | scalar in the range $[3, 2^{29}]$

Length of excitation signal to generate, specified as a scalar in the range $[3, 2^{29}]$.

The requested output length L must be a power of two minus one. Otherwise, the output length increases to the next valid length.

Note If you use the excitation signal generated by the `mls` function to record and estimate the impulse response of a system, then the length of the excitation signal must be at least as long as the impulse response that you want to estimate.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'ExcitationLevel', -5

ExcitationLevel — Level of the excitation signal to generate (dB)

scalar in the range [-42, 0]

Level of the excitation signal to generate in dB, specified as a scalar in the range [-42, 0].

Data Types: single | double

Output Arguments**excitation** — Excitation signal

column vector

Excitation signal generated using the maximum length sequence (MLS) technique, returned as a column vector.

Data Types: single | double

References

- [1] Guy-Bart, Stan, Jean-Jacques Embrechts, and Dominique Archambeau. "Comparison of Different Impulse Response Measurement Techniques." *Journal of Audio Engineering Society*. Vol. 50, Issue 4, 2002, pp. 246-262.

Extended Capabilities**C/C++ Code Generation**

Generate C and C++ code using MATLAB® Coder™.

See Also

impzest | sweeptone | **Impulse Response Measurer**

Introduced in R2018b

sweeptone

Exponential swept sine

Syntax

```
excitation = sweeptone()  
excitation = sweeptone(swDur)  
excitation = sweeptone(swDur,silDur)  
excitation = sweeptone(swDur,silDur,fs)  
excitation = sweeptone( ____,Name,Value)
```

Description

`excitation = sweeptone()` returns an excitation signal generated using the exponential swept sine (ESS) technique. By default, the signal has a 6-second duration, followed by 4 seconds of silence, for a sample rate of 44100 Hz.

`excitation = sweeptone(swDur)` specifies the duration of the exponential swept sine signal.

`excitation = sweeptone(swDur,silDur)` specifies the duration of the silence following the exponential swept sine signal.

`excitation = sweeptone(swDur,silDur,fs)` specifies the sample rate of the sweep tone as `fs` Hz.

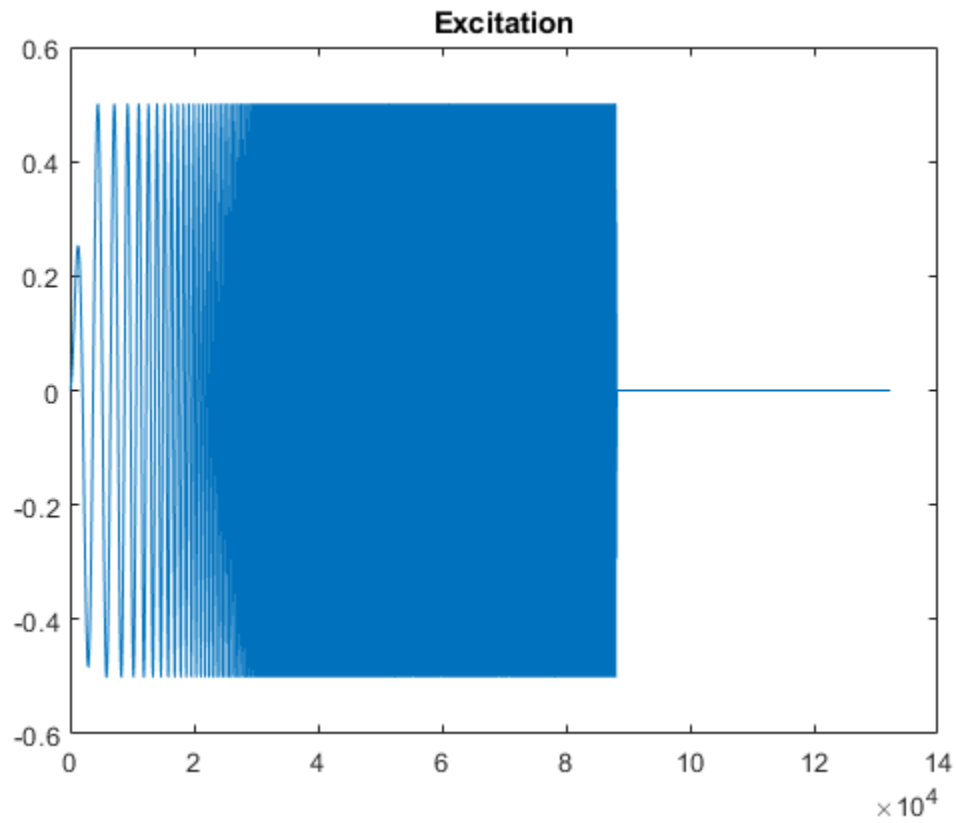
`excitation = sweeptone(____,Name,Value)` specifies options using one or more `Name,Value` pair arguments, in addition to the input arguments in the previous syntaxes.

Examples

Estimate Impulse Response Using Sweep Tone Excitation

Create a sweep tone excitation signal by using the `sweeptone` function.

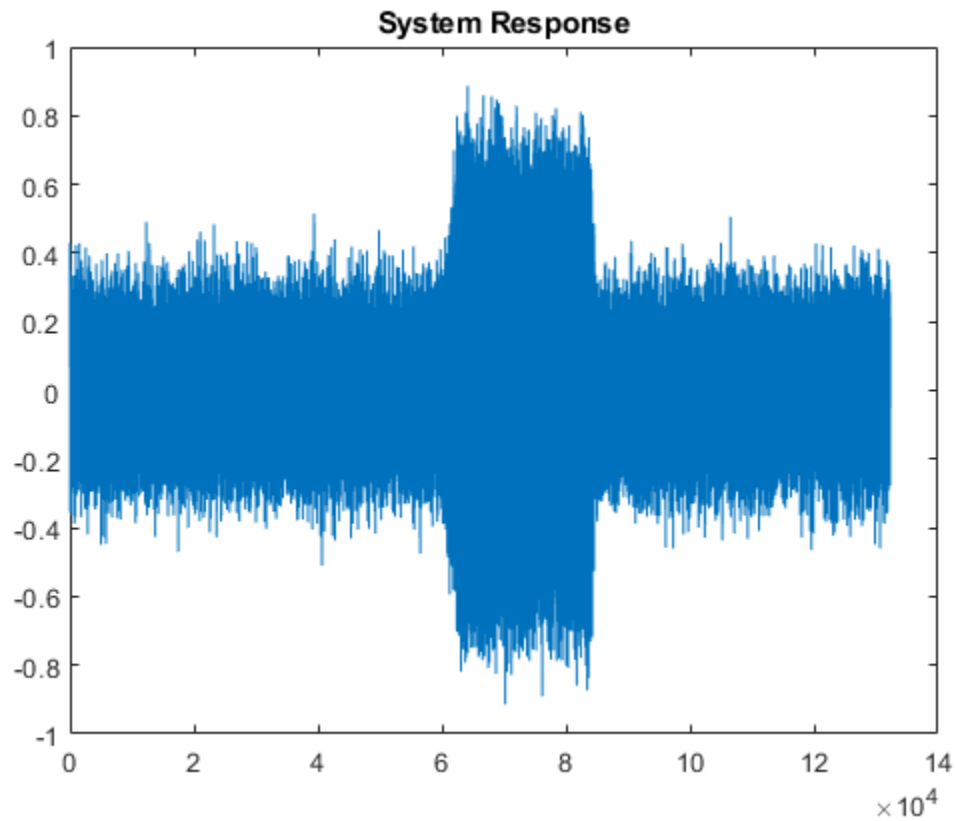
```
excitation = sweeptone(2,1,44100);  
  
plot(excitation)  
title('Excitation')
```



Pass the excitation signal through an infinite impulse response (IIR) filter and add noise to model a real-world recording (system response).

```
[B,A] = butter(10,[.1 .7]);  
rec = filter(B,A,excitation);  
nrec = rec + 0.12*randn(size(rec));
```

```
plot(nrec)  
title('System Response')
```

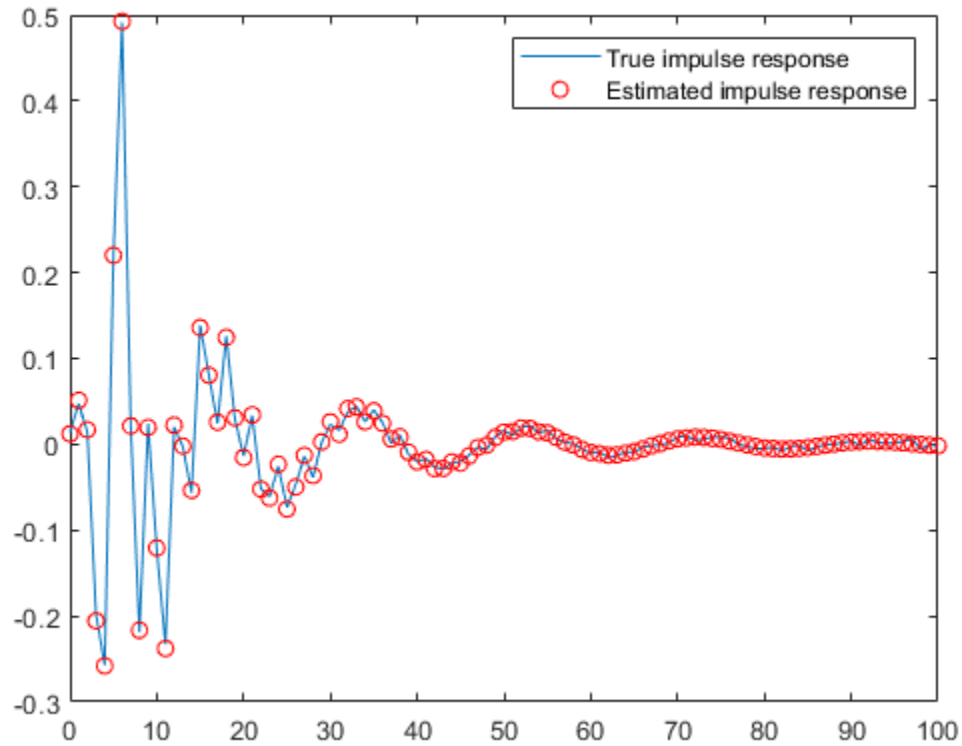


Pass the excitation signal and the system response to the `impzest` function to estimate the impulse response. Truncate the estimate to 100 points. Use `impz` to determine the true impulse response of the system. Plot the true impulse response and the estimated impulse response for comparison.

```
irEstimate = impzest(excitation,nrec);
irEstimate = irEstimate(1:101);

irTrue = impz(B,A,101);
plot(0:100,irEstimate, ...
     0:100,irTrue,'ro')

legend('True impulse response','Estimated impulse response')
```



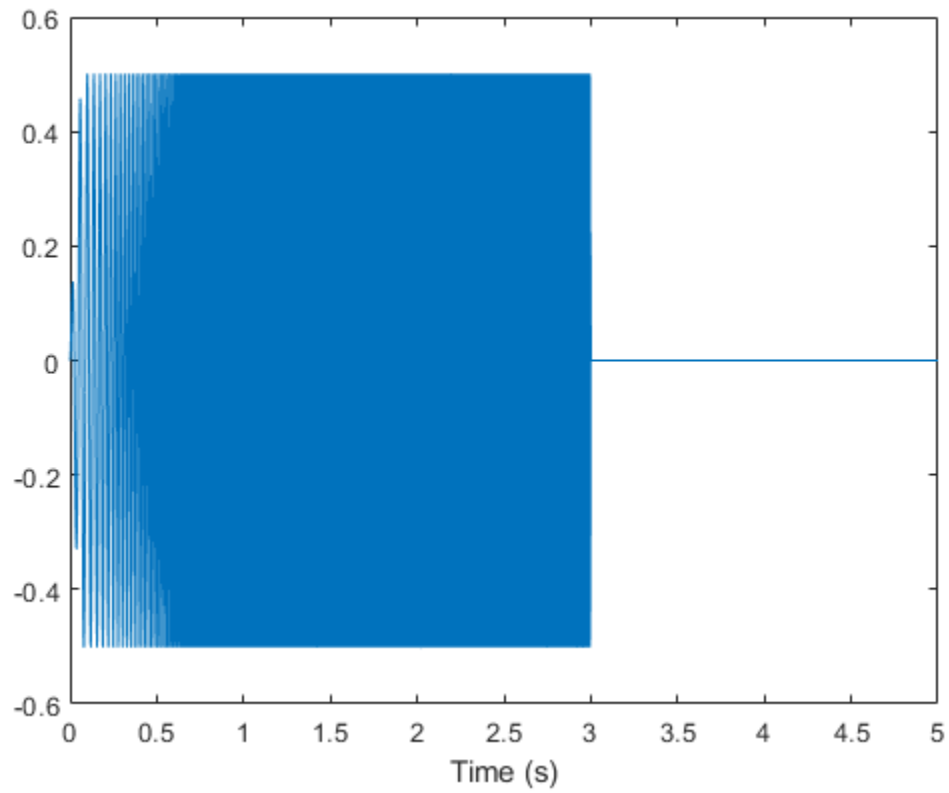
Generate ESS Signal

Generate an exponential swept sine (ESS) signal with a 3-second sweep that goes from 20 Hz to 20 kHz, and ends with a 2-second silence. Specify the sample rate as 48 kHz.

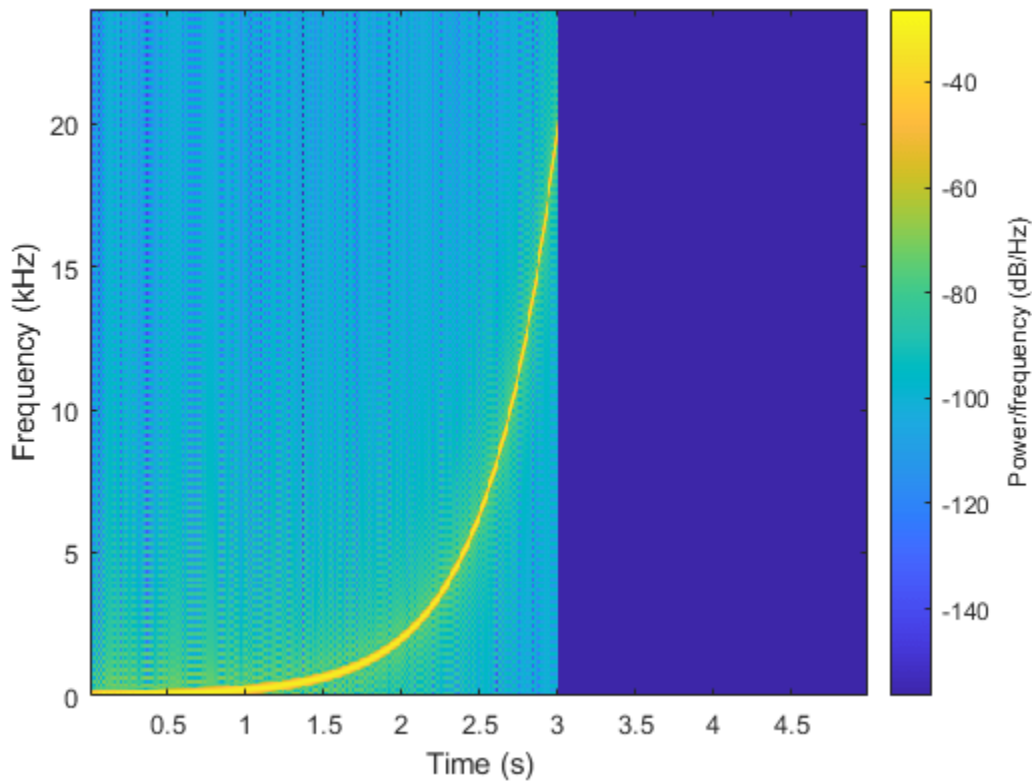
```
fs = 48e3;  
excitation = swepttone(3,2,fs, 'SweepFrequencyRange', [20 20e3]);
```

Visualize the excitation in time and time-frequency.

```
t = (0:numel(excitation)-1)/fs;  
plot(t,excitation)  
xlabel('Time (s)')
```



```
spectrogram(excitation,512,0,1024,fs,'yaxis')
```



Input Arguments

swDur — Duration of exponential swept sine signal (s)

6 (default) | scalar in the range [0.5,15]

Duration of exponential swept sine signal in seconds, specified as a scalar in the range [0.5,15].

The total duration of the excitation signal must be less than or equal to 15 seconds: $\text{swDur} + \text{silDur} \leq 15$.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

silDur — Duration of silence after exponential swept sine signal (s)

4 (default) | scalar in the range (0,14.5]

Duration of silence after exponential swept sine, specified as a scalar in the range (0,14.5].

The total duration of the excitation signal must be less than or equal to 15 seconds: $\text{swDur} + \text{silDur} \leq 15$.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

fs — Sample rate (Hz)

44100 (default) | positive scalar

Sample rate in Hz, specified as a positive scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `'ExcitationLevel', -5`

ExcitationLevel — Level of excitation signal to generate (dB)

-6 (default) | scalar in the range `[-42, 0]`

Level of the excitation signal to generate in dB, specified as a scalar in the range `[-42, 0]`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

SweepFrequencyRange — Range of sweep frequency (Hz)

`[10 22000]` | two-element positive row vector

Range of sweep frequency in Hz, specified as a two-element row vector. The sweep frequency range can be specified low to high or high to low. That is, `[10 22000]` and `[22000 10]` are both valid inputs. The largest value of the sweep frequency range must be less than or equal to $f_s/2$.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

excitation — Excitation signal

column vector

Excitation signal generated using the ESS technique, returned as a column vector. The length of the column vector is approximately $(swDur + silDur) * f_s$ samples.

Data Types: `double`

References

- [1] Farina, Angelo. "Advancements in Impulse Response Measurements by Sine Sweeps." Presented at the *Audio Engineering Society 122nd Convention*, Vienna, Austria, 2007.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`impzest` | `mls` | **Impulse Response Measurer**

Introduced in R2018b

interpolateHRTF

3-D head-related transfer function (HRTF) interpolation

Syntax

```
interpolatedHRTF = interpolateHRTF(HRTF,sourcePositions,  
desiredSourcePositions)  
interpolatedHRTF = interpolateHRTF( ___,Name,Value)
```

Description

`interpolatedHRTF = interpolateHRTF(HRTF,sourcePositions,desiredSourcePositions)` returns the interpolated head-related transfer function (HRTF) at the desired position.

`interpolatedHRTF = interpolateHRTF(___,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Examples

Render 3-D Audio on Headphones

Modify the 3-D audio image of a sound file by filtering it through a head-related transfer function (HRTF). Set the location of the sound source by specifying the desired azimuth and elevation.

```
load 'ReferenceHRTF.mat' hrtfData sourcePosition
```

```
hrtfData = permute(double(hrtfData),[2,3,1]);
```

```
sourcePosition = sourcePosition(:,[1,2]);
```

Calculate the head-related impulse response (HRIR) using the VBAP algorithm at a desired source position. Separate the output, `interpolatedIR`, into the impulse responses for the left and right ears.

```
desiredAz = 110;  
desiredEl = -45;  
desiredPosition = [desiredAz desiredEl];
```

```
interpolatedIR = interpolateHRTF(hrtfData,sourcePosition,desiredPosition, ...  
                                "Algorithm","VBAP");
```

```
leftIR = squeeze(interpolatedIR(:,1,:))';  
rightIR = squeeze(interpolatedIR(:,2,:))';
```

Create a `dsp.AudioFileReader` object to read in a file frame by frame. Create an `audioDeviceWriter` object to play audio to your sound card frame by frame. Create two `dsp.FIRFilter` objects and specify the filter coefficients using the head-related transfer function interpolated impulse responses.


```
fileReader = dsp.AudioFileReader('RockDrums-48-stereo-11secs.mp3');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

```
leftFilter = dsp.FIRFilter('Numerator',leftIR);
rightFilter = dsp.FIRFilter('Numerator',rightIR);
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Feed the stereo audio data through the left and right HRIR filters, respectively.
- 3 Concatenate the left and right channels and write the audio to your output device.

```
while ~isDone(fileReader)
    audioIn = fileReader();

    leftChannel = leftFilter(audioIn(:,1));
    rightChannel = rightFilter(audioIn(:,2));

    deviceWriter([leftChannel,rightChannel]);
end
```

As a best practice, release your System objects when complete.

```
release(deviceWriter)
release(fileReader)
```

Model Moving Source Using HRIR Filtering

Create arrays of head-related impulse responses corresponding to desired source positions. Filter mono input to model a moving source.

Load the ARI HRTF dataset. Cast the `hrtfData` to type double, and reshape it to the required dimensions: (number of source positions)-by-2-by-(number of HRTF samples). Use the first two columns of the `sourcePosition` matrix only, which correspond to the azimuth and elevation of the source in degrees.

```
load 'ReferenceHRTF.mat' hrtfData sourcePosition
```

```
hrtfData = permute(double(hrtfData),[2,3,1]);
```

```
sourcePosition = sourcePosition(:,[1,2]);
```

Specify the desired source positions and then calculate the HRTF at these locations using the `interpolateHRTF` function. Separate the output, `interpolatedIR`, into the impulse responses for the left and right ears.

```
desiredAz = [-120;-60;0;60;120;0;-120;120];
desiredEl = [-90;90;45;0;-45;0;45;45];
desiredPosition = [desiredAz desiredEl];
```

```
interpolatedIR = interpolateHRTF(hrtfData,sourcePosition,desiredPosition);
```

```
leftIR = squeeze(interpolatedIR(:,1,:));
rightIR = squeeze(interpolatedIR(:,2,:));
```

Create an audio file sampled at 48 kHz for compatibility with the HRTF dataset.

```
desiredFs = 48e3;
[audio,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
audio = 0.8*resample(audio,desiredFs,fs);
audiowrite('Counting-16-48-mono-15secs.wav',audio,desiredFs);
```

Create a `dsp.AudioFileReader` object to read in a file frame by frame. Create an `audioDeviceWriter` object to play audio to your sound card frame by frame. Create two `dsp.FIRFilter` objects with `NumeratorSource` set to `Input port`. Setting `NumeratorSource` to `Input port` enables you to modify the filter coefficients while streaming.

```
fileReader = dsp.AudioFileReader('Counting-16-48-mono-15secs.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

```
leftFilter = dsp.FIRFilter('NumeratorSource','Input port');
rightFilter = dsp.FIRFilter('NumeratorSource','Input port');
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Feed the audio data through the left and right HRIR filters.
- 3 Concatenate the left and right channels and write the audio to your output device. If you have a stereo output hardware, such as headphones, you can hear the source shifting position over time.
- 4 Modify the desired source position in 2-second intervals by updating the filter coefficients.

```
durationPerPosition = 2;
samplesPerPosition = durationPerPosition*fileReader.SampleRate;
samplesPerPosition = samplesPerPosition - rem(samplesPerPosition,fileReader.SamplesPerFrame);

sourcePositionIndex = 1;
samplesRead = 0;
while ~isDone(fileReader)
    audioIn = fileReader();
    samplesRead = samplesRead + fileReader.SamplesPerFrame;

    leftChannel = leftFilter(audioIn,leftIR(sourcePositionIndex,:));
    rightChannel = rightFilter(audioIn,rightIR(sourcePositionIndex,:));

    deviceWriter([leftChannel,rightChannel]);

    if mod(samplesRead,samplesPerPosition) == 0
        sourcePositionIndex = sourcePositionIndex + 1;
    end
end
```

As a best practice, release your System objects when complete.

```
release(deviceWriter)
release(fileReader)
```

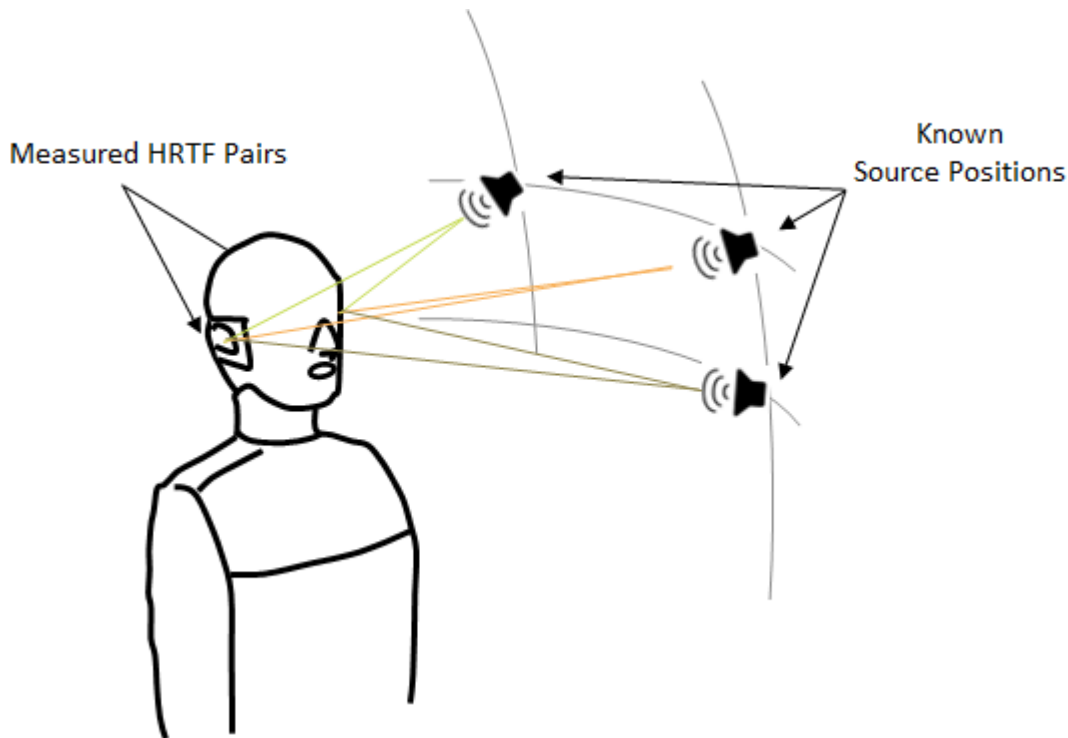
Input Arguments

HRTF — HRTF values measured at source positions

N-by-2-by-*M* array

HRTF values measured at the source positions, specified as a N -by-2-by- M array.

- N -- Number of known HRTF pairs
- M -- Number of samples in each known HRTF



If you specify HRTF with real numbers, the function assumes that the input represents an impulse response, and M corresponds to the length of the impulse response. If you specify HRTF with complex numbers, the function assumes that the input represents a transfer function, and M corresponds to the number of bins in the frequency response. The output of the `interpolateHRTF` function has the same complexity and interpretation as the input.

Data Types: `single` | `double`
 Complex Number Support: Yes

sourcePositions — Source positions corresponding to measured HRTF values

N -by-2 matrix

Source positions corresponding to measured HRTF values, specified as a N -by-2 matrix. N is the number of known HRTF pairs. The two columns correspond to the azimuth and elevation of the source in degrees, respectively.

Azimuth must be in the range $[-180,360]$. You can use the -180 to 180 convention or the 0 to 360 convention.

Elevation must be in the range $[-90,180]$. You can use the -90 to 90 convention or the 0 to 180 convention.

Data Types: `single` | `double`

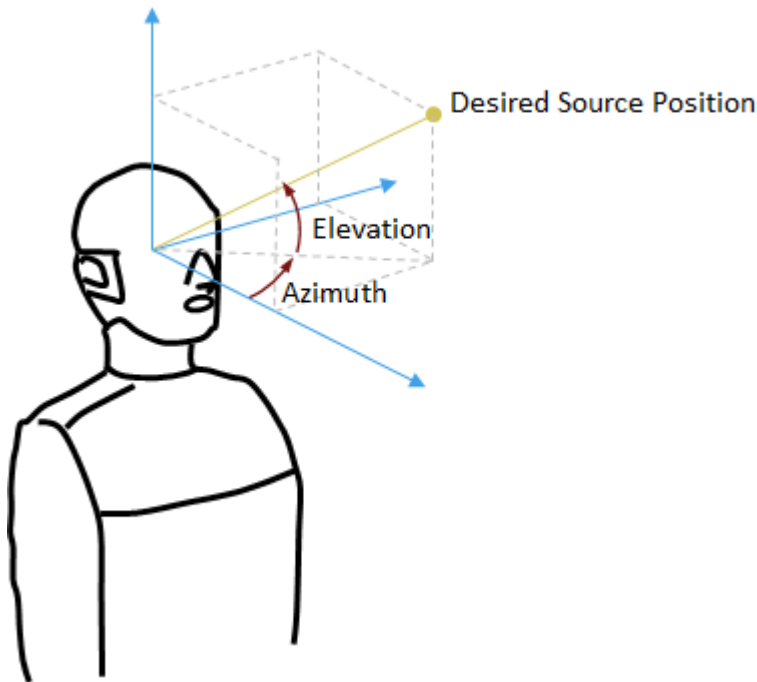
desiredSourcePositions — Desired source positions for HRTF interpolation

P -by-2 matrix

Desired source position for HRTF interpolation, specified as a P -by-2 matrix. P is the number of desired source positions. The columns correspond to the desired azimuth and elevation of the source in degrees, respectively.

Azimuth must be in the range $[-180,360]$. You can use the -180 to 180 convention or the 0 to 360 convention.

Elevation must be in the range $[-90,180]$. You can use the -90 to 90 convention or the 0 to 180 convention.



Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'Algorithm','VBAP'`

Algorithm — Interpolation algorithm

`'Bilinear'` (default) | `'VBAP'`

Interpolation algorithm, specified as `"Bilinear"` or `"VBAP"`.

- `Bilinear` -- 3-D bilinear interpolation, as specified by [1].
- `VBAP` -- Vector base amplitude panning interpolation, as specified by [2].

Data Types: `char` | `string`

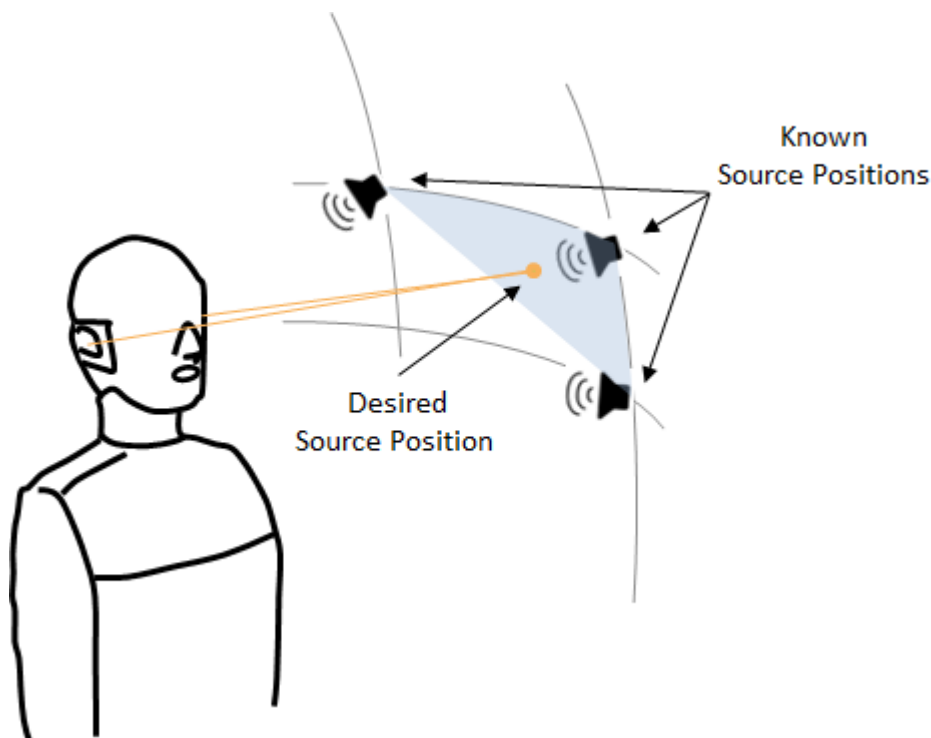
Output Arguments

interpolatedHRTF — Interpolated HRTF

P-by-2-by-*M*

Interpolated HRTF, returned as a *P*-by-2-by-*M* array.

- *P* -- Number of desired source positions, specified by the number of rows in the `desiredSourcePositions` input argument.
- *M* -- Number of samples in each known HRTF, specified by the number of pages in the HRTF input argument.



`interpolatedHRTF` has the same complexity and interpretation as the input. If you specify the input, `HRTF`, with real numbers, the function assumes that the input represents an impulse response. If you specify the input with complex numbers, the function assumes that the input represents a transfer function.

Data Types: `single` | `double`
 Complex Number Support: Yes

References

- [1] F.P. Freeland, L.W.P. Biscainho and P.S.R. Diniz, "Interpolation of Head-Related Transfer Functions (HRTFS): A multi-source approach." *2004 12th European Signal Processing Conference*. Vienna, 2004, pp. 1761-1764.
- [2] Pulkki, Ville. "Virtual Sound Source Positioning Using Vector Based Amplitude Panning." *Journal of Audio Engineering Society*. Vol. 45. Issue 6, pp. 456-466.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`dsp.FIRFilter` | `dsp.FrequencyDomainFIRFilter`

Introduced in R2018b

impzest

Estimate impulse response of audio system

Syntax

```
ir = impzest(excitation,response)
ir = impzest(excitation,response,Name,Value)
```

Description

`ir = impzest(excitation,response)` returns an estimate of the impulse response (IR) based on the excitation and response.

`ir = impzest(excitation,response,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

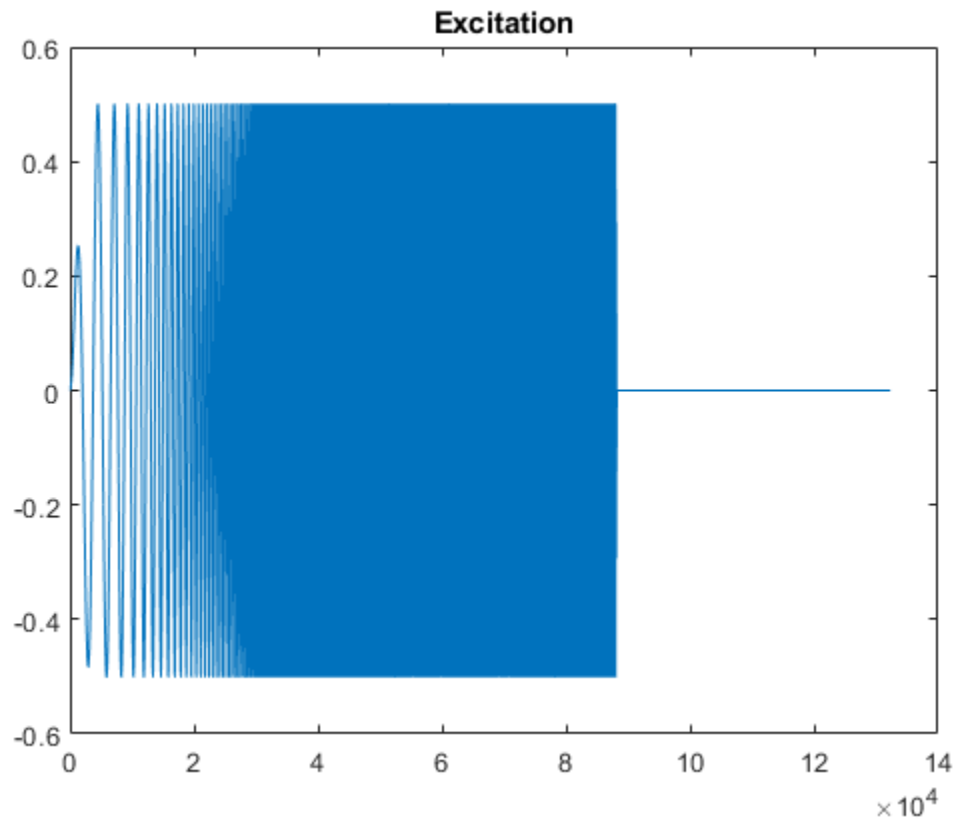
Examples

Estimate Impulse Response Using Sweep Tone Excitation

Create a sweep tone excitation signal by using the `sweeptone` function.

```
excitation = sweeptone(2,1,44100);

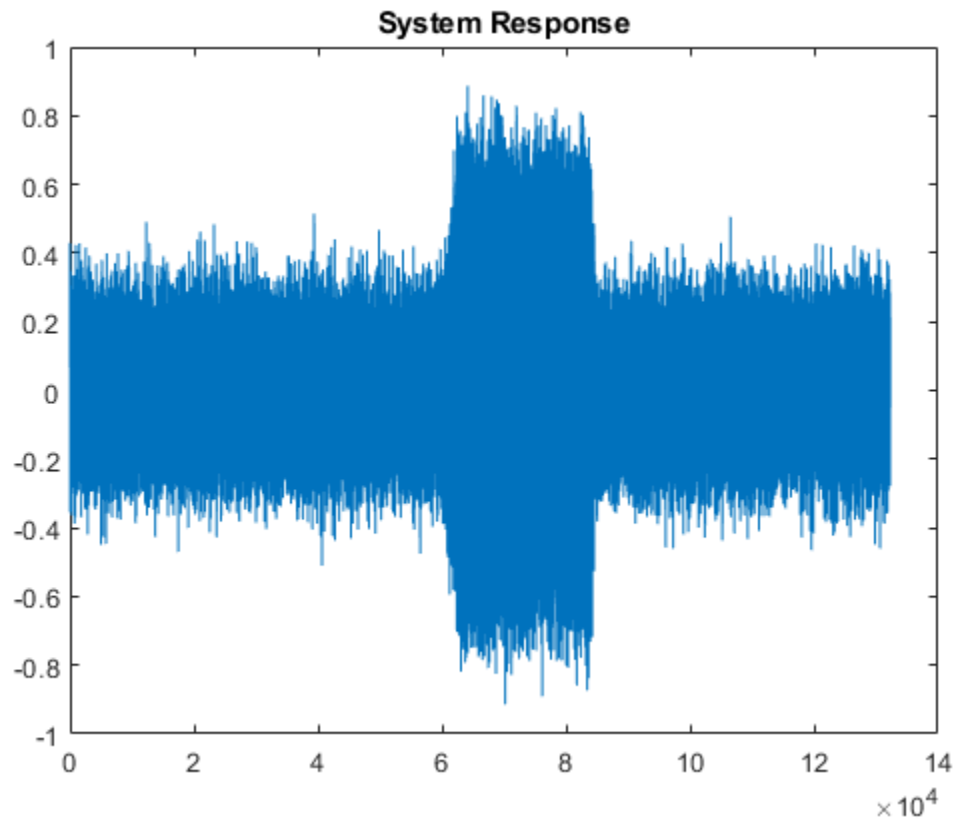
plot(excitation)
title('Excitation')
```



Pass the excitation signal through an infinite impulse response (IIR) filter and add noise to model a real-world recording (system response).

```
[B,A] = butter(10,[.1 .7]);  
rec = filter(B,A,excitation);  
nrec = rec + 0.12*randn(size(rec));
```

```
plot(nrec)  
title('System Response')
```

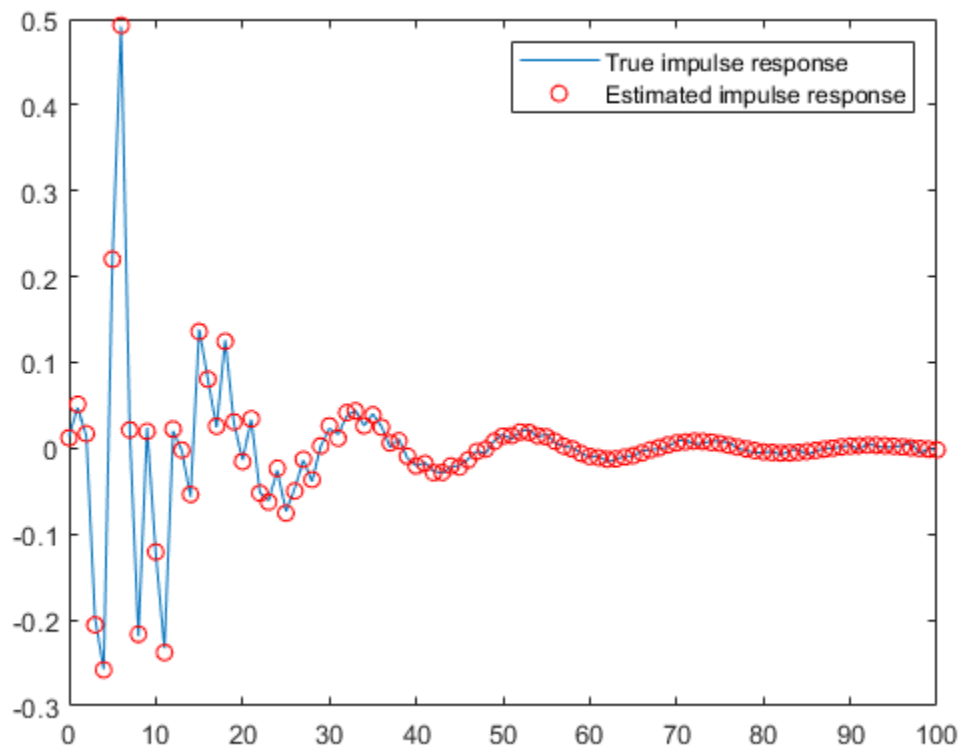



Pass the excitation signal and the system response to the `impzest` function to estimate the impulse response. Truncate the estimate to 100 points. Use `impz` to determine the true impulse response of the system. Plot the true impulse response and the estimated impulse response for comparison.

```
irEstimate = impzest(excitation,nrec);
irEstimate = irEstimate(1:101);

irTrue = impz(B,A,101);
plot(0:100,irEstimate, ...
     0:100,irTrue,'ro')

legend('True impulse response','Estimated impulse response')
```



Estimate Impulse Response Using MLS Excitation

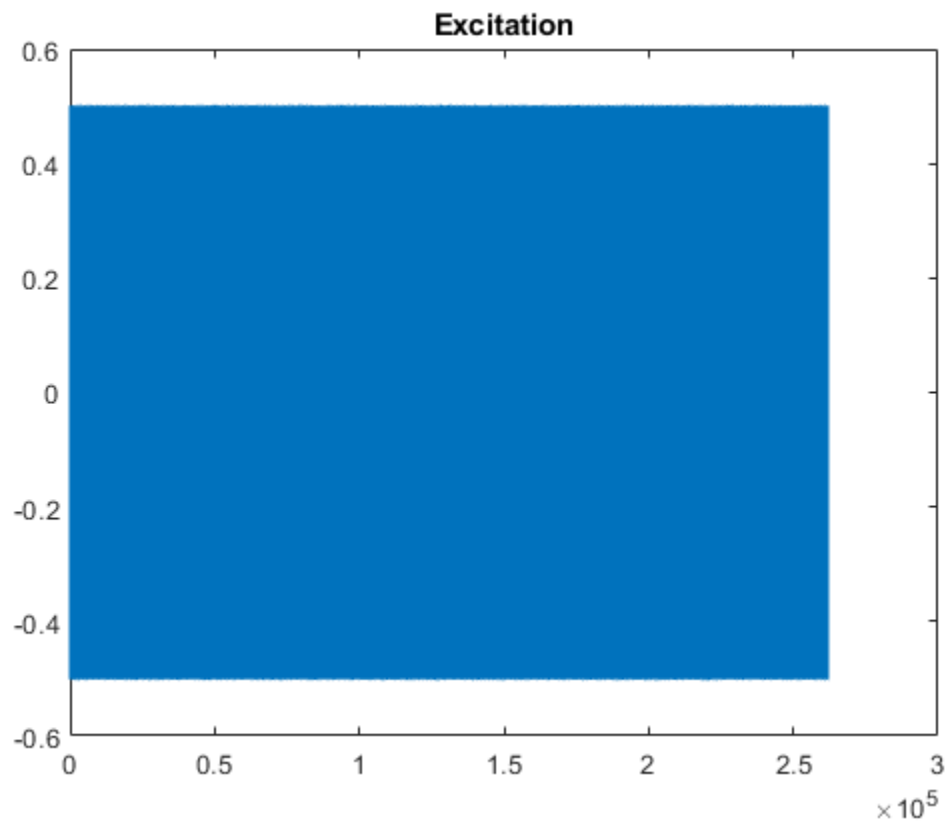
Use `audioread` to read in an impulse response recording. Create a `dsp.FrequencyDomainFIRFilter` object to perform frequency domain filtering using the known impulse response.

```
[irKnown,fs] = audioread('ChurchImpulseResponse-16-44p1-mono-5secs.wav');
systemModel = dsp.FrequencyDomainFIRFilter(irKnown');
```

Create an MLS excitation signal by using the `mls` function. The MLS excitation signal must be longer than the impulse response. Note that the length of the MLS excitation is extended to the next power of two minus one.

```
excitation = mls(numel(irKnown)+1);
```

```
plot(excitation)
title('Excitation')
```



Replicate the excitation signal four times to measure the average of three measurements. The recording of the first MLS sequence does include all the impulse response information, so `impzest` discards it as a warmup run. Pad the excitation signal with zeros to account for the filter latency.

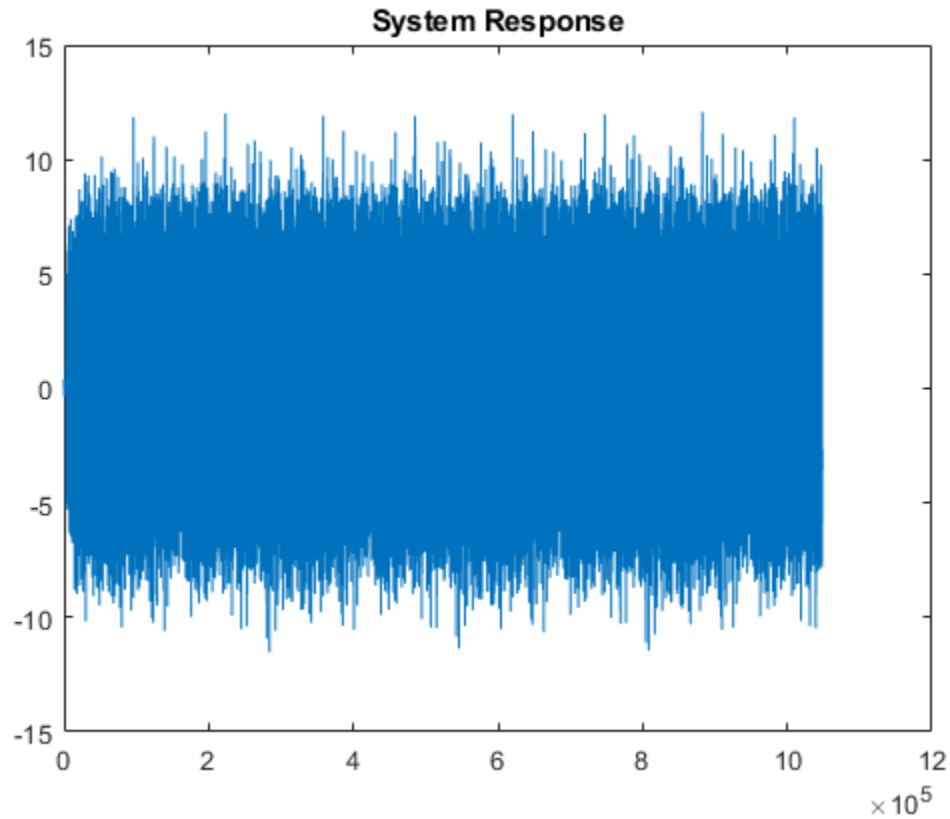
```
numRuns = 4;
excrep = repmat(excitation,numRuns,1);
excrep = [excrep;zeros(numel(irKnown)+1,1)];
```

Pass the excitation signal through the known filter and then add noise to model a real-word recording (system response). Cut the delay introduced at the beginning by the filter.

```
rec = systemModel(excrep);
rec = rec + 0.1*randn(size(rec));

rec = rec(numel(irKnown)+2:end,:);

plot(rec)
title('System Response')
```



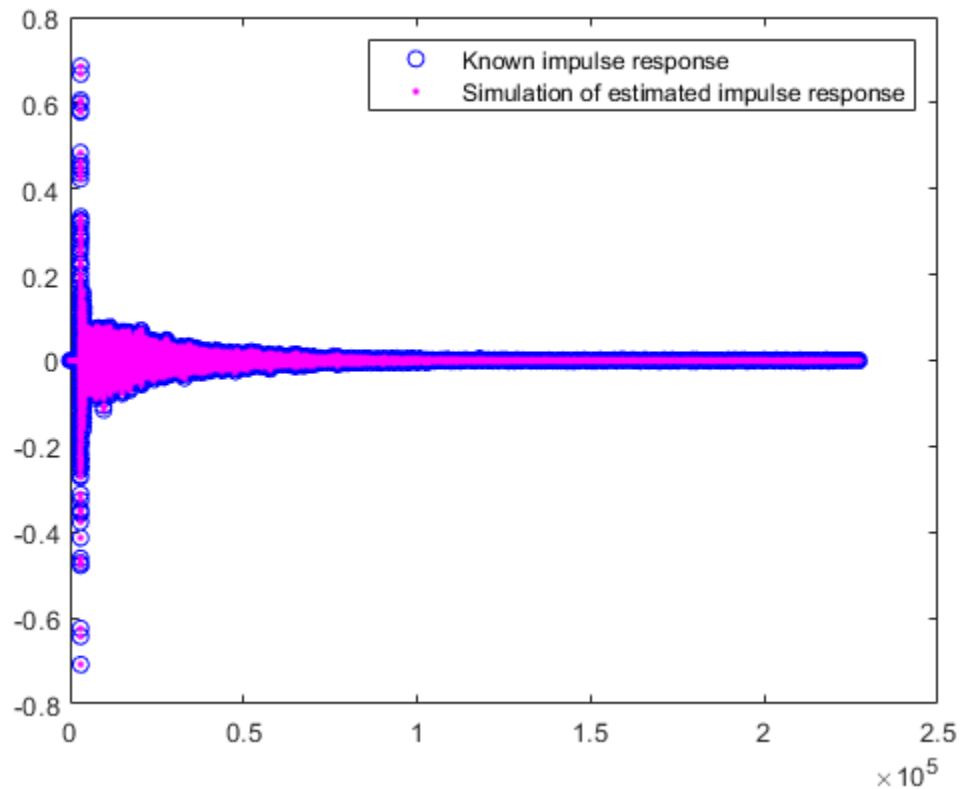
In a real-world scenario, the MLS sequence is played back in the system under test while recording. The recording would be cut so that it begins at the moment the MLS sequence is picked-up and truncated to last the duration of the repeated sequence.

Pass the excitation signal and the system response to the `impzest` function to estimate the impulse response. Plot the known impulse response and the simulation of the estimated impulse response for comparison.

```
irEstimate = impzest(excitation,rec);

samples = 1:numel(irKnown);
plot(samples,irEstimate(samples),'bo', ...
      samples,irKnown(samples),'m.')

legend('Known impulse response','Simulation of estimated impulse response')
```



Input Arguments

excitation — Single period of excitation signal input to audio system

column vector

Single period of excitation signal input to audio system, specified as a column vector.

You can generate excitation signals by using `m`ls (maximum length sequence) or `sweeptone` (exponential sine sweep).

Data Types: `single` | `double`

response — Recorded signal output from audio system

column vector | matrix

Recorded signal output from audio system, specified as a column vector or matrix. If specified as a matrix, each column of the matrix is treated as an independent channel.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'WarmupRuns',2

WarmupRuns — Number of warmup runs in response

nonnegative integer

Number of warmup runs in the response, specified as a nonnegative integer. The `impzest` function estimates the impulse response after discarding the specified number of warmup runs from the response.

The default number of warmup runs depends on whether the excitation signal was generated using the `mls` or `sweeptone` function:

- `mls` -- 1
- `sweeptone` -- 0

Data Types: `single` | `double`

Output Arguments

ir — Estimate of the impulse response of an audio system

column vector | matrix

Estimate of the impulse response of an audio system, returned as a column vector or matrix. The size of `ir` is L -by- C , where:

- L -- MLS length or duration of sweep tone silence
- C -- Number of columns (channels) in the response signal

Data Types: `single` | `double`

References

- [1] Farina, Angelo. "Advancements in Impulse Response Measurements by Sine Sweeps." Presented at the *Audio Engineering Society 122nd Convention*, Vienna, Austria, 2007.
- [2] Guy-Bart, Stan, Jean-Jacques Embrachts, and Dominique Archambeau. "Comparison of Different Impulse Response Measurement Techniques." *Journal of Audio Engineering Society*. Vol. 50, Issue 4, 2002, pp. 246-262.
- [3] Armelloni, Enrico, Christian Giottoli, and Angelo Farina. "Implementation of Real-Time Partitioned Convolution on a DSP Board." *Application of Signal Processing to Audio and Acoustics, 2003 IEEE Workshop*, pp. 71-74. IEEE, 2003.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`sweeptone` | `mls` | **Impulse Response Measurer**

Introduced in R2018b

mididevinfo

MIDI device information

Syntax

```
mididevinfo  
deviceInformation = mididevinfo
```

Description

`mididevinfo` displays a table containing information about the MIDI devices attached to the system.

`deviceInformation = mididevinfo` returns a structure, `deviceInformation`, containing information about the MIDI devices attached to the system.

Note Before starting MATLAB, connect your MIDI device to your computer and turn on the device. For connection instructions, see the instructions for your MIDI device. If you start MATLAB before connecting your device, MATLAB might not recognize your device when you connect it. To correct the problem, restart MATLAB with the device already connected.

Examples

Display MIDI Device Connections

Call `mididevinfo` to display a table containing information about the MIDI devices attached to your system.

```
mididevinfo
```

```
MIDI devices available:  
ID Direction Interface Name  
0 output MMSystem 'Microsoft MIDI Mapper'  
1 input MMSystem 'BCF2000'  
2 input MMSystem 'MIDIIN2 (BCF2000)'  
3 output MMSystem 'Microsoft GS Wavetable Synth'  
4 output MMSystem 'BCF2000'  
5 output MMSystem 'MIDIOUT2 (BCF2000)'  
6 output MMSystem 'MIDIOUT3 (BCF2000)'
```

Return Structure of MIDI Device Connections

Call `mididevinfo` with an output argument to return a structure containing MIDI device information.

```
deviceInformation = mididevinfo
```



```
deviceInformation = struct with fields:  
    input: [0x0 struct]  
    output: [1x2 struct]
```

The `deviceInformation` structure has two fields: `input` and `output`. Both `input` and `output` contain arrays of structures. Each member has three fields: `Name`, `Interface`, and `ID`. Get the device information for the output Microsoft GS Wavetable Synth device.

```
deviceInformation.output(2)
```

```
ans = struct with fields:  
    Name: 'Microsoft GS Wavetable Synth'  
    Interface: 'MMSYSTEM'  
    ID: 1
```

Output Arguments

`deviceInformation` — Description of available devices

struct

Description of available devices, returned as nested structures. The outer structure has two fields: `input` and `output`. The `input` and `output` values are arrays of structures, and each member has three fields: `Name`, `Interface`, and `ID`.

Data Types: struct

See Also

`parameterTuner` | **Audio Test Bench** | `mididevice` | `midimsg` | `midireceive` | `midisend`

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

Introduced in R2018a

pitch

Estimate fundamental frequency of audio signal

Syntax

```
f0 = pitch(audioIn, fs)
f0 = pitch(audioIn, fs, Name=Value)
[f0, loc] = pitch( ___ )
pitch( ___ )
```

Description

`f0 = pitch(audioIn, fs)` returns estimates of the fundamental frequency over time for the audio input, `audioIn`, with sample rate `fs`. Columns of the input are treated as individual channels.

`f0 = pitch(audioIn, fs, Name=Value)` specifies options using one or more name-value arguments.

`[f0, loc] = pitch(___)` returns the locations, `loc`, associated with fundamental frequency estimates. You can specify an input combination from any of the previous syntaxes.

`pitch(___)` with no output arguments plots the estimated pitch against time.

Examples

Estimate Pitch

Read in an audio signal. Call `pitch` to estimate the fundamental frequency over time.

```
[audioIn, fs] = audioread("Hey-16-mono-6secs.ogg");
f0 = pitch(audioIn, fs);
```

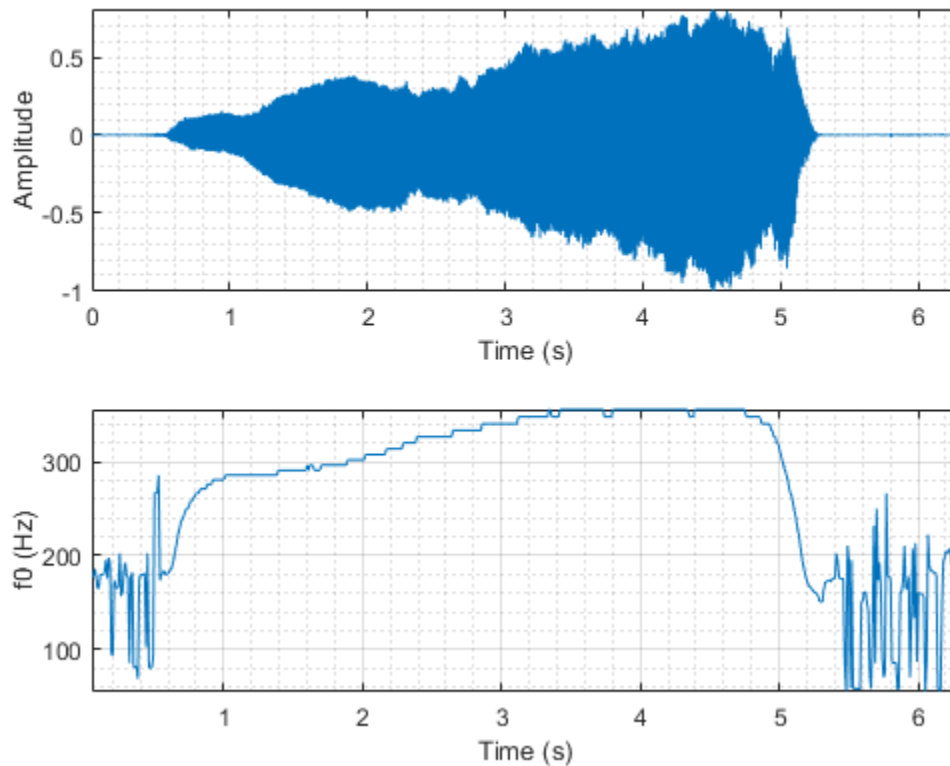
Listen to the audio signal and plot the signal and pitch. The `pitch` function estimates the fundamental frequency over time, but the estimate is only valid for regions that are harmonic.

```
sound(audioIn, fs)

tiledlayout(2,1)

nexttile
t = (0:length(audioIn)-1)/fs;
plot(t, audioIn)
xlabel("Time (s)")
ylabel("Amplitude")
grid minor
axis tight

nexttile
pitch(audioIn, fs)
```



Estimate Pitch For Singing Voice

Read in an audio signal and extract the pitch.

```
[x,fs] = audioread("SingingAMajor-16-mono-18secs.ogg");
t = (0:size(x,1)-1)/fs;

winLength = round(0.05*fs);
overlapLength = round(0.045*fs);
[f0,idx] = pitch(x,fs,Method="SRH",WindowLength=winLength,OverlapLength=overlapLength);
tf0 = idx/fs;
```

Listen to the audio and plot the audio and pitch estimations.

```
sound(x,fs)
```

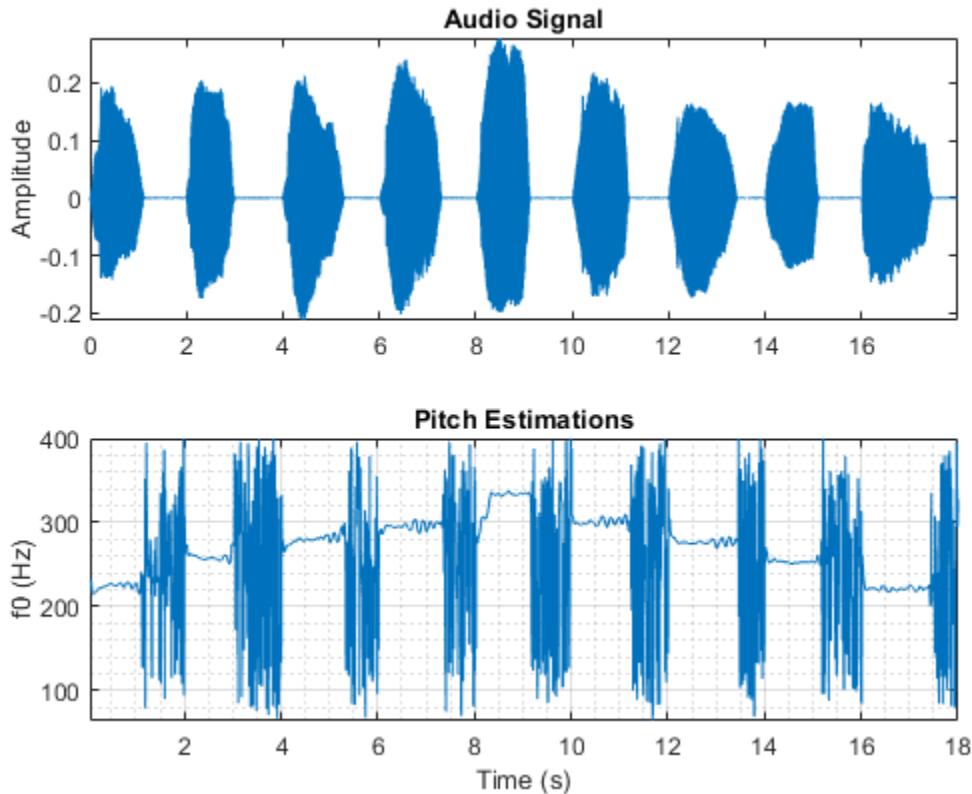
```
figure
tiledlayout(2,1)
```

```
nexttile
plot(t,x)
ylabel("Amplitude")
title("Audio Signal")
axis tight
```

```

nexttile
pitch(x, fs, Method="SRH", WindowLength=winLength, OverlapLength=overlapLength)
title("Pitch Estimations")

```



The `pitch` function estimates the pitch for overlapped analysis windows. The pitch estimates are only valid if the analysis window has a harmonic component. Call the `harmonicRatio` function using the same window and overlap length used for pitch detection. Plot the audio, pitch, and harmonic ratio.

```
hr = harmonicRatio(x, fs, Window=hamming(winLength, "periodic"), OverlapLength=overlapLength);
```

```
figure
tiledlayout(3,1)
```

```

nexttile
plot(t,x)
ylabel("Amplitude")
title("Audio Signal")
axis tight

```

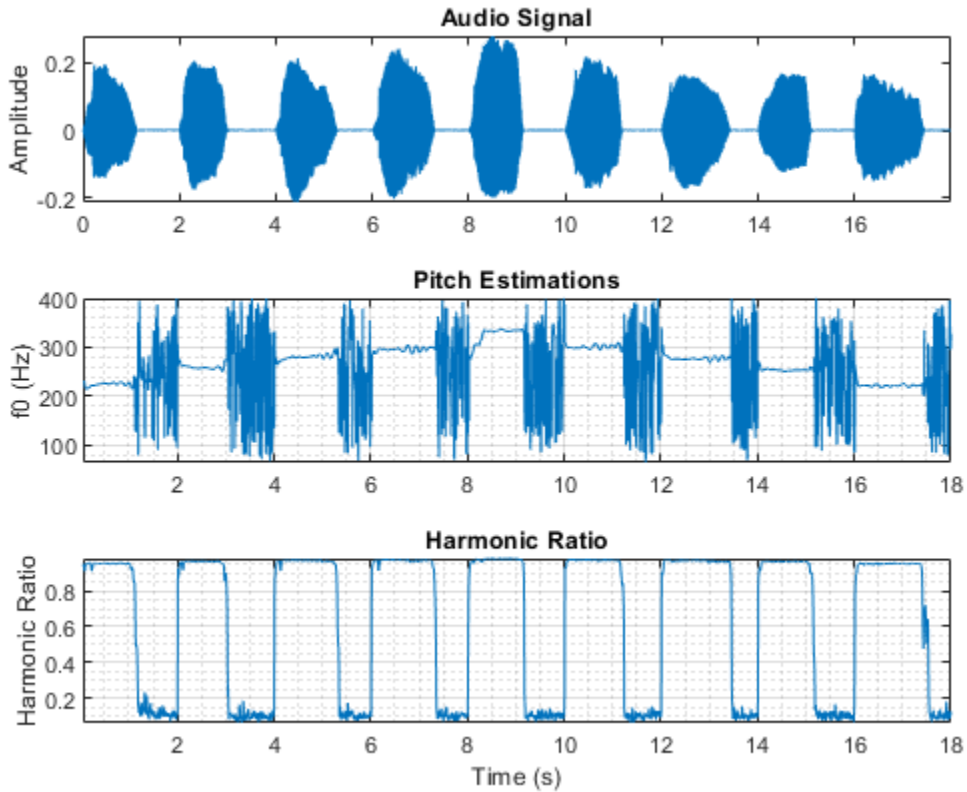
```

nexttile
pitch(x, fs, Method="SRH", WindowLength=winLength, OverlapLength=overlapLength)
title("Pitch Estimations")
xlabel("")

```

```
nexttile
```

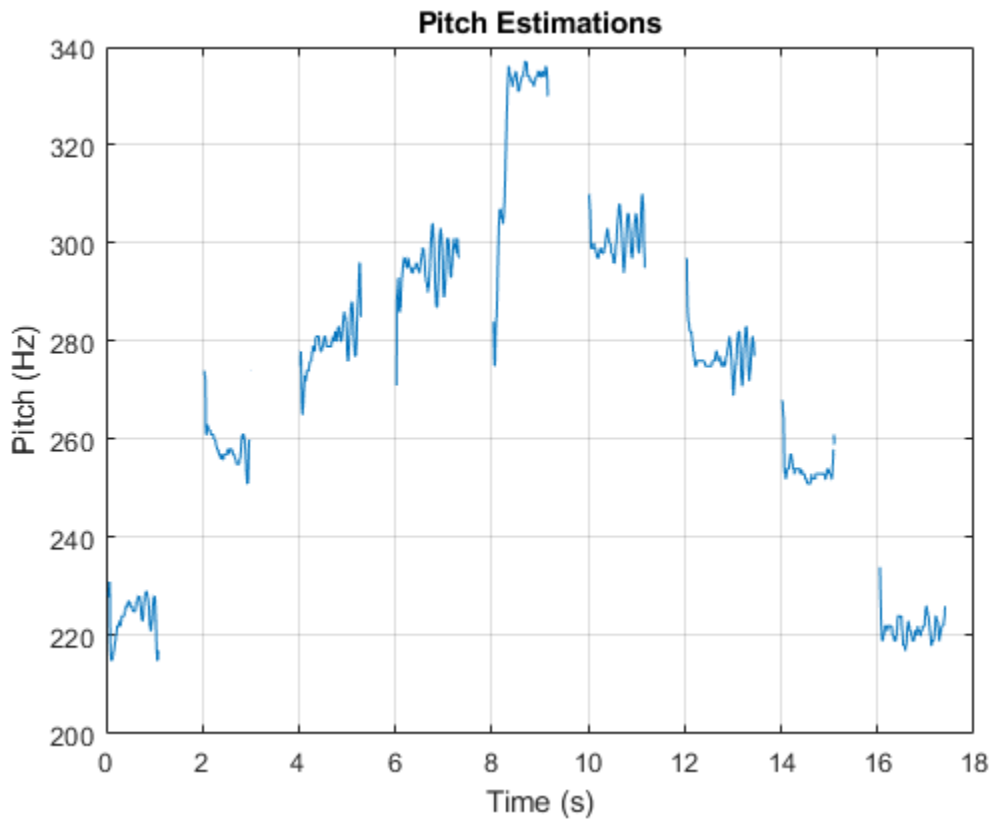
```
harmonicRatio(x,fs,Window=hamming(winLength,"periodic"),OverlapLength=overlapLength)
title("Harmonic Ratio")
```



Use the harmonic ratio as the threshold for valid pitch decisions. If the harmonic ratio is less than the threshold, set the pitch decision to NaN. Plot the results.

```
threshold = 0.9;
f0(hr < threshold) = nan;
```

```
figure
plot(tf0,f0)
xlabel("Time (s)")
ylabel("Pitch (Hz)")
title("Pitch Estimations")
grid on
```



Compare Pitch of Two Voices

Read in an audio signal of a female voice saying "volume up" five times. Listen to the audio.

```
[femaleVoice,fs] = audioread("FemaleVolumeUp-16-mono-11secs.ogg");
sound(femaleVoice,fs)
```

Read in an audio signal of a male voice saying "volume up" five times. Listen to the audio.

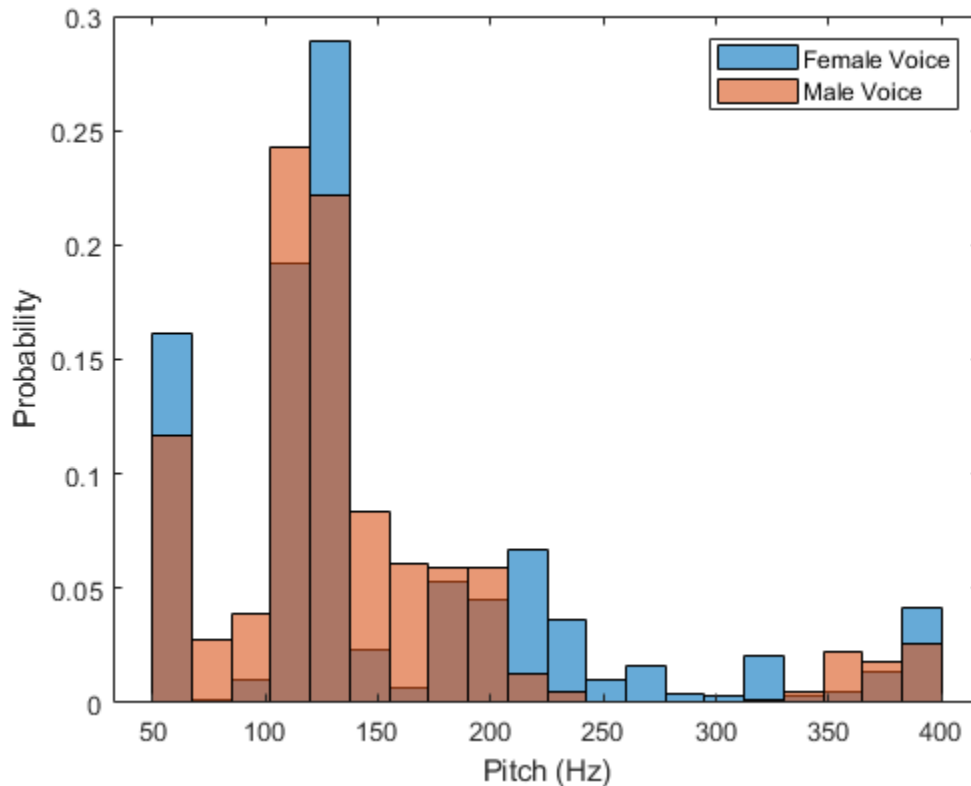
```
maleVoice = audioread("MaleVolumeUp-16-mono-6secs.ogg");
sound(maleVoice,fs)
```

Extract the pitch from both the female and male recordings. Plot histograms of the pitch estimations for the male and female audio recordings. The histograms have a similar shape. This is because the pitch decisions contain results for unvoiced speech and regions of silence.

```
f0Female = pitch(femaleVoice,fs);
f0Male = pitch(maleVoice,fs);

figure
numBins = 20;
histogram(f0Female,numBins,Normalization="probability");
hold on
histogram(f0Male,numBins,Normalization="probability");
legend("Female Voice","Male Voice")
```

```
xlabel("Pitch (Hz)")
ylabel("Probability")
hold off
```



Use the `detectSpeech` function to isolate regions of speech in the audio signal and then extract pitch from only those speech regions.

```
speechIndices = detectSpeech(femaleVoice, fs);
f0Female = [];
for ii = 1:size(speechIndices,1)
    speechSegment = femaleVoice(speechIndices(ii,1):speechIndices(ii,2));
    f0Female = [f0Female;pitch(speechSegment, fs)];
end
```

```
speechIndices = detectSpeech(maleVoice, fs);
f0Male = [];
for ii = 1:size(speechIndices,1)
    speechSegment = maleVoice(speechIndices(ii,1):speechIndices(ii,2));
    f0Male = [f0Male;pitch(speechSegment, fs)];
end
```

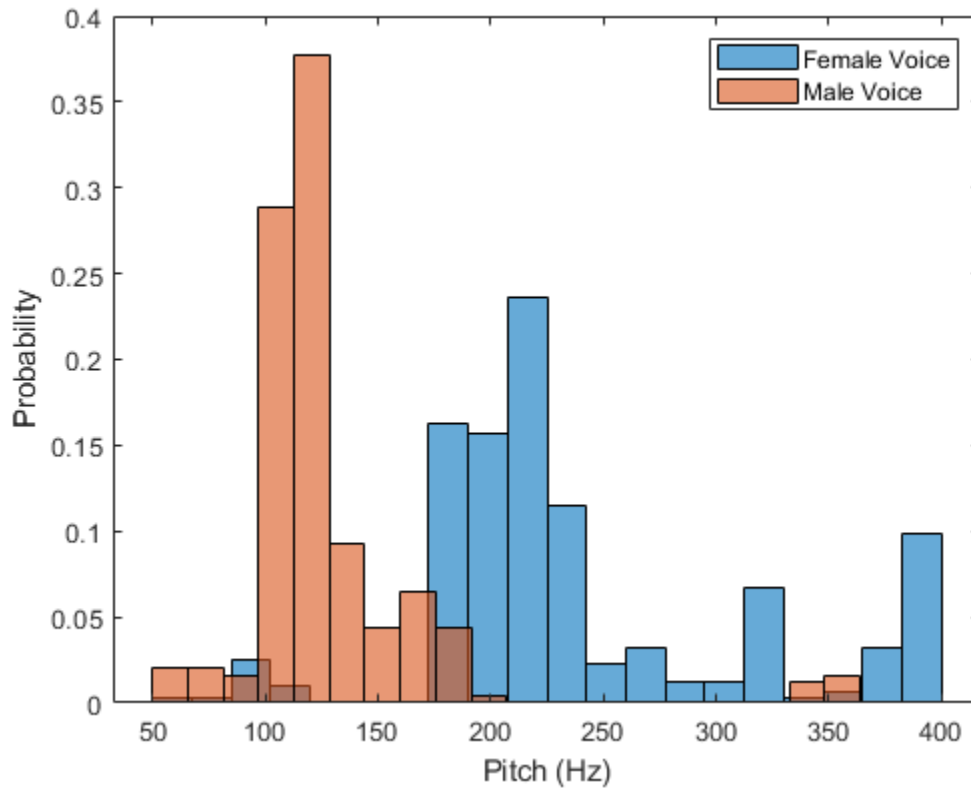
Plot histograms of the pitch estimations for the male and female audio recordings. The pitch distributions now appear as expected.

```
figure
histogram(f0Female,numBins,Normalization="probability");
hold on
histogram(f0Male,numBins,Normalization="probability");
```

```

legend("Female Voice", "Male Voice")
xlabel("Pitch (Hz)")
ylabel("Probability")

```



Estimate Pitch of Musical Signal Using Nondefault Parameters

Load an audio file of the Für Elise introduction and the sample rate of the audio.

```

load FurElise.mat song fs
sound(song, fs)

```

Call the `pitch` function using the pitch estimate filter (PEF), a search range of 50 to 800 Hz, a window duration of 80 ms, an overlap duration of 70 ms, and a median filter length of 10.

```

method = PEF ;
range = [ 50 , 800 ]; % hertz
winDur = 0.08 ; % seconds
overlapDur = 0.07 ; % seconds
medFiltLength = 10 ; % frames

```



```

winLength = round(winDur*fs);
overlapLength = round(overlapDur*fs);
[f0,loc] = pitch(song,fs, ...
    Method=method, ...
    Range=range, ...
    WindowLength=winLength, ...
    OverlapLength=overlapLength, ...
    MedianFilterLength=medFiltLength);

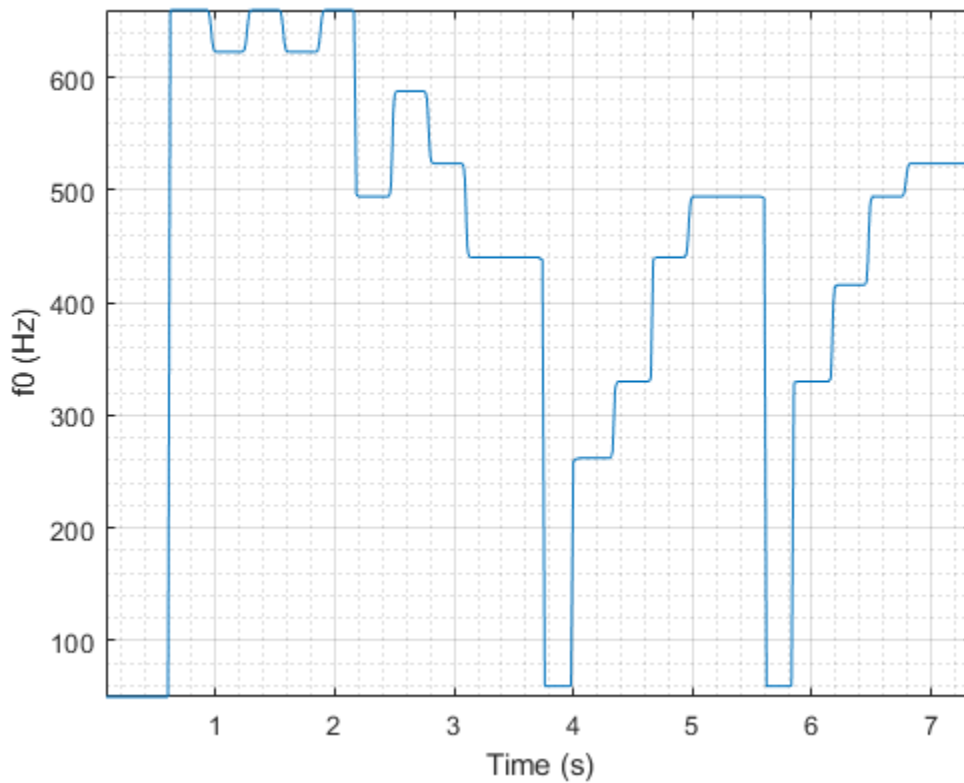
```

Plot the estimated pitch against time.

```

pitch(song,fs, ...
    Method=method, ...
    Range=range, ...
    WindowLength=winLength, ...
    OverlapLength=overlapLength, ...
    MedianFilterLength=medFiltLength);

```



Determine Pitch Contour of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio frame-by-frame.

```
fileReader = dsp.AudioFileReader("SingingAMajor-16-mono-18secs.ogg");
```

Create a `voiceActivityDetector` object to detect the presence of voice in streaming audio.

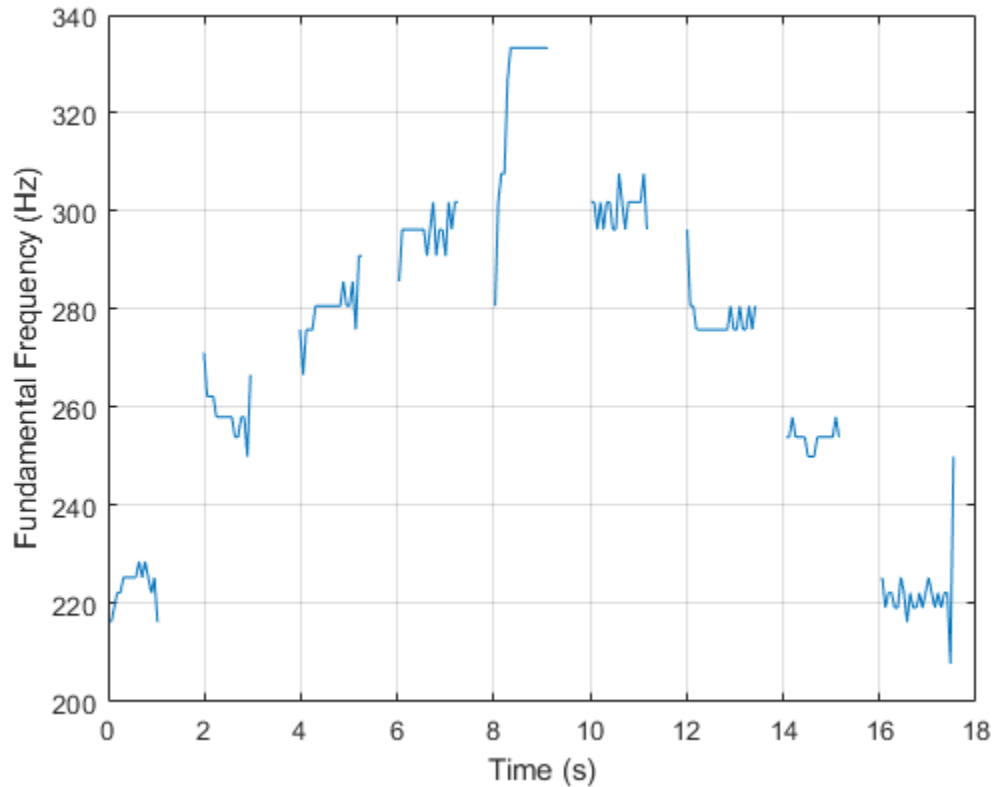
```
VAD = voiceActivityDetector;
```

While there are unread samples, read from the file and determine the probability that the frame contains voice activity. If the frame contains voice activity, call `pitch` to estimate the fundamental frequency of the audio frame. If the frame does not contain voice activity, declare the fundamental frequency as NaN.

```
f0 = [];  
while ~isDone(fileReader)  
    x = fileReader();  
  
    if VAD(x) > 0.99  
        decision = pitch(x,fileReader.SampleRate, ...  
            WindowLength=size(x,1), ...  
            OverlapLength=0, ...  
            Range=[200,340]);  
    else  
        decision = NaN;  
    end  
    f0 = [f0;decision];  
end
```

Plot the detected pitch contour over time.

```
t = linspace(0,(length(f0)*fileReader.SamplesPerFrame)/fileReader.SampleRate,length(f0));  
plot(t,f0)  
ylabel("Fundamental Frequency (Hz)")  
xlabel("Time (s)")  
grid on
```



Compare Pitch Detection Algorithms

The different methods of estimating pitch provide trade-offs in terms of noise robustness, accuracy, optimal lag, and computation expense. In this example, you compare the performance of different pitch detection algorithms in terms of gross pitch error (GPE) and computation time under different noise conditions.

Prepare Test Signals

Load an audio file and determine the number of samples it has. Also load the true pitch corresponding to the audio file. The true pitch was determined as an average of several third-party algorithms on the clean speech file.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
numSamples = size(audioIn,1);
load TruePitch.mat truePitch
```

Create test signals by adding noise to the audio signal at given SNRs. The `mixSNR` function is a convenience function local to this example, which takes a signal, noise, and requested SNR and returns a noisy signal at the request SNR.

```
testSignals = zeros(numSamples,4);

turbine = audioread('Turbine-16-44p1-mono-22secs.wav');
```

```

testSignals(:,1) = mixSNR(audioIn,turbine,20);
testSignals(:,2) = mixSNR(audioIn,turbine,0);

whiteNoiseMaker = dsp.ColoredNoise('Color','white','SamplesPerFrame',size(audioIn,1));
testSignals(:,3) = mixSNR(audioIn,whiteNoiseMaker(),20);
testSignals(:,4) = mixSNR(audioIn,whiteNoiseMaker(),0);

```

Save the noise conditions and algorithm names as cell arrays for labeling and indexing.

```

noiseConditions = {'Turbine (20 dB)','Turbine (0 dB)','WhiteNoise (20 dB)','WhiteNoise (0 dB)'};
algorithms = {'NCF','PEF','CEP','LHS','SRH'};

```

Run Pitch Detection Algorithms

Preallocate arrays to hold pitch decisions for each algorithm and noise condition pair, and the timing information. In a loop, call the `pitch` function on each combination of algorithm and noise condition. Each algorithm has an optimal window length associated with it. In this example, for simplicity, you use the default window length for all algorithms. Use a 3-element median filter to smooth the pitch decisions.

```

f0 = zeros(numel(truePitch),numel(algorithms),numel(noiseConditions));
algorithmTimer = zeros(numel(noiseConditions),numel(algorithms));

```

```

for k = 1:numel(noiseConditions)
    x = testSignals(:,k);
    for i = 1:numel(algorithms)
        tic
        f0temp = pitch(x,fs, ...
            'Range',[50 300], ...
            'Method',algorithms{i}, ...
            'MedianFilterLength',3);
        algorithmTimer(k,i) = toc;
        f0(1:max(numel(f0temp),numel(truePitch)),i,k) = f0temp;
    end
end

```

Compare Gross Pitch Error

Gross pitch error (GPE) is a popular metric when comparing pitch detection algorithms. GPE is defined as the proportion of pitch decisions for which the relative error is higher than a given threshold, traditionally 20% in speech studies. Calculate the GPE and print it to the Command Window.

```

idxToCompare = ~isnan(truePitch);
truePitch = truePitch(idxToCompare);
f0 = f0(idxToCompare,:,:);

p = 0.20;
GPE = mean( abs(f0(1:numel(truePitch),:,:) - truePitch) > truePitch.*p).*100;

for ik = 1:numel(noiseConditions)
    fprintf('\nGPE (p = %0.2f), Noise = %s.\n',p,noiseConditions{ik});
    for i = 1:size(GPE,2)
        fprintf('- %s : %0.1f %%\n',algorithms{i},GPE(1,i,ik))
    end
end

GPE (p = 0.20), Noise = Turbine (20 dB).

```

```
- NCF : 0.9 %
- PEF : 0.4 %
- CEP : 8.2 %
- LHS : 8.2 %
- SRH : 6.0 %
```

GPE (p = 0.20), Noise = Turbine (0 dB).

```
- NCF : 5.6 %
- PEF : 24.5 %
- CEP : 11.6 %
- LHS : 9.4 %
- SRH : 46.8 %
```

GPE (p = 0.20), Noise = WhiteNoise (20 dB).

```
- NCF : 0.9 %
- PEF : 0.0 %
- CEP : 12.9 %
- LHS : 6.9 %
- SRH : 2.6 %
```

GPE (p = 0.20), Noise = WhiteNoise (0 dB).

```
- NCF : 0.4 %
- PEF : 0.0 %
- CEP : 23.6 %
- LHS : 7.3 %
- SRH : 1.7 %
```

Calculate the average time it takes to process one second of data for each of the algorithms and print the results.

```
aT = sum(algorithmTimer)/((numSamples/fs)*numel(noiseConditions));
for ik = 1:numel(algorithms)
    fprintf('- %s : %0.3f (s)\n',algorithms{ik},aT(ik))
end
```

```
- NCF : 0.019 (s)
- PEF : 0.068 (s)
- CEP : 0.017 (s)
- LHS : 0.024 (s)
- SRH : 0.068 (s)
```

Input Arguments

audioIn — Audio input signal

vector | matrix

Audio input signal, specified as a vector or matrix. The columns of the matrix are treated as individual audio channels.

Data Types: single | double

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

The sample rate must be greater than or equal to twice the upper bound of the search range. Specify the search range using the `Range` name-value pair.

Data Types: `single` | `double`

Name-Value Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `pitch(audioIn, fs, Range=[50, 150], Method="PEF")`

Range — Search range for pitch estimates

`[50, 400]` (default) | two-element row vector with increasing positive integer values

Search range for pitch estimates, specified as a two-element row vector with increasing positive integer values. The function searches for a best estimate of the fundamental frequency within the upper and lower band edges specified by the vector, according to the algorithm specified by `Method`. The range is inclusive and units are in Hz.

Valid values for the search range depend on the sample rate, `fs`, and on the values of `WindowLength` and `Method`:

Method	Minimum Range	Maximum Range
"NCF"	$fs/WindowLength < Range(1)$	$Range(2) < fs/2$
"PEF"	$10 < Range(1)$	$Range(2) < \min(4000, fs/2)$
"CEP"	$fs / (2^{\text{nextpow2}(2*WindowLength-1)}) < Range(1)$	$Range(2) < fs/2$
"LHS"	$1 < Range(1)$	$Range(2) < fs/5 - 1$
"SRH"	$1 < Range(1)$	$Range(2) < fs/5 - 1$

Data Types: `single` | `double`

WindowLength — Number of samples in analysis window

`round(fs*0.052)` (default) | integer

Number of samples in the analysis window, specified as an integer in the range `[1, min(size(audioIn,1), 192000)]`. Typical analysis windows are in the range 20-100 ms. The default window length is 52 ms.

Data Types: `single` | `double`

OverlapLength — Number of samples of overlap between adjacent analysis windows

`round(fs*0.042)` (default) | integer

Number of samples of overlap between adjacent analysis windows, specified as an integer in the range `(-inf, WindowLength)`. A negative overlap length indicates non-overlapping analysis windows.

Data Types: `single` | `double`

Method — Method used to estimate pitch

"NCF" (default) | "PEF" | "CEP" | "LHS" | "SRH"

Method used to estimate pitch, specified as "NCF", "PEF", "CEP", "LHS", or "SRH". The different methods of calculating pitch provide trade-offs in terms of noise robustness, accuracy, and computation expense. The algorithms used to calculate pitch are based on the following papers:

- "NCF" -- Normalized Correlation Function [1]
- "PEF" -- Pitch Estimation Filter [2]. The function does not use the amplitude compression described by the paper.
- "CEP" -- Cepstrum Pitch Determination [3]
- "LHS" -- Log-Harmonic Summation [4]
- "SRH" -- Summation of Residual Harmonics [5]

Data Types: char | string

MedianFilterLength — Median filter length used to smooth pitch estimates over time

1 (default) | positive integer

Median filter length used to smooth pitch estimates over time, specified as a positive integer. The default, 1, corresponds to no median filtering. Median filtering is a postprocessing technique used to remove outliers while estimating pitch. The function uses `movmedian` after estimating the pitch using the specified `Method`.

Data Types: single | double

Output Arguments**f0 — Estimated fundamental frequency (Hz)**

scalar | vector | matrix

Estimated fundamental frequency, in Hz, returned as a scalar, vector, or matrix. The number of rows returned depends on the values of the `WindowLength` and `OverlapLength` name-value pairs, and on the input signal size. The number of columns (channels) returned depends on the number of columns of the input signal size.

Data Types: single | double

loc — Locations associated with fundamental frequency estimations

scalar | vector | matrix

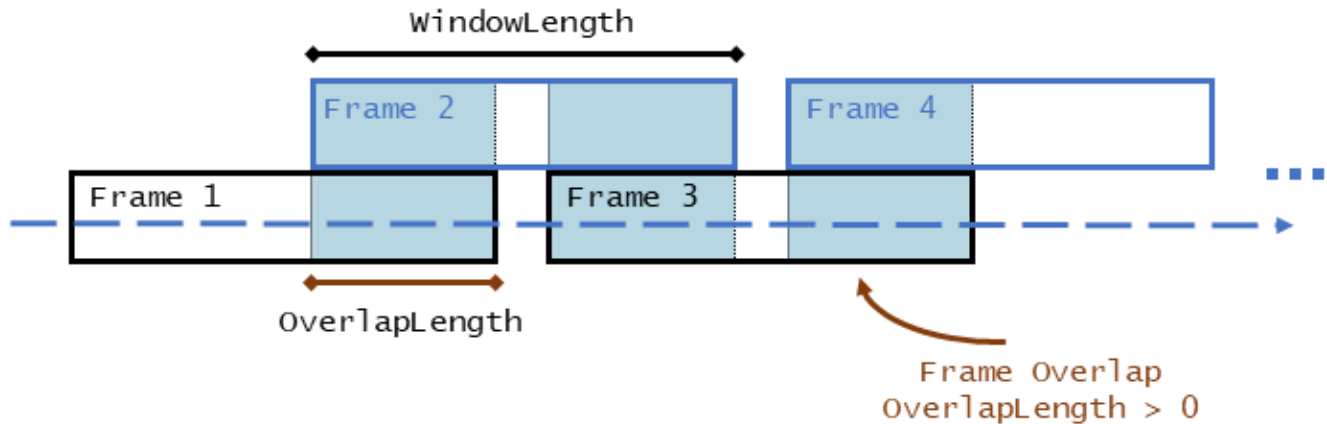
Locations associated with fundamental frequency estimations, returned as a scalar, vector, or matrix the same size as `f0`.

Fundamental frequency is estimated locally over a region of `WindowLength` samples. The values of `loc` correspond to the most recent sample (largest sample number) used to estimate fundamental frequency.

Data Types: single | double

Algorithms

The `pitch` function segments the audio input according to the `WindowLength` and `OverlapLength` arguments. The fundamental frequency is estimated for each frame. The locations output, `loc` contains the most recent samples (largest sample numbers) of the corresponding frame.



For a description of the algorithms used to estimate the fundamental frequency, consult the corresponding references:

- "NCF" -- Normalized Correlation Function [1]
- "PEF" -- Pitch Estimation Filter [2]. The function does not use the amplitude compression described by the paper.
- "CEP" -- Cepstrum Pitch Determination [3]
- "LHS" -- Log-Harmonic Summation [4]
- "SRH" -- Summation of Residual Harmonics [5]

References

- [1] Atal, B.S. "Automatic Speaker Recognition Based on Pitch Contours." *The Journal of the Acoustical Society of America*. Vol. 52, No. 6B, 1972, pp. 1687-1697.
- [2] Gonzalez, Sira, and Mike Brookes. "A Pitch Estimation Filter robust to high levels of noise (PEFAC)." 19th European Signal Processing Conference. Barcelona, 2011, pp. 451-455.
- [3] Noll, Michael A. "Cepstrum Pitch Determination." *The Journal of the Acoustical Society of America*. Vol. 31, No. 2, 1967, pp. 293-309.
- [4] Hermes, Dik J. "Measurement of Pitch by Subharmonic Summation." *The Journal of the Acoustical Society of America*. Vol. 83, No. 1, 1988, pp. 257-264.
- [5] Drugman, Thomas, and Abeer Alwan. "Joint Robust Voicing Detection and Pitch Estimation Based on Residual Harmonics." Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH. 2011, pp. 1973-1976.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`audioFeatureExtractor` | `mfcc` | `detectSpeech` | `harmonicRatio` | `shiftPitch`

Topics

“Pitch Tracking Using Multiple Pitch Estimations and HMM”

“Speaker Identification Using Pitch and MFCC”

“Delay-Based Pitch Shifter”

“Pitch Shifting and Time Dilation Using a Phase Vocoder in MATLAB”

Introduced in R2018a

mfcc

Extract MFCC, log energy, delta, and delta-delta of audio signal

Syntax

```
coeffs = mfcc(audioIn, fs)
coeffs = mfcc( ____, Name=Value)
[coeffs, delta, deltaDelta, loc] = mfcc( ____ )
mfcc( ____ )
```

Description

`coeffs = mfcc(audioIn, fs)` returns the mel frequency cepstral coefficients (MFCCs) for the audio input, sampled at a frequency of `fs` Hz.

`coeffs = mfcc(____, Name=Value)` specifies options using one or more name-value arguments.

Example: `coeffs = mfcc(audioIn, fs, LogEnergy="replace")` returns mel frequency cepstral coefficients for the audio input signal sampled at `fs` Hz. The first coefficient in the `coeffs` vector is replaced with the log energy value.

`[coeffs, delta, deltaDelta, loc] = mfcc(____)` also returns the delta, delta-delta, and location of samples corresponding to each window of data. You can specify an input combination from any of the previous syntaxes.

`mfcc(____)` with no output arguments plots the mel-frequency cepstral coefficients. Before plotting, the coefficients are normalized to have mean 0 and standard deviation 1.

- If the input is in the time domain, the coefficients are plotted against time.
- If the input is in the frequency domain, the coefficients are plotted against frame number.
- If the log-energy is extracted, then it is also plotted.

Examples

Compute Mel Frequency Cepstral Coefficients

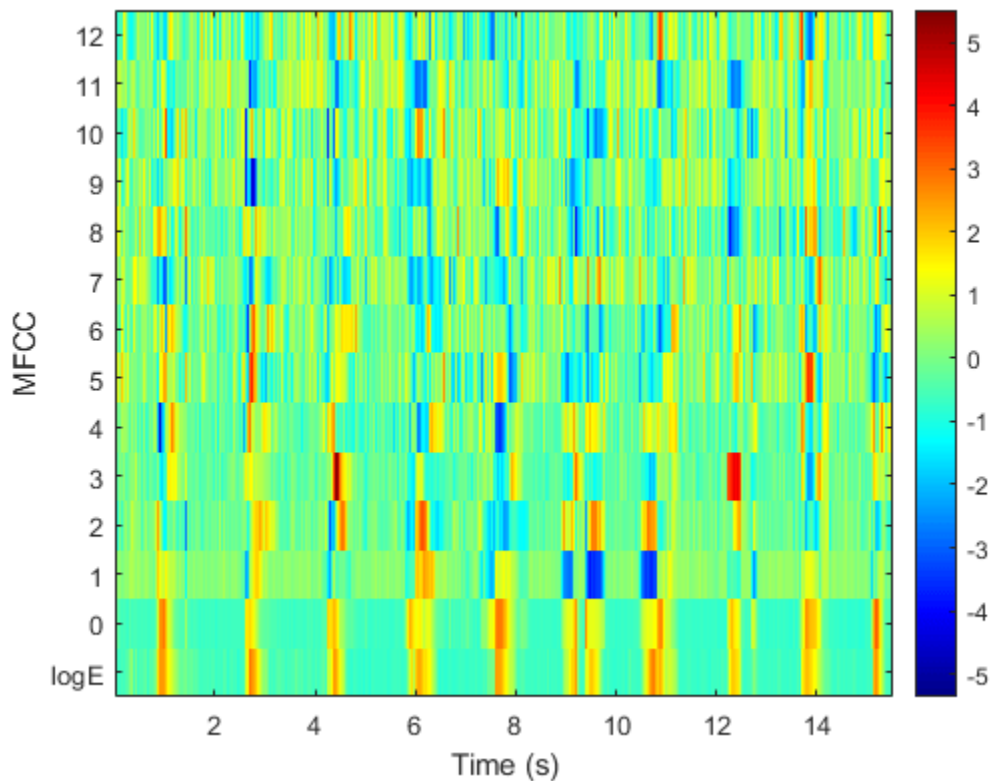
Compute the mel frequency cepstral coefficients of a speech signal using the `mfcc` function. The function returns `delta`, the change in coefficients, and `deltaDelta`, the change in delta values. The log energy value that the function computes can prepend the coefficients vector or replace the first element of the coefficients vector. This is done based on whether you set the `LogEnergy` argument to "append" or "replace".

Read an audio signal from the `Counting-16-44p1-mono-15secs.wav` file using the `audioread` function. The `mfcc` function processes the entire speech data in a batch. Based on the number of input rows, the window length, and the overlap length, `mfcc` partitions the speech into 1551 frames and computes the cepstral features for each frame. Each row in the `coeffs` matrix corresponds to the log-energy value followed by the 13 mel-frequency cepstral coefficients for the corresponding frame of the speech file. The function also computes `loc`, the location of the last sample in each input frame.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
[coeffs,delta,deltaDelta,loc] = mfcc(audioIn,fs);
```

Plot the normalized coefficients.

```
mfcc(audioIn,fs)
```



Extract MFCC from Frequency-Domain Audio

Read in an audio file and convert it to a frequency representation.

```
[audioIn,fs] = audioread("Rainbow-16-8-mono-114secs.wav");
win = hann(1024,"periodic");
S = stft(audioIn,"Window",win,"OverlapLength",512,"Centered",false);
```

To extract the mel-frequency cepstral coefficients, call `mfcc` with the frequency-domain audio. Ignore the log-energy.

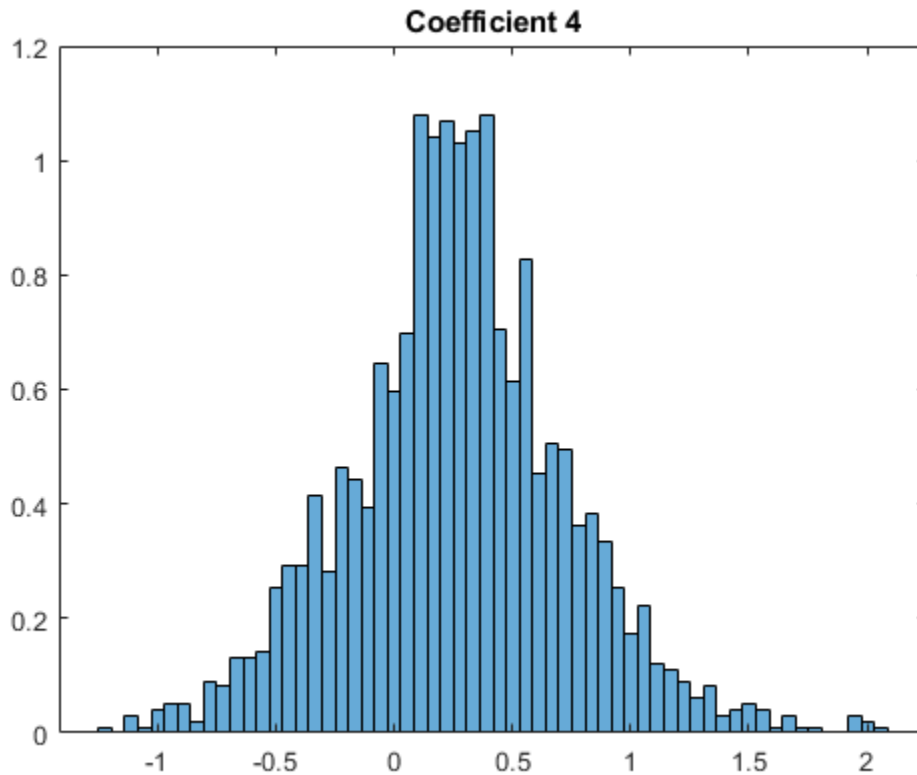
```
coeffs = mfcc(S,fs,"LogEnergy","Ignore");
```

In many applications, MFCC observations are converted to summary statistics for use in classification tasks. Plot a probability density function for one of the mel-frequency cepstral coefficients to observe its distributions.

```

nbins = 60;
coefficientToAnalyze = 4;
histogram(coeffs(:,coefficientToAnalyze+1),nbins,"Normalization","pdf")
title(sprintf("Coefficient %d",coefficientToAnalyze))

```



Input Arguments

audioIn — Input signal

vector | matrix | 3-D array

Input signal, specified as a vector, matrix, or 3-D array.

- If **audioIn** is real, it is interpreted as a time-domain signal and must be a column vector or a matrix. Columns of the matrix are treated as independent audio channels.
- If **audioIn** is complex, it is interpreted as a frequency-domain signal. In this case, **audioIn** must be an L -by- M -by- N array, where L is the number of DFT points, M is the number of individual spectra, and N is the number of individual channels.

Data Types: single | double

Complex Number Support: Yes

fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Name-Value Arguments

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `[coeffs,delta,deltaDelta,loc] = mfcc(audioIn,fs,LogEnergy="replace",DeltaWindowLength=5)` returns mel frequency cepstral coefficients for the audio input signal sampled at `fs` Hz. The first coefficient in the `coeffs` vector is replaced with the log energy value. A set of 5 cepstral coefficients is used to compute the delta and the delta-delta values.

Window — Window applied in time domain

`hamming(round(0.03*fs),"periodic")` (default) | vector

Window applied in time domain, specified as a real vector. The number of elements in the vector must be in the range `[1,size(audioIn,1)]`. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of overlapping samples between adjacent windows

`round(fs*0.02)` (default) | integer

Number of samples overlapped between adjacent windows, specified as an integer in the range `[0,numel(Window))`. If unspecified, `OverlapLength` defaults to `round(0.02*fs)`.

Data Types: `single` | `double`

NumCoeffs — Number of coefficients returned

13 (default) | positive scalar integer

Number of coefficients returned for each window of data, specified as an integer in the range `[2 v]`, where `v` is the number of valid passbands.

The number of valid passbands is defined as `sum(BandEdges <= floor(fs/2))-2`. A passband is valid if its edges fall below `fs/2`, where `fs` is the sample rate of the input audio signal, specified as the second argument, `fs`.

Data Types: `single` | `double`

BandEdges — Band edges of filter bank (Hz)

row vector

Band edges of the filter bank in Hz, specified as a nonnegative monotonically increasing row vector in the range `[0, fs/2]`. The number of band edges must be in the range `[4, 160]`. The `mfcc` function designs half-overlapped triangular filters based on `BandEdges`. This means that all band edges, except for the first and last, are also center frequencies of the designed bandpass filters.

By default, `BandEdges` is a 42-element vector, which results in a 40-band filter bank that spans approximately 133 Hz to 6864 Hz. The default bands are spaced as described in [2].

Data Types: `single` | `double`

FFTLength — Number of bins for calculating DFT

`numel(Window)` (default) | positive scalar integer

Number of bins used to calculate the discrete Fourier transform (DFT) of windowed input samples. The FFT length must be greater than or equal to the number of elements in the `Window`.

Data Types: `single` | `double`

Rectification — Type of non-linear rectification

`"log"` (default) | `"cubic-root"`

Type of nonlinear rectification applied prior to the discrete cosine transform, specified as `"log"` or `"cubic-root"`.

Data Types: `char` | `string`

DeltaWindowLength — Number of coefficients for calculating delta and delta-delta

9 (default) | odd integer greater than 2

Number of coefficients used to calculate the delta and the delta-delta values, specified as an odd integer greater than two. If unspecified, `DeltaWindowLength` defaults to 9.

Deltas are computed using the `audioDelta` function.

Data Types: `single` | `double`

LogEnergy — Specify how the log energy is shown

`"append"` (default) | `"replace"` | `"ignore"`

Specify how the log energy is shown in the coefficients vector output, specified as:

- `"append"` -- The function prepends the log energy to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$.
- `"replace"` -- The function replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is `NumCoeffs`.
- `"ignore"` -- The object does not calculate or return the log energy.

Data Types: `char` | `string`

Output Arguments

coeffs — Mel frequency cepstral coefficients (MFCCs)

`matrix` | 3-D array

Mel frequency cepstral coefficients, returned as an L -by- M matrix or an L -by- M -by- N array, where:

- L -- Number of analysis windows the audio signal is partitioned into. The input size, `Window`, and `OverlapLength` control this dimension: $L = \text{floor}((\text{size}(\text{audioIn},1) - \text{numel}(\text{Window})) / (\text{numel}(\text{Window}) - \text{OverlapLength}) + 1)$.
- M -- Number of coefficients returned per frame. This value is determined by `NumCoeffs` and `LogEnergy`.

When `LogEnergy` is set to:

- "append" -- The function prepends the log energy value to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$.
- "replace" -- The function replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is NumCoeffs .
- "ignore" -- The function does not calculate or return the log energy. The length of the coefficients vector is NumCoeffs .
- N -- Number of input channels (columns). This value is $\text{size}(\text{audioIn}, 2)$.

Data Types: `single` | `double`

delta — Change in coefficients

`matrix` | `array`

Change in coefficients from one frame of data to another, returned as an L -by- M matrix or an L -by- M -by- N array. The `delta` array is the same size and data type as the `coeffs` array.

Data Types: `single` | `double`

deltaDelta — Change in delta values

`matrix` | `array`

Change in `delta` values from one frame of data to another, returned as an L -by- M matrix or an L -by- M -by- N array. The `deltaDelta` array is the same size and data type as the `coeffs` and `delta` arrays.

Data Types: `single` | `double`

loc — Location of the last sample in each input frame

`vector`

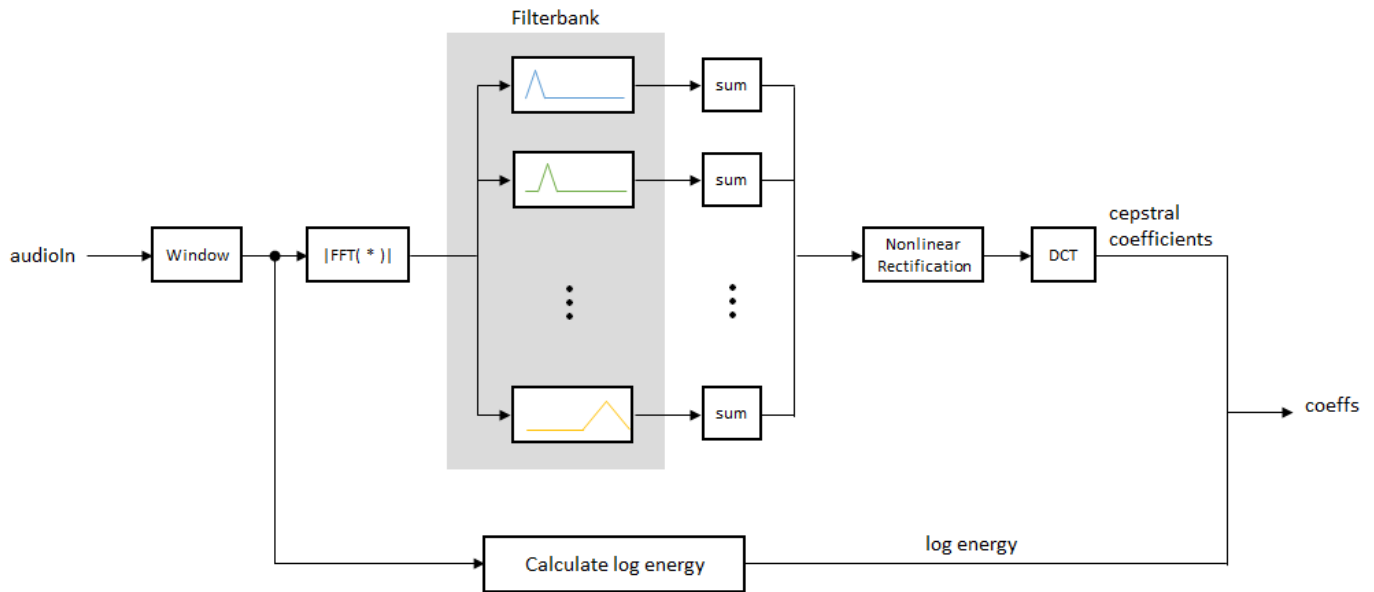
Location of last sample in each analysis window, returned as a column vector with the same number of rows as `coeffs`.

Data Types: `single` | `double`

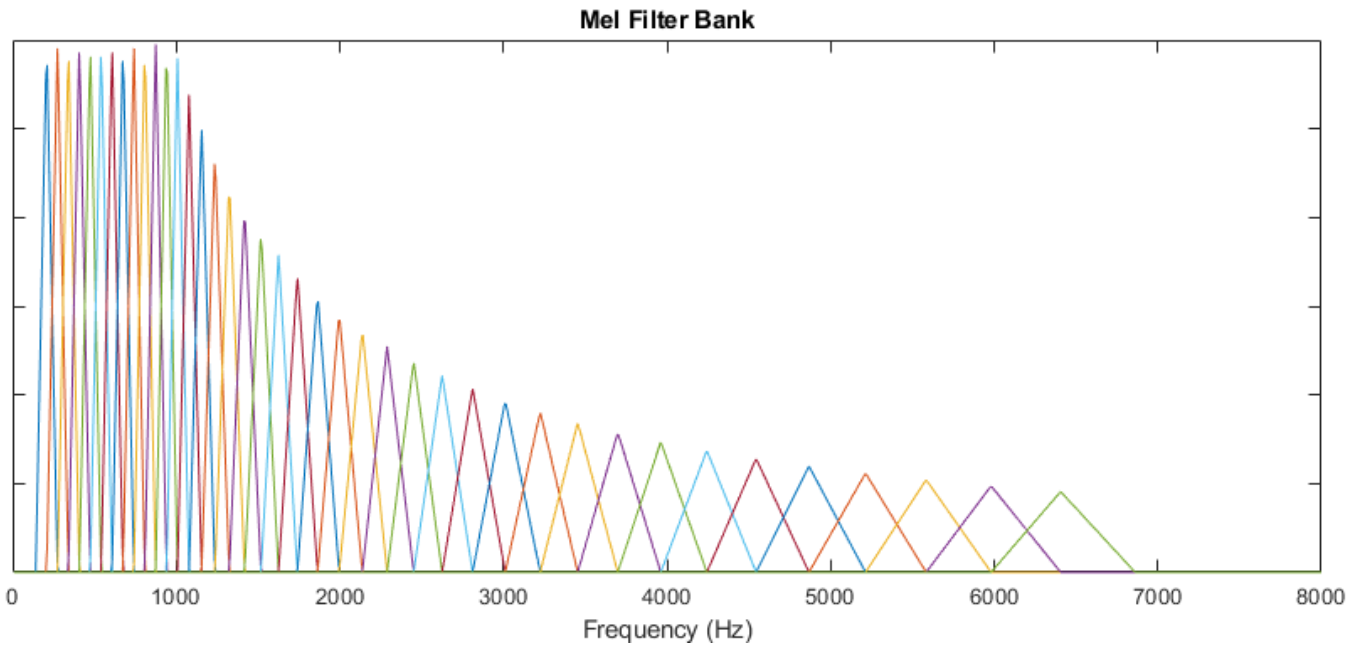
Algorithms

Mel frequency cepstrum coefficients are popular features extracted from speech signals for use in recognition tasks. In the source-filter model of speech, cepstral coefficients are understood to represent the filter (vocal tract). The vocal tract frequency response is relatively smooth, whereas the source of voiced speech can be modeled as an impulse train. As a result, the vocal tract can be estimated by the spectral envelope of a speech segment.

The motivating idea of mel frequency cepstral coefficients is to compress information about the vocal tract (smoothed spectrum) into a small number of coefficients based on an understanding of the cochlea. Although there is no hard standard for calculating the coefficients, the basic steps are outlined by the diagram.



The default mel filter bank linearly spaces the first 10 triangular filters and logarithmically spaces the remaining filters.



The information contained in the zeroth mel frequency cepstral coefficient is often augmented with or replaced by the log energy. The log energy calculation depends on the input domain.

If the input (*audioIn*) is a time-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(x^2))$$

If the input (*audioIn*) is a frequency-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(|x|^2)/\text{FFTLengh})$$

Compatibility Considerations

Delta and delta-delta computation

Behavior changed in R2020b

The delta and delta-delta calculations are now computed using the `audioDelta` function, which has a different startup behavior than the previous algorithm. The default value of the `DeltaWindowLength` parameter has changed from 2 to 9. A delta window length of 2 is no longer supported.

WindowLength will be removed in a future release

Behavior change in future release

The `WindowLength` parameter will be removed from the `mfcc` function in a future release. Use the `Window` parameter instead.

In releases prior to R2020b, you could only specify the length of a time-domain window. The window was always designed as a periodic Hamming window. You can replace instances of the code

```
coeffs = mfcc(audioin,fs,WindowLength=1024);
```

With this code:

```
coeffs = mfcc(audioIn,fs,Window=hamming(1024,"periodic"));
```

References

- [1] Rabiner, Lawrence R., and Ronald W. Schafer. *Theory and Applications of Digital Speech Processing*. Upper Saddle River, NJ: Pearson, 2010.
- [2] Auditory Toolbox. <https://engineering.purdue.edu/~malcolm/interval/1998-010/AuditoryToolboxTechReport.pdf>

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Code Generation

Generate CUDA® code for NVIDIA® GPUs using GPU Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

See Also

Cepstral Feature Extractor | `audioFeatureExtractor` | `audioDelta` | `cepstralCoefficients` | `detectSpeech`

Topics

“Keyword Spotting in Noise Using MFCC and LSTM Networks”

“Speaker Identification Using Pitch and MFCC”

Introduced in R2018a

asio4all

Open settings panel for ASIO driver

Syntax

```
asio4all  
asio4all(deviceName)
```

Description

asio4all opens the settings panel for the ASIO driver associated with the default audio device.

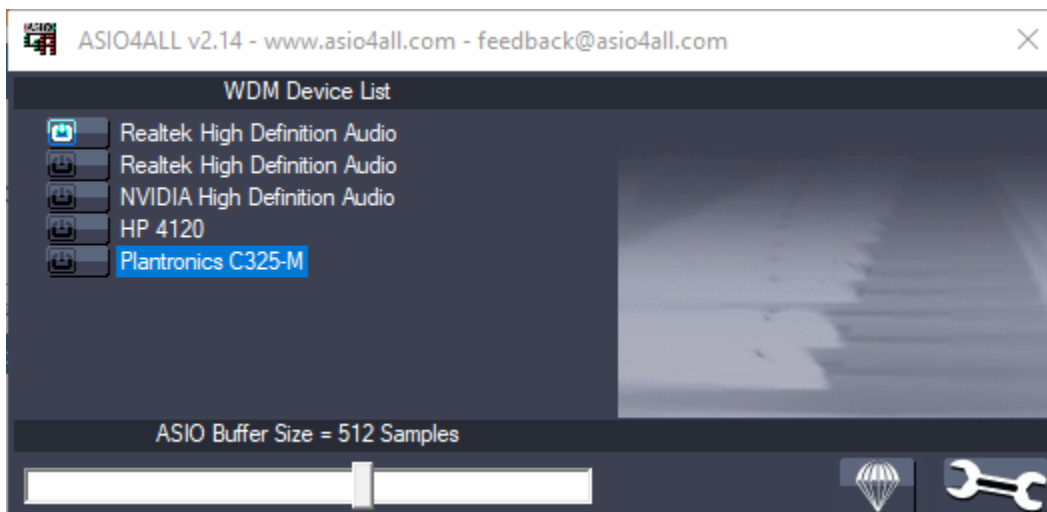
asio4all(deviceName) opens the settings panel for the ASIO driver associated with the audio device, deviceName.

Examples

Open ASIO Settings Panel for Specified Device

Create an audio I/O object, audioPlayerRecorder. Call asio4all with the device associated with audioPlayerRecorder as the argument.

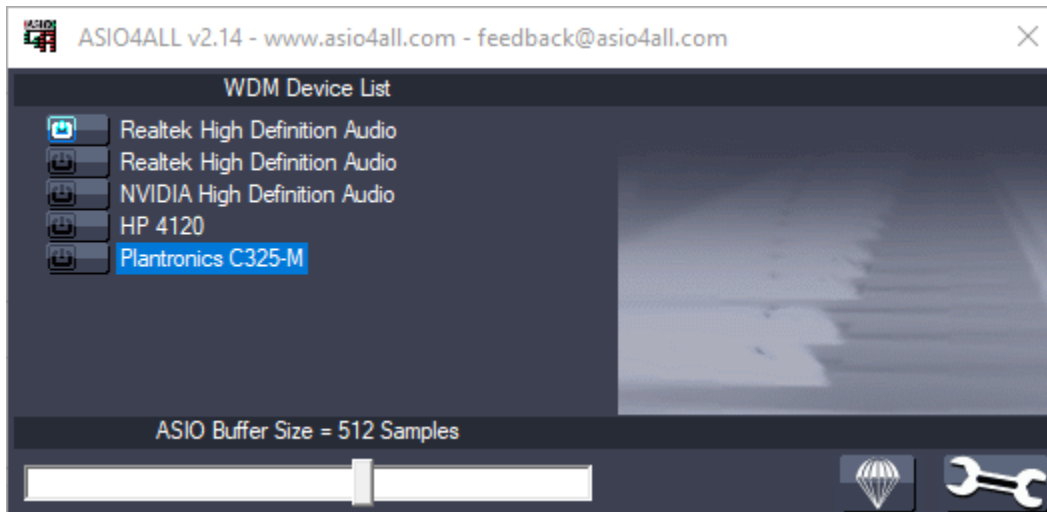
```
playRec = audioPlayerRecorder;  
asio4all(playRec.Device)
```



Open ASIO Settings Panel for Default Device

Call the asio4all function with no arguments.

```
asio4all()
```



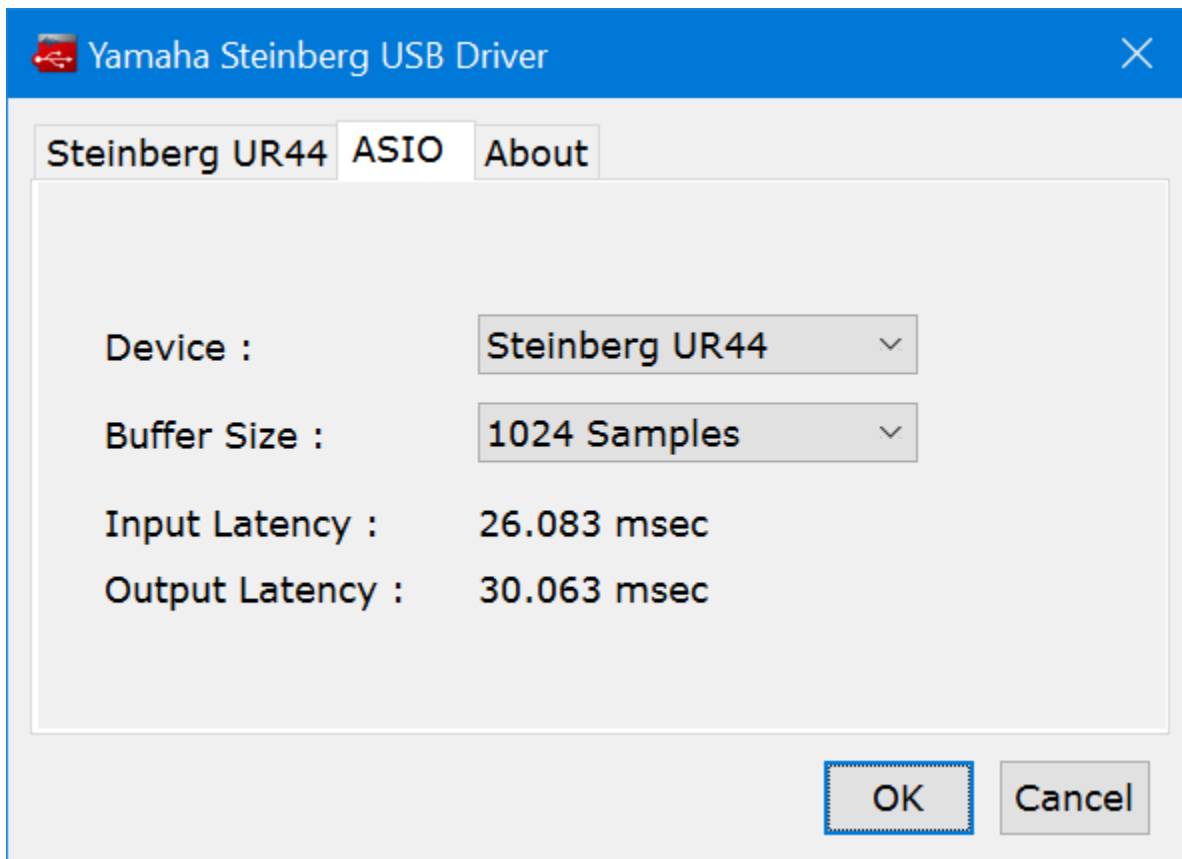
Optimize Latency

To optimize latency when using an ASIO driver, set the buffer size of the ASIO driver to the buffer size of your audio I/O object. In this example, assume the input to your audio device writer is 64 samples per frame. This example requires a Windows machine and an ASIO driver.

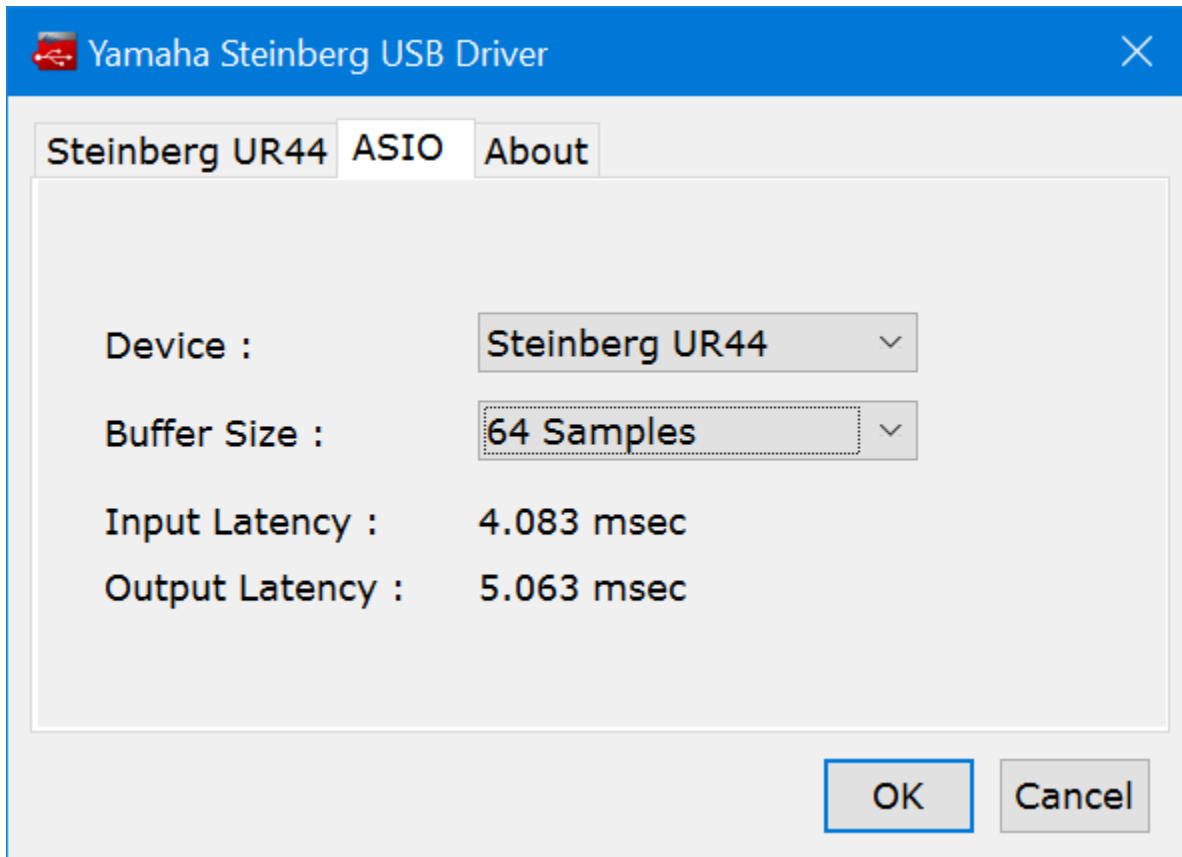
Create an `audioDeviceWriter` System object™. Open the ASIO settings panel for an ASIO-compatible device associated with your device writer.

```
deviceWriter = audioDeviceWriter('Driver', 'ASIO');  
asiosettings(deviceWriter.Device)
```

On the machine in this example, the following dialog opens:



The dialog that opens is specific to your ASIO driver. Set the ASIO buffer size to the desired size, 64.



The latency is now minimized for the frame size of 64 samples. If you want to measure the reduction in latency specific to your system, follow the steps in the “Measure Audio Latency” example.

Input Arguments

deviceName — Name of ASIO-compatible device

default ASIO-compatible device (default) | character vector | string

Name of ASIO-compatible device, specified as a character vector or string. If `deviceName` is not specified, the default ASIO-compatible device is used.

To view a list of valid ASIO device names on your machine, use `getAudioDevices` on an `audioPlayerRecorder`, `audioDeviceReader('Driver','ASIO')`, or `audioDeviceWriter('Driver','ASIO')` object.

Data Types: char | string

Tips

- `asiosettings` is compatible only on Windows machines with ASIO drivers. ASIO drivers do not come pre-installed with Windows.
- `asiosettings` returns an error if called with a locked audio device. For example:

```
aDR = audioDeviceReader('Driver', 'ASIO');  
aDR();  
asioSettings(aDR.Device)
```

```
Error using audio_asioSettings  
PortAudio Error: Device unavailable
```

```
Error in asioSettings (line 77)  
    audio_asioSettings(ID);
```

See Also

[audioDeviceReader](#) | [audioDeviceWriter](#) | [audioPlayerRecorder](#)

Topics

“Audio I/O: Buffering, Latency, and Throughput”

Introduced in R2017b

getAudioDevices

List available audio devices

Syntax

```
devices = getAudioDevices(obj)
```

Description

`devices = getAudioDevices(obj)` returns a list of audio devices that are available and compatible with your audio I/O object, `obj`.

Examples

List Audio Devices Available to `audioDeviceReader`

Create an `audioDeviceReader` object and then call `getAudioDevices` on your object.

```
deviceReader = audioDeviceReader;
devices = getAudioDevices(deviceReader)

devices = 1x4 cell
    {'Default'}    {'Primary Sound Capture Driver'}    {'Headset Microphone (Plantronics C325-M)'}    {'LE...'
```

List Audio Devices Available to `audioDeviceWriter`

Create an `audioDeviceWriter` object, and then call `getAudioDevices` on your object.

```
deviceWriter = audioDeviceWriter;
devices = getAudioDevices(deviceWriter)

devices = 1x6 cell
    {'Default'}    {'Primary Sound Driver'}    {'Headset Earphone (Plantronics C325-M)'}    {'LE...'
```

List Audio Devices Available to `audioPlayerRecorder`

Create an `audioPlayerRecorder` object, and then call `getAudioDevices` on your object.

```
playRec = audioPlayerRecorder;
devices = getAudioDevices(playRec)

devices = 1x2 cell
    {'Default'}    {'ASIO4ALL v2'}
```


Input Arguments

obj — Audio I/O object

audioDeviceReader object | audioDeviceWriter object | audioPlayerRecorder object

Audio I/O object, specified as an audioDeviceReader object, audioDeviceWriter object, or audioPlayerRecorder object.

Data Types: object

Output Arguments

devices — List of available and compatible devices

array

List of available and compatible devices.

For audioDeviceReader and audioDeviceWriter, the list of audio devices depends on the specified Driver property of your object.

For audioPlayerRecorder, the audio devices listed support full-duplex mode and have a platform-appropriate driver:

- Windows® -- ASIO™
- Mac -- CoreAudio
- Linux® -- ALSA

Data Types: cell

See Also

audioDeviceWriter | audioDeviceReader | audioPlayerRecorder

Topics

“Audio I/O: Buffering, Latency, and Throughput”

Introduced in R2016a

audioPluginInterface

Specify audio plugin interface

Syntax

```
PluginInterface = audioPluginInterface
PluginInterface = audioPluginInterface(pluginParameters)
PluginInterface = audioPluginInterface(pluginParameters,gridLayout)
PluginInterface = audioPluginInterface( ____,Name,Value)
```

Description

`PluginInterface = audioPluginInterface` returns an object, `PluginInterface`, that specifies the interface of an audio plugin in a digital audio workstation (DAW) environment. It also specifies interface attributes, such as naming.

`PluginInterface = audioPluginInterface(pluginParameters)` specifies audio plugin parameters, which are user-facing values associated with audio plugin properties. See `audioPluginParameter` for more details.

`PluginInterface = audioPluginInterface(pluginParameters,gridLayout)` specifies a grid layout for audio plugin parameter UI controls.

`PluginInterface = audioPluginInterface(____,Name,Value)` specifies `audioPluginInterface` properties using one or more `Name,Value` pair arguments.

Examples

Specify Default Audio Plugin Interface

Create a basic audio plugin class definition file.

```
classdef myAudioPlugin < audioPlugin
    methods
        function out = process(~,in)
            out = in;
        end
    end
end
```

Add a constant property, `PluginInterface`, which is specified as an `audioPluginInterface` object.

```
classdef myAudioPlugin < audioPlugin
    properties (Constant)
        PluginInterface = audioPluginInterface;
    end
    methods
        function out = process(~,in)
            out = in;
        end
    end
end
```

```

        end
    end
end

```

Associate Property with Parameter

Create a basic audio plugin class definition file. Specify a property, `Gain`, and a processing function that multiplies input by `Gain`.

```

classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

Add a constant property, `PluginInterface`, which is specified as an `audioPluginInterface` object.

```

classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface;
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

Pass `audioPluginParameter` to `audioPluginInterface`. To associate the plugin property, `Gain`, to a plugin parameter, specify the first argument of `audioPluginParameter` as the property name, `'Gain'`.

```

classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface(...
            audioPluginParameter('Gain'));
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

If you generate and deploy `myAudioPlugin` to a digital audio workstation (DAW) environment, the plugin property, `Gain`, synchronizes with a user-facing plugin parameter.

Specify Interface Properties

Create a basic audio plugin class definition file. Specify the plugin name, vendor name, vendor version, unique identification, number of input channels, number of output channels, and a yellow background.

```
classdef monoGain < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('Gain'), ...
            'PluginName', 'Simple Gain', ...
            'VendorName', 'Cool Company', ...
            'VendorVersion', '1.0.0', ...
            'UniqueId', '1a1Z', ...
            'InputChannels', 1, ...
            'OutputChannels', 1, ...
            'BackgroundColor', 'y');
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end
```

Input Arguments

pluginParameters — Audio plugin parameters

none (default) | one or more `audioPluginParameter` objects

Audio plugin parameters, specified as one or more `audioPluginParameter` objects.

To create an audio plugin parameter, use the `audioPluginParameter` function. In a digital audio workstation (DAW) environment, audio plugin parameters synchronize plugin class properties with user-facing parameters.

gridLayout — Layout for plugin UI

none (default) | `audioPluginGridLayout` object

Audio plugin grid layout, specified as an `audioPluginGridLayout` object.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'PluginName', 'cool effect', 'VendorVersion', '1.0.2' specifies the name of the generated audio plugin as 'cool effect' and the vendor version as '1.0.2'.

PluginName — Name of generated plugin

name of plugin class (default) | character vector | string

Name of your generated plugin, as seen by a host audio application, specified as a comma-separated pair consisting of 'PluginName' and a character vector or string of up to 127 characters. If 'PluginName' is not specified, the generated plugin is given the name of the audio plugin class it is generated from.

VendorName — Vendor name of plugin creator

' ' (default) | character vector

Vendor name of the plugin creator, specified as the comma-separated pair 'VendorName' and a character vector of up to 127 characters.

VendorVersion — Vendor version

'1.0.0' (default) | dot-separated character vector or string

Vendor version used to track plugin releases, specified as a comma-separated pair consisting of 'VendorVersion' and a dot-separated character vector or string of 1-3 integers in the range 0 to 9.

Example: '1'

Example: '1.4'

Example: '1.3.5'

UniqueId — Unique identifier of plugin

'Mwap' (default) | four-element character vector or string

Unique identifier for your plugin, specified as a comma-separated pair consisting of 'UniqueID' and a four-element character vector or string, used for recognition in certain digital audio workstation (DAW) environments.

InputChannels — Input channels

2 (default) | integer | vector of integers

Input channels, specified as a comma-separated pair consisting of 'InputChannels' and an integer or vector of integers. The input channels are the number of input data arguments and associated channels (columns) passed to the processing function of your audio plugin.

Example: 'InputChannels', 3 calls the processing function with one data argument containing 3 channels.

Example: 'InputChannels', [2,4,1,5] calls the processing function with 4 data arguments. The first argument contains 2 channels, the second contains 4 channels, the third contains 1 channel, and the fourth contains 5 channels.

Note This property is not applicable for audio source plugins, and must be omitted.

OutputChannels — Output channels

2 (default) | integer | vector of integers

Output channels, specified a comma-separated pair consisting of 'OutputChannels' and an integer or vector of integers. The output channels are the number of input data arguments and associated channels (columns) passed from the processing function of your audio plugin.

Example: 'OutputChannels', 3 specifies the processing function to output one data argument containing 3 channels.

Example: 'OutputChannels', [2,4,1,5] specifies the processing function to output 4 data arguments. The first argument contains 2 channels, the second contains 4 channels, the third contains 1 channel, and the fourth contains 5 channels.

BackgroundColor – Color used for GUI background









RGB triplet | short name | long name

Color used for GUI background, specified as short or long color name string, or an RGB triplet



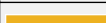


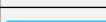

Example: 'BackgroundColor', [1 1 0] specifies the GUI background to be yellow.

Example: 'BackgroundColor', 'y' specifies the GUI background to be yellow.

Example: 'BackgroundColor', 'yellow' specifies the GUI background to be yellow.

Color Name	Short Name	RGB Triplet	Hexadecimal Color Code	Appearance
'red'	'r'	[1 0 0]	'#FF0000'	
'green'	'g'	[0 1 0]	'#00FF00'	
'blue'	'b'	[0 0 1]	'#0000FF'	
'cyan'	'c'	[0 1 1]	'#00FFFF'	
'magenta'	'm'	[1 0 1]	'#FF00FF'	
'yellow'	'y'	[1 1 0]	'#FFFF00'	
'black'	'k'	[0 0 0]	'#000000'	
'white'	'w'	[1 1 1]	'#FFFFFF'	

Here are the RGB triplets and hexadecimal color codes for the default colors MATLAB uses in many types of plots.

RGB Triplet	Hexadecimal Color Code	Appearance
[0 0.4470 0.7410]	'#0072BD'	
[0.8500 0.3250 0.0980]	'#D95319'	
[0.9290 0.6940 0.1250]	'#EDB120'	
[0.4940 0.1840 0.5560]	'#7E2F8E'	
[0.4660 0.6740 0.1880]	'#77AC30'	
[0.3010 0.7450 0.9330]	'#4DBEEE'	
[0.6350 0.0780 0.1840]	'#A2142F'	

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | logical | char | string

BackgroundImage – Image used for GUI background

char | string

Image used for GUI background, specified by its file name using either a character vector or string. If the file is not on path, you must specify the full file path. Supported file types are PNG, GIF, and JPG.

The background image may include transparencies, in which case the `BackgroundColor` is used.

Example: `'BackgroundImage','Sunrise.png'` specifies the GUI background image to be the 'Sunrise' image.

Example: `'BackgroundImage',fullfile(matlabroot,"mySkins","Sunset.jpg")` specifies the GUI background to be the 'Sunset' image.

Data Types: `char` | `string`

See Also

`audioPlugin` | `audioPluginSource` | `audioPluginParameter` | `generateAudioPlugin` | `validateAudioPlugin` | `audioPluginGridLayout`

Topics

"Audio Plugins in MATLAB"

Introduced in R2016a

audioPluginParameter

Specify audio plugin parameters

Syntax

```
pluginParameter = audioPluginParameter(propertyName)
pluginParameter = audioPluginParameter(propertyName,Name,Value)
```

Description

`pluginParameter = audioPluginParameter(propertyName)` returns an object, `pluginParameter`, that associates an audio plugin parameter to the audio plugin property specified by `propertyName`. Use the plugin parameter object, `pluginParameter`, as an argument to `audioPluginInterface` in your plugin class definition.

In a digital audio workstation (DAW) environment, or when using **Audio Test Bench** or `parameterTuner` in the MATLAB environment, plugin parameters are tunable, user-facing values with defined ranges mapped to controls. When you modify a parameter value using a control, the associated plugin property is also modified. If the audio-processing algorithm of the plugin depends on properties, the algorithm is also modified.

To visualize the relationship between plugin properties, parameters, and the environment in which a plugin is run, see “Implementation of Audio Plugin Parameters” on page 2-511.

`pluginParameter = audioPluginParameter(propertyName,Name,Value)` specifies `audioPluginParameter` properties using one or more `Name,Value` pair arguments.

Examples

Associate Property with Parameter

Create a basic audio plugin class definition file. Specify a property, `Gain`, and a processing function that multiplies input by `Gain`.

```
classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end
```

Add a constant property, `PluginInterface`, which is specified as an `audioPluginInterface` object.

```
classdef myAudioPlugin < audioPlugin
    properties
```



```

        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface;
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

Pass `audioPluginParameter` to `audioPluginInterface`. To associate the plugin property, `Gain`, to a plugin parameter, specify the first argument of `audioPluginParameter` as the property name, `'Gain'`.

```

classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('Gain'));
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

Specify Parameter Information

Create a basic plugin class definition file. Specify `'DisplayName'` as `'Awesome Gain'`, `'Label'` as `'linear'`, and `'Mapping'` as `{'lin',0,20}`.

```

classdef myAudioPlugin < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('Gain', ...
                'DisplayName','Awesome Gain', ...
                'Label','linear', ...
                'Mapping',{'lin',0,20}));
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end

```

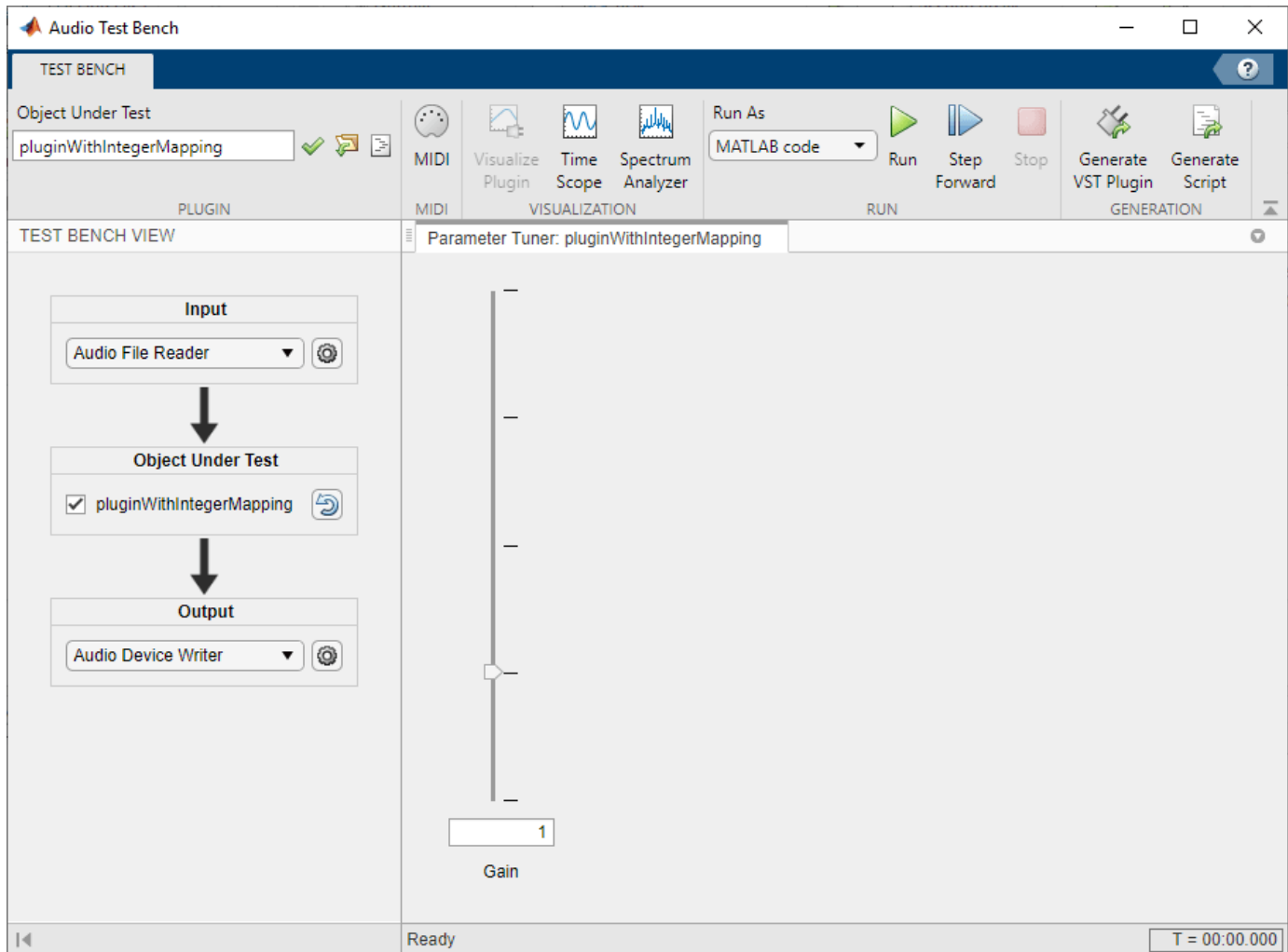
Integer Parameter Mapping

The following class definition uses integer parameter mapping to define the relationship between a property and a parameter. You can use the plugin created from this class to tune the linear gain of an audio signal in integer steps from 0 to 3.

```
classdef pluginWithIntegerMapping < audioPlugin
    properties
        Gain = 1;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('Gain', ...
                'Mapping',{'int',0,4}, ...
                'Layout',[1,1], ...
                'Style','vslider'), ...
            audioPluginGridLayout('RowHeight',[400,20]));
    end
    methods
        function out = process(plugin,in)
            out = in*plugin.Gain;
        end
    end
end
```

To run the plugin, save the class definition to a local folder and then call the Audio Test Bench.

```
audioTestBench(pluginWithIntegerMapping)
```



Power Parameter Mapping

The following class definition uses power parameter mapping to define the relationship between a property and a parameter. You can use the plugin created from this class to tune the gain of an audio signal in dB.

```
classdef pluginWithPowerMapping < audioPlugin
    properties
        Gain = 0;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('Gain', ...
                'Label','dB', ...
                'Mapping',{'pow', 1/3, -140, 12}, ...
                'Style','rotary', ...
                'Layout',[1,1]), ...
            audioPluginGridLayout);
    end
end
```

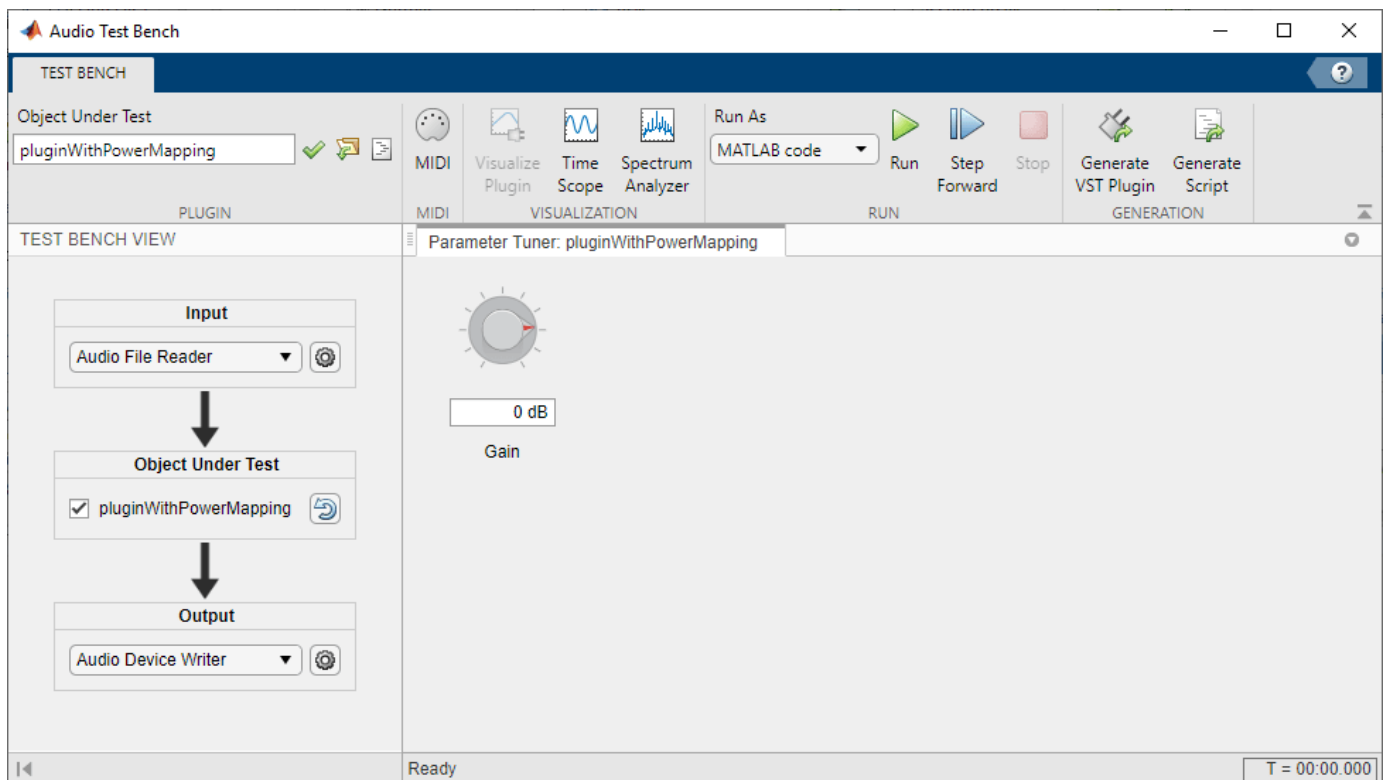
```

end
methods
    function out = process(plugin,in)
        dBGain = 10^(plugin.Gain/20);
        out = in*dBGain;
    end
end
end

```

To run the plugin, save the class definition to a local folder and then call the Audio Test Bench.

```
audioTestBench(pluginWithPowerMapping)
```



Logarithmic Parameter Mapping

The following class definition uses logarithmic parameter mapping to define the relationship between a property and a parameter. You can use the plugin created from this class to tune the center frequency of a single-band EQ filter from 100 to 10000.

```

classdef pluginWithLogMapping < audioPlugin
    properties
        EQ
        CenterFrequency = 1000;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('CenterFrequency', ...

```

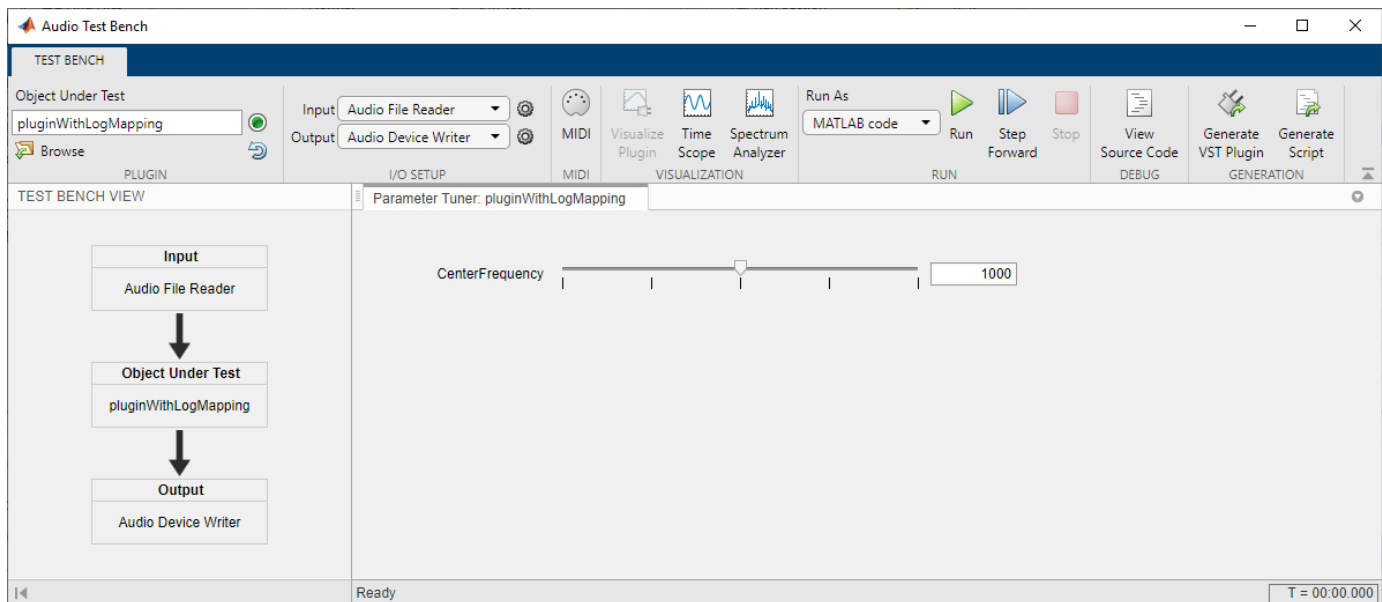
```

        'Mapping', {'log',100,10000}));
end
methods
function plugin = pluginWithLogMapping
    plugin.EQ = multibandParametricEQ('NumEQBands',1, ...
        'PeakGains',20, ...
        'Frequencies',plugin.CenterFrequency);
end
function out = process(plugin,in)
    out = plugin.EQ(in);
end
function set.CenterFrequency(plugin,val)
    plugin.CenterFrequency = val;
    plugin.EQ.Frequencies = val;
end
function reset(plugin)
    plugin.EQ.SampleRate = getSampleRate(plugin);
end
end
end

```

To run the plugin, save the class definition to a local folder and then call the Audio Test Bench.

```
audioTestBench(pluginWithLogMapping)
```



Enumeration for Logical Properties Parameter Mapping

The following class definition uses enumeration parameter mapping to define the relationship between a property and a parameter. You can use the plugin created from this class to block or pass through the audio signal by tuning the PassThrough parameter.

```

classdef pluginWithLogicalEnumMapping < audioPlugin
    properties

```

```

        PassThrough = true;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface( ...
            audioPluginParameter('PassThrough', ...
                'Mapping', {'enum','Block signal','Pass through'}, ...
                'Layout',[1,1], ...
                'Style','vtoggle', ...
                'DisplayNameLocation','none'), ...
            audioPluginGridLayout);
    end
    methods
        function out = process(plugin,in)
            if plugin.PassThrough
                out = in;
            else
                out = zeros(size(in));
            end
        end
    end
end
end
end

```

To run the plugin, save the class definition to a local folder and then create an audio I/O stream loop.

First, create objects to read from a file and write to your device.

```

fileReader = dsp.AudioFileReader('Engine-16-44p1-stereo-20sec.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

```

Create a plugin object and set the sample rate to the sample rate of the file.

```

passThrough = pluginWithLogicalEnumMapping;
setSampleRate(passThrough,fileReader.SampleRate)

```

Open a parameterTuner so that you can toggle the logical parameter of the plugin while stream processing.

```

parameterTuner(passThrough)

```

While the file contains unread data:

- 1 Read a frame from the file.
- 2 Feed the frame through the plugin
- 3 Write the processed audio to your device.

While the audio stream runs, toggle the PassThrough parameter and listen to the effect.

```

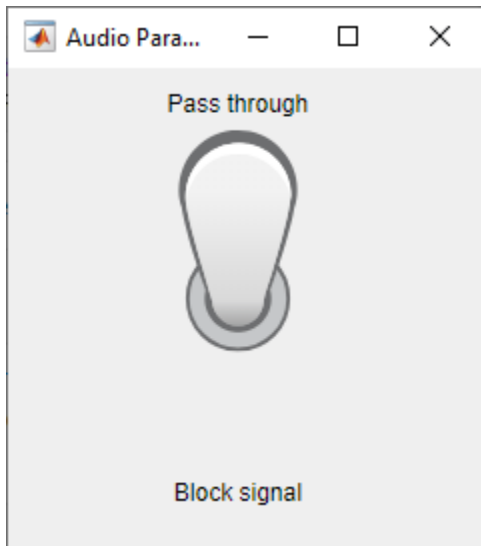
while ~isDone(fileReader)
    audioIn = fileReader();

    audioOut = process(passThrough,audioIn);

    deviceWriter(audioOut);

    drawnow limitrate
end

```



'enum' for Enumeration Class Parameter Mapping

The following class definitions comprise a simple example of enumeration parameter mapping for properties defined by an enumeration class. You can specify the operating mode of the plugin created from this class by tuning the `Mode` parameter.

Plugin Class Definition

```

classdef pluginWithEnumMapping < audioPlugin
    properties
        Mode = OperatingMode.boost;
    end
    properties (Constant)
        PluginInterface = audioPluginInterface(...
            audioPluginParameter('Mode',...
                'Mapping',{ 'enum', '+6 dB', '-6 dB', 'silence', 'white noise'}));
    end
    methods
        function out = process(plugin,in)
            switch (plugin.Mode)
                case OperatingMode.boost
                    out = in * 2;
                case OperatingMode.cut
                    out = in / 2;
                case OperatingMode.mute
                    out = zeros(size(in));
                case OperatingMode.noise
                    out = rand(size(in)) - 0.5;
                otherwise
                    out = in;
            end
        end
    end
end
end
end

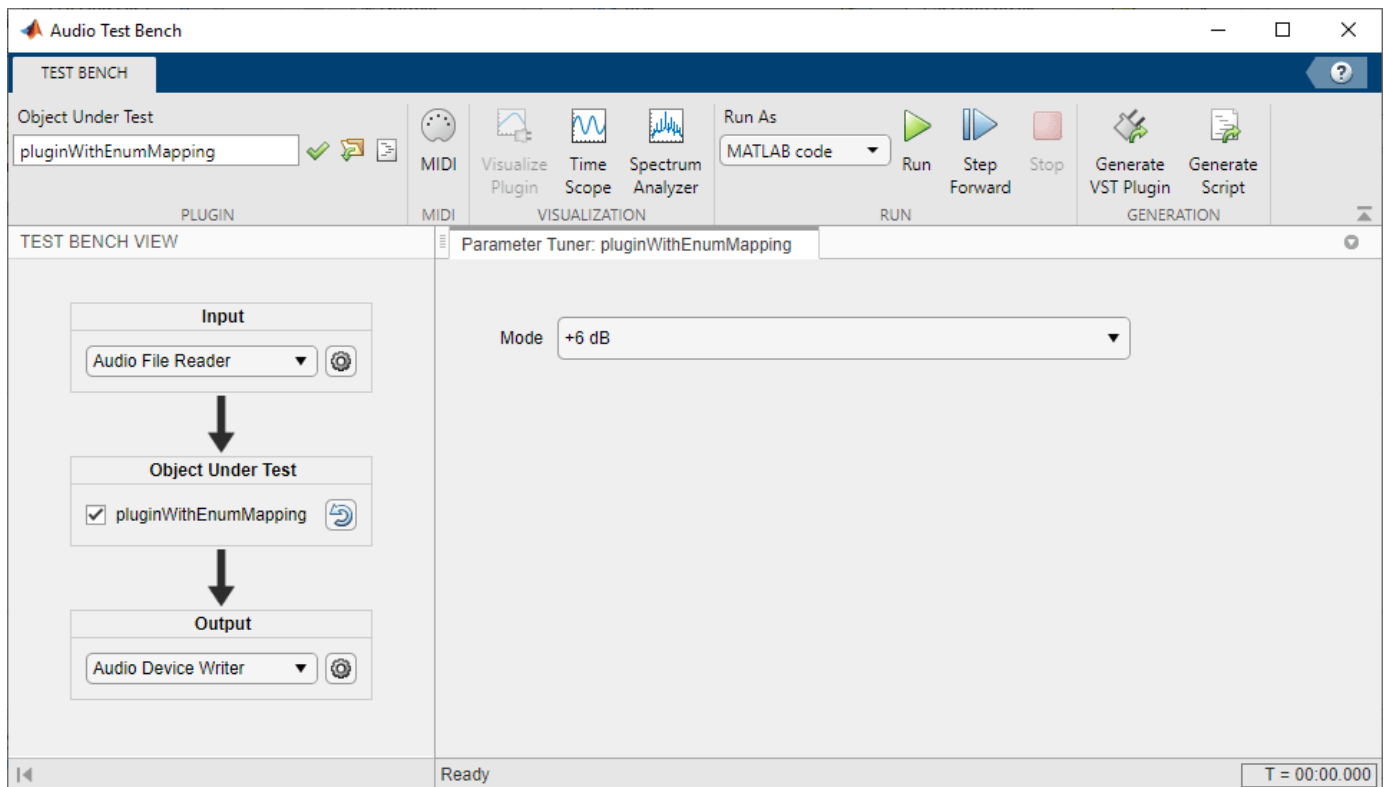
```

Enumeration Class Definition

```
classdef OperatingMode < int8
    enumeration
        boost (0)
        cut (1)
        mute (2)
        noise (3)
    end
end
```

To run the plugin, save the plugin and enumeration class definition files to a local folder. Then call the Audio Test Bench on the plugin class.

```
audioTestBench(pluginWithEnumMapping)
```



Input Arguments

propertyName — Name of audio plugin property

character vector | string

Name of the audio plugin property that you want to associate with a parameter, specified as a character vector or string. Enter the property name exactly as it is defined in the property section of your audio plugin class.

Data Types: char | string

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'DisplayName', 'Gain', 'Label', 'dB'` specifies the display name of your parameter as `'Gain'` and the display label for parameter value units as `'dB'`.

Mappings

Mapping — Mapping between property and parameter range

cell array

Mapping between property and parameter range, specified as the comma-separated pair consisting of `'Mapping'` and a cell array.

Parameter range mapping specifies a mapping between a property and the associated parameter range.

The first element of the cell array is a character vector specifying the kind of mapping. The valid values are `'lin'`, `'log'`, `'pow'`, `'int'`, and `'enum'`. The subsequent elements of the cell array depend on the kind of mapping. The valid mappings depend on the property data type.

Property Data Type	Valid Mappings	Default
double	<code>'lin', 'log', 'pow', 'int'</code>	<code>{'lin', 0, 1}</code>
logical	<code>'enum'</code>	<code>{'enum', 'off', 'on'}</code>
enumeration class	<code>'enum'</code>	enumeration names

Mapping	Description	Example
<code>'lin'</code>	Specifies a linear relationship with given minimum and maximum values. $(\text{property value}) = \min + (\max - \min) \times (\text{parameter value})$	<code>{'lin', 0, 24}</code> specifies a linear relationship with a minimum of 0 and maximum of 24. Example: “Specify Parameter Information” on page 2-499
<code>'log'</code>	Specifies a logarithmic relationship with given minimum and maximum values, where the control position maps to the logarithm of the property value. The minimum value must be greater than 0. $(\text{property value}) = \min \times (\max/\min)^{(\text{parameter value})}$	<code>{'log', 1, 22050}</code> specifies a logarithmic relationship with a minimum of 1 and a maximum of 22,050. Example: “Logarithmic Parameter Mapping” on page 2-502

Mapping	Description	Example
'pow'	Specifies a power law relationship with given exponent, minimum, and maximum values. The property value is related to the control position raised to the exponent: $(property\ value) = \min + (\max - \min) \times (parameter\ value)^{exp}$	{'pow', 1/3, -140, 12} specifies a power law relationship with an exponent of 1/3, a minimum of -140, and a maximum of 12. Example: “Power Parameter Mapping” on page 2-501
'int'	Quantizes the control position and maps it to the range of consecutive integers with given minimum and maximum values. $(property\ value) = \text{floor}(0.5 + \min + (\max - \min) \times (parameter\ value))$	{'int', 0, 3} specifies a linear, quantized relationship with a minimum of 0 and maximum of 3. The property value is mapped as an integer in the range [0, 3]. Example: “Integer Parameter Mapping” on page 2-499
'enum' (logical)	Optionally provides character vectors for display on the plugin dialog box.	{'enum', 'Block signal', 'Passthrough'} specifies the character vector 'Block signal' if the parameter value is false and 'Passthrough' if the parameter value is true. Example: “Enumeration for Logical Properties Parameter Mapping” on page 2-503
'enum' (enumeration class)	Optionally provides character vectors for the members of the enumeration class.	{'enum', '+6 dB', '-6 dB', 'silence', 'white noise'} specifies the character vectors '+6 dB', '-6 dB', 'silence', and 'white noise'. Example: “'enum' for Enumeration Class Parameter Mapping” on page 2-505

Graphical User Interface

Layout — Grid cells occupied by parameter control

[row, column] (single-cell specification) | [upper, left; lower, right] (multi-cell specification)

Grid cells occupied by parameter control, specified as a comma-separated pair consisting of 'Layout' and a two-element row vector or 2-by-2 matrix. To use a single cell, specify [row, column] of the cell. To span multiple cells, specify the upper left and lower right cells as [upper, left; lower, right].

Example: 'Layout', [2,3]

Example: 'Layout', [2,3;3,6]

Dependencies

To enable this name-value pair, pass an `audioPluginGridLayout` object to `audioPluginInterface`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

DisplayName — Display name of parameter

associated property name (default) | character vector | string

Display name of your parameter, specified as a comma-separated pair consisting of 'DisplayName' and a character vector or string. If 'DisplayName' is not specified, the name of the associated property is used.

Data Types: char | string

DisplayNameLocation — Location of display name

'left' | 'right' | 'above' | 'below' | 'none'

Location of DisplayName, specified as a comma-separated pair consisting of 'DisplayNameLocation' and 'left', 'right', 'above', 'below', or 'none'. The location of the display name is defined relative to the Layout:

- 1 'left' -- The display name is located in the column to the left of Layout and spans the same rows as Layout.
- 2 'right' -- The display name is located in the column to the right of Layout and spans the same rows as Layout.
- 3 'above' -- The display name is located in the row above Layout and spans the same columns as Layout
- 4 'below' -- The display name is located in the row below Layout and spans the same columns as Layout.
- 5 'none' -- DisplayName is suppressed.

Example: 'DisplayNameLocation', 'left'

Dependencies

To enable this name-value pair, pass an audioPluginGridLayout object to audioPluginInterface.

Data Types: char | string

Label — Display label for parameter value units

' ' (default) | character vector | string

Display label for parameter value units, specified as a comma-separated pair consisting of 'Label' and a character vector or string.

The 'Label' name-value pair is ignored for nonnumeric parameters.

Data Types: char | string

Style — Visual control for plugin parameter

'hslider' | 'vslider' | 'rotaryknob' | 'checkbox' | 'vrock' | 'vtoggle' | 'dropdown'

Visual control for plugin parameter, specified as a comma-separated pair consisting of 'Style' and a string or character vector:

Style	Description
'hslider'	Horizontal slider

Style	Description
'vslider'	Vertical slider
'rotaryknob'	Rotary knob
'checkbox'	Check box
'vrocker'	Vertical rocker switch
'vtoggle'	Vertical toggle switch
'dropdown'	Dropdown

Default and valid styles depends on the plugin parameter Mapping and corresponding property class:

Mapping	Property Class	Default Style	Additional Valid Style
lin	single	hslider	vslider
log	double		rotaryknob
pow			
int			
enum	logical	checkbox	dropdown vrocker vtoggle
enum	enumeration with 2 values	vrocker	dropdown vtoggle
enum	enumeration	dropdown	

Dependencies

To enable this name-value pair, pass an `audioPluginGridLayout` object to `audioPluginInterface`.

Data Types: `char` | `string`

Filmstrip — Name of PNG, GIF, or JPG graphics file

`character vector` | `string`

Name of PNG, GIF, or JPG graphics file, specified as the comma-separated pair consisting of 'Filmstrip' and a character vector or string. The graphics file contains a sequence of images of controls.

Filmstrips enable you to replace default control graphics with your own custom images. Filmstrips support all control Style values except for dropdowns. A filmstrip is a single image created by concatenating smaller images called frames. Each frame is an image of a control in a particular position. For example, a filmstrip for a switch contains two frames: one depicting the "off" state and another depicting the "on" state. Frames can be concatenated vertically or horizontally. Suppose that the switch frames are 50 pixels wide by 100 pixels high. Then vertical concatenation produces a 50-by-200 pixel filmstrip image, with the top frame used for the switch "off" state. Horizontal concatenation produces a 100-by-100 pixel image, with the left frame used for the switch "off" state.

Filmstrips for sliders and knobs typically contain many more frames. The top/left frame corresponds to the minimum control position, and the bottom/right frame corresponds to the maximum control position. The relative control position determines which frame is displayed for a given parameter value.

Dependencies

To enable this name-value pair, pass an `audioPluginGridLayout` object to `audioPluginInterface` and specify `'FilmstripFrameSize'`.

Data Types: `char` | `string`

FilmstripFrameSize — Size of individual frames (pixels)

[width, height]

Size of individual frames in the film strip in pixels, specified as the comma-separated pair consisting of `'FilmstripFrameSize'` and a two-element row vector of integers that specify [width, height].

Dependencies

To enable this name-value pair, pass an `audioPluginGridLayout` object to `audioPluginInterface` and specify a `'Filmstrip'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

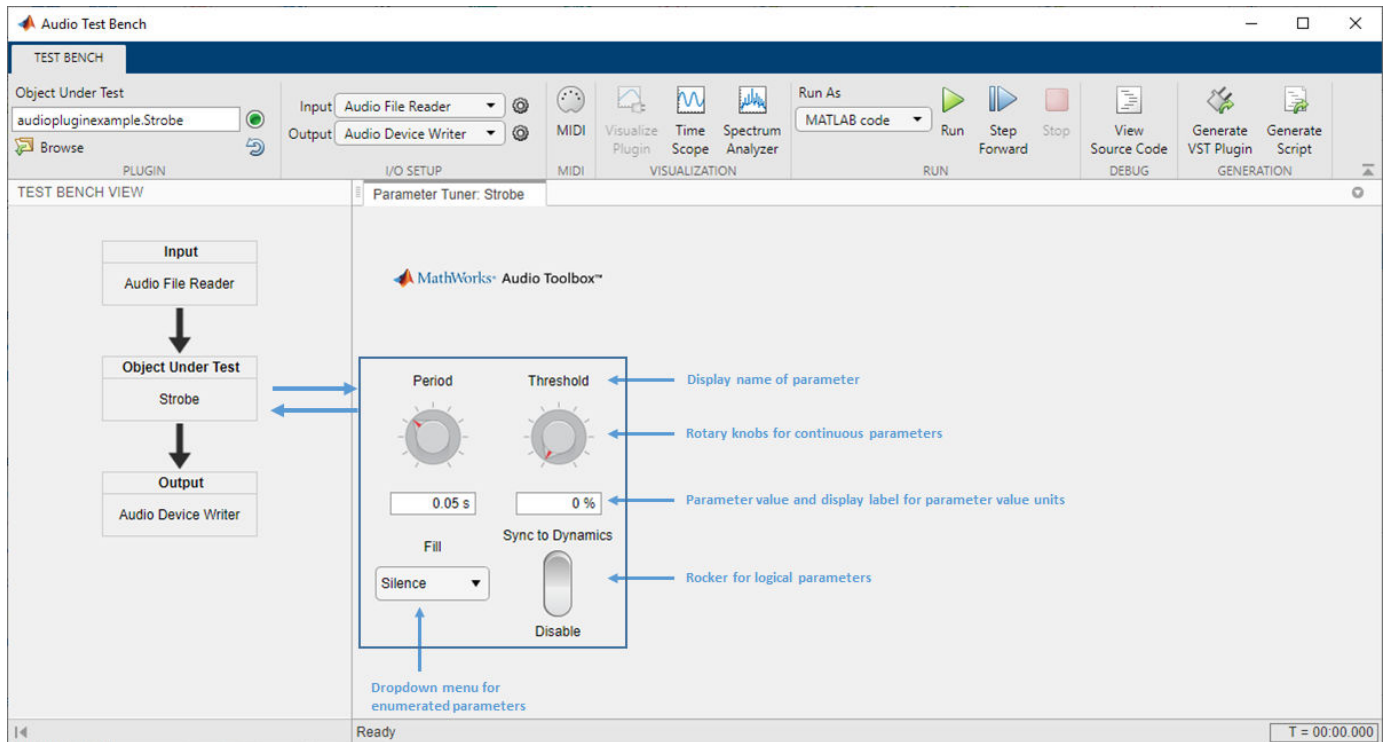
To learn how to design a graphic user interface, see “Design User Interface for Audio Plugin”.

More About

Implementation of Audio Plugin Parameters

Audio plugin parameters are visible and tunable in both the MATLAB and digital audio workstation (DAW) environments. The different environments and corresponding renderings of the audio plugin parameters are outlined here. For an example describing how your class definition maps to the UI, see “Design User Interface for Audio Plugin”.

MATLAB Environment Using Audio Test Bench. Use **Audio Test Bench** to interact with plugin parameters in the MATLAB environment in a complete GUI-based workflow. Using the **Audio Test Bench**, you can specify audio input and output, analyze your plugin using time- and frequency-domain scopes, connect to MIDI controls, and validate and generate your plugin. The **Audio Test Bench** honors the graphical user interface you specified in `audioPluginParameter`, `audioPluginGridLayout`, and `audioPluginInterface` (except for filmstrips).



MATLAB Environment Using parameterTuner. Use parameterTuner to interact with plugin parameters in the MATLAB environment while developing, analyzing, or using your plugin in a programmatic workflow. The parameterTuner honors the graphical user interface you specified in `audioPluginParameter`, `audioPluginGridLayout`, and `audioPluginInterface` (except for filmstrips).

```

% Create test bench input and output
fileReader = dsp.AudioFileReader('RockDrums-44pi-stereo-11secs.mp3', ...
    'PlayCount',Inf, ...
    'SamplesPerFrame',256);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

% Set up the system under test
sut = audiopluginexample.Strobe;
setSampleRate(sut,fileReader.SampleRate);

% Open parameterTuner for interactive tuning during simulation
tuner = parameterTuner(sut);

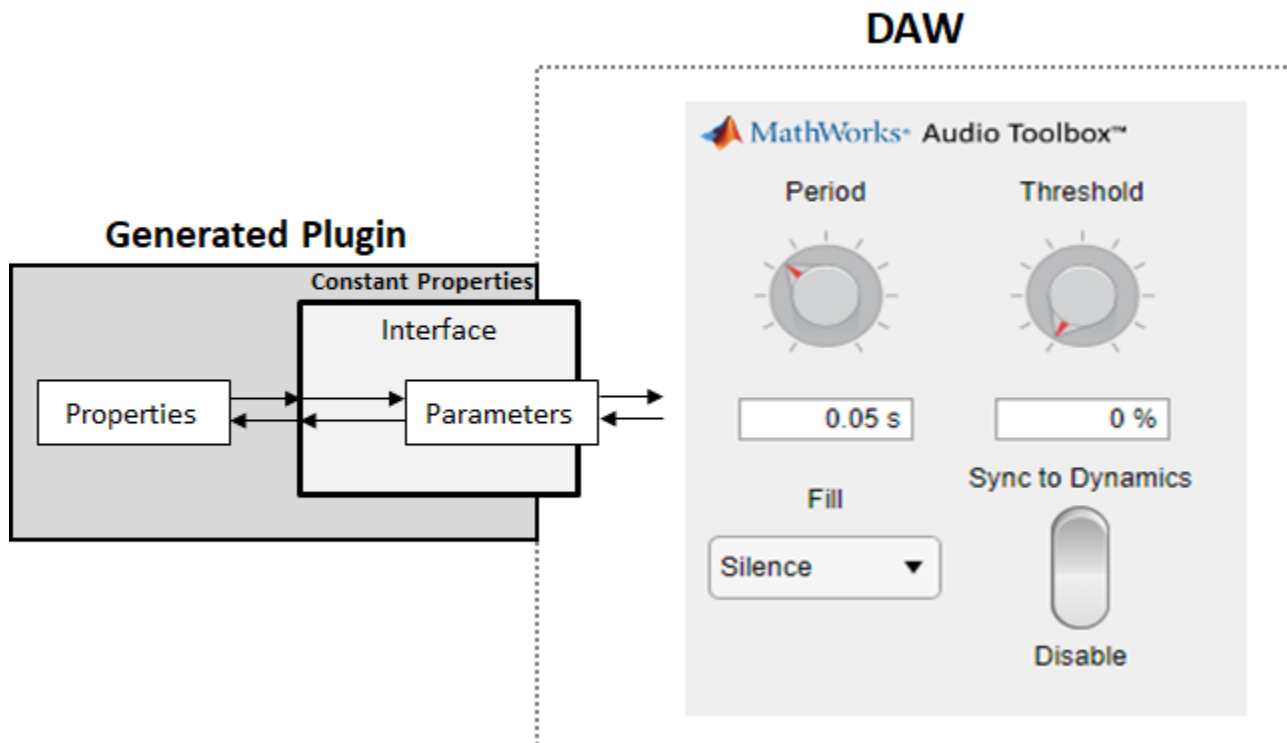
% Stream processing loop
while ~isDone(fileReader)
    in = fileReader();
    out = process(sut,in);
    drawnow limitrate
end

% Clean up
release(fileReader)
release(deviceWriter)

```



DAW Environment. Use `generateAudioPlugin` to deploy your audio plugin to a DAW environment. The DAW environment determines the exact layout of plugin parameters as seen by the plugin user.



See Also

[audioPlugin](#) | [audioPluginSource](#) | [audioPluginInterface](#) | [validateAudioPlugin](#) | [generateAudioPlugin](#) | **Audio Test Bench** | [parameterTuner](#)

Topics

“Design an Audio Plugin”
“Design User Interface for Audio Plugin”
“Export a MATLAB Plugin to a DAW”
“Audio Plugin Example Gallery”

Introduced in R2016a

configureMIDI

Configure MIDI connections between audio object and MIDI controller

Syntax

```
configureMIDI(audioObject)
configureMIDI(audioObject,propertyName)
configureMIDI(audioObject,propertyName,controlNumber)
configureMIDI(audioObject,propertyName,controlNumber,'DeviceName',
deviceNameValue)
```

Description

`configureMIDI(audioObject)` opens a MIDI configuration user interface (UI). Use the UI to synchronize parameters of the plugin, `audioObject`, to MIDI controls on your default MIDI device. You can also generate MATLAB code corresponding to the MIDI configuration developed using the `configureMIDI` UI.

To set your default device, type this syntax in the command line:

```
setpref midi DefaultDevice deviceNameValue
```

`deviceNameValue` is the MIDI device name, assigned by the device manufacturer or host operating system. Use `midiid` to get the device name corresponding to your MIDI device.

`configureMIDI(audioObject,propertyName)` makes the property, `propertyName`, respond to any control on the default MIDI device.

`configureMIDI(audioObject,propertyName,controlNumber)` makes the property respond to the MIDI control specified by `controlNumber`.

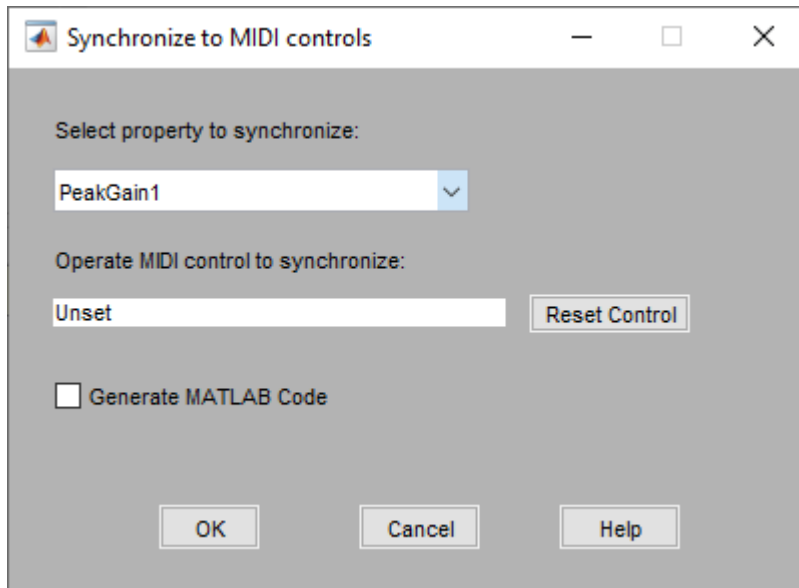
`configureMIDI(audioObject,propertyName,controlNumber,'DeviceName',deviceNameValue)` makes the property respond to the MIDI control specified by `controlNumber` on the device specified by `deviceNameValue`.

Examples

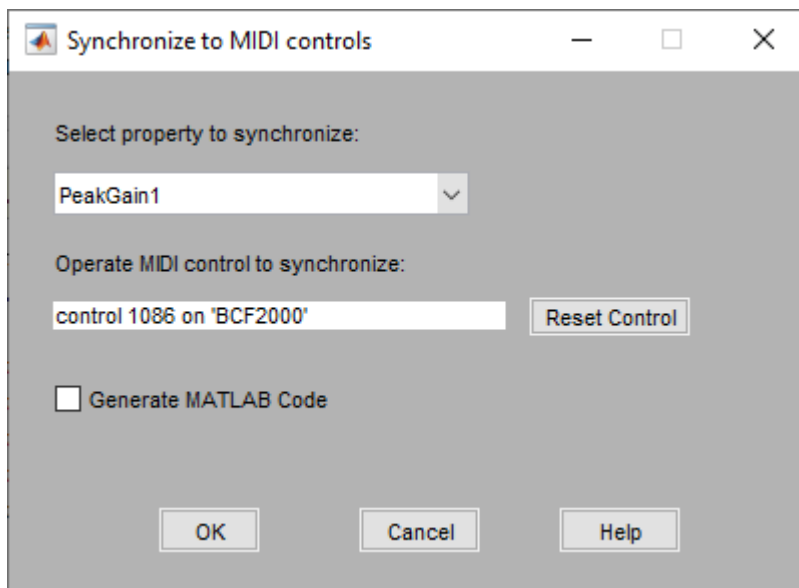
Synchronize Plugin Parameters to MIDI Controls

- 1 Open the MIDI configuration UI for a parametric equalizer plugin object.

```
parametricEQPlugin = audiopluginexample.ParametricEqualizerWithUDP;
configureMIDI(parametricEQPlugin)
```
- 2 In the UI, select a property to synchronize with your default MIDI device.



- 3 On your MIDI device, operate the control that you want to synchronize to the selected plugin property. The control appears in the **Operate MIDI control to synchronize** box.



- 4 Repeat steps 2 and 3 as needed to synchronize multiple properties to multiple MIDI controls.
To disconnect the property and control currently displayed on your configureMIDI UI, click **Reset Control**.
- 5 Click **OK**.

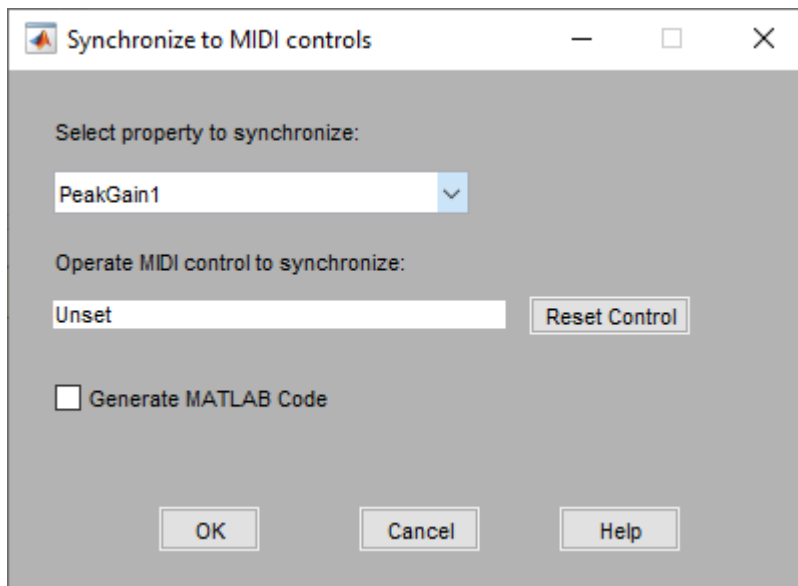
The specified MIDI controls and properties are now synchronized.

Generate MATLAB Code from configureMIDI UI

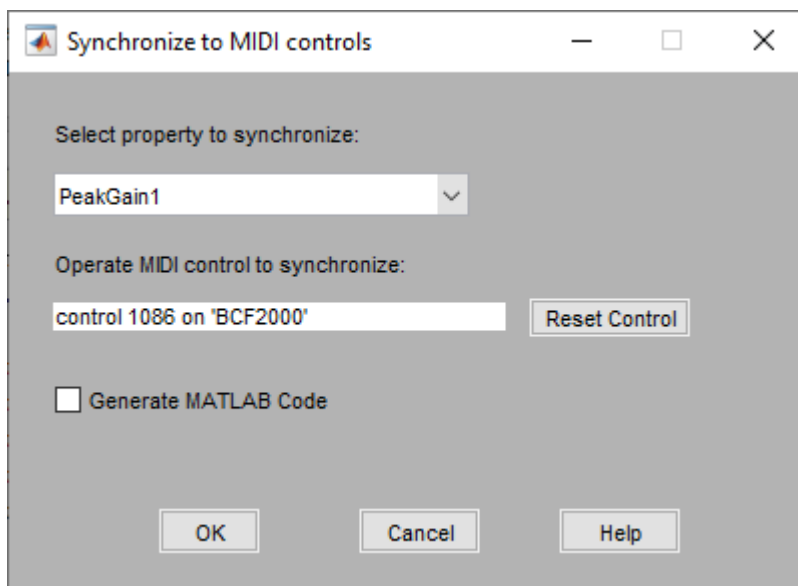
Generate MATLAB code corresponding to the MIDI configuration developed using the configureMIDI UI. You can embed the MATLAB code in your simulation so that you do not need to reopen the UI to restore your chosen MIDI connections.

- 1 Open the MIDI configuration UI for a parametric equalizer plugin object.

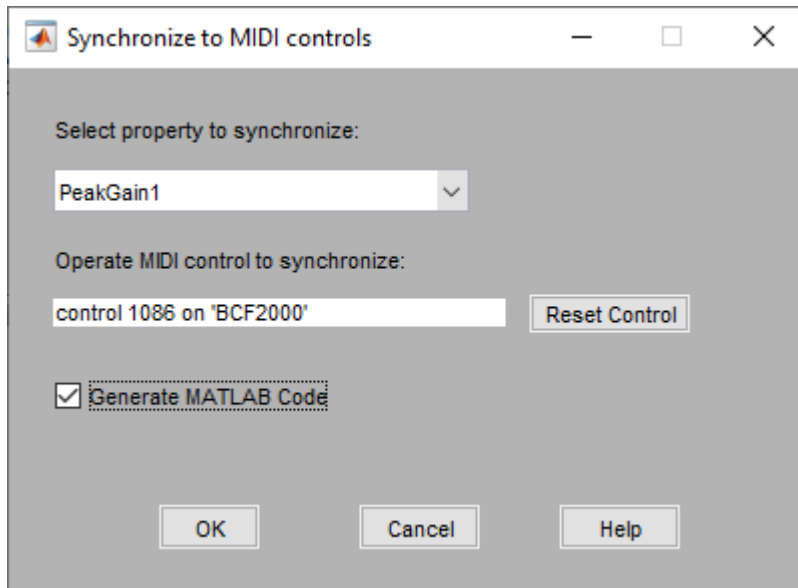
```
parametricEQPlugin = audiopluginexample.ParametricEqualizerWithUDP;
configureMIDI(parametricEQPlugin)
```
- 2 In the UI, select a property to synchronize with your default MIDI device.



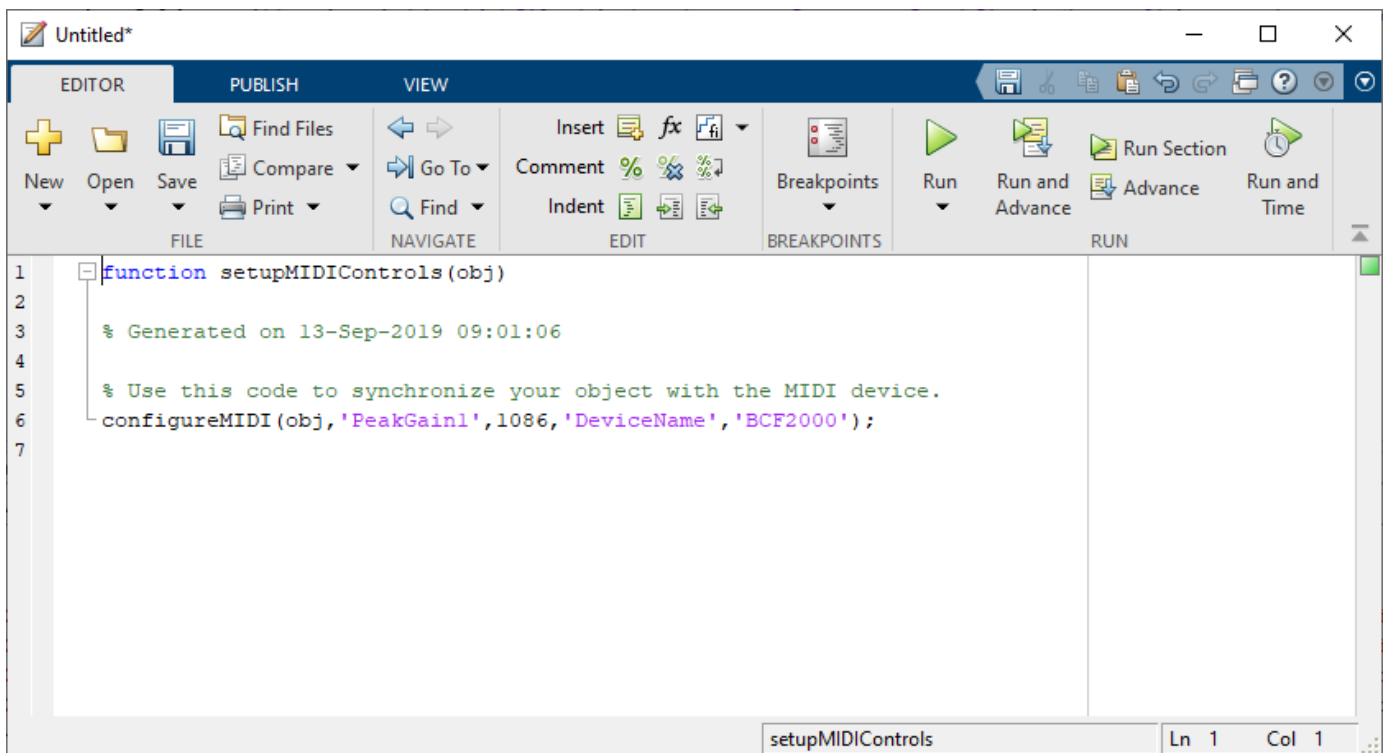
- 3 On your MIDI device, operate the control that you want to synchronize to the selected plugin property. The control appears in the **Operate MIDI control to synchronize** box.



- 4 Select the **Generate MATLAB Code** check box.



- 5 Click **OK**. The generated MATLAB code corresponds to the MIDI configuration that you developed.



Make Plugin Property Respond to Any MIDI Control

Make a plugin property respond to any control on your default MIDI device.

```
parametricEQPlugin = audiopluginexample.ParametricEqualizerWithUDP;
configureMIDI(parametricEQPlugin, 'CenterFrequency1');
```

Make Plugin Property Respond to Specific MIDI Control on Default MIDI Device

Make a plugin property respond to a specific MIDI control on your default MIDI device.

Create an object of the audio plugin example
audiopluginexample.ParametricEqualizerWithUDP.

```
parametricEQPlugin = audiopluginexample.ParametricEqualizerWithUDP;
```

Use `midiid` to identify a MIDI control to synchronize with your property.

```
[controlNumber,device] = midiid
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

```
controlNumber =
    1083
```

```
device =
    'BCF2000'
```

Use `configureMIDI` to synchronize your chosen MIDI control, specified by `controlNumber`, with a property.

```
configureMIDI(parametricEQPlugin, 'CenterFrequency1', controlNumber);
```

Make Plugin Property Respond to Specific MIDI Control on a Specific MIDI Device

Make a plugin property respond to any control on your default MIDI device.

Create an object of the audio plugin example,
audiopluginexample.ParametricEqualizerWithUDP.

```
parametricEQPlugin = audiopluginexample.ParametricEqualizerWithUDP;
```

Use `midiid` to identify a specific MIDI control on a specific MIDI device.

```
[controlNumber,device] = midiid
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

```
controlNumber =
    1087
```

```
device =
```

```
'BCF2000'
```

Use `configureMIDI` to synchronize a property with your chosen MIDI control, specified by `controlNumber`, on your chosen MIDI device, specified by `device`.

```
configureMIDI(parametricEQPlugin, 'CenterFrequency1', controlNumber, 'DeviceName', device)
```

Input Arguments

audioObject — Audio object

object

Audio plugin or compatible System object, specified as an object that inherits from the `audioPlugin` class or an object of a compatible Audio Toolbox System object.

propertyName — Name of object property

character vector | string

Name of the object property, specified as a character vector. Enter the property name exactly as it is defined in the property section of your audio plugin or Audio Toolbox System object.

controlNumber — MIDI device control number

integer

MIDI device control number, specified as an integer. The value is assigned to the control by the device manufacturer. It is used for identification purposes.

deviceNameValue — MIDI device name

character vector | string

MIDI device name, assigned by the device manufacturer or host operating system, specified as a character vector. If you do not specify a MIDI device name, the default MIDI device is used.

Limitations

For MIDI connections established by `configureMIDI`, moving a MIDI control sends a callback to update the associated property values. To synchronize your MIDI device in an audio stream loop, you might need to use the `drawnow` command for the callback to process immediately. For efficiency, use the `drawnow limitrate` syntax.

For example, to synchronize your MIDI device and audio object, uncomment the `drawnow limitrate` command from this code:

```
fileReader = dsp.AudioFileReader('Filename', 'RockDrums-44p1-stereo-11secs.mp3');
deviceWriter = audioDeviceWriter;
dRC = compressor;

configureMIDI(compressor, 'Threshold')

while ~isDone(fileReader)
    input = fileReader();
    output = dRC(input);
    deviceWriter(output);
%     drawnow limitrate;
```

end

```
release(fileReader);  
release(deviceWriter);
```

If your audio stream loop includes visualizing data on a scope, such as `dsp.SpectrumAnalyzer`, `timescope`, or `dsp.ArrayPlot`, the `drawnow` command is not required.

See Also

`audioPlugin` | `getMIDIConnections` | `midicontrols` | `midiread` | `midiid` | `midisync` | `midicallback` | `disconnectMIDI`

Topics

“MIDI Control for Audio Plugins”

“MIDI Control Surface Interface”

Introduced in R2016a

designParamEQ

Design parametric equalizer

Syntax

```
[B,A] = designParamEQ(N,gain,centerFreq,bandwidth)
[B,A] = designParamEQ(N,gain,centerFreq,bandwidth,mode)
[B,A] = designParamEQ( ___,Name,Value)
```

Description

`[B,A] = designParamEQ(N,gain,centerFreq,bandwidth)` designs an Nth-order parametric equalizer with specified gain, center frequency, and bandwidth. **B** and **A** are matrices of numerator and denominator coefficients, with columns corresponding to cascaded second-order section (SOS) filters.



`[B,A] = designParamEQ(N,gain,centerFreq,bandwidth,mode)` specifies whether the parametric equalizer is implemented with second-order sections or fourth-order sections (FOS).



`[B,A] = designParamEQ(___,Name,Value)` specifies options using one or more **Name,Value** pair arguments.



Examples



Design Two-Band Parametric Equalizer

Specify the filter order, peak gain in dB, normalized center frequencies, and normalized bandwidth of the bands of your parametric equalizer.

```
N = [ 2 , ...
      4  ];

gain = [ 6 , ...
        -4  ];

centerFreq = [ 0.25 , ...
               0.75  ];

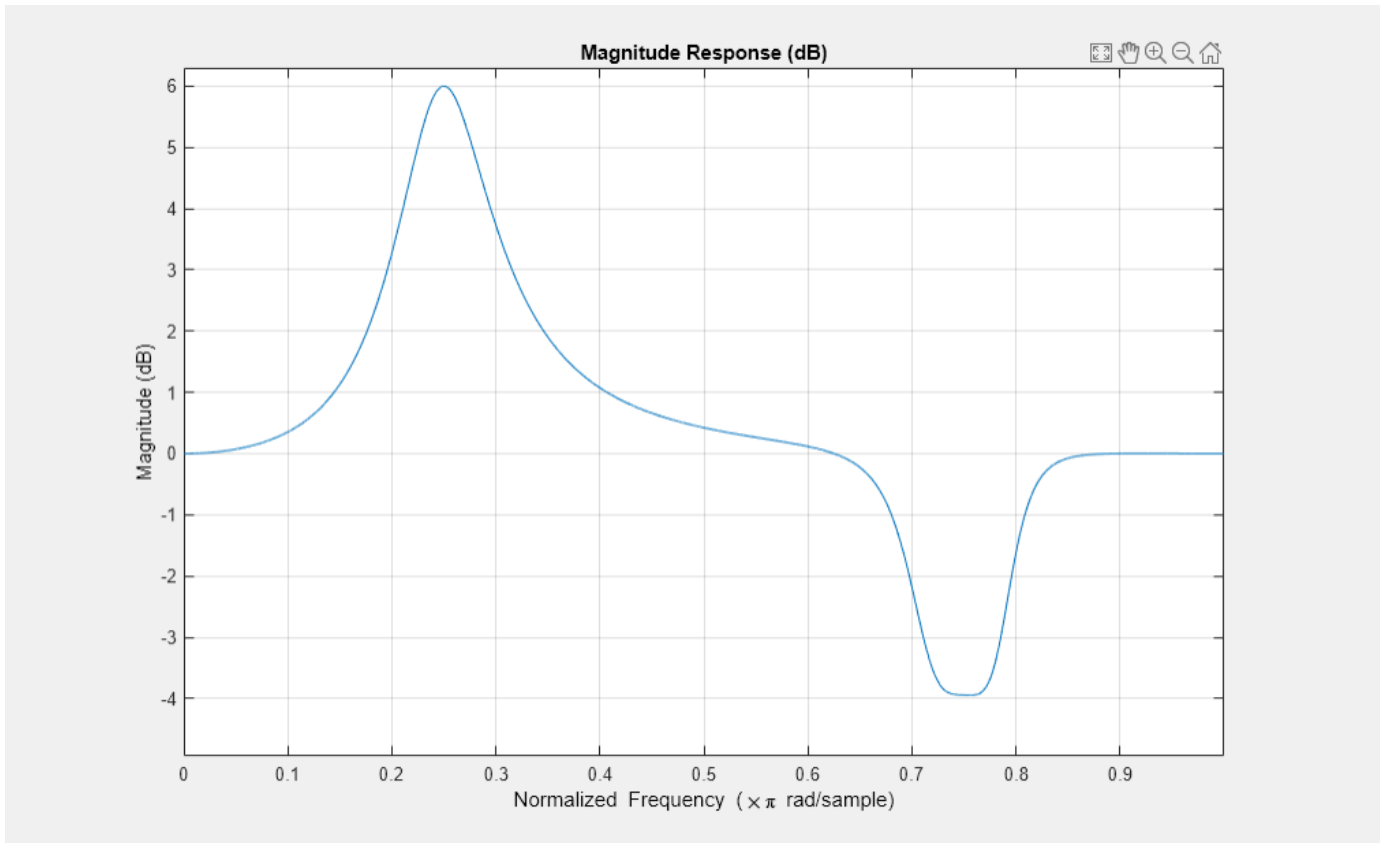
bandwidth = [ 0.12 , ...
              0.1  ];
```

Generate the filter coefficients using the specified parameters.

```
[B,A] = designParamEQ(N,gain,centerFreq,bandwidth,"Orientation","row");
```


Visualize your filter design.

```
fvtool([B,A]);
```



Filter Audio Using SOS Parametric Equalizer

Design a second-order sections (SOS) parametric equalizer using `designParamEQ` and filter an audio stream.

Create audio file reader and audio device writer System objects. Use the sample rate of the reader as the sample rate of the writer.

```
frameSize = 256;
```

```
fileReader = dsp.AudioFileReader("RockGuitar-16-44p1-stereo-72secs.wav", "SamplesPerFrame", frameSize);
```

```
sampleRate = fileReader.SampleRate;
```

```
deviceWriter = audioDeviceWriter("SampleRate", sampleRate);
```

Play the audio signal through your device.

```
count = 0;
while count < 2500
    audio = fileReader();
```

```

        deviceWriter(audio);
        count = count + 1;
    end
    reset(fileReader)

```

Design an SOS parametric equalizer suitable for use with `dsp.BiquadFilter`.

```

N = [4,4];
gain = [-25,35];
centerFreq = [0.01,0.5];
bandwidth = [0.35,0.5];
[B,A] = designParamEQ(N,gain,centerFreq,bandwidth);

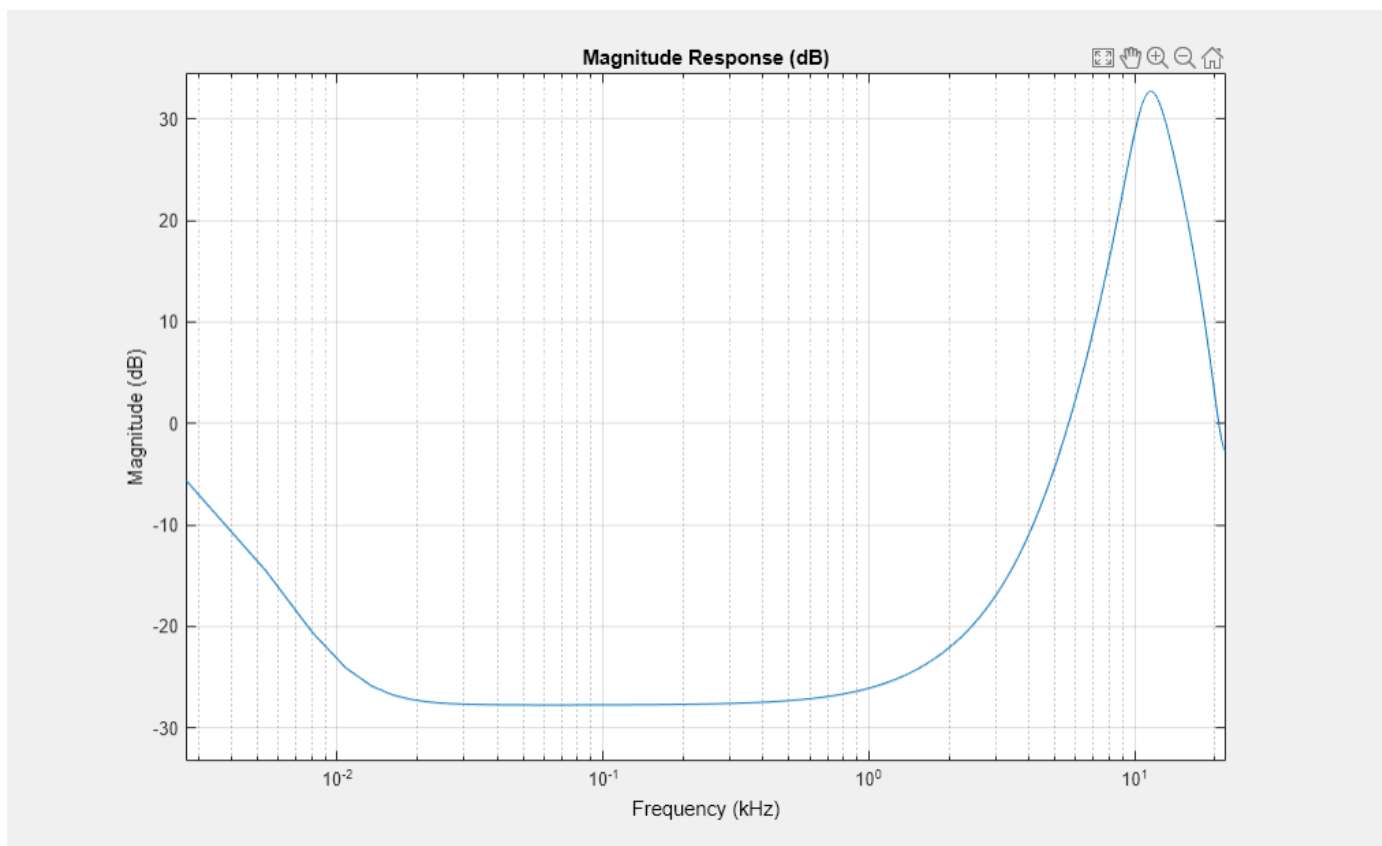
```

Visualize your filter design. Call `designParamEQ` with the same design specifications. Specify the output orientation as "row" so that it is suitable for use with `fvtool`.

```

[Bvisualize,Avisualize] = designParamEQ(N,gain,centerFreq,bandwidth,"Orientation","row");
fvtool([Bvisualize,Avisualize], ...
    "Fs",fileReader.SampleRate, ...
    "FrequencyScale","Log");

```



Create a biquad filter.

```

myFilter = dsp.BiquadFilter( ...
    "SOSMatrixSource","Input port", ...
    "ScaleValuesInputPort",false);

```

Create a spectrum analyzer to visualize the original audio signal and the audio signal passed through your parametric equalizer.

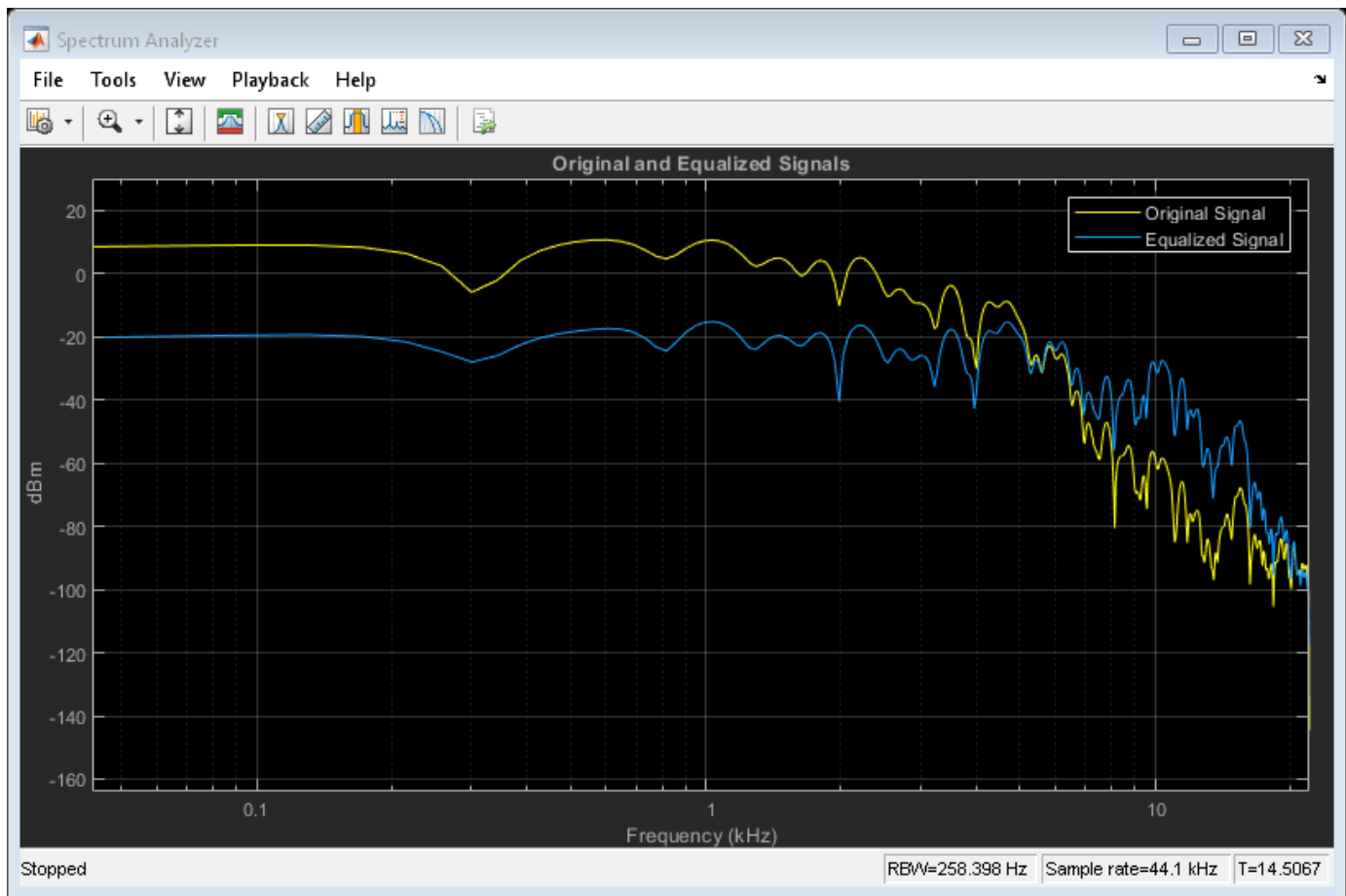
```
scope = dsp.SpectrumAnalyzer( ...
    "SampleRate",sampleRate, ...
    "PlotAsTwoSidedSpectrum",false, ...
    "FrequencyScale","Log", ...
    "FrequencyResolutionMethod","WindowLength", ...
    "WindowLength",frameSize, ...
    "Title","Original and Equalized Signals", ...
    "ShowLegend",true, ...
    "ChannelNames",{ 'Original Signal', 'Equalized Signal' });
```

Play the filtered audio signal and visualize the original and filtered spectrums.

```
count = 0;
while count < 2500
    originalSignal = fileReader();
    equalizedSignal = myFilter(originalSignal,B,A);
    scope([originalSignal(:,1),equalizedSignal(:,1)]);
    deviceWriter(equalizedSignal);
    count = count + 1;
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(scope)
```



Filter Audio Using FOS Parametric Equalizer

Design a fourth-order sections (FOS) parametric equalizer using `designParamEQ` and filter an audio stream.

Construct audio file reader and audio device writer System objects. Use the sample rate of the reader as the sample rate of the writer.

```
frameSize = 256;

fileReader = dsp.AudioFileReader( ...
    "RockGuitar-16-44p1-stereo-72secs.wav", ...
    SamplesPerFrame=frameSize);

sampleRate = fileReader.SampleRate;

deviceWriter = audioDeviceWriter( ...
    SampleRate=sampleRate);

Play the audio signal through your device.

count = 0;
while count < 2500
```

```

    x = fileReader();
    deviceWriter(x);
    count = count + 1;
end
reset(fileReader)

```

Design FOS parametric equalizer coefficients.

```

N = [2,4];
gain = [5,10];
centerFreq = [0.025,0.65];
bandwidth = [0.025,0.35];
mode = "fos";

```

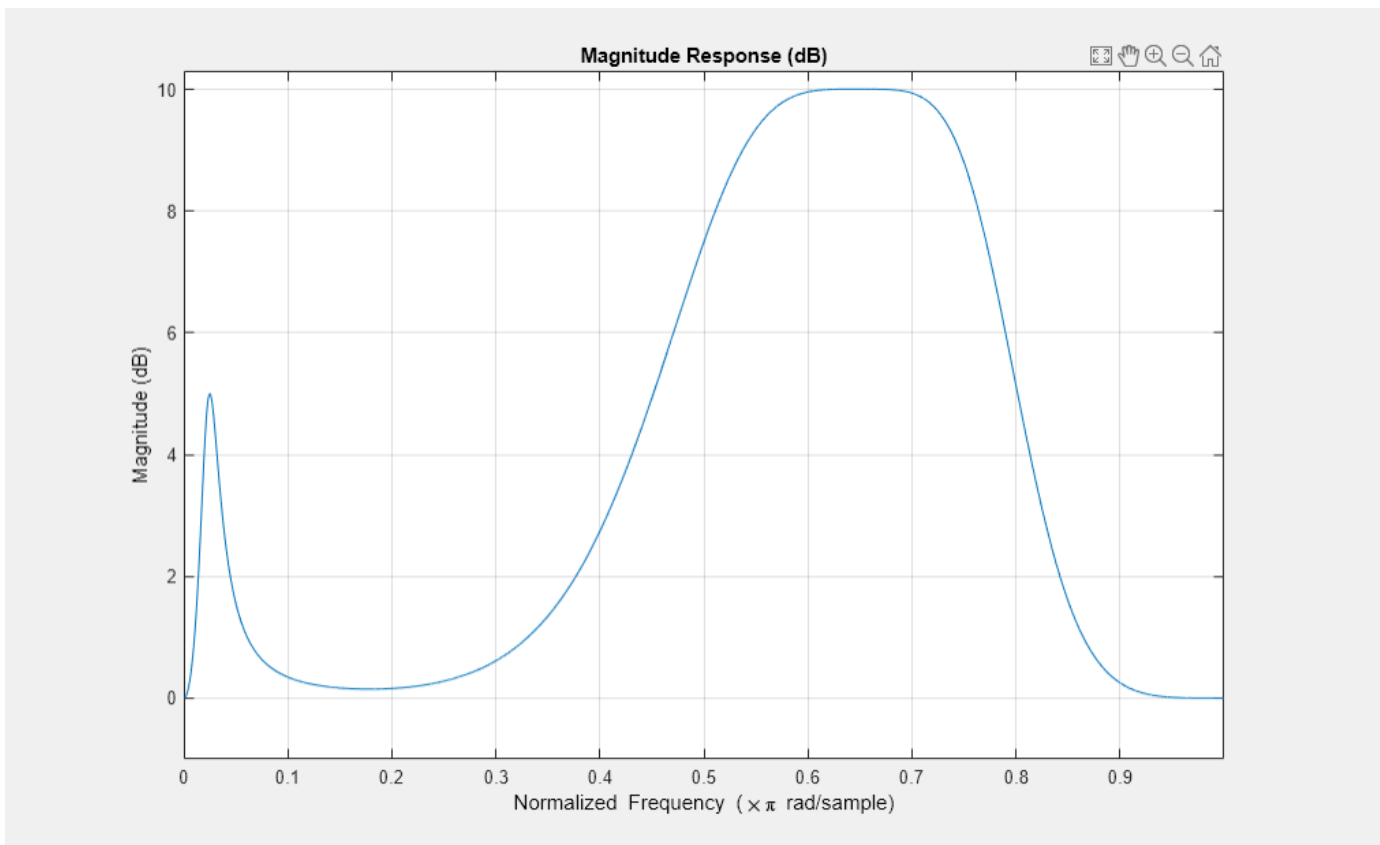
```
[B,A] = designParamEQ(N,gain,centerFreq,bandwidth,mode,Orientation="row");
```

Construct FOS IIR filters.

```
myFilter = dsp.FourthOrderSectionFilter(B,A);
```

Visualize the frequency response of your parametric equalizer.

```
fvtool(myFilter)
```



Construct a spectrum analyzer to visualize the original audio signal and the audio signal passed through your parametric equalizer.

```
scope = dsp.SpectrumAnalyzer( ...
    SampleRate=sampleRate, ...

```

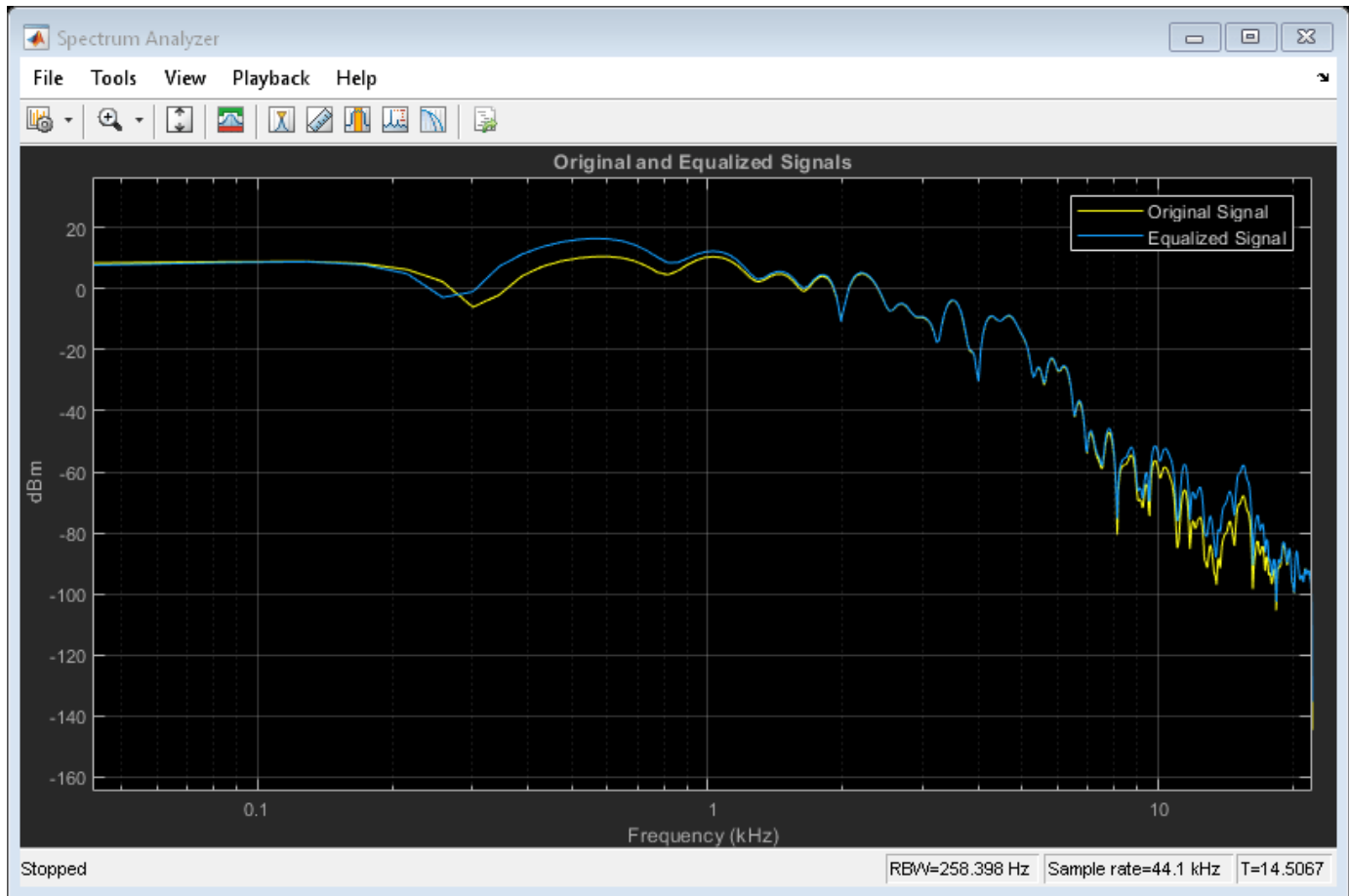
```
PlotAsTwoSidedSpectrum=false, ...  
FrequencyScale="Log", ...  
FrequencyResolutionMethod="WindowLength", ...  
WindowLength=frameSize, ...  
Title="Original and Equalized Signals", ...  
ShowLegend=true, ...  
ChannelNames={'Original Signal','Equalized Signal'});
```

Play the filtered audio signal and visualize the original and filtered spectra.

```
count = 0;  
while count < 2500  
    x = fileReader();  
    y = myFilter(x);  
  
    scope([x(:,1),y(:,1)]);  
  
    deviceWriter(y);  
  
    count = count + 1;  
end
```

As a best practice, release your objects once done.

```
release(fileReader)  
release(deviceWriter)  
release(scope)
```



Input Arguments

N — Filter order

scalar | row vector

Filter order, specified as a scalar or row vector the same length as `centerFreq`. Elements of the vector must be even integers.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

gain — Peak gain (dB)

scalar | row vector

Peak gain in dB, specified as a scalar or row vector the same length as `centerFreq`. Elements of the vector must be real-valued.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

centerFreq — Normalized center frequency of equalizer bands

scalar | row vector

Normalized center frequency of equalizer bands, specified as a scalar or row vector of real values in the range 0 to 1, where 1 corresponds to the Nyquist frequency (π rad/sample). If `centerFreq` is specified as a row vector, separate equalizers are designed for each element of `centerFreq`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

bandwidth — Normalized bandwidth

`scalar` | `row vector`

Normalized bandwidth, specified as a scalar or row vector the same length as `centerFreq`. Elements of the vector are specified as real values in the range 0 to 1, where 1 corresponds to the Nyquist frequency (π rad/sample).

Normalized bandwidth is measured at `gain/2` dB. If `gain` is set to `-Inf` (notch filter), normalized bandwidth is measured at the 3 dB attenuation point: $10 \times \log_{10}(0.5)$.

To convert octave bandwidth to normalized bandwidth, calculate the associated Q -factor as

$$Q = \frac{\sqrt{2^{(\text{octave bandwidth})}}}{2^{(\text{octave bandwidth})} - 1}.$$

Then convert to bandwidth

$$\text{bandwidth} = \frac{\text{centerFreq}}{Q}.$$

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

mode — Design mode

`'sos'` (default) | `'fos'`

Design mode, specified as `'sos'` or `'fos'`.

- `'sos'` -- Implements your equalizer as cascaded second-order filters.
- `'fos'` -- Implements your equalizer as cascaded fourth-order filters. Because fourth-order sections do not require the computation of roots, they are generally more computationally efficient.

Data Types: `char` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'Orientation','row'`

Orientation — Orientation of returned filter coefficients

`"column"` (default) | `"row"`

Orientation of returned filter coefficients, specified as the comma-separated pair consisting of `'Orientation'` and `"column"` or `"row"`:

- Set 'Orientation' to "row" for interoperability with **FVTool**, `dsp.DynamicFilterVisualizer`, and `dsp.FourthOrderSectionFilter`.
- Set 'Orientation' to "column" for interoperability with `dsp.BiquadFilter`.

Data Types: char | string

Output Arguments

B — Numerator filter coefficients

matrix

Numerator filter coefficients, returned as a matrix. The size and interpretation of B depends on the Orientation and mode:

- If 'Orientation' is set to "column" and mode is set to "sos", then B is returned as an L -by-3 matrix. Each column corresponds to the numerator coefficients of your cascaded second-order sections.
- If 'Orientation' is set to "column" and mode is set to "fos", then B is returned as an L -by-5 matrix. Each column corresponds to the numerator coefficients of your cascaded fourth-order sections.
- If 'Orientation' is set to "row" and mode is set to "sos", then B is returned as a 3-by- L matrix. Each row corresponds to the numerator coefficients of your cascaded second-order sections.
- If 'Orientation' is set to "row" and mode is set to "fos", then B is returned as a 5-by- L matrix. Each row corresponds to the numerator coefficients of your cascaded fourth-order sections.

A — Denominator filter coefficients

matrix

Denominator filter coefficients, returned as a matrix. The size and interpretation of A depends on the Orientation and mode:

- If 'Orientation' is set to "column" and mode is set to "sos", then A is returned as an L -by-2 matrix. Each column corresponds to the denominator coefficients of your cascaded second-order sections. A does not include the leading unity coefficients.
- If 'Orientation' is set to "column" and mode is set to "fos", then A is returned as an L -by-4 matrix. Each column corresponds to the denominator coefficients of your cascaded fourth-order sections. A does not include the leading unity coefficients.
- If 'Orientation' is set to "row" and mode is set to "sos", then A is returned as a 3-by- L matrix. Each row corresponds to the denominator coefficients of your cascaded second-order sections.
- If 'Orientation' is set to "row" and mode is set to "fos", then A is returned as a 5-by- L matrix. Each row corresponds to the denominator coefficients of your cascaded fourth-order sections.

References

- [1] Orfanidis, Sophocles J. "High-Order Digital Parametric Equalizer Design." *Journal of the Audio Engineering Society*. Vol. 53, November 2005, pp. 1026-1046.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`designVarSlopeFilter` | `designShelvingEQ` | `multibandParametricEQ` | `dsp.BiquadFilter`

Topics

“Parametric Equalizer Design”
“Equalization”

Introduced in R2016a

designShelvingEQ

Design shelving equalizer

Syntax

```
[B,A] = designShelvingEQ(gain,slope,Fc)
[B,A] = designShelvingEQ(gain,slope,Fc,type)
[B,A] = designShelvingEQ( ___,Orientation=ornt)
```

Description

`[B,A] = designShelvingEQ(gain,slope,Fc)` designs a low-shelf equalizer with the specified gain, slope, and cutoff frequency `Fc`. `B` and `A` are the numerator and denominator coefficients, respectively, of a single second-order section (biquad) IIR filter.

`[B,A] = designShelvingEQ(gain,slope,Fc,type)` specifies the design type as a low-shelving or high-shelving equalizer.

`[B,A] = designShelvingEQ(___,Orientation=ornt)` specifies the orientation of the returned filter coefficients as "column" or "row".

Examples

Filter Audio Using Low-Shelf Equalizer

Create audio file reader and audio device writer objects. Use the sample rate of the reader as the sample rate of the writer.

```
frameSize = 256;
```

```
fileReader = dsp.AudioFileReader("RockGuitar-16-44p1-stereo-72secs.wav",SamplesPerFrame=frameSize);
```

```
deviceWriter = audioDeviceWriter(SampleRate=fileReader.SampleRate);
```

Play the audio signal through your device.

```
count = 0;
while count < 2500
    audio = step(fileReader);
    play(deviceWriter,audio);
    count = count + 1;
end
```

```
reset(fileReader)
```

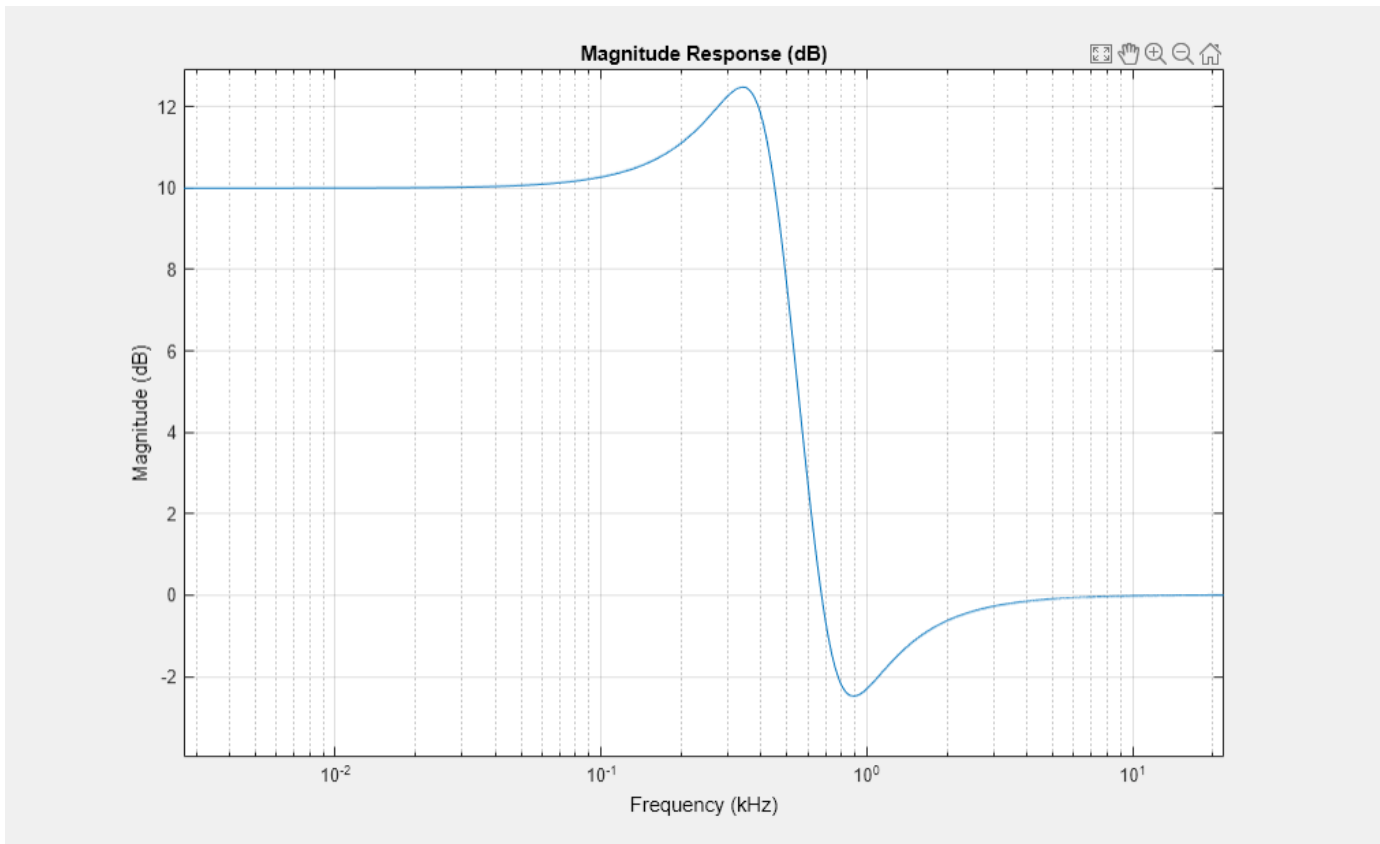
Design a second-order sections (SOS) low-shelf equalizer.

```
gain = 10;
slope = 3;
Fc = 0.025;
```

```
[B,A] = designShelvingEQ(gain,slope,Fc);
```

Visualize your shelving filter design.

```
SOS = [B',[1,A']];
fvtool(dsp.BiquadFilter(SOSMatrix=SOS), ...
    Fs=fileReader.SampleRate, ...
    FrequencyScale="log")
```



Create a biquad filter object.

```
myFilter = dsp.BiquadFilter( ...
    SOSMatrixSource="Input port", ...
    ScaleValuesInputPort=false);
```

Create a spectrum analyzer object to visualize the original audio signal and the audio signal passed through your low-shelf equalizer.

```
scope = dsp.SpectrumAnalyzer( ...
    SampleRate=fileReader.SampleRate, ...
    PlotAsTwoSidedSpectrum=false, ...
    FrequencyScale="log", ...
    FrequencyResolutionMethod="WindowLength", ...
    WindowLength=frameSize, ...
    Title="Original and Equalized Signal", ...
    ShowLegend=true, ...
    ChannelNames={'Original Signal','Equalized Signal'});
```

Play the equalized audio signal and visualize the original and equalized spectrums.

```

count = 0;
while count < 2500
    originalSignal = fileReader();
    equalizedSignal = myFilter(originalSignal,B,A);
    scope([originalSignal(:,1),equalizedSignal(:,1)]);
    deviceWriter(equalizedSignal);
    count = count + 1;
end

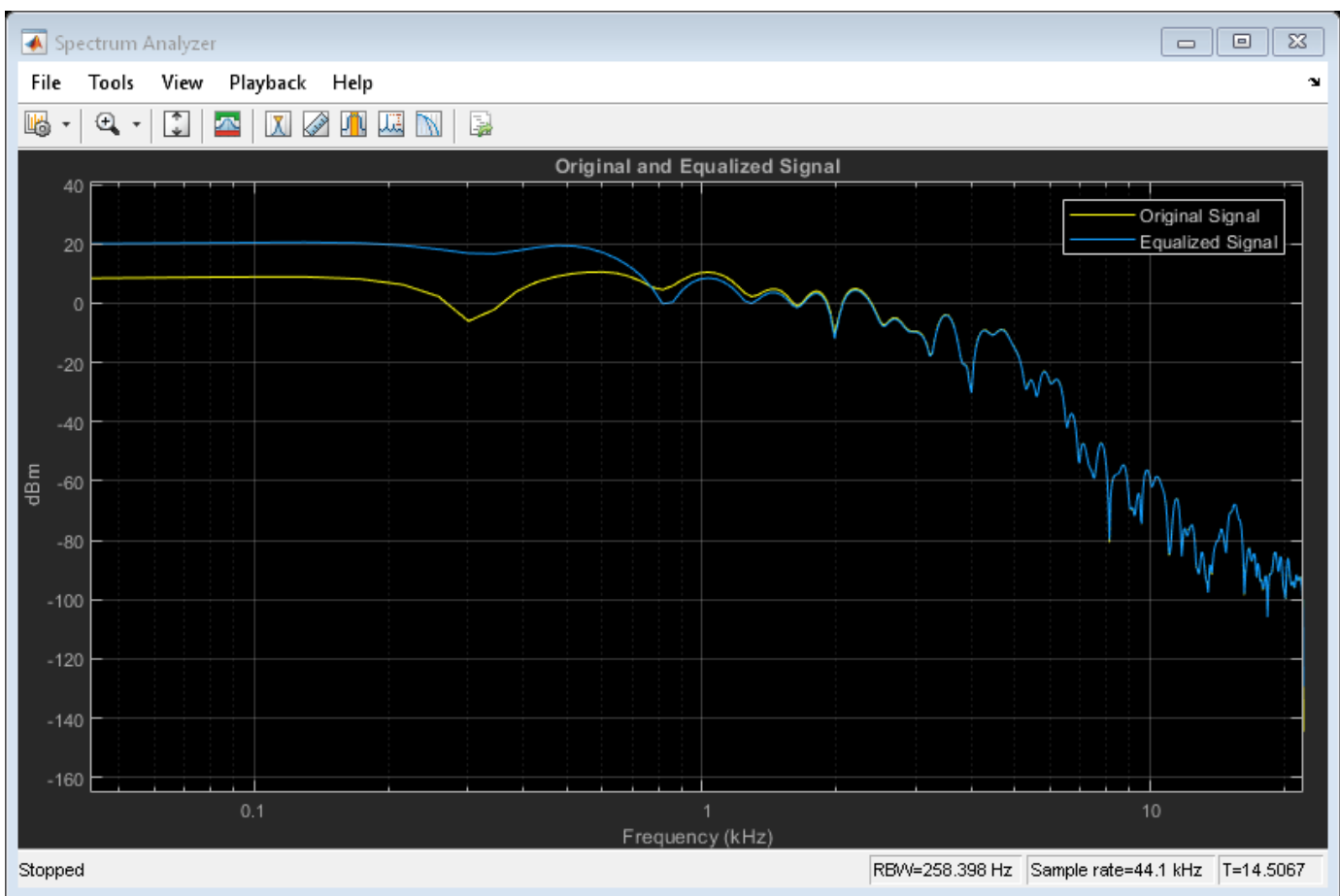
```

As a best practice, release your objects once done.

```

release(fileReader)
release(deviceWriter)
release(scope)

```



Design High-Shelf Equalizer

Design three second-order IIR high shelf equalizers using `designShelvingEQ`. The three shelving equalizers use three separate gain specifications.

Specify sample rate, peak gain, slope coefficient, and normalized cutoff frequency for the three shelving equalizers. The sample rate is in Hz. The peak gain is in dB.

```

Fs = 44.1e3;

gain1 = -6;
gain2 = 6;
gain3 = 12;

slope = 0.8;

Fc = 18000/(Fs/2);

```

Design the filter coefficients using the specified parameters.

```

[B1,A1] = designShelvingEQ(gain1,slope,Fc,"hi",Orientation="row");
[B2,A2] = designShelvingEQ(gain2,slope,Fc,"hi",Orientation="row");
[B3,A3] = designShelvingEQ(gain3,slope,Fc,"hi",Orientation="row");

```

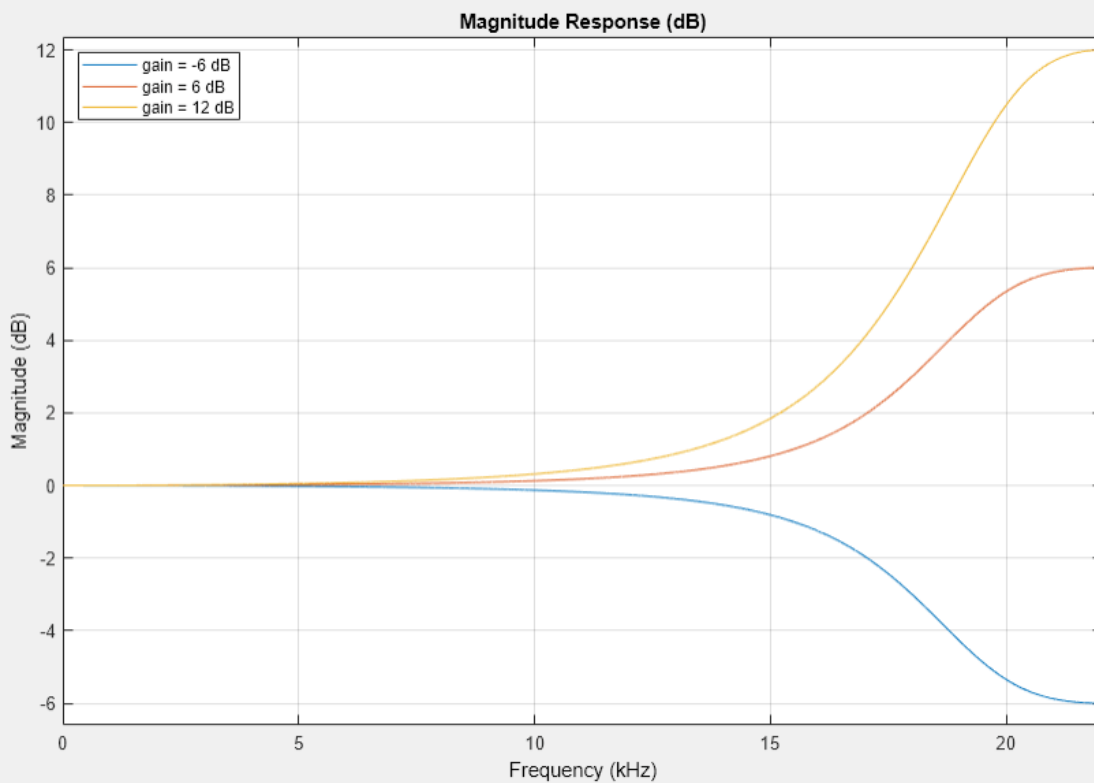
Visualize your filter design.

```

fvtool([B1,A1;[1 0 0 1 0 0]], ...
       [B2,A2;[1 0 0 1 0 0]], ...
       [B3,A3;[1 0 0 1 0 0]], ...
       Fs=Fs);

legend(fvt,"gain = "+[gain1 gain2 gain3]+" dB",Location="northwest")

```



Design Low-Shelf Equalizer

Design three second-order IIR low-shelf equalizers using `designShelvingEQ`. The three shelving equalizers use three separate slope specifications.

Specify sampling frequency, peak gain, slope coefficient, and normalized cutoff frequency for three shelving equalizers. The sampling frequency is in Hz. The peak gain is in dB.

```
Fs = 44.1e3;
```

```
gain = 5;
```

```
slope1 = 0.5;
```

```
slope2 = 0.75;
```

```
slope3 = 1;
```

```
Fc = 1000/(Fs/2);
```

Design the filter coefficients using the specified parameters.

```
[B1,A1] = designShelvingEQ(gain,slope1,Fc,Orientation="row");
```

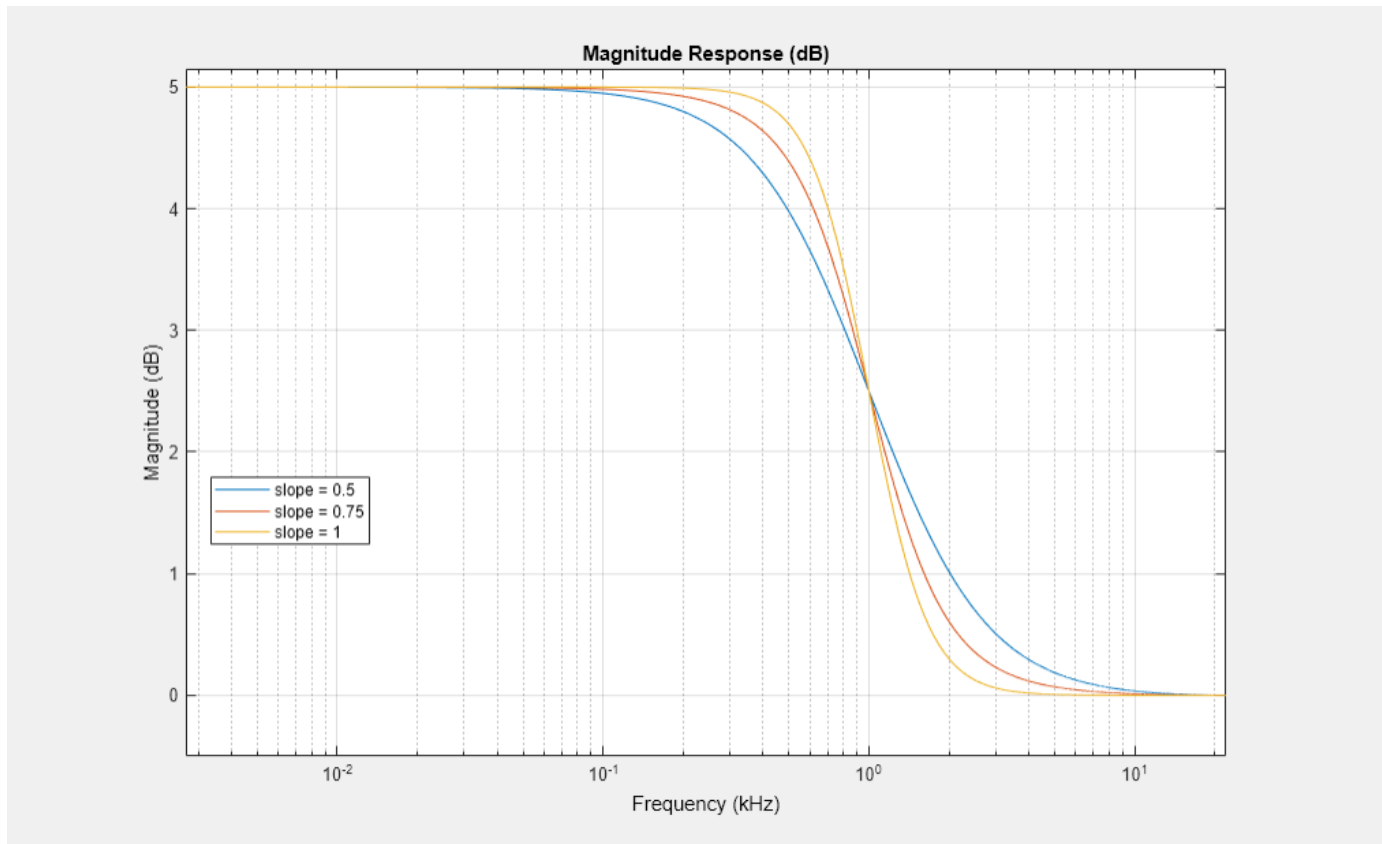
```
[B2,A2] = designShelvingEQ(gain,slope2,Fc,Orientation="row");
```

```
[B3,A3] = designShelvingEQ(gain,slope3,Fc,Orientation="row");
```

Visualize your filter design.

```
fvt = fvtool( ...  
    dsp.BiquadFilter([B1,A1]), ...  
    dsp.BiquadFilter([B2,A2]), ...  
    dsp.BiquadFilter([B3,A3]), ...  
    Fs=Fs, ...  
    FrequencyScale="log");
```

```
legend(fvt,"slope = 0.5","slope = 0.75","slope = 1")
```



Input Arguments

gain — Peak gain (dB)

real scalar

Peak gain in dB, specified as a real scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

slope — Slope coefficient

positive scalar

Slope coefficient, specified as a positive scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Fc — Normalized cutoff frequency

real scalar in the range [0, 1]

Normalized cutoff frequency, specified as a real scalar in the range [0, 1], where 1 corresponds to the Nyquist frequency (π rad/sample).

Normalized cutoff frequency is implemented as half the shelving filter gain, or $\text{gain}/2$ dB.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

type – Filter type`"lo" (default) | 'hi'`

Filter type, specified as "lo" or "hi".

- "lo"-- Low shelving equalizer
- "hi"-- High shelving equalizer

Data Types: `char` | `string`

ornt – Orientation of returned filter coefficients`"column" (default) | "row"`

Orientation of returned filter coefficients, specified as "column" or "row".

- Set `ornt` to "row" for interoperability with **FVTool**, `dsp.DynamicFilterVisualizer`, and `dsp.FourthOrderSectionFilter`.
- Set `ornt` to "column" for interoperability with `dsp.BiquadFilter`.

Data Types: `char` | `string`

Output Arguments

B – Numerator filter coefficients`three-element column vector | three-element row vector`

Numerator filter coefficients, returned as a vector. The size and interpretation of `B` depend on the orientation, `ornt`:

- If `ornt` is set to "column", then `B` is returned as a three-element column vector.
- If `ornt` is set to "row", then `B` is returned as a three-element row vector.

.

A – Denominator filter coefficients`two-element column vector | three-element row vector`

Denominator filter coefficients of the designed second-order IIR filter, returned as a vector. The size and interpretation of `A` depend on the orientation, `ornt`:

- If `ornt` is set to "column", then `A` is returned as a two-element column vector. `A` does not include the leading unity coefficient.
- If `ornt` is set to "row", then `A` is returned as a three-element row vector.

References

- [1] Bristow-Johnson, Robert. "Cookbook Formulae for Audio EQ Biquad Filter Coefficients." Accessed September 13, 2021. <https://webaudio.github.io/Audio-EQ-Cookbook/Audio-EQ-Cookbook.txt>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

Blocks

Shelving Filter

Objects

shelvingFilter | multibandParametricEQ

Functions

designParamEQ | designVarSlopeFilter

Topics

“Parametric Equalizer Design”

“Equalization”

Introduced in R2016a

designVarSlopeFilter

Design variable slope lowpass or highpass IIR filter

Syntax

```
[B,A] = designVarSlopeFilter(slope,Fc)
[B,A] = designVarSlopeFilter(slope,Fc,type)
[B,A] = designVarSlopeFilter( ___,Name,Value)
```

Description

`[B,A] = designVarSlopeFilter(slope,Fc)` designs a lowpass filter with the specified slope and cutoff frequency. B and A are matrices of numerator and denominator coefficients, with columns corresponding to cascaded second-order sections (SOS).

`[B,A] = designVarSlopeFilter(slope,Fc,type)` specifies the design type as a lowpass or highpass filter.

`[B,A] = designVarSlopeFilter(___,Name,Value)` specifies options using one or more Name,Value pair arguments.

Examples

Design Lowpass IIR Filter

Design two second-order section (SOS) lowpass IIR filters using `designVarSlopeFilter`.

Specify the sampling frequency, slope, and normalized cutoff frequency for two lowpass IIR filters. The sampling frequency is in Hz. The slope is in dB/octave.

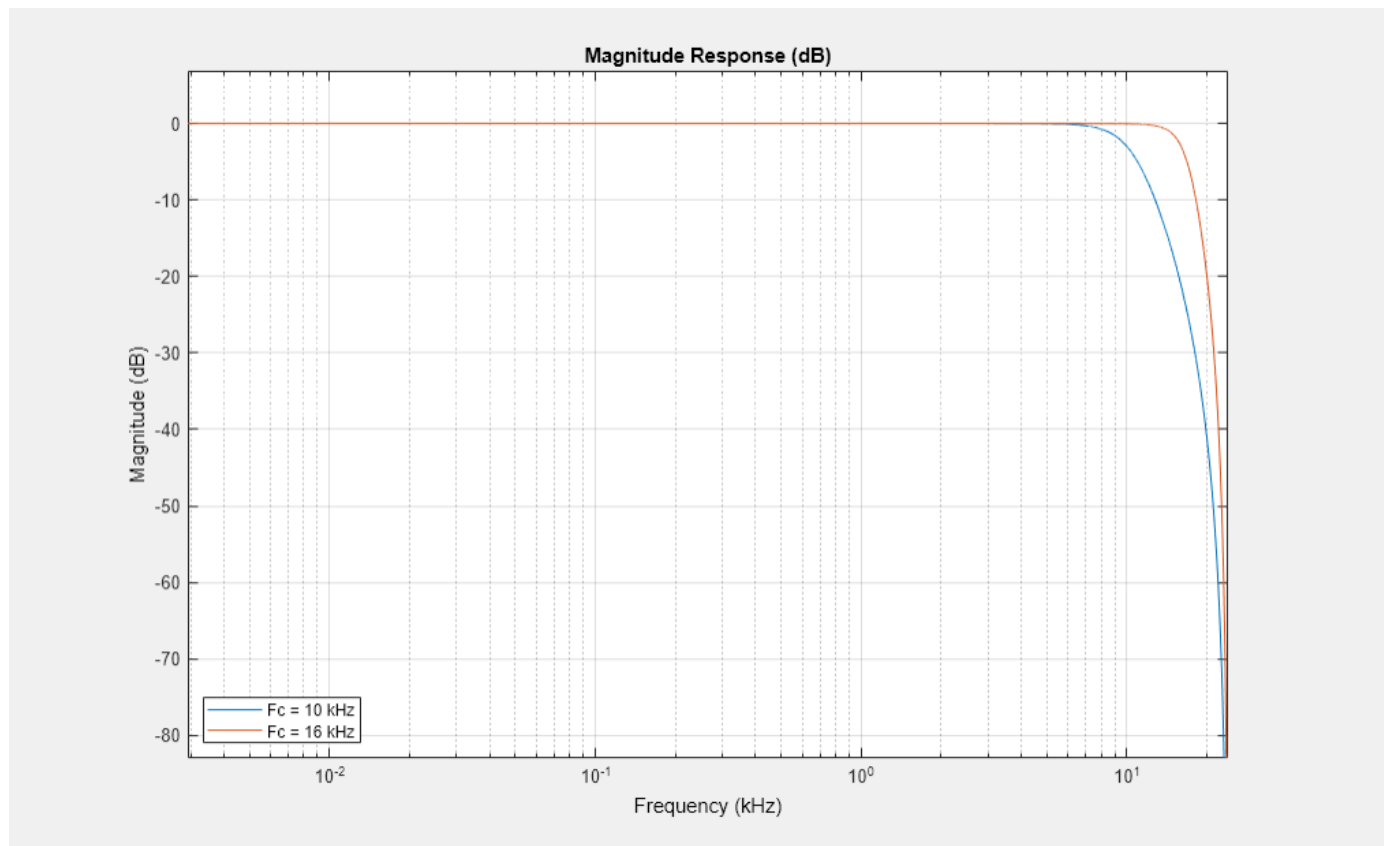
```
Fs = 48e3;
slope = 18;
Fc1 = 10e3/(Fs/2);
Fc2 = 16e3/(Fs/2);
```

Design the filter coefficients using the specified parameters.

```
[B1,A1] = designVarSlopeFilter(slope,Fc1,"Orientation","row");
[B2,A2] = designVarSlopeFilter(slope,Fc2,"Orientation","row");
```

Visualize your filter design.

```
fvt = fvtool([B1,A1],[B2,A2],Fs=Fs,FrequencyScale="log");
legend(fvt,"Fc = 10 kHz","Fc = 16 kHz",Location="southwest")
```



Process Audio Using Lowpass Filter

Design a second-order section (SOS) lowpass IIR filter using `designVarSlopeFilter`. Use your lowpass filter to process an audio signal.

Create audio file reader and audio device writer objects. Use the sample rate of the reader as the sample rate of the writer.

```
frameSize = 256;

fileReader = dsp.AudioFileReader( ...
    "RockGuitar-16-44p1-stereo-72secs.wav", ...
    SamplesPerFrame=frameSize);

sampleRate = fileReader.SampleRate;

deviceWriter = audioDeviceWriter( ...
    SampleRate=sampleRate);

Play the audio signal through your device.

count = 0;
while count < 2500
    audio = fileReader();
    deviceWriter(audio);
```

```

    count = count + 1;
end
reset(fileReader)

```

Design a lowpass filter with a 12 dB/octave slope and a 0.15 normalized cutoff frequency.

```

slope = 12;
cutoff = 0.15;
[B,A] = designVarSlopeFilter(slope,cutoff);

```

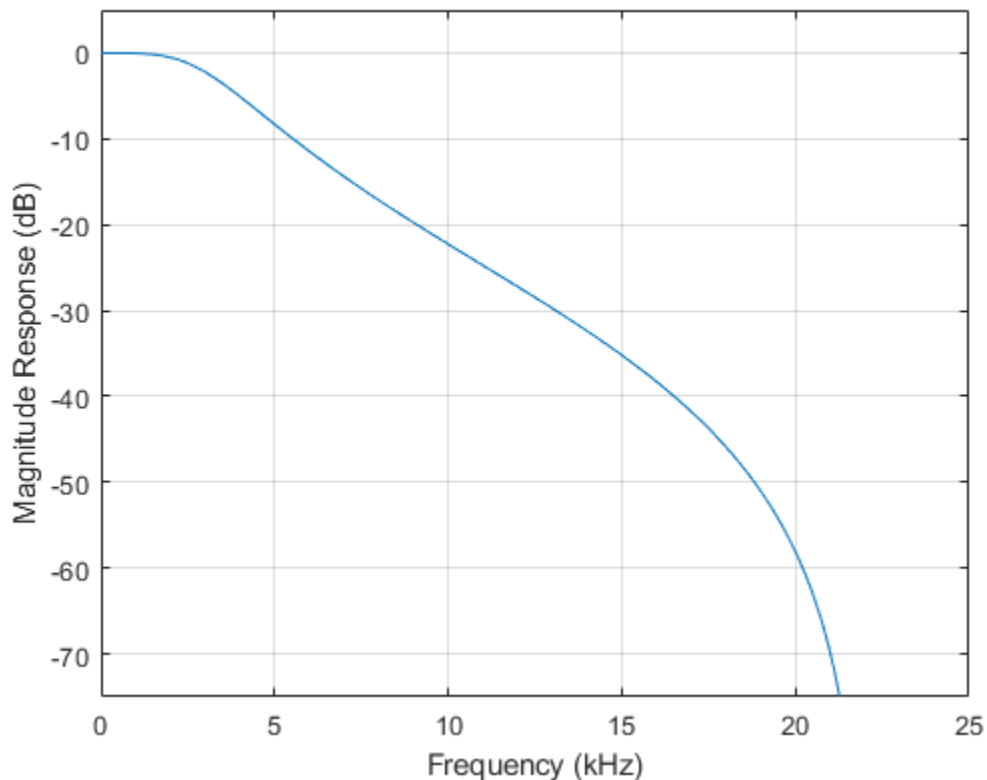
Visualize your filter design. To output filter coefficients suitable for `freqz`, call `designVarSlopeFilter` again with the same design specifications but with `Orientation` set to "row".

```

[Bvisualize,Avisualize] = designVarSlopeFilter(slope,cutoff,Orientation="row");

[h,f] = freqz([Bvisualize Avisualize],[],sampleRate);
plot(f/1000,mag2db(abs(h)))
grid
ylim([-75 5])
xlabel("Frequency (kHz)")
ylabel("Magnitude Response (dB)")

```



Create a biquad filter:

```

myFilter = dsp.BiquadFilter( ...
    SOSMatrixSource="Input port", ...
    ScaleValuesInputPort=false);

```

Create a spectrum analyzer to visualize the original audio signal and the audio signal passed through your lowpass filter.

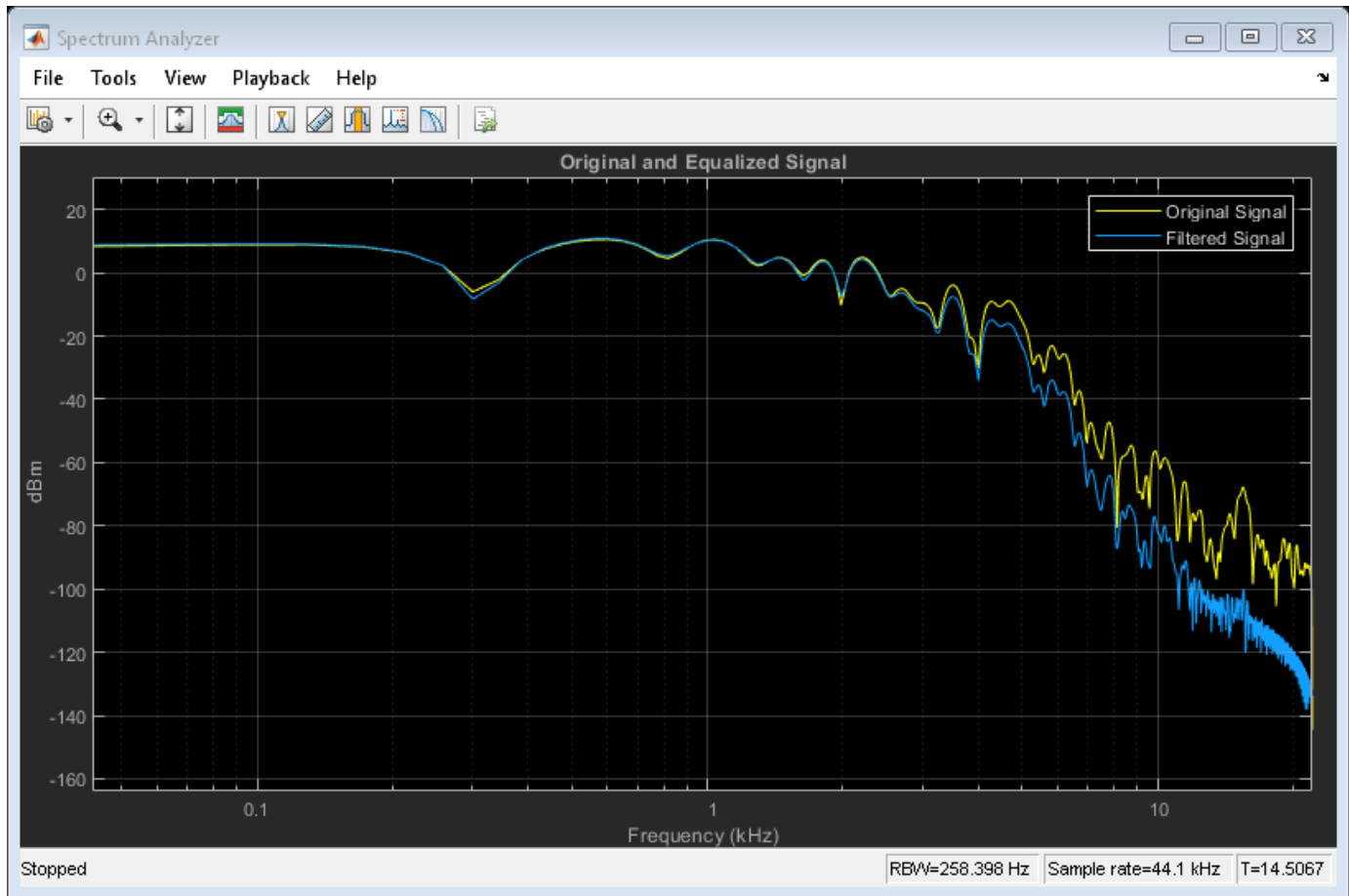
```
scope = dsp.SpectrumAnalyzer( ...  
    SampleRate=sampleRate, ...  
    PlotAsTwoSidedSpectrum=false, ...  
    FrequencyScale="Log", ...  
    FrequencyResolutionMethod="WindowLength", ...  
    WindowLength=frameSize, ...  
    Title="Original and Equalized Signal", ...  
    ShowLegend=true, ...  
    ChannelNames={'Original Signal','Filtered Signal'});
```

Play the filtered audio signal and visualize the original and filtered spectrums.

```
count = 0;  
while count < 2500  
    originalSignal = fileReader();  
    filteredSignal = myFilter(originalSignal,B,A);  
    scope([originalSignal(:,1),filteredSignal(:,1)]);  
    deviceWriter(filteredSignal);  
    count = count + 1;  
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)  
release(fileReader)  
release(scope)
```



Design Highpass IIR Filter

Design two second-order section (SOS) highpass IIR filters using `designVarSlopeFilter`.

Specify the sampling frequency in Hz, the slope in dB/octave, and the normalized cutoff frequency.

```
Fs = 48e3;
slope1 = 18;
slope2 = 36;
Fc = 4000/(Fs/2);
```

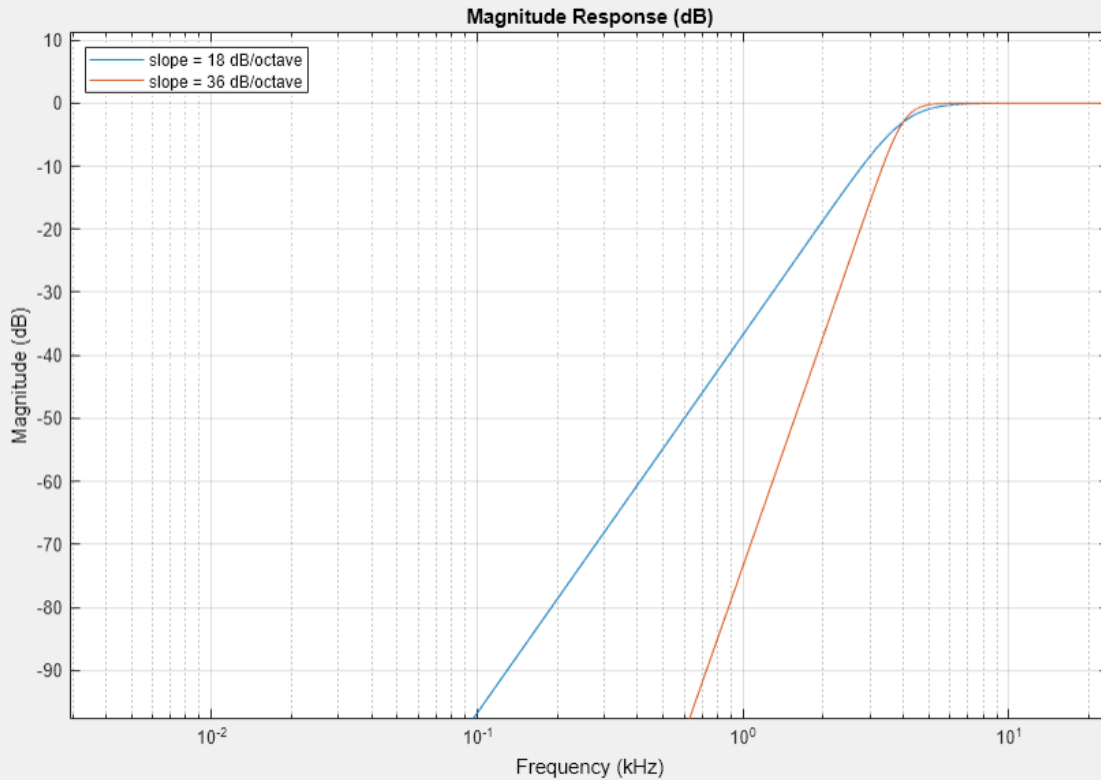
Design the filter coefficients using the specified parameters.

```
[B1,A1] = designVarSlopeFilter(slope1,Fc,"hi","Orientation","row");
[B2,A2] = designVarSlopeFilter(slope2,Fc,"hi","Orientation","row");
```

Visualize your filter design.

```
fvt = fvtool([B1,A1],[B2,A2],...
            "Fs",Fs,...
            "FrequencyScale","Log");
legend(fvt,"slope = 18 dB/octave", ...
```

```
"slope = 36 dB/octave", ...
"Location", "NorthWest")
```



Diminish Plosives from Speech Signal

Plosives are consonant sounds resulting from a sudden release of airflow. They are most pronounced in words beginning with *p*, *d*, and *g* sounds. Plosives can be emphasized by the recording process and are often displeasurable to hear. In this example, you minimize the plosives of a speech signal by applying highpass filtering and low-band compression.

Create a `dsp.AudioFileReader` object and a `audioDeviceWriter` object to read an audio signal from a file and write an audio signal to a device. Play the unprocessed signal. Then release the file reader and device writer.

```
fileReader = dsp.AudioFileReader('audioPlosives.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

while ~isDone(fileReader)
    audioIn = fileReader();
    deviceWriter(audioIn);
end
release(deviceWriter)
release(fileReader)
```


Design a highpass filter with a steep rolloff of all frequencies below 120 Hz. Use a `dsp.BiquadFilter` object to implement the highpass filter design. Create a crossover filter with one crossover at 250 Hz. The crossover filter enables you to separate the band of interest for processing. Create a dynamic range compressor to compress the dynamic range of plosive sounds. To apply no make-up gain, set the `MakeUpGainMode` to "Property" and use the default 0 dB `MakeUpGain` property value. Create a time scope to visualize the processed and unprocessed audio signal.

```
[B,A] = designVarSlopeFilter(48,120/(fileReader.SampleRate/2),"hi");
biquadFilter = dsp.BiquadFilter( ...
    "SOSMatrixSource","Input port", ...
    "ScaleValuesInputPort",false);

crossFilt = crossoverFilter( ...
    "SampleRate",fileReader.SampleRate, ...
    "NumCrossovers",1, ...
    "CrossoverFrequencies",250, ...
    "CrossoverSlopes",48);

dRCompressor = compressor( ...
    "Threshold",-35, ...
    "Ratio",10, ...
    "KneeWidth",20, ...
    "AttackTime",1e-4, ...
    "ReleaseTime",3e-1, ...
    "MakeUpGainMode","Property", ...
    "SampleRate",fileReader.SampleRate);

scope = timescope( ...
    "SampleRate",fileReader.SampleRate, ...
    "TimeSpanSource","property","TimeSpan",3, ...
    "BufferLength",fileReader.SampleRate*3*2, ...
    "YLimits",[-1 1], ...
    "ShowGrid",true, ...
    "ShowLegend",true, ...
    "ChannelNames",{ 'Original', 'Processed' });
```

In an audio stream loop:

- 1 Read in a frame of the audio file.
- 2 Apply highpass filtering using your biquad filter.
- 3 Split the audio signal into two bands.
- 4 Apply dynamic range compression to the lower band.
- 5 Remix the channels.
- 6 Write the processed audio signal to your audio device for listening.
- 7 Visualize the processed and unprocessed signals on a time scope.

As a best practice, release your objects once done.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioIn = biquadFilter(audioIn,B,A);
    [band1,band2] = crossFilt(audioIn);
    band1compressed = dRCompressor(band1);
    audioOut = band1compressed + band2;
```

```

    deviceWriter(audioOut);
    scope([audioIn audioOut])
end

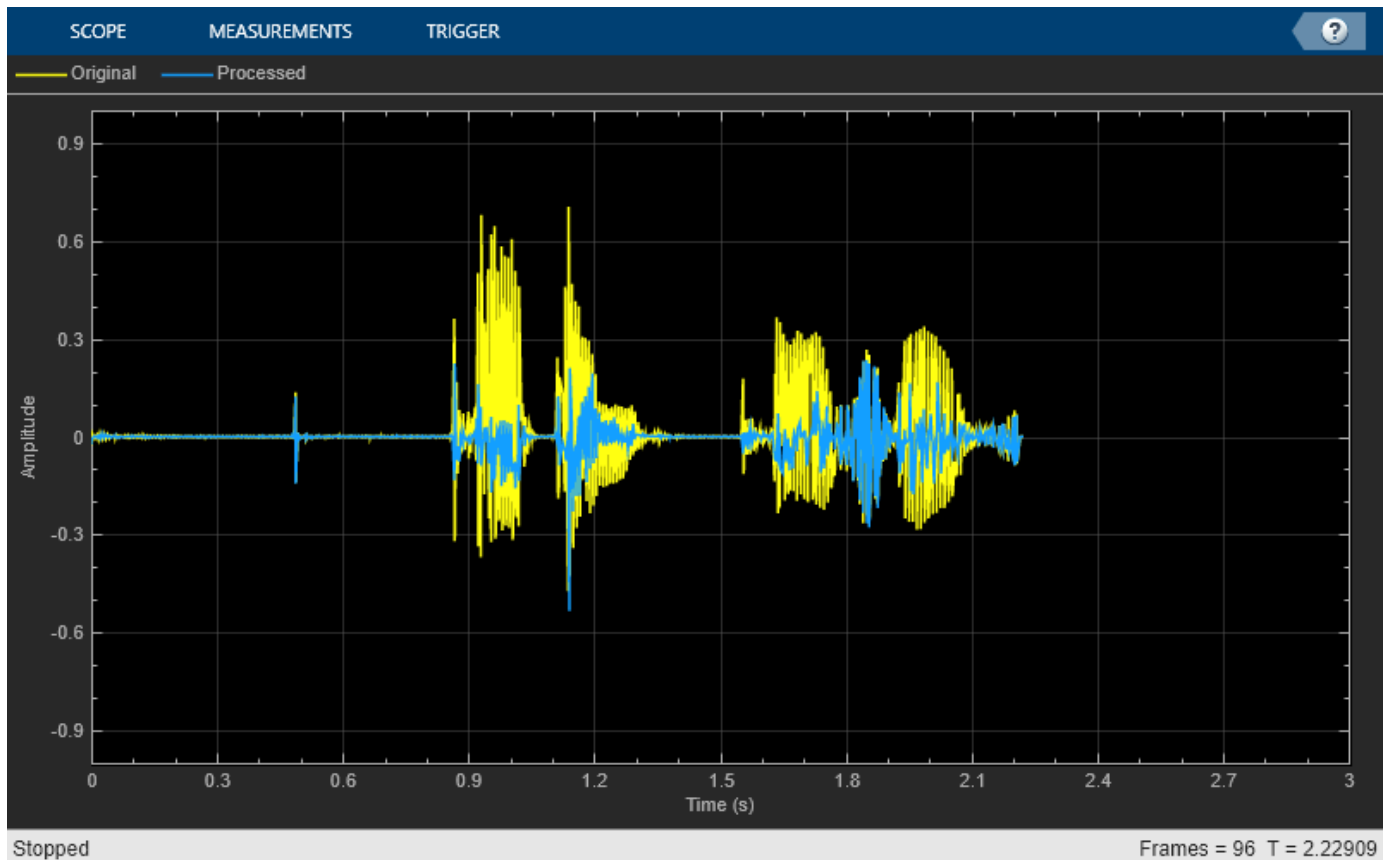
```

As a best practice, release your objects once done.

```

release(deviceWriter)
release(fileReader)
release(crossFilt)
release(dRCompressor)
release(scope)

```



Input Arguments

slope — Filter slope (dB/octave)

real scalar in the range [0:6:48]

Filter slope in dB/octave, specified as a real scalar in the range [0:6:48]. Values that are not multiples of 6 are rounded.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Fc — Normalized cutoff frequency

real scalar in the range 0 to 1

Normalized cutoff frequency, specified as a real scalar in the range 0 to 1, where 1 corresponds to the Nyquist frequency (π rad/sample).

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

type — Filter type

'lo' (default) | 'hi'

Filter type, specified as 'lo' or 'hi'.

- 'lo' -- Lowpass filter
- 'hi' -- Highpass filter

Data Types: `char` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'Orientation', "row"

Orientation — Orientation of returned filter coefficients

"column" (default) | "row"

Orientation of returned filter coefficients, specified as the comma-separated pair consisting of 'Orientation' and "column" or "row":

- Set 'Orientation' to "row" for interoperability with **FVTool**, `dsp.DynamicFilterVisualizer`, and `dsp.FourthOrderSectionFilter`.
- Set 'Orientation' to "column" for interoperability with `dsp.BiquadFilter`.

Data Types: `char` | `string`

Output Arguments

B — Numerator filter coefficients

3-by-4 matrix | 4-by-3 matrix

Numerator filter coefficients, returned as a matrix. The size and interpretation of `B` depends on the `Orientation`:

- If 'Orientation' is set to "column", then `B` is returned as a 3-by-4 matrix. Each column of `B` corresponds to the numerator coefficients of a different second-order section of your cascaded IIR filter.
- If 'Orientation' is set to "row", then `B` is returned as a 4-by-3 matrix. Each row of `B` corresponds to the numerator coefficients of a different second-order section of your cascaded IIR filter.

A — Denominator filter coefficients

2-by-4 matrix | 4-by-3 matrix

Denominator filter coefficients, returned as a matrix. The size and interpretation of A depends on the **Orientation**:

- If '**Orientation**' is set to "column", then A is returned as a 2-by-4 matrix. Each column of A corresponds to the denominator coefficients of a different second-order section of your cascaded IIR filter. A does not include the leading unity coefficient for each section.
- If '**Orientation**' is set to "row", then B is returned as a 4-by-3 matrix. Each row of B corresponds to the denominator coefficients of a different second-order section of your cascaded IIR filter.

References

[1] Orfanidis, Sophocles J. "High-Order Digital Parametric Equalizer Design." *Journal of the Audio Engineering Society*. Vol. 53, November 2005, pp. 1026-1046.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

[designShelvingEQ](#) | [designParamEQ](#) | [multibandParametricEQ](#)

Topics

"Parametric Equalizer Design"
"Equalization"

Introduced in R2016a

disconnectMIDI

Disconnect MIDI controls from audio object

Syntax

```
disconnectMIDI(audioObject)
```

Description

`disconnectMIDI(audioObject)` disconnects MIDI controls from your audio object, `audioObject`. Only those MIDI connections established using `configureMIDI` are disconnected.

Examples

Disconnect MIDI Controls from Audio Plugin

Create an object of the audio plugin example `audiopluginexample.Echo`.

```
echoPlugin = audiopluginexample.Echo;
```

Get the MIDI connections of `echoPlugin` and verify that it has no MIDI connections.

```
myMIDIConnections = getMIDIConnections(echoPlugin);
isempty(myMIDIConnections)
```

```
ans =
```

```
    1
```

Add MIDI connections using `configureMIDI`.

```
configureMIDI(echoPlugin, 'Delay1');
```

Get the MIDI connections of `echoPlugin` using `getMIDIConnections`. The MIDI connections you configured are saved as a structure. View details of the MIDI connections using dot notation.

```
myMIDIConnections = getMIDIConnections(echoPlugin);
myMIDIConnections.Delay1
```

```
ans =
```

```
    Law: 'lin'
    Min: 0
    Max: 1
MIDIControl: 'any control on 'BCF2000''
```

Use `disconnectMIDI` to remove MIDI connections between your `echoPlugin` object and your MIDI device.

```
disconnectMIDI(echoPlugin);
```

Get MIDI connections of `echoPlugin` and verify that you have successfully disconnected MIDI controls from your plugin.

```
myMIDIConnections = getMIDIConnections(echoPlugin);  
isempty(myMIDIConnections)
```

```
ans =
```

```
1
```

Input Arguments

audioObject – Audio object

object

Audio plugin or compatible System object, specified as an object that inherits from the `audioPlugin` class or an object of a compatible Audio Toolbox System object.

See Also

Classes

`audioPlugin` | `audioPluginSource`

Functions

`configureMIDI` | `getMIDIConnections` | `midicontrols` | `midiread` | `midiid` | `midisync` | `midicallback`

Topics

“MIDI Control for Audio Plugins”

“MIDI Control Surface Interface”

Introduced in R2016a

fdesign.parmeq

(To be removed) Parametric equalizer filter specification

Compatibility

Note The `fdesign.parmeq` filter specification object will be removed in a future release. Existing instances of the object continue to run. For new code, use the `designParamEQ` function instead. For more information, see “Compatibility Considerations” on page 2-555.

Syntax

```
d = fdesign.parmeq(spec, specvalue1, specvalue2, ...)
d = fdesign.parmeq(... fs)
```

Description

`d = fdesign.parmeq(spec, specvalue1, specvalue2, ...)` constructs a parametric equalizer filter design object, where `spec` is a non-case sensitive character vector. The choices for `spec` are as follows:

- 'F0, BW, BWp, Gref, G0, GBW, Gp' (minimum order default)
- 'F0, BW, BWst, Gref, G0, GBW, Gst'
- 'F0, BW, BWp, Gref, G0, GBW, Gp, Gst'
- 'N, F0, BW, Gref, G0, GBW'
- 'N, F0, BW, Gref, G0, GBW, Gp'
- 'N, F0, Fc, Qa, G0'
- 'N, F0, Fc, S, G0'
- 'N, F0, BW, Gref, G0, GBW, Gst'
- 'N, F0, BW, Gref, G0, GBW, Gp, Gst'
- 'N, Flow, Fhigh, Gref, G0, GBW'
- 'N, Flow, Fhigh, Gref, G0, GBW, Gp'
- 'N, Flow, Fhigh, Gref, G0, GBW, Gst'
- 'N, Flow, Fhigh, Gref, G0, GBW, Gp, Gst'

where the parameters are defined as follows:

Parameter	Definition	Unit
BW	Bandwidth	
BWp	Passband Bandwidth	
BWst	Stopband Bandwidth	

Parameter	Definition	Unit
Gref	Reference Gain	decibels
G0	Center Frequency Gain	decibels
GBW	Gain at which Bandwidth (BW) is measured	decibels
Gp	Passband Gain	decibels
Gst	Stopband Gain	decibels
N	Filter Order	
F0	Center Frequency	
Fc	Cutoff Frequency	
Fhigh	Higher Frequency at Gain GBW	
Flow	Lower Frequency at Gain GBW	
Qa	Quality Factor	
S	Slope Parameter for Shelving Filters	

Regardless of the specification chosen, there are some conditions that apply to the specification parameters. These are as follows:

- Specifications for parametric equalizers must be given in decibels
- To boost the input signal, set $G0 > Gref$; to cut, set $Gref > G0$
- For boost: $G0 > Gp > GBW > Gst > Gref$; For cut: $G0 < Gp < GBW < Gst < Gref$
- Bandwidth must satisfy: $BWst > BW > BWp$

`d = fdesign.paremeq(... fs)` adds the input sampling frequency. `fs` must be specified as a scalar trailing the other numerical values provided, and is assumed to be in Hz.

Examples

Design Parametric Equalizers

Design a Chebyshev Type II parametric equalizer filter that cuts by 12 dB.

```
parametricEQ = fdesign.paremeq('N,Flow,Fhigh,Gref,G0,GBW,Gst', ...
    4,0.3,0.5,0,-12,-10,-1);

parametricEQBiquad = design(parametricEQ,'cheby2','SystemObject',true);
fvtool(parametricEQBiquad)
```

Design a 4th-order lowpass shelving filter with a normalized cutoff frequency of 0.25, a quality factor of 10, and an 8 dB boost gain.

```
parametricEQ = fdesign.paremeq('N,F0,Fc,Qa,G0',4,0,0.25,10,8);
parametricEQBiquad = design(parametricEQ,'SystemObject',true);
fvtool(parametricEQBiquad)
```

Design 4th-order highpass shelving filters with slopes of 1.5 and 3.


```
N = 4; % Filter order
F0 = 1; % Center Frequency (normalized)
Fc = 0.4; % Cutoff Frequency (normalized)
G0 = 10; % Center Frequency Gain (dB)

S1 = 1.5; % Slope for filter design 1
S2 = 3; % Slope for filter design 2

filter = fdesign.parmeq('N,F0,Fc,S,G0',N,F0,Fc,S1,G0);
filterDesignS1 = design(filter,'SystemObject',true);

filter.S = S2;
filterDesignS2 = design(filter,'SystemObject',true);

filterVisualization = fvtool(filterDesignS1,filterDesignS2);
legend(filterVisualization,'Slope = 1.5','Slope = 3');
```

Compatibility Considerations

fdesign.parmeq will be removed

Warns starting in R2022a

The `fdesign.parmeq` filter specification object will be removed in a future release. Existing instances of the object continue to run. For new code, use the `designParamEQ` function instead.

Update Code

This table shows how the object is typically used and explains how to update the existing code to use the `designParamEQ` function.

Discouraged Usage	Recommended Replacement
<p>Design based on Filter Bandwidth</p> <pre> Fs = 48e3; N = 2; Q = 10; G = 9; % 9 dB % Normalized center frequency Wo1 = 2000/(Fs/2); Wo2 = 12000/(Fs/2); % Normalized bandwidth BW1 = Wo1/Q; BW2 = Wo2/Q; PEQ = fdesign.paremeq('N,F0,BW,Gref,G0,GBW',N,F0,BW,Gref,G0,GBW); BQ1 = design(PEQ,'SystemObject',true); PEQ.BW = BW2; PEQ.F0 = Wo2; BQ2 = design(PEQ,'SystemObject',true); % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'BW1 = 200 Hz; Q = 10','BW2 = 1200 Hz; Q = 10');</pre>	<p>Design based on Filter Bandwidth</p> <pre> Fs = 48e3; N = 2; Q = 10; G = 9; % 9 dB % Normalized center frequency Wo1 = 2000/(Fs/2); Wo2 = 12000/(Fs/2); % Normalized bandwidth BW1 = Wo1/Q; BW2 = Wo2/Q; [B1,A1] = designParamEQ(N,G,Wo1,BW1); [B2,A2] = designParamEQ(N,G,Wo2,BW2); BQ1 = dsp.BiquadFilter('SOSMatrix',[B1.',[1,A1.]]); BQ2 = dsp.BiquadFilter('SOSMatrix',[B2.',[1,A2.]]); % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'BW1 = 200 Hz; Q = 10','BW2 = 1200 Hz; Q = 10');</pre>
<p>Design based on Quality factor</p> <pre> Fs = 48e3; N = 2; G = 15; % 15 dB % Quality factor Q1 = 0.48; Q2 = 1/sqrt(2); % Normalized center frequency % F0 = 1 designs a highpass filter % F0 can either be 0 or 1 in this configuration F0 = 1; % Cutoff Frequency Fc = 6e3/(Fs/2); PEQ = fdesign.paremeq('N,F0,Fc,Qa,G0',N,F0,Fc,Qa,G0); BQ1 = design(PEQ,'SystemObject',true); PEQ.Qa = Q2; BQ2 = design(PEQ,'SystemObject',true); % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'Q = 0.48','Q = 0.7071');</pre>	<p>Design based on Quality factor</p> <pre> Fs = 48e3; N = 2; G = 15; % 15 dB % Quality factor Q1 = 0.48; Q2 = 1/sqrt(2); % Normalized center frequency Wo = 6000/(Fs/2); % Normalized bandwidth BW1 = Wo/Q1; BW2 = Wo/Q2; [B1,A1] = designParamEQ(N,G,Wo,BW1); [B2,A2] = designParamEQ(N,G,Wo,BW2); BQ1 = dsp.BiquadFilter('SOSMatrix',[B1.',[1,A1.]]); BQ2 = dsp.BiquadFilter('SOSMatrix',[B2.',[1,A2.]]); % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'Q = 0.48','Q = 0.7071');</pre>

Discouraged Usage	Recommended Replacement
<p>Low shelf and high shelf filters</p> <pre> Fs = 48e3; N = 4; G = 10; % 10 dB % Normalized center frequency Wo1 = 0; % Lowpass filter % Corresponds to Fs/2 (Hz) or pi (rad/sample) Wo2 = 1; % Highpass filter % Bandwidth occurs at 7.4 dB in this case BW = 1000/(Fs/2); PEQ = fdesign.parmeq('N,F0,BW,Gref,G0,GBW',N,F0,BW,Gref,G0,GBW); BQ1 = design(PEQ,'SystemObject',true); PEQ.F0 = Wo2; BQ2 = design(PEQ,'SystemObject',true); % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'Low Shelf Filter','High Shelf Filter');</pre>	<p>Low shelf and high shelf filters</p> <pre> Fs = 48e3; N = 4; G = 10; % 10 dB % Normalized center frequency Wo1 = 0; % Lowpass filter % Corresponds to Fs/2 (Hz) or pi (rad/sample) Wo2 = 1; % Highpass filter % Bandwidth occurs at 7.4 dB in this case BW = 1000/(Fs/2); [B1,A1] = designParamEQ(N,G,Wo1,BW); [B2,A2] = designParamEQ(N,G,Wo2,BW); BQ1 = dsp.BiquadFilter('SOSMatrix',[B1.',[ones(2,1),A1.]]; BQ2 = dsp.BiquadFilter('SOSMatrix',[B2.',[ones(2,1),A2.]]; % Visualize the filters hfvt = fvtool(BQ1,BQ2,'Fs',Fs,'Color','white'); legend(hfvt,'Low Shelf Filter','High Shelf Filter');</pre>

See Also

fdesign | designShelvingEQ | designParamEQ | designVarSlopeFilter | multibandParametricEQ

Topics

“Parametric Equalizer Design”
“Equalization”

generateAudioPlugin

Generate audio plugin from MATLAB class

Syntax

```
generateAudioPlugin className  
generateAudioPlugin options className
```

Description

`generateAudioPlugin className` generates a VST 2 audio plugin from a MATLAB class specified by `className`. See Supported Compilers for a list of compilers supported by `generateAudioPlugin`.

`generateAudioPlugin options className` specifies a nondefault plugin type, output folder, file name, or file type. You can use the `-juceproject` option to create a zip file containing generated C/C++ code and a JUCER project. Options can be specified in any grouping, and in any order.

Examples

Generate Audio Plugin

```
generateAudioPlugin audiopluginexample.Echo
```

.....

A VST 2 plugin with file name `Echo` is saved to your current folder. The extension of your plugin depends on your operating system.

Specify Output Folder for Generated Plugin

```
mkdir(fullfile(pwd,'myPluginFolder'))  
generateAudioPlugin -outdir myPluginFolder audiopluginexample.Echo
```

.....

A VST 2 plugin with file name `Echo` is saved to your specified folder, `myPluginFolder`. The extension of your plugin depends on your operating system.

Specify File Name of Generated Plugin

```
generateAudioPlugin -output awesomeEffect audiopluginexample.Echo
```

.....

A VST 2 plugin with file name `awesomeEffect` is saved to your current folder. The extension of your plugin depends on your operating system.

Specify Output Folder and File Name of Generated Plugin

```
mkdir(fullfile(pwd, 'myPluginFolder'))
generateAudioPlugin -output coolEffect -outdir myPluginFolder audiopluginexample.Echo
.....
```

A VST 2 plugin with file name coolEffect is saved to your specified folder, myPluginFolder. The extension of your plugin depends on your operating system.

Generate win32 Plugin from win64 System

```
generateAudioPlugin -win32 audiopluginexample.Echo
.....
```

A 32-bit VST 2 plugin with file name Echo.dll is saved to your current folder.

Generate JUCE-Compatible Zip File

```
generateAudioPlugin -juceproject audiopluginexample.Echo
```

A zip file containing generated C/C++ code and a JUCER project file suitable for use with JUCE 5.3.2 to 6.0.8 is saved to your current folder.

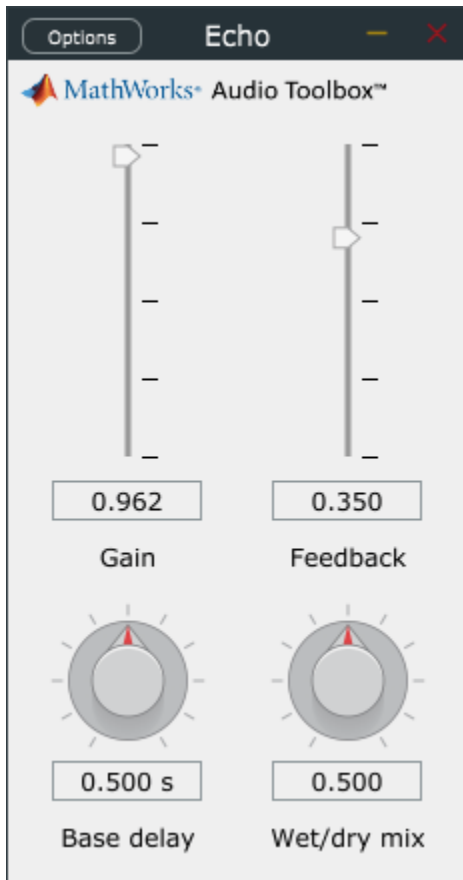
Generate Standalone Executable

To generate a binary standalone executable, use the -exe option. The following command saves Echo.exe to your current folder.

```
generateAudioPlugin -exe audiopluginexample.Echo
.....
```

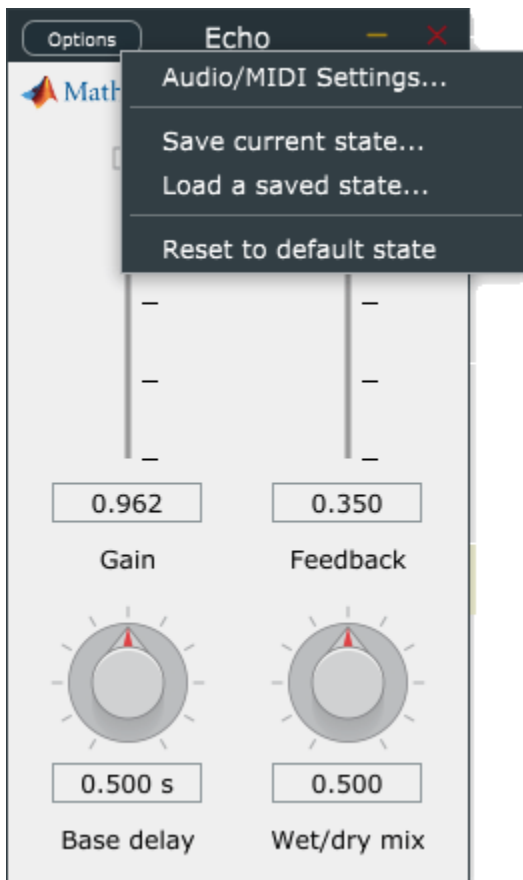
When you execute the generated code, the UI you defined in your audio plugin opens.

```
eval('!Echo.exe')
```



The standalone executable enables you to:

- Configure audio input and output from the plugin. Synchronizing parameters with MIDI devices is not currently supported.
- Save and load states.
- Reset states to default values.



Input Arguments

options — Options to specify output folder, plugin name, and file type

```
-au | -vst | -vst3 | -exe | -juceproject | -output fileName | -outdir folder | -win32 | -mac64universal | -audioconfig cfg
```

Options can be specified in any grouping, and in any order.

Option	Description
-au	Generates an Audio Unit (AU) v2 audio plugin binary. This syntax is valid only on macOS.
-vst	Generates a VST 2 audio plugin binary. By default, generateAudioPlugin generates a VST 2 plugin.
-vst3	Generates a VST 3 audio plugin binary. This option adds a Bypass parameter to the plugin.
-exe	Generates a standalone executable for your audio plugin. When you evaluate the generated code, the UI you defined in your audio plugin opens. You can control the input to your plugin and the output from your plugin using Options .

Option	Description
-juceproject	Creates a zip file containing generated C/C++ code and a JUCER project file suitable for use with JUCE 5.3.2 to 6.0.8. You can use the generated zip file to modify the generated plugin or compile it to a format other than VST 2.4. This option requires a MATLAB Coder™ license. To use the generated files with JUCE, you must obtain your own appropriately licensed copy of JUCE.
-output <i>fileName</i>	Specifies the file name of the generated plugin or zip file. The appropriate extension is appended to the <i>fileName</i> based on the platform on which the plugin or zip file is generated. By default, the plugin or zip file is named after the class.
-outdir <i>folder</i>	Generates a plugin or zip file to a specific folder. By default, the generated plugin is placed in the current folder. If <i>folder</i> is not in the current folder, specify the exact path.
-win32	Creates a 32-bit audio plugin. Valid only on win64 Windows platforms. This option does not support the <code>coder.DeepLearningConfig('mklDnn')</code> deep learning library configuration, the 'Intel AVX (Windows)' code replacement library, or the 'DSP Intel AVX2-FMA (Windows)' code replacement library.
-mac64universal	Creates a Mac audio plugin for use on Intel® and Apple Silicon. This option works only on Macintosh platforms. This option does not support the <code>coder.DeepLearningConfig('mklDnn')</code> deep learning library configuration or any code replacement libraries.
-audioconfig <i>cfg</i>	Generates a plugin that uses a deep learning network or a code replacement library. See <code>audioPluginConfig</code> for more details.

Only the -juceproject option is supported in MATLAB Online.

className — Name of plugin class to generate

plugin class

Name of the plugin class to generate. The plugin class must be on the MATLAB path. It must derive from either the `audioPlugin` class or the `audioPluginSource` class.

You can specify the plugin class to generate by specifying its class name or file name. For example, the following syntaxes perform equivalent operations:

- `generateAudioPlugin myPlugin`
- `generateAudioPlugin myPlugin.m`

If you want to specify the plugin class by file name, and your plugin class is inside a package, you must specify the package as a file path. For example, the following syntaxes perform equivalent operations:

- `generateAudioPlugin myPluginPackage.myPlugin`
- `generateAudioPlugin +myPluginPackage/myPlugin.m`

Limitations

Build problems can occur when using folder names with spaces. For more information, see “Build Process Support for Folder Names” (Simulink Coder) and Why is the build process failing for a shipped model in Simulink or for a model run in Accelerator mode?.

More About

Generated VST Plugin File Extension

The extension of your generated VST plugin depends on your operating system.

Operating System	File Extension
Windows	.dll
macOS	.vst

See Also

[parameterTuner](#) | [Audio Test Bench](#) | [validateAudioPlugin](#) | [loadAudioPlugin](#) | [audioPlugin](#) | [audioPluginSource](#) | [audioPluginConfig](#)

Topics

“Audio Plugins in MATLAB”

“Export a MATLAB Plugin to a DAW”

Introduced in R2016a

integratedLoudness

Measure integrated loudness and loudness range

Syntax

```
loudness = integratedLoudness(audioIn,Fs)
loudness = integratedLoudness(audioIn,Fs,channelWeights)
[loudness,loudnessRange] = integratedLoudness( ___ )
```

Description

`loudness = integratedLoudness(audioIn,Fs)` returns the integrated loudness of an audio signal, `audioIn`, with sample rate `Fs`. The ITU-R BS.1770-4 and EBU R 128 standards define the algorithms to calculate integrated loudness.

`loudness = integratedLoudness(audioIn,Fs,channelWeights)` specifies the channel weights used to compute the integrated loudness. `channelWeights` must be a row vector with the same number of elements as the number of channels in `audioIn`.

`[loudness,loudnessRange] = integratedLoudness(___)` returns the loudness range of the audio signal using either of the previous syntaxes. The EBU R 128 Tech 3342 standard defines the loudness range computation.

Examples

Determine Integrated Loudness

Determine the integrated loudness of an audio signal.

Create a two-second sine wave with a 0 dB amplitude, a 1 kHz frequency, and a 48 kHz sample rate.

```
sampleRate = 48e3;
increment = sampleRate*2;
amplitude = 10^(0/20);
frequency = 1e3;

sineGenerator = audioOscillator( ...
    'SampleRate',sampleRate, ...
    'SamplesPerFrame',increment, ...
    'Amplitude',amplitude, ...
    'Frequency',frequency);

signal = sineGenerator();
```

Calculate the integrated loudness of the audio signal at the specified sample rate.

```
loudness = integratedLoudness(signal,sampleRate)

loudness = -3.0036
```

Specify Nondefault Channel Weights

Read in a four-channel audio signal. Specify a nondefault weighting vector with four elements.

```
[signal,fs] = audioread('AudioArray-16-16-4channels-20secs.wav');
weightingVector = [1,0.8,0.8,1.2];
```

Calculate the integrated loudness with the default channel weighting and the nondefault channel weighting vector.

```
standardLoudness = integratedLoudness(signal,fs,weightingVector)
standardLoudness = -11.6825
nonStandardLoudness = integratedLoudness(signal,fs)
nonStandardLoudness = -11.0121
```

Determine Loudness Range

Read in an audio signal. Clip 3 five-second intervals out of the signal.

```
[x,fs] = audioread('FunkyDrums-44p1-stereo-25secs.mp3');
x1 = x(1:fs*5,:);
x2 = x(5e5:5e5+5*fs,:);
x3 = x(end-5*fs:end,:);
```

Calculate the loudness and loudness range of the total signal and of each interval.

```
[L,LRA] = integratedLoudness(x,fs);
[L1,LRA1] = integratedLoudness(x1,fs);
[L2,LRA2] = integratedLoudness(x2,fs);
[L3,LRA3] = integratedLoudness(x3,fs);

fprintf(['Loudness: %0.2f\n', ...
        'Loudness range: %0.2f\n\n', ...
        'Beginning loudness: %0.2f\n', ...
        'Beginning loudness range: %0.2f\n\n', ...
        'Middle loudness: %0.2f\n', ...
        'Middle loudness range: %0.2f\n\n', ...
        'End loudness: %0.2f\n', ...
        'End loudness range: %0.2f\n'], ...
        L,LRA,L1,LRA1,L2,LRA2,L3,LRA3);
```

```
Loudness: -22.98
Loudness range: 1.50
```

```
Beginning loudness: -23.38
Beginning loudness range: 1.18
```

```
Middle loudness: -22.97
Middle loudness range: 1.14
```

```
End loudness: -22.10
End loudness range: 1.82
```

Input Arguments

audioIn — Input signal

matrix

Input signal, specified as a matrix. The columns of the matrix are treated as audio channels.

The maximum number of columns of the input signal depends on your `channelWeights` specification:

- If you use the default `channelWeights`, the input signal has a maximum of five channels. Specify the channels in this order: [Left, Right, Center, Left surround, Right surround].
- If you specify nondefault `channelWeights`, the input signal must have the same number of columns as the number of elements in the `channelWeights` vector.

Data Types: `single` | `double`

Fs — Sample rate (Hz)

positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

channelWeights — Linear weighting applied to each input channel

[1.0, 1.0, 1.0, 1.41, 1.41] (default) | nonnegative row vector

Linear weighting applied to each input channel, specified as a row vector of nonnegative values. The number of elements in the row vector must be equal to or greater than the number of input channels. Excess values in the vector are ignored.

The default channel weights follow the ITU-R BS.1170-4 standard. To use the default channel weights, specify the channels of the `audioIn` matrix in this order: [Left, Right, Center, Left surround, Right surround].

It is a best practice to specify the `channelWeights` vector in order: [Left, Right, Center, Left surround, Right surround].

Data Types: `single` | `double`

Output Arguments

Loudness — Integrated loudness (LUFS)

scalar

Integrated loudness in loudness units relative to full scale (LUFS), returned as a scalar.

The ITU-R BS.1770-4 and EBU R 128 standards define the integrated loudness. The algorithm computes the loudness by breaking down the audio signal into 0.4-second segments with 75% overlap. If the input signal is less than 0.4 seconds, `Loudness` is returned empty.

Data Types: `single` | `double`

LoudnessRange — Loudness range (LU)

scalar

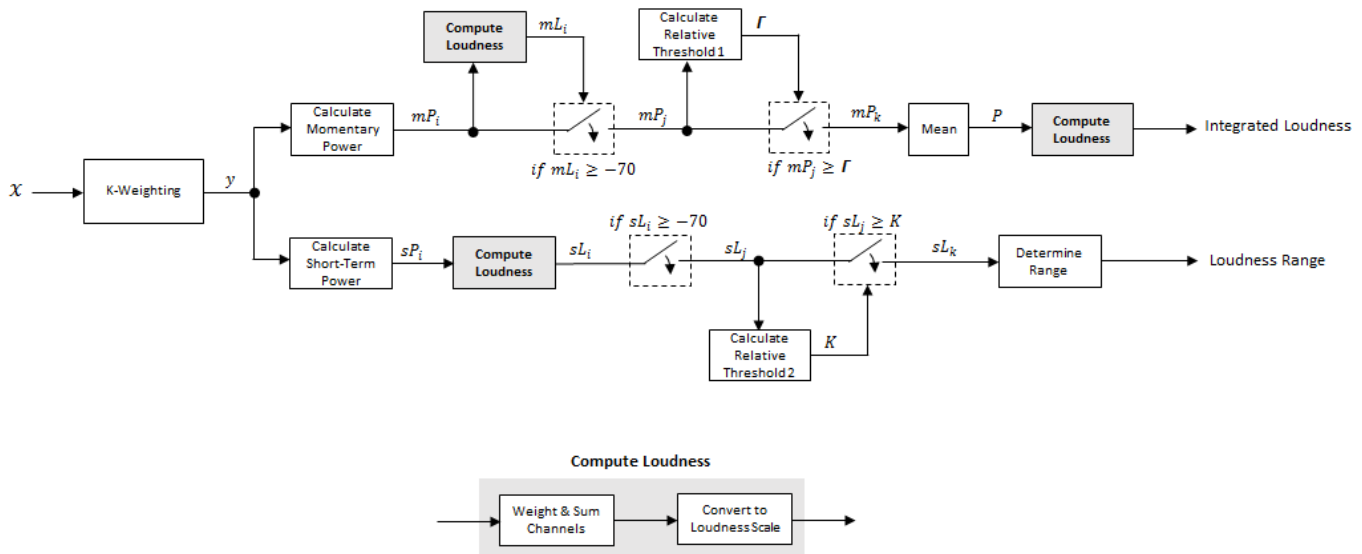
Loudness range in loudness units (LU), returned as a scalar.

The EBU R 128 Tech 3342 standard defines the loudness range. The algorithm computes the loudness range by breaking down the audio into 3-second segments with 2.9-second overlap. If the input signal is less than three seconds, LoudnessRange is returned empty.

Data Types: single | double

Algorithms

The `integratedLoudness` function returns the integrated loudness and loudness range (LRA) of an audio signal. You can specify any number of channels and nondefault channel weights used for loudness measurements. The `integratedLoudness` algorithm is described for the general case of n channels.



Integrated Loudness and Loudness Range

The input channels, x , pass through a K-weighted weighting filter. The K-weighted filter shapes the frequency spectrum to reflect perceived loudness.

Integrated Loudness

- 1 The K-weighted channels, y , are divided into 0.4-second segments with 0.3-second overlap. The power (mean square) of each segment of the K-weighted channels is calculated:

$$mP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- mP_i is the momentary power of the i th segment of a channel.
- w is the segment length in samples.

- 2 The momentary loudness, mL , is computed for each segment:

$$mL_i = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times mP_{(i,c)} \right) \quad LUFS$$

- G_c is the weighting for channel c .

- 3 The momentary power is gated using the momentary loudness calculation:

$$mP_i \rightarrow mP_j$$

$$j = \{ i \mid mL_i \geq -70 \}$$

- 4 The relative threshold, Γ , is computed:

$$\Gamma = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times l_c \right) - 10$$

l_c is the mean momentary power of channel c :

$$l_c = \frac{1}{|j|} \sum_j mP_{(j,c)}$$

- 5 The momentary power subset, mP_j , is gated using the relative threshold:

$$mP_j \rightarrow mP_k$$

$$k = \{ j \mid mP_j \geq \Gamma \}$$

- 6 The momentary power segments are averaged:

$$P = \frac{1}{|k|} \sum_k mP_k$$

- 7 The integrated loudness is computed by passing the mean momentary power subset, P , through the Compute Loudness system:

$$\text{Integrated Loudness} = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times P_c \right) \quad LUFS$$

Loudness Range

- 1 The K -weighted channels, y , are divided into 3-second segments with 2.9-second overlap. The power (mean square) of each segment of the K -weighted channels is calculated:

$$sP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- sP_i is the short-term power of the i th segment of a channel.
- w is the segment length in samples.

- 2 The short-term loudness, sL , is computed for each segment:

$$sL_i = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times sP_{(i,c)} \right)$$

- G_c is the weighting for channel c .

- 3 The short-term loudness is gated using an absolute threshold:

$$sL_i \rightarrow sL_j$$

$$j = \{ i \mid sL_i \geq -70 \}$$

- 4 The gated short-term loudness is converted back to linear, and then the mean is taken:

$$sP_j = \frac{1}{|j|} \sum_j 10^{(sL_j/10)}$$

The relative threshold, K , is computed:

$$K = -20 + 10 \log_{10}(sP_j)$$

- 5 The short-term loudness subset, sL_j , is gated using the relative threshold:

$$sL_j \rightarrow sL_k$$

$$k = \{ j \mid sL_j \geq K \}$$

- 6 The short-term loudness subset, sL_k , is sorted. The loudness range is calculated as between the 10th and 95th percentiles of the distribution, and is returned in loudness units (LU).

References

- [1] International Telecommunication Union; Radiocommunication Sector. *Algorithms to Measure Audio Programme Loudness and True-Peak Audio Level*. ITU-R BS.1770-4. 2015.
- [2] European Broadcasting Union. *Loudness Normalisation and Permitted Maximum Level of Audio Signals*. EBU R 128. 2014.
- [3] European Broadcasting Union. *Loudness Metering: 'EBU Mode' Metering to Supplement EBU R 128 Loudness Normalization*. EBU R 128 Tech 3341. 2014.
- [4] European Broadcasting Union. *Loudness Range: A Measure to Supplement EBU R 128 Loudness Normalization*. EBU R 128 Tech 3342. 2016.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

loudnessMeter | weightingFilter | Loudness Meter

Introduced in R2016b

getMIDIConnections

Get MIDI connections of audio object

Syntax

```
connectionInfo = getMIDIConnections(audioObject)
```

Description

`connectionInfo = getMIDIConnections(audioObject)` returns a structure, `connectionInfo`, containing information about the MIDI connections for your audio object, `audioObject`. Only those MIDI connections established using `configureMIDI` are returned.

The `connectionInfo` structure contains a substructure for each tunable property of `audioObject` that has established MIDI connections. Each substructure contains the control number, the device name of the corresponding MIDI control, and the property mapping information (mapping rule, minimum value, and maximum value).

Examples

Get MIDI Connections of Plugin

Create an object of the audio plugin example `audiopluginexample.Echo`.

```
echoEffect = audiopluginexample.Echo;
```

Use `configureMIDI` to synchronize `echoEffect` properties with specific MIDI controls on the default MIDI device.

```
configureMIDI(echoEffect, 'Delay1', 1001);  
configureMIDI(echoEffect, 'Gain1', 1002);  
configureMIDI(echoEffect, 'Delay2', 1003);  
configureMIDI(echoEffect, 'Gain2', 1004);
```

Use `getMIDIConnections` to view the MIDI connections you established.

```
connectionInfo = getMIDIConnections(echoEffect)
```

```
connectionInfo =
```

```
    Delay1: [1x1 struct]  
    Gain1: [1x1 struct]  
    Delay2: [1x1 struct]  
    Gain2: [1x1 struct]
```

View details of the `Delay1` MIDI connection using dot notation.

```
connectionInfo.Delay1
```

```
ans =
```



```
    Law: 'lin'  
    Min: 0  
    Max: 1  
MIDIControl: 'control 1001 on 'nanoKONTROL2''
```

Input Arguments

audioObject — Audio object
object

Audio plugin or compatible System object, specified as an object that inherits from the `audioPlugin` class or an object of a compatible Audio Toolbox System object.

Output Arguments

connectionInfo — Information about MIDI connection
structure

Information about MIDI connection between the specified audio plugin object and MIDI devices, returned as a structure. Only those MIDI connections established using `configureMIDI` are returned. The `connectionInfo` structure contains a substructure for each established MIDI connection. Each substructure contains the control number, the device name of the corresponding MIDI control, and the property mapping information (mapping rule, minimum value, and maximum value).

See Also

Classes

`audioPlugin` | `audioPluginSource`

Functions

`disconnectMIDI` | `configureMIDI` | `midicontrols` | `midiread` | `midiid` | `midisync` | `midicallback`

Topics

“MIDI Control for Audio Plugins”

“MIDI Control Surface Interface”

Introduced in R2016a

loadAudioPlugin

Load VST, VST 3, and AU plugins into MATLAB environment

Syntax

```
hostedPlugin = loadAudioPlugin(pluginpath)
```

Description

`hostedPlugin = loadAudioPlugin(pluginpath)` loads the 64-bit VST, VST 3, or AU audio plugin specified by `pluginpath`. On Windows, you can load VST and VST 3 plugins. On macOS, you can load AU, VST, and VST 3 plugins.

Your hosted plugin has two display modes: `Parameters` and `Properties`. The default display mode is `Properties`.

- `Parameters` -- Interact with normalized parameter values of the hosted plugin using `set` and `get` functions.
- `Properties` -- Interact with heuristically interpreted parameters with real-world values. You can use standard dot notation to set and get the values while using this mode.

You can specify the display mode of the hosted plugin using standard dot notation, for example:

```
hostedPlugin.DisplayMode = 'Parameters';
```

See “Host External Audio Plugins” for a discussion of display modes and a walkthrough of both modes of interaction.

You can interact with and exercise the hosted plugin using the following functions.

Process Audio

- `audioOut = process(hostedPlugin, audioIn)`

Returns an audio signal processed according to the algorithm and parameters of the hosted plugin. For source plugins, call `process` without an audio input.

Set and Get Normalized Parameter Values

- `value = getParameter(hostedPlugin, parameter)`

Returns the normalized value of the specified hosted plugin parameter. Normalized values are in the range `[0,1]`. You can specify a parameter by its name or by its index. To specify the name, use a character vector.

- `setParameter(hostedPlugin, parameter, newValue)`

Sets the normalized value of the specified hosted plugin parameter to `newValue`. Normalized values are in the range `[0,1]`.

Get High-Level Information About the Hosted Plugin

- `dispParameter(hostedPlugin)`
Displays all parameters and associated indices, values, displayed values, and display labels of the hosted plugin.
- `pluginInfo = info(hostedPlugin)`
Returns a structure containing information about the hosted plugin.

Set the Environment in Which the Plugin Is Run

- `frameSize = getSamplesPerFrame(hostedPlugin)`
Returns the frame size that the hosted plugin returns in subsequent calls to its processing function (source plugins only).
- `setSamplesPerFrame(hostedPlugin, frameSize)`
Sets the frame size that the hosted plugin must return in subsequent calls to its processing function (source plugins only).
- `setSampleRate(hostedPlugin, sampleRate)`
Sets the sample rate of the hosted plugin.
- `sampleRate = getSampleRate(hostedPlugin)`
Returns the sample rate in Hz at which the plugin is being run.

Examples

Host External Plugins in MATLAB

Use `loadAudioPlugin` to host a VST external plugin and a VST external source plugin in MATLAB®.

Use the `fullfile` command to determine the full path to the oscillator VST plugin and parametric equalizer VST plugin included with Audio Toolbox™. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
oscPluginPath = ...
    fullfile(matlabroot, 'toolbox/audio/samples/oscillator.dll');
EQPluginPath = ...
    fullfile(matlabroot, 'toolbox/audio/samples/ParametricEqualizer.dll');
```

Create external plugin objects by calling `loadAudioPlugin` for each of the plugin paths.

```
hostedSourcePlugin = loadAudioPlugin(oscPluginPath);
hostedPlugin = loadAudioPlugin(EQPluginPath);
```

Hosted plugins derive from either the `externalAudioPlugin` or `externalAudioSourcePlugin` class. Because `oscillator.dll` is a source audio plugin, the hosted object derives from `externalAudioSourcePlugin`. Use `class()` to verify the classes of the hosted plugins.

```
class(hostedPlugin)
```

```
ans =  
'externalAudioPlugin'  
  
class(hostedSourcePlugin)  
  
ans =  
'externalAudioPluginSource'
```

Call the hosted plugins to display basic information about them. This information includes the format, the plugin name, the number of channels in and out, and the tunable properties of the plugin. Source plugins also display the frame size of the plugin.

hostedSourcePlugin

```
hostedSourcePlugin =  
  VST plugin 'oscillator'  source, 1 out, 256 samples  
  
  Frequency: 100 Hz  
  Amplitude: 1 AU  
  DCOffset: 0 AU
```

hostedPlugin

```
hostedPlugin =  
  VST plugin 'ParametricEQ'  2 in, 2 out  
  
  LowPeakGain: 0 dB  
  LowCenterFrequency: 100 Hz  
  LowQFactor: 2  
  MediumPeakGain: 0 dB  
  MediumCenterFrequency: 1000 Hz  
  MediumQFactor: 2  
  HighPeakGain: 0 dB  
  HighCenterFrequency: 10000 Hz  
  HighQFactor: 2
```

Run External Plugin in MATLAB

Load a VST audio plugin into MATLAB™ by specifying its full path. If you are using a Mac, replace the .dll file extension with .vst.

```
pluginPath = fullfile(matlabroot,'toolbox','audio','samples','ParametricEqualizer.dll');  
hostedPlugin = loadAudioPlugin(pluginPath);
```

Create input and output objects for an audio stream loop that reads from a file and writes to your audio device. Set the sample rate of the hosted plugin to the sample rate of the input to the plugin.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');  
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);  
setSampleRate(hostedPlugin,fileReader.SampleRate);
```

Set the MediumPeakGain property to -20 dB.

```
hostedPlugin.MediumPeakGain = -20;
```

Use the hosted plugin to process the audio file in an audio stream loop. Sweep the medium peak gain upward in the loop to hear the effect.

```

while hostedPlugin.MediumPeakGain < 19
    hostedPlugin.MediumPeakGain = hostedPlugin.MediumPeakGain + 0.04;
    x = fileReader();
    y = process(hostedPlugin,x);
    deviceWriter(y);
end

release(fileReader)
release(deviceWriter)

```

Run External Source Plugin in MATLAB

Load a VST audio source plugin into MATLAB™ by specifying its full path. If you are using a Mac, replace the .dll file extension with .vst.

```

pluginPath = fullfile(matlabroot,'toolbox','audio','samples','oscillator.dll');
hostedSourcePlugin = loadAudioPlugin(pluginPath);

```

Set the Amplitude property to 0.5. Set the Frequency property to 16 kHz.

```

hostedSourcePlugin.Amplitude = 0.5;
hostedSourcePlugin.Frequency = 16000;

```

Set the sample rate at which to run the plugin. Create an output object to write to your audio device.

```

setSampleRate(hostedSourcePlugin,44100);
deviceWriter = audioDeviceWriter('SampleRate',44100);

```

Use the hosted source plugin to output an audio stream. The processing in the audio stream loop ramps the frequency parameter down and then up.

```

k = 1;
for i = 1:1000
    hostedSourcePlugin.Frequency = hostedSourcePlugin.Frequency - 30*k;
    y = process(hostedSourcePlugin);
    deviceWriter(y);
    if (hostedSourcePlugin.Frequency - 30 <= 0.1) || (hostedSourcePlugin.Frequency + 30 >= 20e3)
        k = -1*k;
    end
end

release(deviceWriter)

```

Input Arguments

pluginpath — Location of external plugin

character vector | string

Location of the external plugin, specified as a character vector. Use the full path to specify the audio plugin you want to host in MATLAB. If the plugin is located in the current folder, specify it by its name.

Example: `loadAudioPlugin('coolPlugin.dll')`

Example: `loadAudioPlugin('C:\Program Files\VSTPlugins\coolPlugin.dll')`

Plugin Path for Mac

For macOS, the plugin locations are predetermined depending on if the plugin was saved system wide or for a particular user.

This table shows the system-wide paths.

Plugin Type	Path
VST 2	/Library/Audio/Plug-Ins/VST/coolPlugin.vst
VST 3	/Library/Audio/Plug-Ins/VST3/coolPlugin.vst3
AU	/Library/Audio/Plug-Ins/Components/coolPlugin.component

This table shows the user-specific paths.

Plugin Type	Path
VST 2	~/Library/Audio/Plug-Ins/VST/coolPlugin.vst
VST 3	~/Library/Audio/Plug-Ins/VST3/coolPlugin.vst3
AU	~/Library/Audio/Plug-Ins/Components/coolPlugin.component

Output Arguments

hostedPlugin — Object of external plugin

`externalAudioPlugin` | `externalAudioSourcePlugin`

Object of an external plugin, derived from the `externalAudioPlugin` or `externalAudioSourcePlugin` class. You can interact with the hosted plugin as a DAW would, with the additional functionality of the MATLAB environment.

Limitations

- The `loadAudioPlugin` function supports 64-bit plugins only. You cannot load 32-bit plugins using the `loadAudioPlugin` function.
- Saving an external plugin as a MAT-file and then loading it preserves the external settings and parameters of the plugin but does not preserve its internal state or memory. Do not save and load your plugins when you are processing audio.

See Also

`parameterTuner` | **Audio Test Bench** | `audioPlugin` | `audioPluginSource` | `externalAudioPlugin` | `externalAudioPluginSource`

Topics

“Host External Audio Plugins”

Introduced in R2016b

midicallback

Call function handle when MIDI controls change value

Syntax

```
oldFunctionHandle = midicallback(midicontrolsObject,functionHandle)
oldFunctionHandle = midicallback(midicontrolsObject,[])
currentFunctionHandle = midicallback(midicontrolsObject)
```

Description

`oldFunctionHandle = midicallback(midicontrolsObject,functionHandle)` sets `functionHandle` as the function handle called when `midicontrolsObject` changes value, and returns the previous function handle, `oldFunctionHandle`.

`oldFunctionHandle = midicallback(midicontrolsObject,[])` clears the function handle.

`currentFunctionHandle = midicallback(midicontrolsObject)` returns the current function handle.

Examples

Interactively Read MIDI Controls

Create a default MIDI controls object. Use `midicallback` to associate an anonymous function with your MIDI controls object, `mc`.

```
mc = midicontrols;
midicallback(mc,@(x)disp(midiread(x)));
```

Move any control on your default MIDI device to display its current normalized value on the command line.

```
0.5079
0.5000
0.4921
0.4841
0.4762
0.4683
0.4603
0.4683
```

Use midicallback to Update Plot

Use `midid` to identify the name of your MIDI device and a specified control. Move the MIDI control you want to identify.

```
[controlNumber,deviceName] = midid;
```

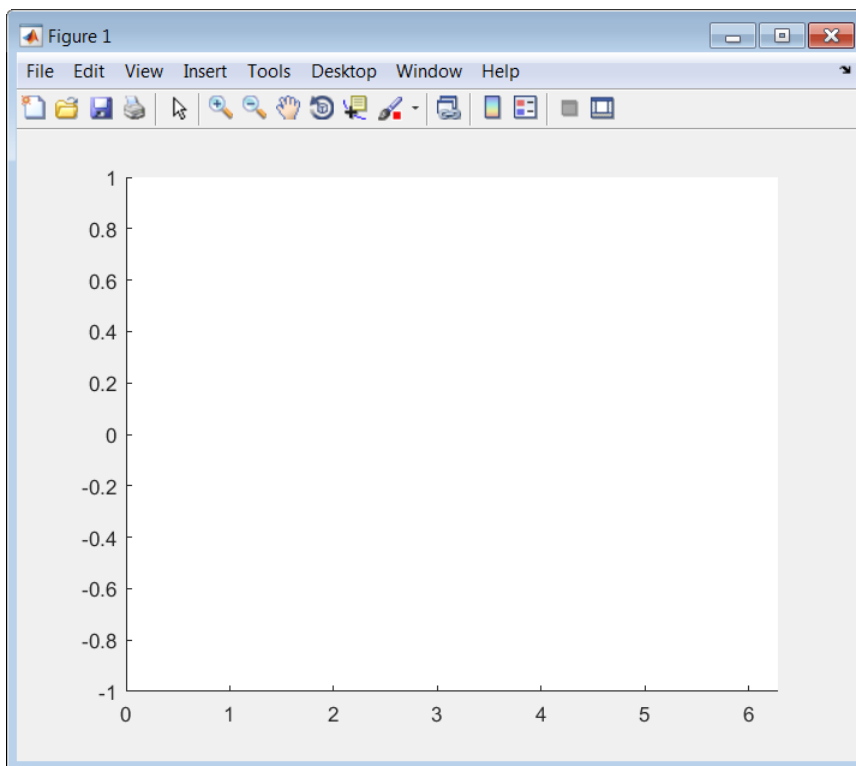
Move the control you wish to identify; type ^C to abort.
Waiting for control message...

Create an object that responds to the control you specified.

```
midicontrolsObject = midicontrols(controlNumber);
```

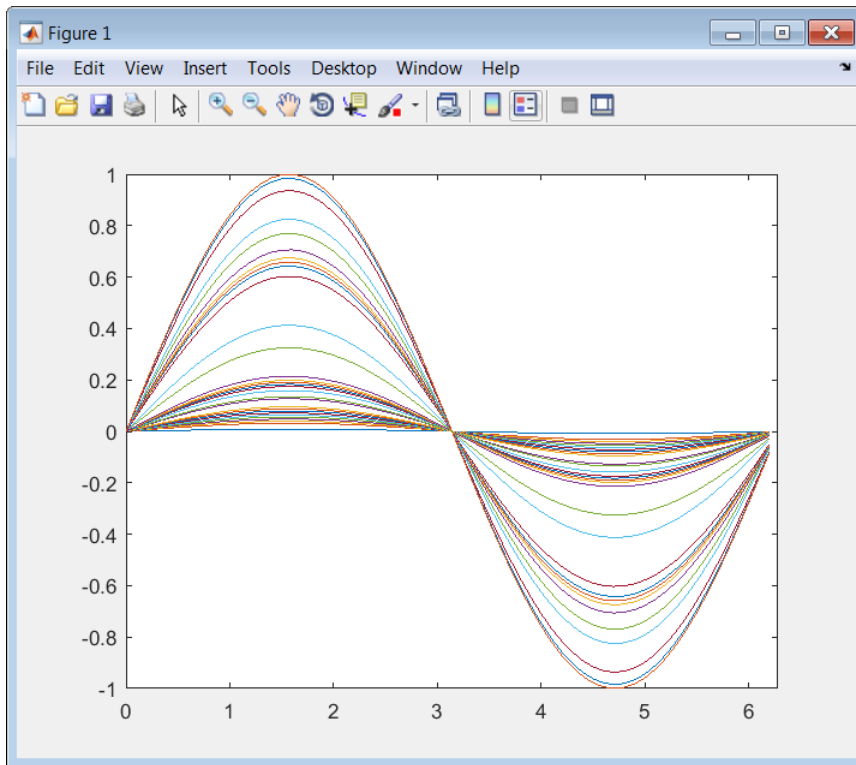
Define a function that plots a sinusoid with the amplitude set by your MIDI control. Make the axis constant.

```
axis([0,2*pi,-1,1]);  
axis manual  
hold on  
sinePlotter = @(obj) plot(0:0.1:2*pi,midiread(obj).*sin(0:0.1:2*pi));
```



Use the `midicallback` function to associate your `sinePlotter` function with the control specified by your `midicontrolsObject`. Move your specified MIDI control. The plot updates automatically with the sinusoid amplitude specified by your MIDI control.

```
midicallback(midicontrolsObject,sinePlotter)
```

Change Function Handle Associated with MIDI Control

Create an object that responds to any control on the default MIDI device.

```
midicontrolsObject = midicontrols;
```

Define an anonymous function to display the current value of the MIDI control. Use `midicallback` to associate your MIDI control object with the function you created. Verify that your object is associated with your function.

```
displayControlValue = @(object) disp(midiread(object));
midicallback(midicontrolsObject,displayControlValue);
currentFunctionHandle = midicallback(midicontrolsObject)
```

```
currentFunctionHandle =
    @(object)disp(midiread(object))
```

Move any control on your default MIDI device to display its current normalized value on the command line.

```
0.3095
0.4603
0.6746
0.7381
```

```
0.8175
```

```
0.8571
```

```
0.9048
```

Define an anonymous function to print the current value of the MIDI control rounded to two significant digits. Use `midicallback` to associate your MIDI controls object with the function you created. Return the old function handle.

```
displayRoundedControlValue = @(object) fprintf('%.2f\n',midiread(object));  
oldFunctionHandle = midicallback(midicontrolsObject,displayRoundedControlValue)
```

```
oldFunctionHandle =
```

```
    @(object)disp(midiread(object))
```

Move a control to display its current normalized value rounded to two significant digits.

```
0.91
```

```
0.83
```

```
0.67
```

```
0.49
```

```
0.29
```

```
0.18
```

```
0.05
```

Remove the association between the object and the function. Return the old function handle.

```
oldFunctionHandle = midicallback(midicontrolsObject,[])
```

```
oldFunctionHandle =
```

```
    @(object)fprintf('%.2f\n',midiread(object))
```

Verify that no function is associated with your MIDI controls object.

```
currentFunctionHandle = midicallback(midicontrolsObject)
```

```
currentFunctionHandle =
```

```
    []
```

Associate a Function with MIDI Controls

Define this function and save it to your current folder.

```
function plotSine(midicontrolsObject)
```

```
frequency = midiread(midicontrolsObject);
```

```
x = 0:0.01:10;
```

```
sinusoid = sin(2*pi*frequency.*x);
```

```
plot(x,sinusoid)
```

```
axis([0,10,-1.1,1.1]);
```

```

ylabel('Amplitude');
xlabel('Time (s)');
title('Sine Plot')
legend(sprintf('Frequency = %0.2f Hz', frequency));

```

end

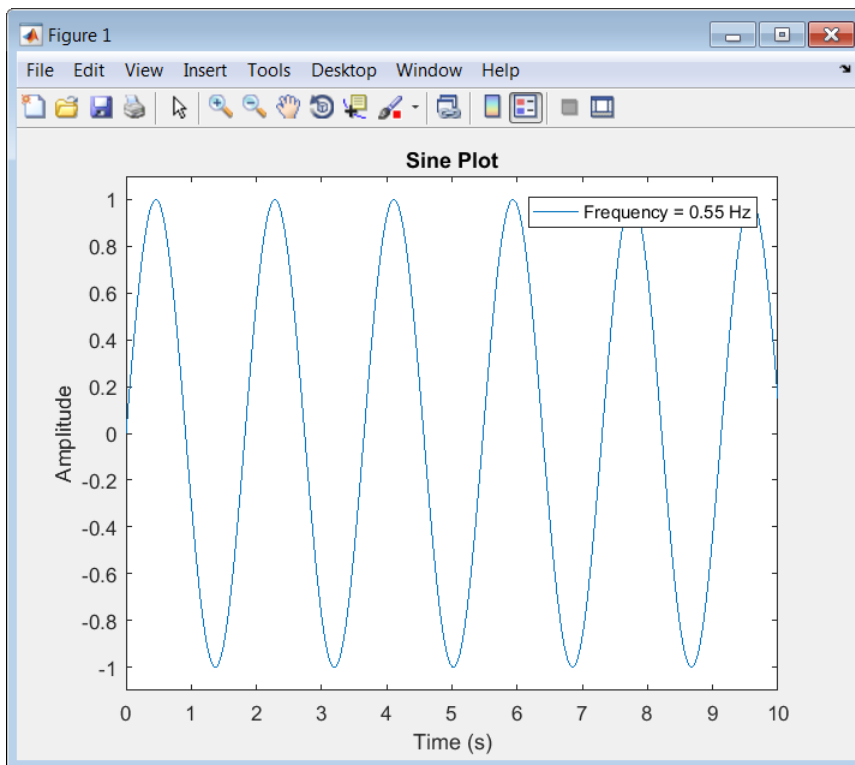
Create a `midicontrols` object. Create a function handle for your `plotSine` function. Use `midicallback` to associate your `midicontrolsObject` with `plotSineHandle`.

Move any controller on your MIDI device to plot a sinusoid. The sinusoid frequency updates when you move MIDI controls.

```

midicontrolsObject = midicontrols;
plotSineHandle = @plotSine;
midicallback(midicontrolsObject,plotSineHandle);

```



Input Arguments

midicontrolsObject — Object that listens to the controls on a MIDI device
object

Object that listens to the controls on a MIDI device, specified as an object created by `midicontrols`.

functionHandle — New function handle
function handle

New function handle, specified as a function handle that contains one input argument. The new function handle is called when `midicontrolsObject` changes value. For information on what function handles are, see “Function Handles”.

Output Arguments

oldFunctionHandle – Old function handle

function handle

Old function handle set by the previous call to `midicallback`, returned as a function handle.

currentFunctionHandle – Current function handle

function handle

The function handle set by the most recent call to `midicallback`, returned as a function handle.

See Also

`parameterTuner` | **Audio Test Bench** | `getMIDIConnections` | `configureMIDI` | `disconnectMIDI` | `midicontrols` | `midiread` | `midisync` | `midiid` | `setpref`

Topics

“MIDI Control Surface Interface”

“MIDI Control for Audio Plugins”

Introduced in R2016a

midicontrols

Open group of MIDI controls for reading

Syntax

```
midicontrolsObject = midicontrols
midicontrolsObject = midicontrols(controlNumbers)
midicontrolsObject = midicontrols(controlNumbers,initialValues)
midicontrolsObject = midicontrols( ____, 'MIDIDevice',deviceName)
midicontrolsObject = midicontrols( ____, 'OutputMode',mode)
```

Description

`midicontrolsObject = midicontrols` returns an object that listens to all controls on your default MIDI device.

Call `midiread` with the object to return the values of controls on your MIDI device. If you call `midiread` before a control is moved, `midiread` returns the initial value of your `midicontrols` object.

`midicontrolsObject = midicontrols(controlNumbers)` listens to controls specified by `controlNumbers` on your default MIDI device.

`midicontrolsObject = midicontrols(controlNumbers,initialValues)` specifies `initialValues` associated with `controlNumbers`.

`midicontrolsObject = midicontrols(____, 'MIDIDevice',deviceName)` specifies the MIDI device your `midicontrols` object listens to, using any of the previous syntaxes.

`midicontrolsObject = midicontrols(____, 'OutputMode',mode)` specifies the range of values returned by `midiread` and accepted as `initialValues` for `midicontrols` and as `controlValues` for `midisync`.

Examples

Listen to Any Control on Default Device

Create a `midicontrols` object and read the default control value.

```
midicontrolsObject = midicontrols
midiread(midicontrolsObject)

midicontrolsObject =
midicontrols object: any control on 'BCF2000'

ans =
    0
```

Move any control on your MIDI device. Use `midiread` to return the most recent value of the last control moved.

```
midiread(midicontrolsObject)
ans =
    0.3810
```

Listen to Specific Control

Use `midiid` to identify the name of your MIDI device and a specified control. Move the MIDI control you want to identify.

```
[controlNumber,deviceName] = midiid;
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message...
```

Create an object that responds to the control you specified.

```
midicontrolsObject = midicontrols(controlNumber);
```

Move your selected MIDI control, and then use `midiread` to return its most recent value.

```
midicontrolsObject = midiread(midicontrolsObject);
ans =
    0.4048
```

Specify Control Numbers and Initial Value

Determine the control numbers of four different controls on your MIDI device.

```
[controlNumber1,~] = midiid;
[controlNumber2,~] = midiid;
[controlNumber3,~] = midiid;
[controlNumber4,~] = midiid;

controlNumbers = [controlNumber1,controlNumber3;...
                 controlNumber2,controlNumber4]
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

```
controlNumbers =
    1081    1085
    1082    1087
```

Create a `midicontrols` object that listens to your specified controls. Specify an initial value for all controls.

```
initialValue = 0.5;
midicontrolsObject = midicontrols(controlNumbers,initialValue);
```

Move one of your specified controls, and then read the latest value of all your specified controls.

```
midiread(midicontrolsObject)
```

```
ans =
```

```
    0.0873    0.5000
    0.5000    0.5000
```

Specify Controls Numbers, Initial Value, and Output Mode

Determine the control numbers of two different controls on your MIDI device.

```
[controlNumber1,~] = midiid;
[controlNumber2,~] = midiid;
```

```
controlNumbers = [controlNumber1,controlNumber2];
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

Create a `midicontrols` object that listens to your specified controls. Specify an initial value for all controls.

```
initialValue = 12;
midicontrolsObject = midicontrols(controlNumbers,initialValue,'OutputMode','rawmidi');
```

Move one of your specified controls, and then read the latest value of all your specified controls.

```
midiread(midicontrolsObject)
```

```
ans =
```

```
    63    12
```

Set the Default MIDI Device

Assume that your MIDI device is a Behringer BCF2000. Enter this syntax at the MATLAB command line:

```
setpref midi DefaultDevice BCF2000
```

This preference persists across MATLAB sessions. You do not need to set it again unless you want to change your default device.

Specify Control Numbers and MIDI Device Name

Assume that your MIDI device is a Behringer BCF2000 and has a control with identification number 1001. Create a `midicontrols` object, which listens to control number 1001 on your Behringer BCF2000 device.

```
midicontrolsObject = midicontrols(1001, 'MIDIDevice', 'BCF2000');
```

Input Arguments

`controlNumbers` — MIDI device control numbers

integer | array of integers

MIDI device control numbers, specified as an integer or array of integers. Use `mididiid` to interactively identify the control numbers of your device. See “MIDI Device Control Numbers” on page 2-587 for an advanced explanation of how `controlNumbers` are determined.

If you specify `controlNumbers` as an empty vector, `[]`, then the `midicontrols` object responds to any control on your MIDI device.

Example: 1081

Data Types: double | single | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

`initialValues` — Initial values of MIDI controls

0 (default) | scalar | array the same size as `controlNumbers`

Initial values of MIDI controls, specified as a scalar or an array the same size as `controlNumbers`. If you specify `initialValues` as a scalar, all controls specified by `controlNumbers` are assigned that value.

The value associated with your MIDI controls cannot be determined until you move a MIDI control. If you specify an initial value associated with your MIDI control, the initial value is returned by the `midiread` function until the MIDI control is moved.

- If `OutputMode` is specified as 'normalized', then initial values must be in the range [0,1]. Actual initial values are quantized and can be slightly different from initial values specified when your `midicontrols` object is created.
- If `OutputMode` is specified as 'rawmidi', then initial values must be integers in the range [0,127]

Example: 0.3

Example: [0,0.3,0.6]

Example: 5

Example: [5;15;20]

Data Types: double | single | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

`deviceName` — MIDI device name

character vector | string

MIDI device name, assigned by the device manufacturer or host operating system, specified as a string. The specified `deviceName` can be a substring of the exact name of your device. If you do not

specify `deviceName`, the default MIDI device is used. See “Set the Default MIDI Device” on page 2-585 for an example of specifying a default MIDI device.

If you do not set a default MIDI device, the host operating system chooses the default device in an unspecified way. As a best practice, use `midid` to identify the name of the device you want.

Example: `'MIDIDevice', 'BCF2000 MIDI 1'`

Data Types: `char` | `string`

mode — Output mode for MIDI control value

`'normalized'` (default) | `'rawmidi'`

Output mode for MIDI control value, specified as `'normalized'` or `'rawmidi'`.

- `'normalized'` — Values of your MIDI control are normalized. If your `midicontrols` object is called by `midiread`, then values in the range [0,1] are returned.
- `'rawmidi'` — Values of your MIDI control are not normalized. If your `midicontrols` object is called by `midiread`, then integer values in the range [0,127] are returned.

Example: `'OutputMode', 'normalized'`

Example: `'OutputMode', 'rawmidi'`

Data Types: `char` | `string`

Output Arguments

midicontrolsObject — Object that listens to the controls on a MIDI device

object

Object that listens to the controls on a MIDI device.

More About

MIDI Device Control Numbers

MATLAB defines MIDI device control numbers as $(MIDI\ Channel\ Number) \times 1000 + (MIDI\ Controller\ Number)$.

- MIDI Channel Number is the transmission channel that your device uses to send messages. This value is in the range 1-16.
- MIDI Controller Number is a number assigned to an individual control on your MIDI device. This value is in the range 1-127.

Your MIDI device determines the values of *MIDI Channel Number* and *MIDI Controller Number*.

See Also

`parameterTuner` | **Audio Test Bench** | `getMIDIConnections` | `configureMIDI` | `disconnectMIDI` | `midicallback` | `midiread` | `midisync` | `midid` | `setpref`

Topics

“MIDI Control Surface Interface”

“MIDI Control for Audio Plugins”

Introduced in R2016a

midiid

Interactively identify MIDI control

Syntax

```
[controlNumber,deviceName] = midiid
```

Description

[controlNumber,deviceName] = midiid returns the control number and device name of the MIDI control you move. Call the function and then move the control you want to identify. The function detects which control you move and returns the control number and device name that specify that control.

Examples

Identify Control Number and Device Name

Call `midiid` and then move the control you want to identify on the MIDI device you want to identify.

```
[ctl,dev] = midiid;
```

```
Move the control you wish to identify; type ^C to abort.  
Waiting for control message...
```

```
ctl =  
1002  
dev =  
nanoKONTROL
```

Output Arguments

controlNumber — MIDI device control number

integer

MIDI device control number, specified as an integer. The device manufacturer assigns the value to the control for identification purposes.

deviceName — MIDI device name

string

MIDI device name assigned by the device manufacturer or host operating system, specified as a string.

See Also

[getMIDIConnections](#) | [configureMIDI](#) | [disconnectMIDI](#) | [midiread](#) | [midisync](#) | [midicallback](#) | [setpref](#) | [parameterTuner](#) | **Audio Test Bench**

Topics

“MIDI Control Surface Interface”

“MIDI Control for Audio Plugins”

Introduced in R2016a

midiread

Return most recent value of MIDI controls

Syntax

```
controlValues = midiread(midicontrolsObject)
```

Description

`controlValues = midiread(midicontrolsObject)` returns the most recent value of the MIDI controls associated with the specified `midicontrolsObject`. To create this object, use the `midicontrols` function.

Examples

Read Control Values of MIDI Device

```
midicontrolsObject = midicontrols;
controlValue = midiread(midicontrolsObject);
```

Read Multiple Control Values of MIDI Device

Identify two MIDI controls on your MIDI device.

```
[controlOne,~] = midiid
[controlTwo,~] = midiid
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

```
controlOne =
    1081
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

```
controlTwo =
    1082
```

Create a MIDI controls object that listens to both controls you identified.

```
controlNumbers = [controlOne,controlTwo];
midicontrolsObject = midicontrols(controlNumbers);
```

Move your specified MIDI controls and return their values. The values are returned as a vector that corresponds to your control numbers vector, `controlNumbers`.

```
tic
while toc < 5
    controlValues = midiread(midicontrolsObject)
end

controlValues =

    0.0397    0.0556
```

Read Control Values in an Audio Stream Loop

Use `midid` to identify the name of your MIDI device and a specified control. Move the MIDI control you want to identify.

```
[controlNumber, deviceName] = midid;
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

Create a MIDI controls object. The value associated with your MIDI controls object cannot be determined until you move the MIDI control. Specify an initial value associated with your MIDI control. The `midiread` function returns the initial value until the MIDI control is moved.

```
initialControlValue = 1;
midicontrolsObject = midicontrols(controlNumber,initialControlValue);
```

Create a `dsp.AudioFileReader` System object with default settings. Create an `audioDeviceWriter` System object and specify the sample rate.

```
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3');
deviceWriter = audioDeviceWriter(...
    'SampleRate',fileReader.SampleRate);
```

In an audio stream loop, read an audio signal frame from the file, apply gain specified by the control on your MIDI device, and then write the frame to your audio output device. By default, the control value returned by `midiread` is normalized.

```
while ~isDone(fileReader)
    audioData = step(fileReader);

    controlValue = midiread(midicontrolsObject);

    gain = controlValue*2;
    audioDataWithGain = audioData*gain;

    play(deviceWriter, audioDataWithGain);
end
```

Close the input file and release your output device.

```
release(fileReader);  
release(deviceWriter);
```

Input Arguments

midicontrolsObject — Object that listens to the controls on a MIDI device
object

Object that listens to the controls on a MIDI device, specified as an object created by `midicontrols`.

Output Arguments

controlValues — Most recent values of MIDI controls
[0, 1] (default) | integer values in the range [0, 127]

Most recent values of MIDI controls, returned as normalized values in the range [0, 1], or as integer values in the range [0, 127]. The output values depend on the `OutputMode` specified when your `midicontrols` object is created.

- If `OutputMode` was specified as 'normalized', then `midiread` returns values in the range [0, 1]. The default `OutputMode` is 'normalized'.
- If `OutputMode` was specified as 'rawmidi', then `midiread` returns integer values in the range [0, 127], and no quantization is required.

See Also

[Audio Test Bench](#) | [parameterTuner](#) | [getMIDIConnections](#) | [configureMIDI](#) | [disconnectMIDI](#) | [midicontrols](#) | [midicallback](#) | [midisync](#) | [midiid](#) | [setpref](#)

Topics

“MIDI Control Surface Interface”

“MIDI Control for Audio Plugins”

Introduced in R2016a

midisync

Send values to MIDI controls for synchronization

Syntax

```
midisync(midicontrolsObject)
midisync(midicontrolsObject,controlValues)
```

Description

`midisync(midicontrolsObject)` sends the initial values of controls to your MIDI device, as specified by your MIDI controls object. To create this object, use the `midicontrols` function. If your MIDI device can receive and respond to messages, it adjusts its controls as specified.

Note Many MIDI devices are not bidirectional. Calling `midisync` with a unidirectional device has no effect. `midisync` cannot tell whether a value is successfully sent to a device or even whether the device is bidirectional. If sending a value fails, no errors or warnings are generated.

`midisync(midicontrolsObject,controlValues)` sends `controlValues` to the MIDI controls associated with the specified `midicontrolsObject`.

Examples

Synchronize MIDI Control to Initial Value

Use `midiid` to identify a control on your default MIDI device.

```
[controlNumber,~] = midiid;
```

```
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
```

Create a MIDI controls object. Specify an initial value for your control. Call `midisync` to set the specified control on your device to the initial value.

```
initialValue = 0.5;
midicontrolsObject = midicontrols(controlNumber,initialValue);
midisync(midicontrolsObject);
```

Synchronize MIDI Control to Specified Value

Use `midiid` to identify three controls on your default MIDI device.

```
[controlNumber1,~] = midiid;
[controlNumber2,~] = midiid;
[controlNumber3,~] = midiid;
controlNumbers = [controlNumber1,controlNumber2,controlNumber3];
```



```

Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done
Move the control you wish to identify; type ^C to abort.
Waiting for control message... done

```

Create a MIDI controls object. Specify initial values for your controls. Call `midisync` to set the specified control on your device to the initial value.

```

controlValues = [0,0,1];
midicontrolsObject = midicontrols(controlNumbers,controlValues);
midisync(midicontrolsObject);

```

Create a loop that updates your control values and synchronizes those values to the physical controls on your device.

```

for i = 1:100
    controlValues = controlValues + [0.006,0.008,-0.008];
    midisync(midicontrolsObject,controlValues);
    pause(0.1)
end

```

Create UI Slider and Synchronize with MIDI Control

Define this function and save it to your current folder.

```

function trivialmidigui(controlNumber,deviceName)

    slider = uicontrol('Style','slider');
    mc = midicontrols(controlNumber,'MIDIDevice',deviceName);
    midisync(mc);
    set(slider,'Callback',@slidercb);
    midicallback(mc, @mccb);

    function slidercb(slider,~)
        val = get(slider,'Value');
        midisync(mc, val);
        disp(val);
    end

    function mccb(mc)
        val = midiread(mc);
        set(slider,'Value',val);
        disp(val);
    end
end

```

Use `midiid` to identify a control number and device name. Call the function you created, specifying the control number and device name as inputs.

```

[controlNumber,deviceName] = midiid;
trivialmidigui(controlNumber,deviceName)

```

The slider on the user interface is synchronized with the specified control on your device. Move one to see the other respond.

Input Arguments

midicontrolsObject – Object that listens to the controls on a MIDI device

object

Object that listens to the controls on a MIDI device, specified as an object created by `midicontrols`.

controlValues – Values sent to MIDI device

initial values specified by `midicontrolsObject` (default) | scalar | array

Values sent to MIDI device, specified as a scalar or an array the same size as `controlNumbers` of the associated `midicontrols` object. If you do not specify `controlValues`, the default value is the `initialValues` of the associated `midicontrols` object.

The possible range for `controlValues` depends on the `OutputMode` of the associated `midicontrols` object.

- If `OutputMode` is specified as 'normalized', then `controlValues` must consist of values in the range [0,1]. The default `OutputMode` is 'normalized'.
- If `OutputMode` is specified as 'rawmidi', then `controlValues` must consist of integer values in the range [0,127].

Example: 0.3

Example: [0,0.3,0.6]

Example: 5

Example: [5;15;20]

Data Types: double | single | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

See Also

Audio Test Bench | `parameterTuner` | `getMIDIConnections` | `configureMIDI` | `disconnectMIDI` | `midicontrols` | `midiread` | `midicallback` | `midiid` | `setpref`

Topics

“MIDI Control Surface Interface”

“MIDI Control for Audio Plugins”

Introduced in R2016a

validateAudioPlugin

Test MATLAB source code for audio plugin

Syntax

```
validateAudioPlugin classname  
validateAudioPlugin options classname
```

Description

`validateAudioPlugin classname` generates and runs a “Test Bench Procedure” on page 2-599 that exercises your audio plugin class.

`validateAudioPlugin options classname` specifies options to modify the default “Test Bench Procedure” on page 2-599.

Examples

Validate Audio Plugin

```
validateAudioPlugin audiopluginexample.Echo
```

```
Checking plug-in class 'audiopluginexample.Echo'... passed.  
Generating testbench file 'testbench_Echo.m'... done.  
Running testbench... passed.  
Generating mex file 'testbench_Echo_mex.mexw64'... done.  
Running mex testbench... passed.  
Deleting testbench.  
Ready to generate audio plug-in.
```

Skip MEX Version of Test Bench

```
validateAudioPlugin -nomex audiopluginexample.Echo
```

```
Checking plug-in class 'audiopluginexample.Echo'... passed.  
Generating testbench file 'testbench_Echo.m'... done.  
Running testbench... passed.  
Skipping mex.  
Deleting testbench.
```

Keep Test Benches After Validation

```
validateAudioPlugin -keeptestbench audiopluginexample.Echo
```

```
Checking plug-in class 'audiopluginexample.Echo'... passed.  
Generating testbench file 'testbench_Echo.m'... done.  
Running testbench... passed.  
Generating mex file 'testbench_Echo_mex.mexw64'... done.
```

```
Running mex testbench... passed.  
Keeping testbench.  
Ready to generate audio plug-in.
```

Two test benches are saved to your current folder:

- `testbench_Echo.m`
- `testbench_Echo_mex.mexw64`

Skip MEX Version and Keep Test Bench

```
validateAudioPlugin -keeptestbench -nomex audiopluginexample.Echo
```

```
Checking plug-in class 'audiopluginexample.Echo'... passed.  
Generating testbench file 'testbench_Echo.m'... done.  
Running testbench... passed.  
Skipping mex.  
Keeping testbench.
```

One test bench is saved to your current folder:

- `testbench_Echo.m`

Input Arguments

options — Options to modify test bench procedure

```
-nomex | -keeptestbench | -audioconfig cfg
```

Options to modify test bench procedure, specified as `-nomex`, `-keeptestbench`, or `-audioconfig cfg`. Options can be specified together or separately, and in any order.

- `-nomex` -- `validateAudioPlugin` does not generate and run a MEX version of the test bench file. This option significantly reduces run time of the test bench procedure.
- `-keeptestbench` -- `validateAudioPlugin` saves the generated test benches to the current folder.
- `-audioconfig cfg` — Input the deep learning coder configuration property `cfg` to `validateAudioPlugin`. See `audioPluginConfig` for more details

classname — Name of the plugin class to validate

```
plugin class
```

Name of the plugin class to validate. The plugin class must derive from either the `audioPlugin` class or the `audioPluginSource` class. The `validateAudioPlugin` function exercises an instance of the specified plugin class.

You can specify the plugin class to validate by specifying its class name or file name. For example, the following syntaxes perform equivalent operations:

- `validateAudioPlugin myPlugin`
- `validateAudioPlugin myPlugin.m`

If you want to specify the plugin class by file name, and your plugin class is inside a package, you must specify the package as a file path. For example, the following syntaxes perform equivalent operations:

- `validateAudioPlugin myPluginPackage.myPlugin`
- `validateAudioPlugin +myPluginPackage/myPlugin.m`

Limitations

The `validateAudioPlugin` function is compatible with Windows and Mac operating systems. It is not compatible with Linux.

More About

Test Bench Procedure

The `validateAudioPlugin` function uses dynamic testing to find common audio plugin programming mistakes not found by the static checks performed by `generateAudioPlugin`. The function:

- 1 Runs a subset of error checks performed by `generateAudioPlugin`.
- 2 Generates and runs a MATLAB test bench to exercise the class.
- 3 Generates and runs a MEX version of the test bench.
- 4 Removes the generated test benches.

If the plugin class fails testing, step 4 is automatically omitted. To debug your plugin, step through the saved generated test bench.

If you use the `-keeptestbench` option, or if an error occurs during validation, the test bench files are saved to your current folder.

See Also

`generateAudioPlugin` | **Audio Test Bench** | `parameterTuner` | `audioPlugin` | `audioPluginSource` | `audioPluginConfig`

Topics

“Audio Plugins in MATLAB”

Introduced in R2016a

acousticLoudness

Perceived loudness of acoustic signal

Syntax

```
loudness = acousticLoudness(audioIn, fs)
loudness = acousticLoudness(audioIn, fs, calibrationFactor)
loudness = acousticLoudness(SPLIn)
loudness = acousticLoudness( ____, Name, Value)

[loudness, specificLoudness] = acousticLoudness( ____ )

[loudness, specificLoudness, perc] = acousticLoudness( ____, 'TimeVarying', true)
[loudness, specificLoudness, perc] = acousticLoudness( ____, 'TimeVarying', true,
'Percentiles', p)

acousticLoudness( ____ )
```

Description

`loudness = acousticLoudness(audioIn, fs)` returns loudness in sones according to ISO 532-1 (Zwicker).

`loudness = acousticLoudness(audioIn, fs, calibrationFactor)` specifies a nondefault microphone calibration factor used to compute loudness.

`loudness = acousticLoudness(SPLIn)` computes loudness using one-third-octave-band sound pressure levels (SPL).

`loudness = acousticLoudness(____, Name, Value)` specifies options using one or more `Name, Value` pair arguments.

Example: `loudness = acousticLoudness(audioIn, fs, 'Method', 'ISO 532-2')` returns loudness according to ISO 532-2 (Moore-Glasberg).

`[loudness, specificLoudness] = acousticLoudness(____)` also returns the specific loudness.

`[loudness, specificLoudness, perc] = acousticLoudness(____, 'TimeVarying', true)` also returns percentile loudness.

`[loudness, specificLoudness, perc] = acousticLoudness(____, 'TimeVarying', true, 'Percentiles', p)` specifies nondefault percentiles to return.

`acousticLoudness(____)` with no output arguments plots specific loudness and displays loudness textually. If `TimeVarying` is true, both loudness and specific loudness are plotted, with the latter in 3-D.

Examples

Measure Acoustic Loudness

Measure the ISO 532-1 stationary free-field loudness. Assume the recording level is calibrated such that a 1 kHz tone registers as 100 dB on a SPL meter.

```
[audioIn,fs] = audioread('WashingMachine-16-44p1-stereo-10secs.wav');  
loudness = acousticLoudness(audioIn,fs)  
loudness = 1x2  
    28.2688    27.7643
```

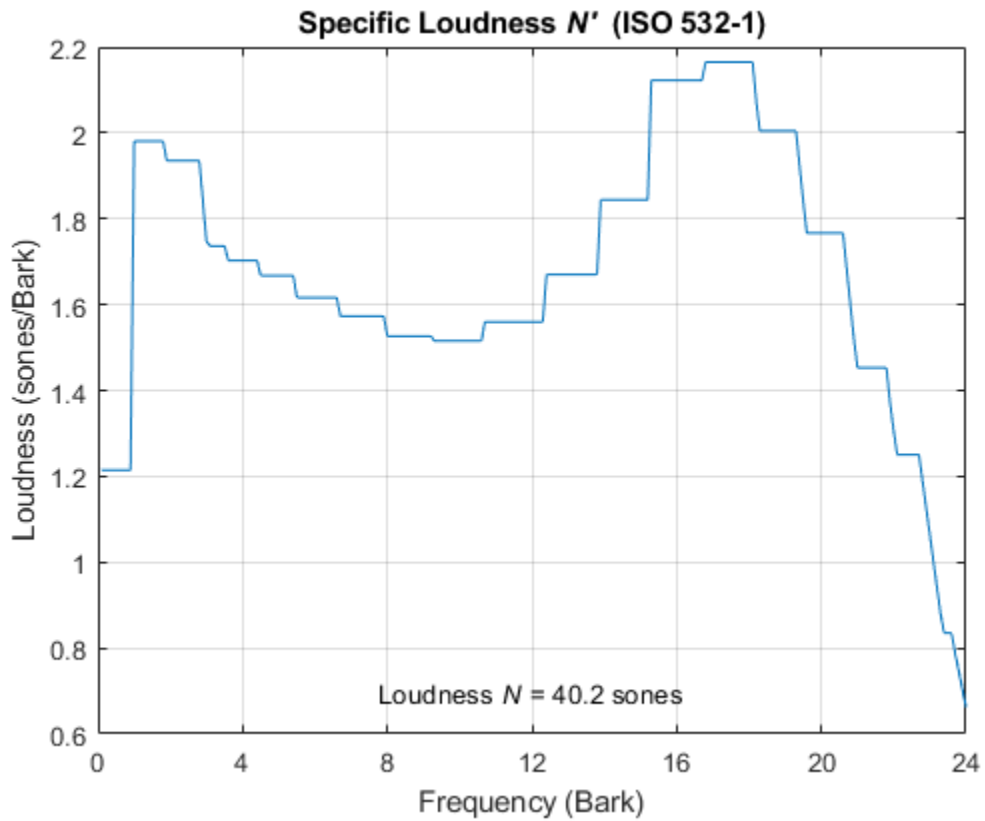
Measure Loudness and Sharpness of Stationary Signals

Create two stationary signals with equivalent power: a pink noise signal and a white noise signal.

```
fs = 48e3;  
dur = 5;  
pnoise = 2*pinknoise(dur*fs);  
wnoise = rand(dur*fs,1) - 0.5;  
wnoise = wnoise*sqrt(var(pnoise)/var(wnoise));
```

Call `acousticLoudness` using the default ISO 532-1 (Zwicker) method and no output arguments to plot the loudness of the pink noise. Call `acousticLoudness` again, this time with output arguments, to get the specific loudness.

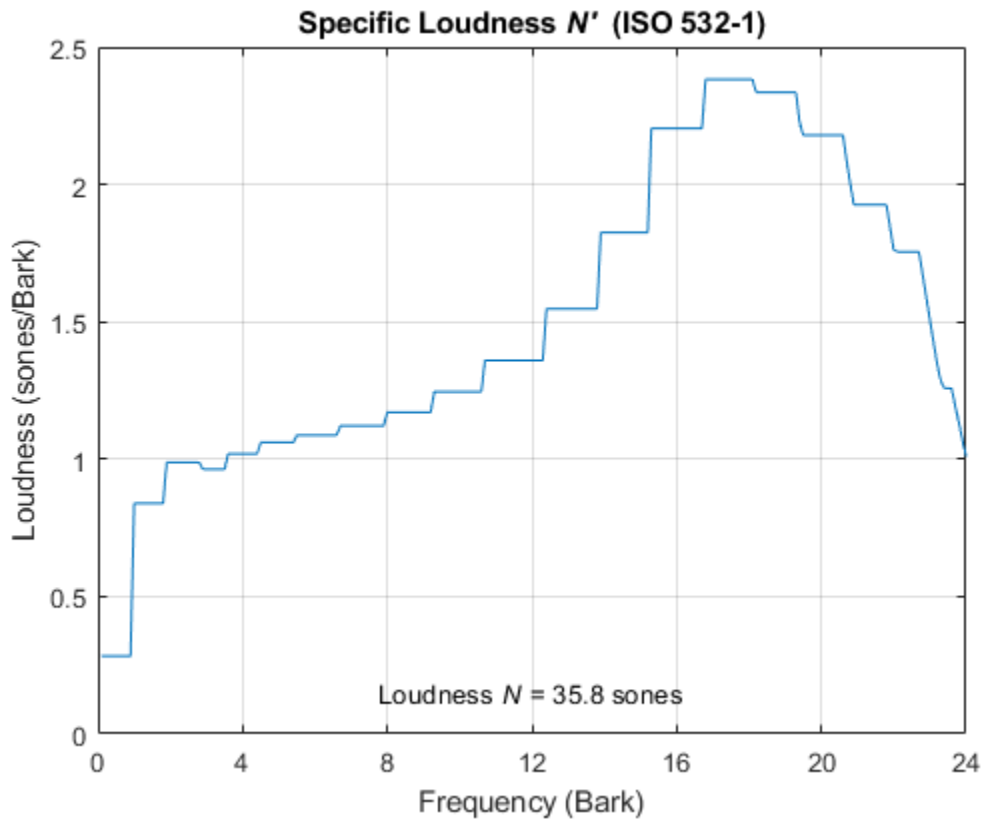
```
figure  
acousticLoudness(pnoise,fs)
```



```
[~,pSpecificLoudness] = acousticLoudness(pnoise,fs);
```

Plot the loudness for the white noise signal and then get the specific loudness values.

```
figure  
acousticLoudness(wnoise,fs)
```

```
[~,wSpecificLoudness] = acousticLoudness(wnoise,fs);
```

Call the `acousticSharpness` function to compare the sharpness of the pink noise and white noise.

```
pSharpness = acousticSharpness(pSpecificLoudness);
wSharpness = acousticSharpness(wSpecificLoudness);
fprintf('Sharpness of pink noise = %0.2f acum\n',pSharpness)
```

```
Sharpness of pink noise = 2.00 acum
```

```
fprintf('Sharpness of white noise = %0.2f acum\n',wSharpness)
```

```
Sharpness of white noise = 2.62 acum
```

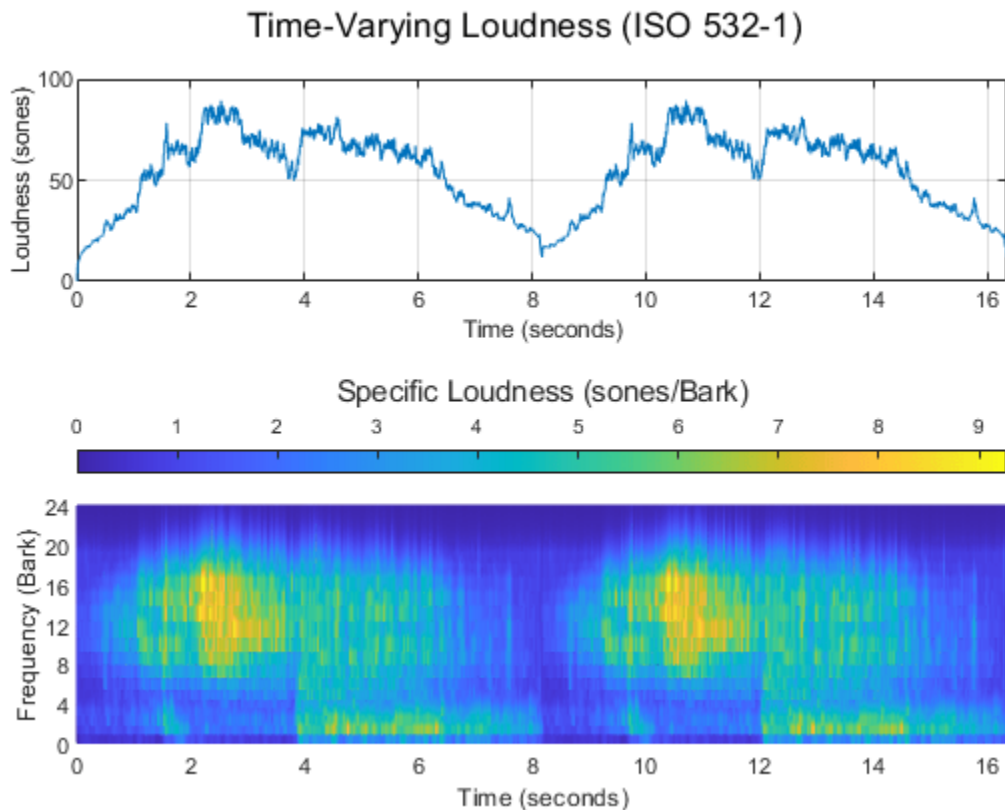
Time-Varying Loudness and Percentiles

Read in an audio file.

```
[audioIn,fs] = audioread('JetAirplane-16-11p025-mono-16secs.wav');
```

Plot the time-varying acoustic loudness in accordance with ISO 532-1 and get the percentiles. Listen to the audio signal.

```
acousticLoudness(audioIn,fs,'SoundField','diffuse','TimeVarying',true)
```



```
sound(audioIn, fs)
```

Call `acousticLoudness` again with the same inputs and get the percentiles. Print the *Nmax* and *N5* percentiles. The *Nmax* percentile is the maximum loudness reported. The *N5* percentile is the loudness below which is 95% of the reported loudness.

```
[~,~,perc] = acousticLoudness(audioIn,fs, 'SoundField', 'diffuse', 'TimeVarying', true);
fprintf('Max loudness = %0.2f soness\n',perc(1))
```

```
Max loudness = 89.48 soness
```

```
fprintf('N5 loudness = %0.2f soness\n',perc(2))
```

```
N5 loudness = 81.77 soness
```

Measure Acoustic Loudness from Sound Pressure Level

Read in an audio file.

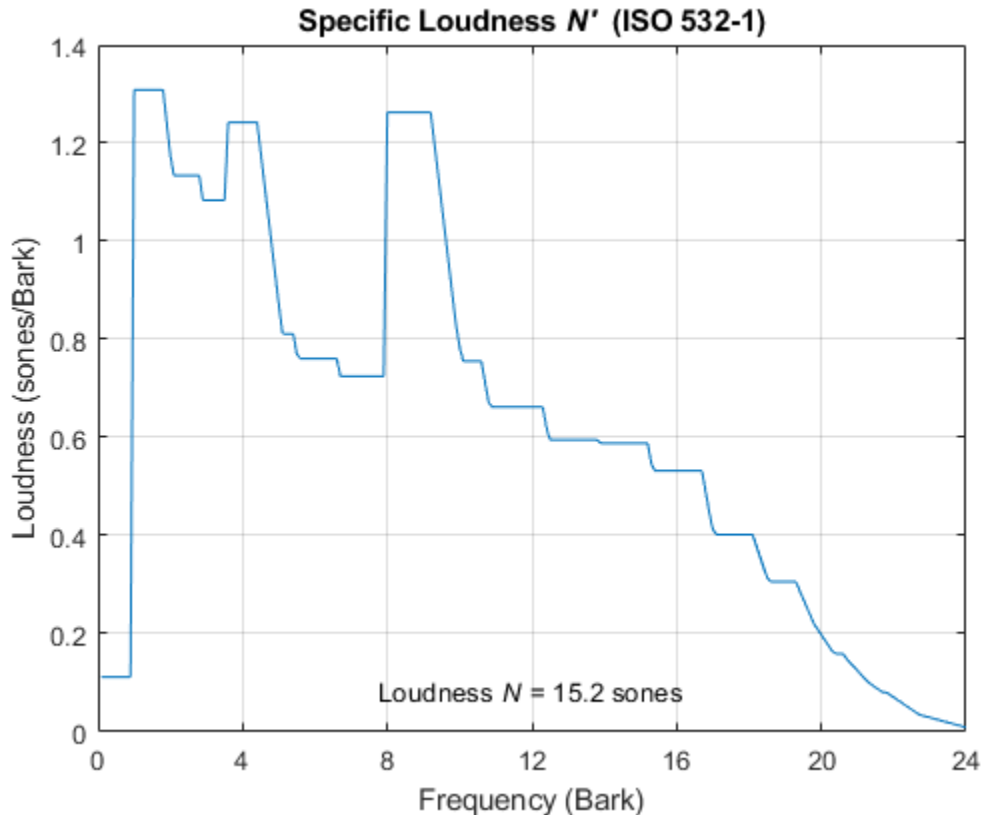
```
[audioIn,fs] = audioread('Turbine-16-44p1-mono-22secs.wav');
```

Call `acousticLoudness` with no output arguments to plot the specific loudness. Assume a calibration factor of 0.15 and a reference pressure of 21 micropascals. To determine the calibration factor specific to your audio system, use the `calibrateMicrophone` function.

```

calibrationFactor = 0.15;
refPressure = 21e-6;
acousticLoudness(audioIn,fs,calibrationFactor,'PressureReference',refPressure)

```



`acousticLoudness` enables you to specify an intermediate representation, sound pressure levels, instead of a time-domain input. This enables you to reuse intermediate SPL calculations. Another advantage is that if your physical SPL meter does not report loudness in accordance to ISO 532-1 or ISO 531-2, you can use the reported 1/3-octave SPLs to calculate standard-compliant loudness.

To calculate sound pressure levels from an audio signal, first create an `splMeter` object. Call the `splMeter` object with the audio input.

```

spl = splMeter("SampleRate",fs,"Bandwidth","1/3 octave", ...
    "CalibrationFactor",calibrationFactor,"PressureReference",refPressure, ...
    "FrequencyWeighting","Z-weighting","OctaveFilterOrder",6);

```

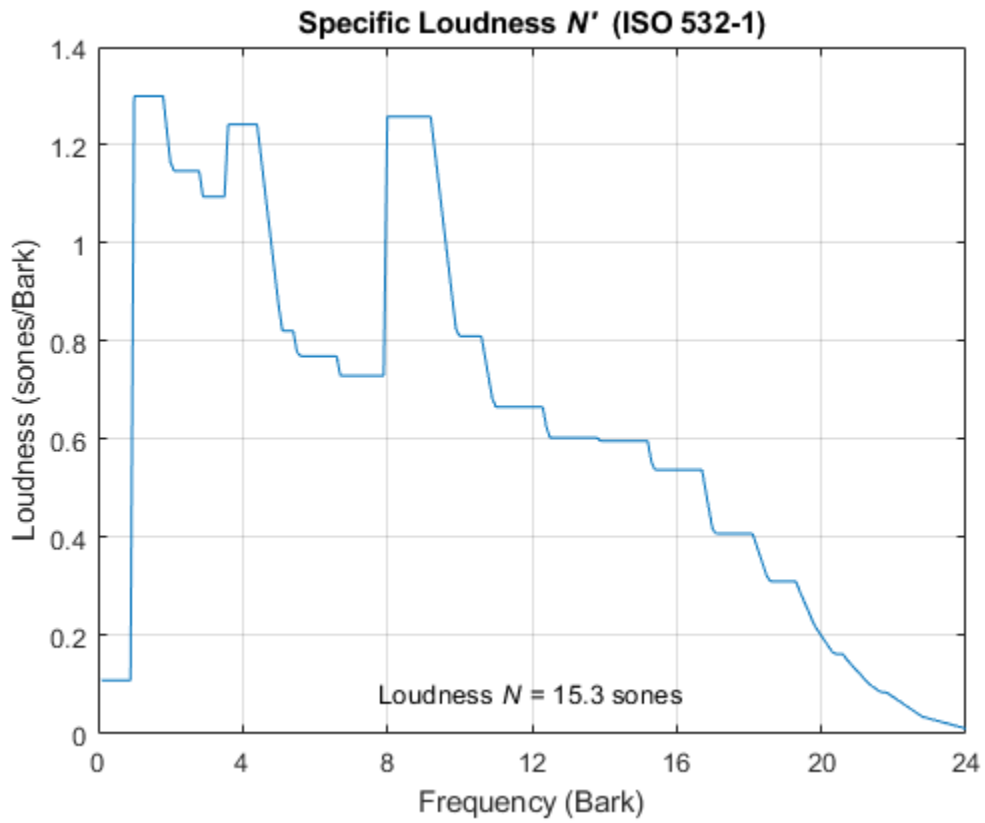
```
splMeasurement = spl(audioIn);
```

Compute the mean SPL level, skipping the first 0.2 seconds. Only keep the bands from 25 Hz to 12.5 kHz (the first 28 bands).

```
SPLIn = mean(splMeasurement(ceil(0.2*fs):end,1:28));
```

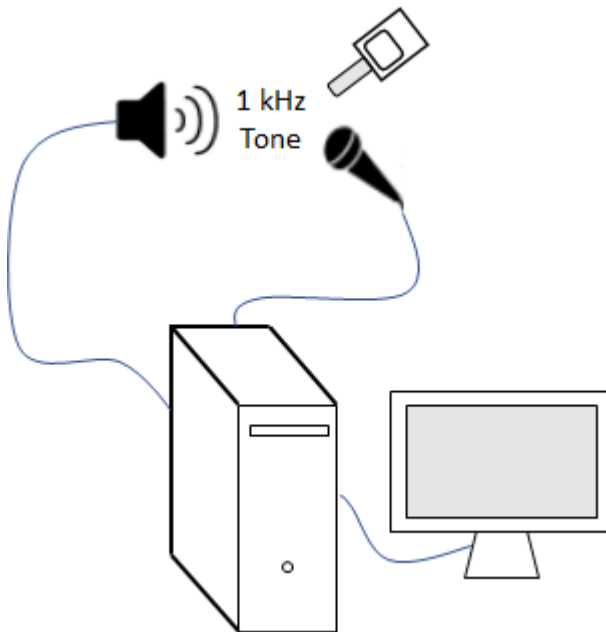
Using the SPL input, call `acousticLoudness` with no output arguments to plot the specific loudness.

```
acousticLoudness(SPLIn)
```



Loudness Measurements Using Calibrated Microphone

Set up an experiment as indicated by the diagram.



Create an `audioDeviceReader` object to read from the microphone and an `audioDeviceWriter` object to write to your speaker.

```
fs = 48e3;
deviceReader = audioDeviceReader(fs);
deviceWriter = audioDeviceWriter(fs);
```

Create an `audioOscillator` object to generate a 1 kHz sinusoid.

```
osc = audioOscillator("sine",1e3,"SampleRate",fs);
```

Create a `dsp.AsyncBuffer` object to buffer data acquired from the microphone.

```
dur = 5;
buff = dsp.AsyncBuffer(dur*fs);
```

For five seconds, play the sinusoid through your speaker and record using your microphone. While the audio streams, note the loudness as reported by your SPL meter. Once complete, read the contents of the buffer object.

```
numFrames = dur*(fs/osc.SamplesPerFrame);
for ii = 1:numFrames
    audioOut = osc();
    deviceWriter(audioOut);

    audioIn = deviceReader();
    write(buff,audioIn);
end
```

```
SPLreading = 60.4;
```

```
micRecording = read(buff);
```

To compute the calibration factor for the microphone, use the `calibrateMicrophone` function.

```
calibrationFactor = calibrateMicrophone(micRecording,deviceReader.SampleRate,SPLreading);
```

Call `acousticLoudness` with the microphone recording, sample rate, and calibration factor. The loudness reported from `acousticLoudness` is the true acoustic loudness measurement as specified by 532-1.

```
loudness = acousticLoudness(micRecording,deviceReader.SampleRate,calibrationFactor)
loudness = 14.7902
```

You can now use the calibration factor you determined to measure the loudness of any sound that is acquired through the same microphone recording chain.

Plot Specific Loudness Over Hertz

Read in an audio signal.

```
[audioIn,fs] = audioread('TrainWhistle-16-44p1-mono-9secs.wav');
```

ISO 532-1

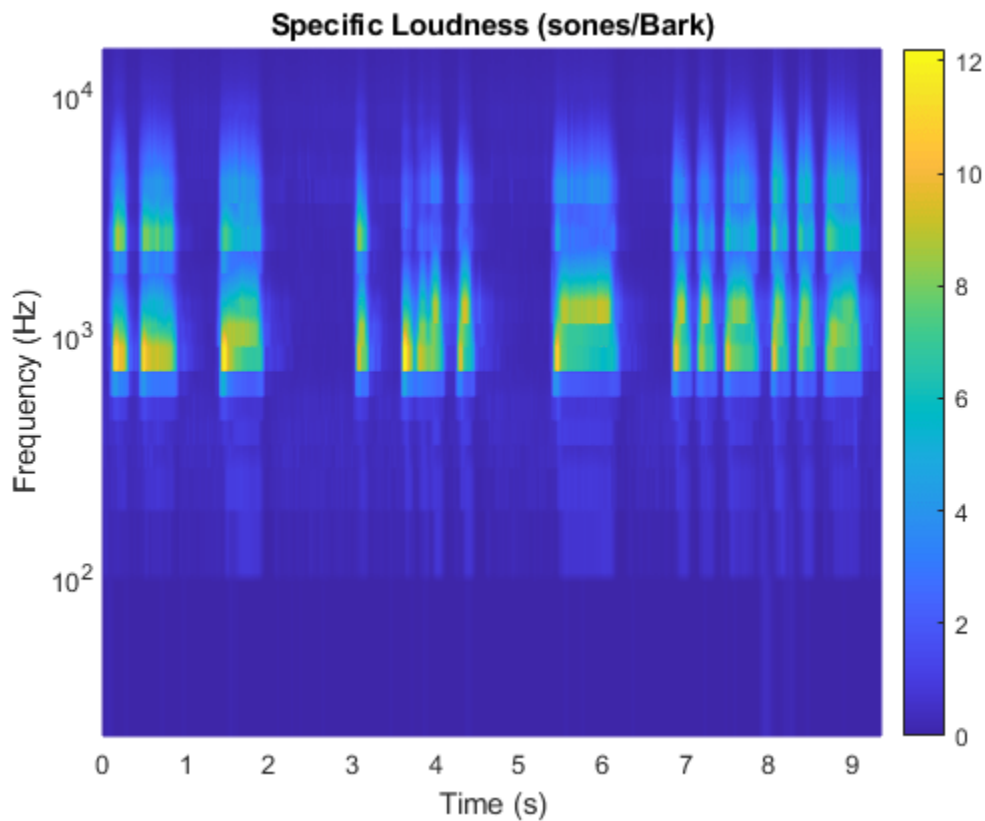
Determine the time-varying specific loudness according to the default method (ISO 532-1).

```
[~,specificLoudness] = acousticLoudness(audioIn,fs,'TimeVarying',true);
```

ISO 532-1 reports specific loudness over Bark, where the Bark bins are `0.1:0.1:24`. Convert the Bark bins to Hz and then plot the specific loudness over Hz across time.

```
barkBins = 0.1:0.1:24;
hzBins = bark2hz(barkBins);

t = 0:2e-3:2e-3*(size(specificLoudness,1)-1);
surf(t,hzBins,sum(specificLoudness,3).','EdgeColor','interp')
set(gca,'YScale','log')
view([0 90])
axis tight
xlabel('Time (s)')
ylabel('Frequency (Hz)')
colorbar
title('Specific Loudness (sones/Bark)')
```



ISO 532-2

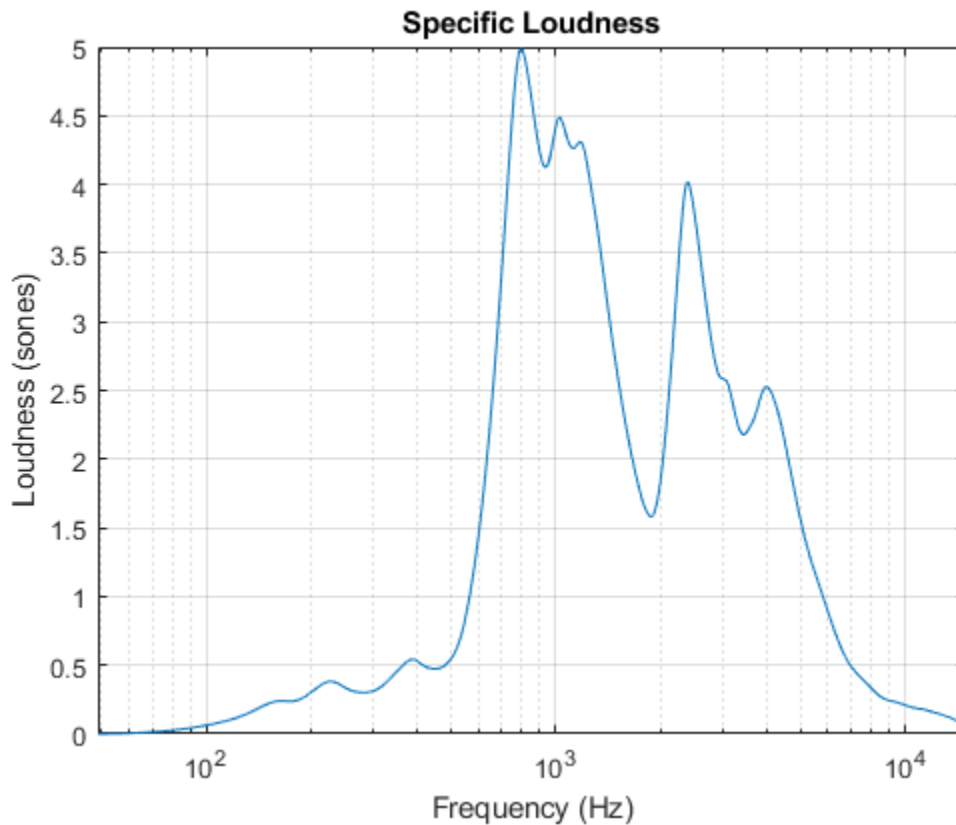
Determine the stationary specific loudness according to the Moore-Glasberg method (ISO 532-2).

```
[~,specificLoudness] = acousticLoudness(audioIn,fs,'Method','ISO 532-2');
```

ISO 532-2 reports specific loudness over the ERB scale, where the ERB bins are $1.8:0.1:38.9$. The unit of the ERB scale is sometimes referred to as Cam. Convert the ERB bins to Hz and then plot the specific loudness.

```
erbBins = 1.8:0.1:38.9;
hzbins = erb2hz(erbBins);

semilogx(hzbins,specificLoudness)
xlabel('Frequency (Hz)')
ylabel('Loudness (sones)')
title('Specific Loudness')
grid on
```



Loudness Using Custom Earphone Responses

Read in an audio file.

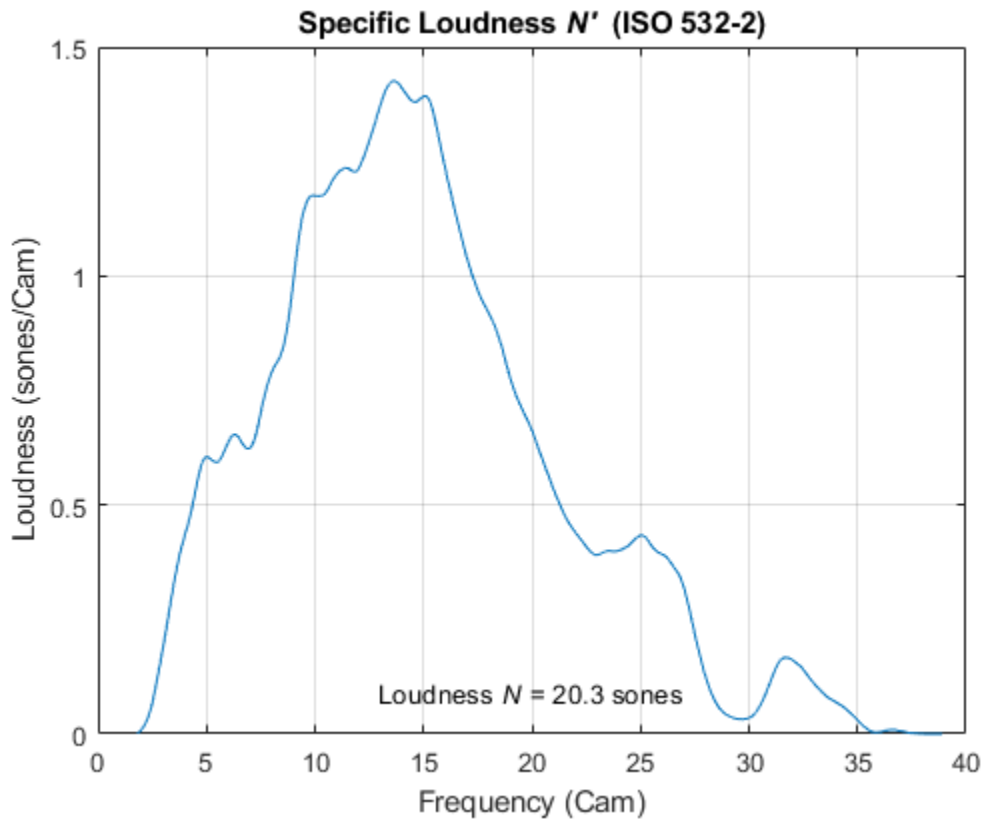
```
[x,fs] = audioread('WashingMachine-16-44p1-stereo-10secs.wav');
```

ISO 532-2 enables you to specify a custom earphone response when calculating loudness. Create a 30-by-2 matrix where the first column is the frequency and the second column is the earphone's deviation from a flat response.

```
tdh = [ 0, 80, 100, 200, 500, 574, 660, 758, 871, 1000, 1149, 1320, 1516, 1741,
        2297, 2639, 3031, 3482, 4000, 4500, 5000, 5743, 6598, 7579, 8706, 10000, 12000, 16000,
        -50, -15.3, -13.8, -8.1, -0.5, 0.4, 0.8, 0.9, 0.5, 0.1, -0.8, -1.5, -2.3, -3.2,
        -4.2, -4.3, -4.3, -3.9, -3.2, -2.3, -1.1, -0.3, -2, -5.4, -9, -12.1, -15.2, -30,
```

Calculate the loudness using ISO 532-2. Specify `SoundField` as earphones and the earphone response as the matrix you just created.

```
acousticLoudness(x,fs,'Method','ISO 532-2','SoundField','earphones','EarphoneResponse',tdh)
```

Streaming Calculation of Stationary Loudness

Create a `dsp.AudioFileReader` object to read in an audio signal frame-by-frame. Specify a frame duration of 50 ms. This will be the frame duration over which you calculate stationary loudness.

```
fileReader = dsp.AudioFileReader('Engine-16-44p1-stereo-20sec.wav');
```

```
frameDur = 0.05;
```

```
fileReader.SamplesPerFrame = round(fileReader.SampleRate*frameDur);
```

Create an `audioDeviceWriter` object to write audio to your default output device.

```
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

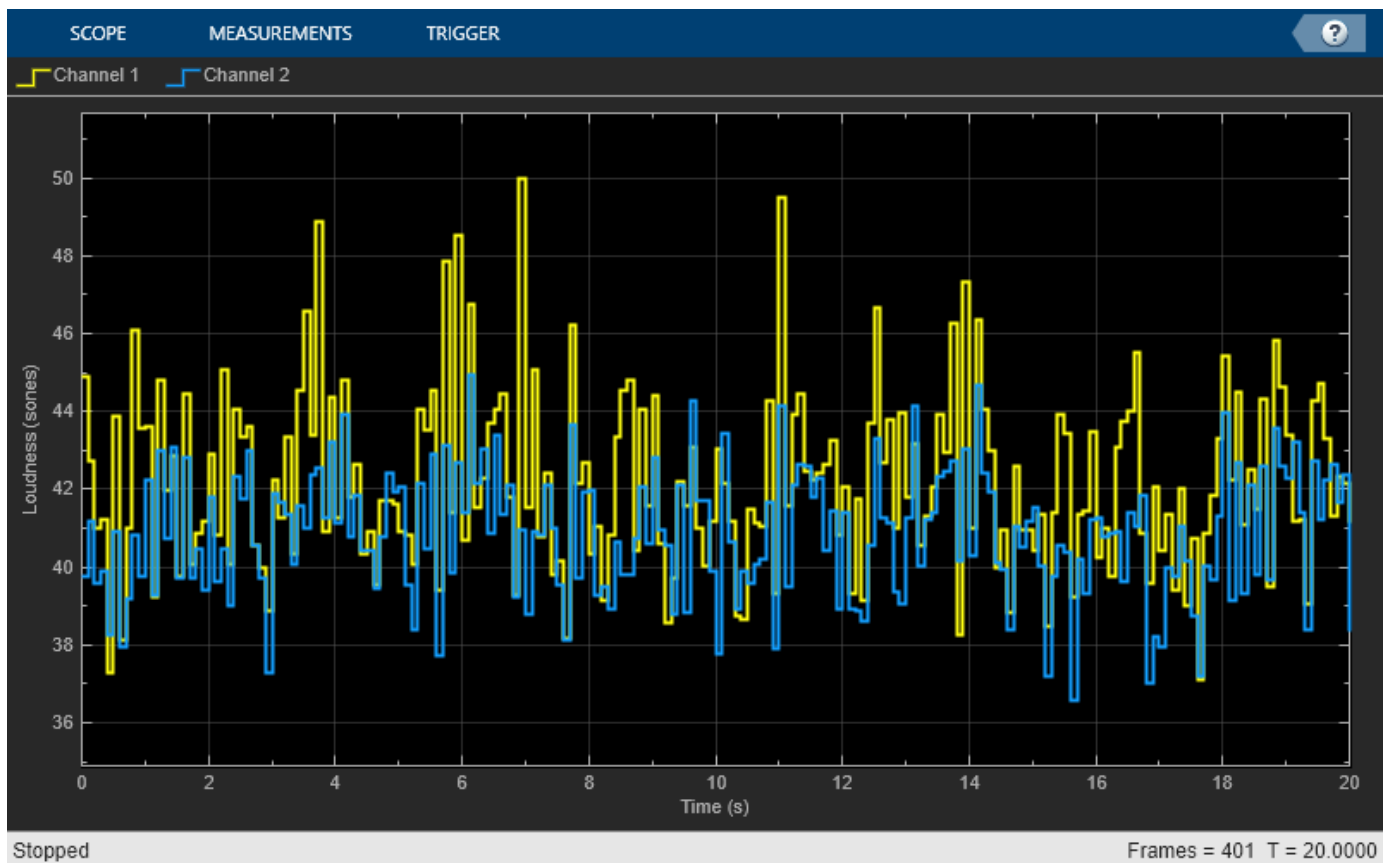
Create a `timescope` object to display stationary loudness over time.

```
scope = timescope( ...
    'SampleRate',1/frameDur, ...
    'YLabel','Loudness (sones)', ...
    'ShowGrid',true, ...
    'PlotType','Stairs', ...
    'TimeSpanSource','property', ...
    'TimeSpan',20, ...
    'AxesScaling','Auto', ...
    'ShowLegend',true);
```

In a loop:

- 1 Read a frame from the audio file.
- 2 Calculate the stationary loudness of that frame.
- 3 Play the sound through your output device.
- 4 Write the loudness to the scope.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    loudness = acousticLoudness(audioIn,fileReader.SampleRate);
    deviceWriter(audioIn);
    scope(loudness)
end
release(fileReader)
release(deviceWriter)
release(scope)
```



Input Arguments

audioIn — Audio input

column vector | 2-column matrix

Audio input, specified as a column vector (mono) or matrix with two columns (stereo).

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate in Hz, specified as a positive scalar. The recommended sample rate for new recordings is 48 kHz.

Note The minimum acceptable sample rate is 8 kHz.

Data Types: `single` | `double`

calibrationFactor — Microphone calibration factor

`sqrt(8)` | positive scalar

Microphone calibration factor, specified as a positive scalar. The default calibration factor corresponds to a full-scale 1 kHz sine wave with a sound pressure level of 100 dB (SPL). To compute the calibration factor specific to your system, use the `calibrateMicrophone` function.

Data Types: `single` | `double`

SPLIn — Sound pressure level (dB)

1-by-28-by-*C* | 1-by-29-by-*C*

Sound pressure level (SPL) in dB, specified as a 1-by-28-by-*C* array or a 1-by-29-by-*C* array, depending on the `Method`:

- If `Method` is set to `'ISO 532-1'`, specify `SPLIn` as a 1-by-28-by-*C* array, where 28 corresponds to one-third-octave bands between 25 Hz and 12.5 kHz, and *C* is the number of channels.
- If `Method` is set to `'ISO 532-2'`, specify `SPLIn` as a 1-by-29-by-*C* array, where 29 corresponds to one-third-octave bands between 25 Hz and 16 kHz, and *C* is the number of channels.

For both methods, the SPL input should be measured with a flat frequency weighting (Z-weighting).

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `acousticLoudness(audioIn,fs,'Method','ISO 532-2')`

Method — Loudness calculation method

`'ISO 532-1'` (default) | `'ISO 532-2'`

Loudness calculation method, specified as `'ISO 532-1'` [1] or `'ISO 532-2'` [2].

Note Only in the ISO 532-1 method, output is reported for each channel independently, and stationary signals are processed after discarding up to the first 0.2 seconds of the signal at the output of the internal 1/3-octave filters.

Data Types: char | string

TimeVarying — Input is time-varying

false (default) | true

Input is time-varying, specified as true or false.

Dependencies

To set TimeVarying to true, you must set Method to 'ISO 532-1'.

Data Types: logical

SoundField — Sound field of audio recording

'free' (default) | 'diffuse' | 'eardrum' | 'earphones'

Sound field of audio recording, specified as a character vector or scalar string. The possible values for SoundField depend on the Method:

- 'ISO 532-1' -- 'free', 'diffuse'
- 'ISO 532-2' -- 'free', 'diffuse', 'eardrum', 'earphones'

Data Types: char | string

EarphoneResponse — Earphone response

[0, 0] (default) | M -by-2 matrix

Earphone response, specified as an M -by-2 matrix containing M frequency-amplitude pairs that describe the earphone's deviations from a flat response. The form is as specified in an ISO 11904-1:2002 earphone correction file. Specify the frequency in increasing order in Hz. Specify the amplitude deviation in decibels. Intermediate values are computed by linear interpolation. Values out of the given range are set to the nearest frequency-amplitude pair. The default value corresponds to a flat response.

Dependencies

To specify EarphoneResponse, you must set SoundField to 'earphones'.

Data Types: single | double

PressureReference — Reference pressure (Pa)

20e-6 (default) | positive scalar

Reference pressure for dB calculation in pascals, specified as a positive scalar. The default value, 20 micropascals, is the common value for air.

Dependencies

PressureReference is only used for time-domain input signals.

Data Types: single | double

Percentiles — Percentiles at which to calculate percentile loudness

[0, 5] (default) | vector with values in the range [0, 100]

Percentiles at which to calculate percentile loudness, specified as a vector with values in the range [0, 100]. The defaults, 0 and 5, correspond to the N_{\max} and N_5 percentiles, respectively [1].

Percentile loudness refers to the loudness that is reached or exceeded in $X\%$ of the measured time intervals, where X is the specified percentile.

Data Types: `single` | `double`

TimeResolution — Time resolution of the output

`'standard'` (default) | `'high'`

Time resolution of the output, specified as a character vector or scalar string. The time interval is 2 ms in `'standard'` resolution, or 0.5 ms in `'high'` resolution. The default is `'standard'` (ISO 532-1 compliant).

Data Types: `char` | `string`

Output Arguments

Loudness — Loudness (sones)

K -by-1 | K -by-2

Loudness in sones, returned as a K -by-1 column vector or K -by-2 matrix of independent channels. If `TimeVarying` is set to `false`, K is equal to 1. If `TimeVarying` is set to `true`, then loudness is computed every 2 ms. If `Method` is set to `'ISO 532-2'`, then loudness is computed using a binaural model and always returned as a K -by-1 column vector.

specificLoudness — Specific loudness

K -by-240-by- C | K -by-372-by- C

Specific loudness, returned as a K -by-240-by- C array or a K -by-372-by- C array. The first dimension of specific loudness, K , matches the first dimension of `loudness`. The third dimension of specific loudness, C , matches the second dimension of `loudness`. The second dimension of specific loudness depends on the `Method` used to calculate loudness:

- If `Method` is set to `'ISO 532-1'`, then specific loudness is reported in sones/Bark on a scale from 0.1 to 24, inclusive, in 0.1 increments.
- If `Method` is set to `'ISO 532-2'`, then specific loudness is reported in sones/Cam on a scale from 1.8 to 38.9, inclusive, in 0.1 increments.

perc — Percentile loudness (sones)

p -by-1 vector (mono input) | p -by-2 matrix (stereo input)

Percentile loudness in sones, returned as a p -by-1 vector or p -by-2 matrix. The number of rows, p , is equal to the number of Percentiles.

Percentile loudness refers to the loudness that is reached or exceeded in $X\%$ of the measured time intervals, where X is the specified percentile.

Dependencies

The percentiles output argument is valid only if `TimeVarying` is set to `true`. If `TimeVarying` is set to `false`, the `perc` output is empty.

Algorithms

Loudness and loudness level are perceptual attributes of sound. Due to differences among people, measurements of loudness and loudness level should be considered statistical estimators. The ISO

532 series specifies procedures for estimating loudness and loudness level as perceived by persons with ontologically normal hearing under specific listening conditions.

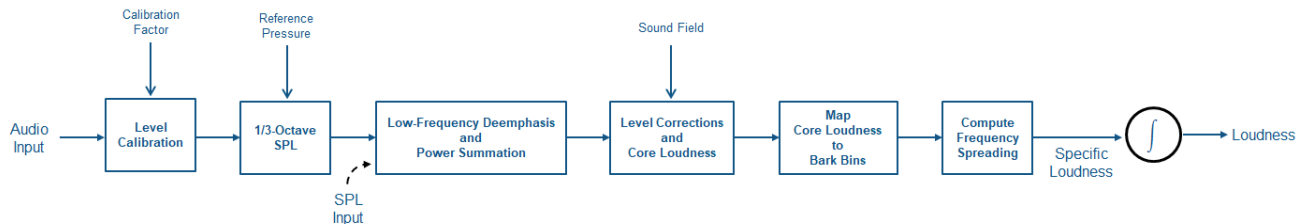
ISO 532-1 and ISO 532-2 specify two different methods for calculating loudness, but leave it to the user to select the appropriate method for a given situation.

ISO 532-1:2017(E) - Zwicker Method

ISO 532-1:2017(E) describes methods for calculating acoustic loudness of stationary and time-varying signals.

Stationary Signals

This method is based on DIN 45631:1991. The algorithm differs from ISO 532:1975, method B, by specifying corrections for low frequencies.

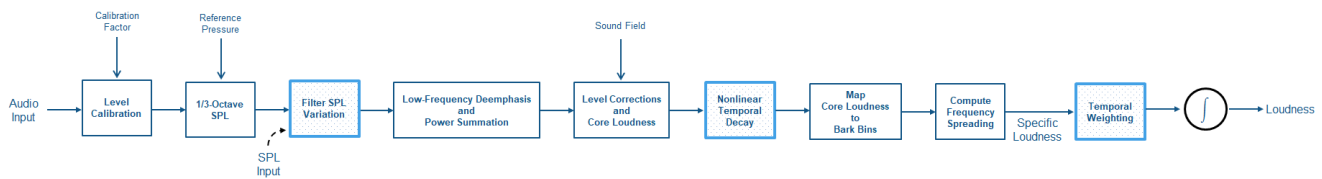


The diagram and the steps provide a high-level overview of the sequence of the method. For details, see [1].

- 1 The time-domain signal level is adjusted according to the `CalibrationFactor`. The following steps of the algorithm assume a true known signal level.
- 2 The signal is transformed to a 1/3 octave SPL representation using fractional octave band filtering. The filter bank consists of 28 filters between 25 Hz to 12.5 kHz. The output from this stage is in dB and normalized by the reference pressure.
- 3 Low frequency 1/3 octave bands are de-emphasized according to a fixed weighting table. Some of the low-frequency bands are combined to form a total of 20 critical bands.
- 4 The levels of the critical bands are corrected for filter bandwidth and the critical band level at the threshold of quiet, and then transformed to core loudness.
- 5 Core loudness is mapped to Bark bins.
- 6 Frequency spreading is computed using a table of level- and frequency-dependent slopes.
- 7 Loudness is calculated as the integral of specific loudness, taking into account the frequency-spreading slopes.

Time-Varying Signals

This method is based on DIN 45631/A1:2010, and is designed to properly simulate the duration-dependent behavior of loudness perception for short impulses. The method for time-varying sounds is a generalization of the Zwicker approach to stationary signals. If the generalized version is applied to stationary sounds, it gives the same loudness values as the non-generalized form for stationary signals.

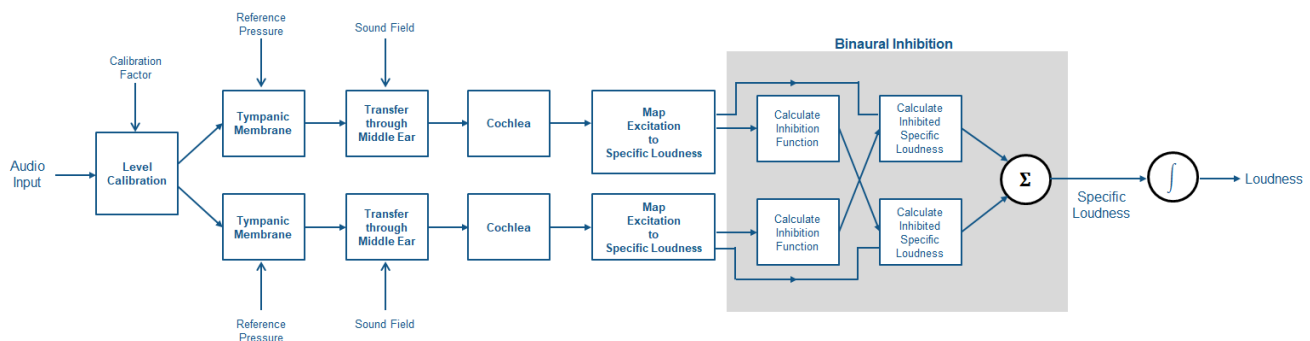


The diagram and the steps provide a high-level overview of the sequence of the method. For details, see [1].

- 1 The time-domain signal level is adjusted according to the **CalibrationFactor**. The following steps of the algorithm assume a true known signal level.
- 2 The signal is transformed to a 1/3 octave SPL representation using fractional octave band filtering. The filter bank consists of 28 filters between 25 Hz to 12.5 kHz. The output from this stage is in dB and normalized by the reference pressure.
- 3 The SPL bands are smoothed along time according to band-dependent filters.
- 4 Low frequency 1/3 octave bands are de-emphasized according to a fixed weighting table. Some of the low-frequency bands are combined to form a total of 20 critical bands.
- 5 The levels of the critical bands are corrected for filter bandwidth and the critical band level at the threshold of quiet, and then transformed to core loudness.
- 6 Nonlinear temporal decay is simulated using a diode-capacitor-resistor network. This models the steep perceptual drop after short signals when compared to long signals.
- 7 Core loudness is mapped to Bark bins.
- 8 Frequency spreading is computed using a table of level- and frequency-dependent slopes.
- 9 Temporal weighting is applied to simulate the duration-dependence of loudness perception.
- 10 Loudness is calculated as the integral of specific loudness, taking into account the frequency-spreading slopes.

ISO 532-2:2017(E) - Moore-Glasberg Method

ISO 532-2:2017(E) describes a binaural model for calculating acoustic loudness of stationary signals. The method in ISO 532-2 differs from those in ISO 532:1975: it improves the calculated loudness in the low frequency range and the binaural model allows for different sounds for each ear. ISO 532-2 provides a good match to the equal loudness level contours defined in ISO 226:2003, and the threshold of hearing defined in ISO 389-7:2005.



The diagram and the steps provide a high-level overview of the sequence of the method. For details, see [2].

- 1** The time-domain signal level is adjusted according to the `CalibrationFactor`. The following steps of the algorithm assume a true known signal level.
- 2** The signal is transformed to a spectral representation. The spectral representation is transformed according to fixed filters representing the transfer of sound through the tympanic membrane (eardrum). The spectrum is scaled according to the reference pressure.
- 3** The signal is transformed using a model of the inner ear. Again, the transfer function is given by a fixed filter specified in the standard. The filter choice depends on the specified sound field.
- 4** The signal is transformed from the sound spectrum to an excitation pattern at the basilar membrane. The transformation is accomplished using a series of rounded-exponential filters spread on the ERB scale.
- 5** The excitation pattern is converted to specific loudness.
- 6** The specific loudness is passed through a model of binary inhibition, where a signal at one ear inhibits the loudness evoked by a signal at the other ear. The output from this stage is the specific loudness in sones/ERB.
- 7** The specific loudness is integrated over the ERB scale to give the loudness in sones.

References

- [1] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [2] ISO 532-2:2017(E). "Acoustics - Methods for calculating loudness - Part 2: Moore-Glasberg method." *International Organization for Standardization*.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`splMeter` | `acousticSharpness` | `calibrateMicrophone` | `sone2phon` | `phon2sone` | `acousticFluctuation` | `acousticRoughness`

Topics

"Effect of Soundproofing on Perceived Noise Levels"

Introduced in R2020a

acousticSharpness

Perceived sharpness of acoustic signal

Syntax

```
sharpness = acousticSharpness(audioIn,fs)
sharpness = acousticSharpness(audioIn,fs,calibrationFactor)
sharpness = acousticSharpness(SPLIn)
sharpness = acousticSharpness(specificLoudnessIn)
sharpness = acousticSharpness( ____,Name,Value)
acousticSharpness( ____,TimeVarying,true)
```

Description

`sharpness = acousticSharpness(audioIn,fs)` returns sharpness in acum according to DIN 45692 [2] and ISO 532-1:2017(E) [1].

`sharpness = acousticSharpness(audioIn,fs,calibrationFactor)` specifies a nondefault microphone calibration factor used to compute loudness.

`sharpness = acousticSharpness(SPLIn)` computes sharpness using one-third-octave-band sound pressure levels (SPL).

`sharpness = acousticSharpness(specificLoudnessIn)` computes sharpness using specific loudness.

`sharpness = acousticSharpness(____,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Example: `sharpness = acousticSharpness(audioIn,fs,calibrationFactor,'SoundField','diffuse')` returns sharpness assuming a diffuse sound field.

`acousticSharpness(____,TimeVarying,true)` with no output arguments plots sharpness relative to time.

Examples

Acoustic Sharpness of Audio Signal

Compute the acoustic sharpness of turbine noise. Assume it is stationary and was recorded in a diffuse sound field.

```
[audioIn,fs] = audioread('Turbine-16-44p1-mono-22secs.wav');
sharpness = acousticSharpness(audioIn,fs,'SoundField','diffuse');
fprintf('Acoustic sharpness = %0.2f acum\n',sharpness)
Acoustic sharpness = 1.11 acum
```

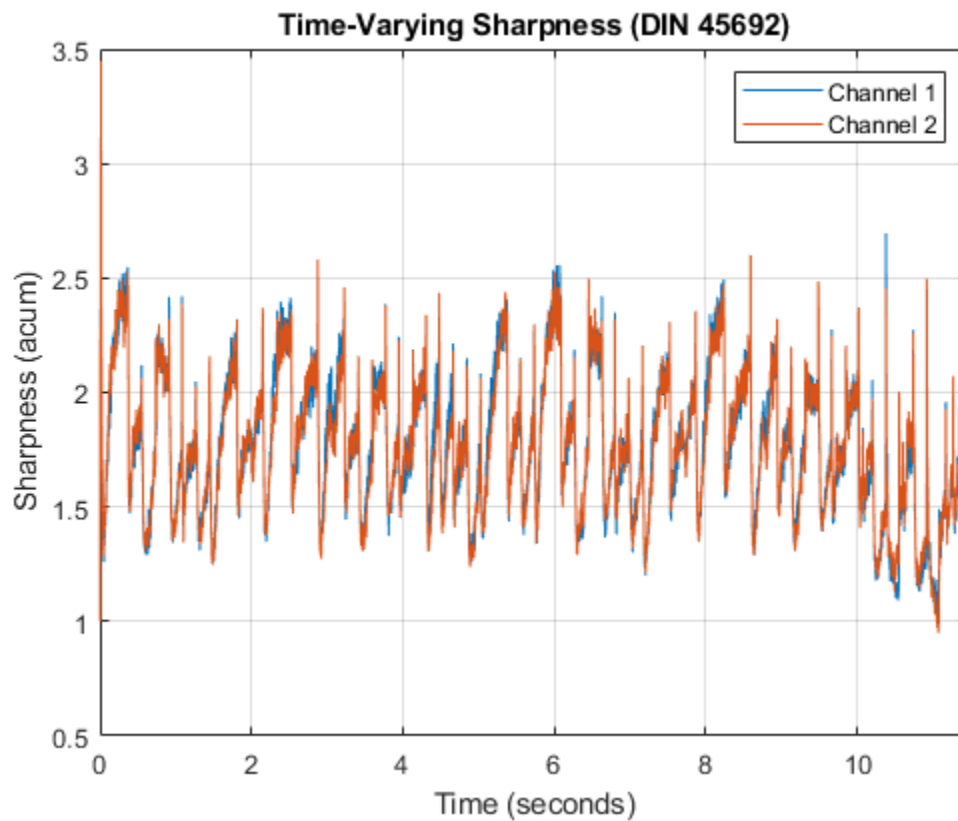
Time-Varying Sharpness

Read in an audio signal.

```
[audioIn,fs] = audioread('RockDrums-48-stereo-11secs.mp3');
```

Plot the time-varying sharpness of the signal. Listen to the signal.

```
acousticSharpness(audioIn,fs,'TimeVarying',true)
```



```
sound(audioIn,fs)
```

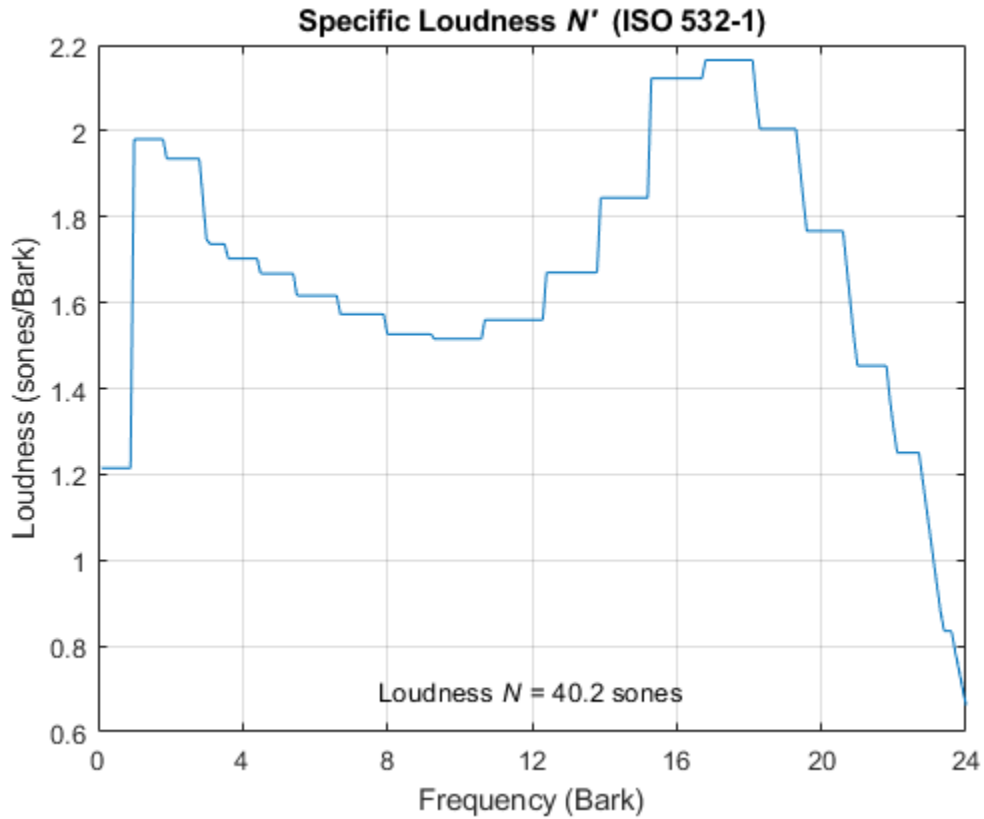
Measure Loudness and Sharpness of Stationary Signals

Create two stationary signals with equivalent power: a pink noise signal and a white noise signal.

```
fs = 48e3;
dur = 5;
pnoise = 2*pinknoise(dur*fs);
wnoise = rand(dur*fs,1) - 0.5;
wnoise = wnoise*sqrt(var(pnoise)/var(wnoise));
```

Call `acousticLoudness` using the default ISO 532-1 (Zwicker) method and no output arguments to plot the loudness of the pink noise. Call `acousticLoudness` again, this time with output arguments, to get the specific loudness.

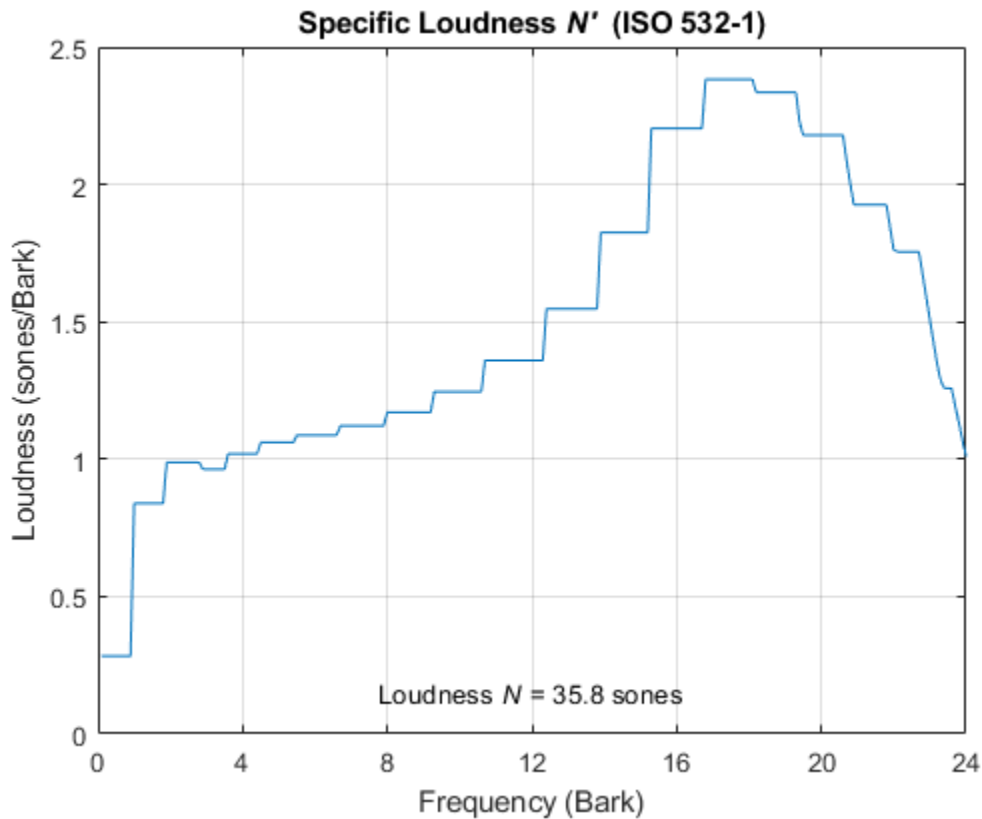
```
figure  
acousticLoudness(pnoise, fs)
```



```
[~,pSpecificLoudness] = acousticLoudness(pnoise, fs);
```

Plot the loudness for the white noise signal and then get the specific loudness values.

```
figure  
acousticLoudness(wnoise, fs)
```



```
[~,wSpecificLoudness] = acousticLoudness(wnoise,fs);
```

Call the `acousticSharpness` function to compare the sharpness of the pink noise and white noise.

```
pSharpness = acousticSharpness(pSpecificLoudness);
wSharpness = acousticSharpness(wSpecificLoudness);
fprintf('Sharpness of pink noise = %0.2f acum\n',pSharpness)
```

```
Sharpness of pink noise = 2.00 acum
```

```
fprintf('Sharpness of white noise = %0.2f acum\n',wSharpness)
```

```
Sharpness of white noise = 2.62 acum
```

Effect of Input Levels on Acoustic Sharpness

Create a pink noise signal with a 48 kHz sample rate and a duration of 5 seconds.

```
fs = 48e3;
n = fs*5;
pnoise = pinknoise(n);
```

Specify a vector to sweep over the dB range from -60 to 20. Create a gain vector which, when multiplied by the original signal, results in a signal with the desired output level.

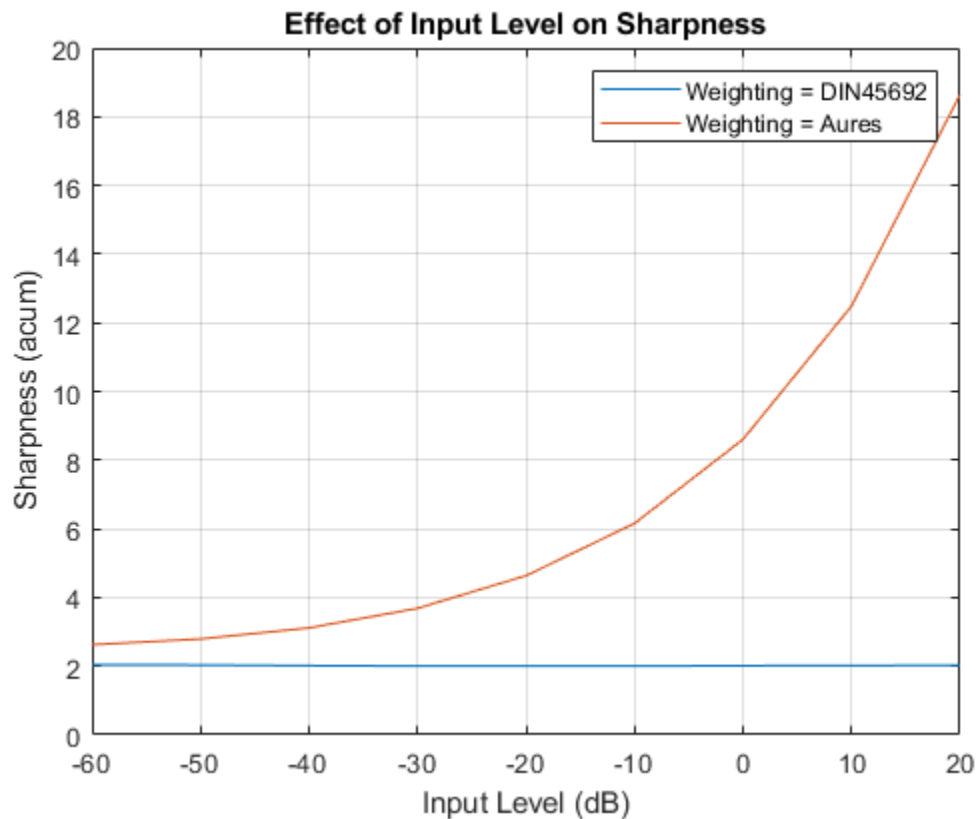
```
dB Sweep = -60:10:20;
coefSweep = sqrt((10.^(dB Sweep/10))/var(pnoise));
```

Call `acousticSharpness` in a loop with the different signal levels. Determine the sharpness using the default DIN 45692 frequency weighting and the Aures frequency weighting.

```
sharpnessDIN45692 = zeros(numel(dBSweep),1);
sharpnessAures = zeros(numel(dBSweep),1);
for ii = 1:numel(dBSweep)
    signal = pnoise*coefSweep(ii);
    sharpnessDIN45692(ii) = acousticSharpness(signal,fs);
    sharpnessAures(ii) = acousticSharpness(signal,fs,'Weighting','Aures');
end
```

Display the effect of the input level on the acoustic sharpness. The Aures frequency weighting method is more sensitive to the input level.

```
plot(dBSweep,sharpnessDIN45692,dBSweep,sharpnessAures)
legend('Weighting = DIN45692','Weighting = Aures')
xlabel('Input Level (dB)')
ylabel('Sharpness (acum)')
title('Effect of Input Level on Sharpness')
axis([dBSweep(1) dB Sweep(end) 0 20])
grid on
```



Compare Time-Varying Sharpness of Music Genres

Read in two audio files: one of an electric guitar with distortion and one of an acoustic guitar. Both audio files have a sample rate of 44.1 kHz. For easy comparison, convert the rock guitar signal to mono and shorten the soft guitar signal to the length of the rock guitar signal.

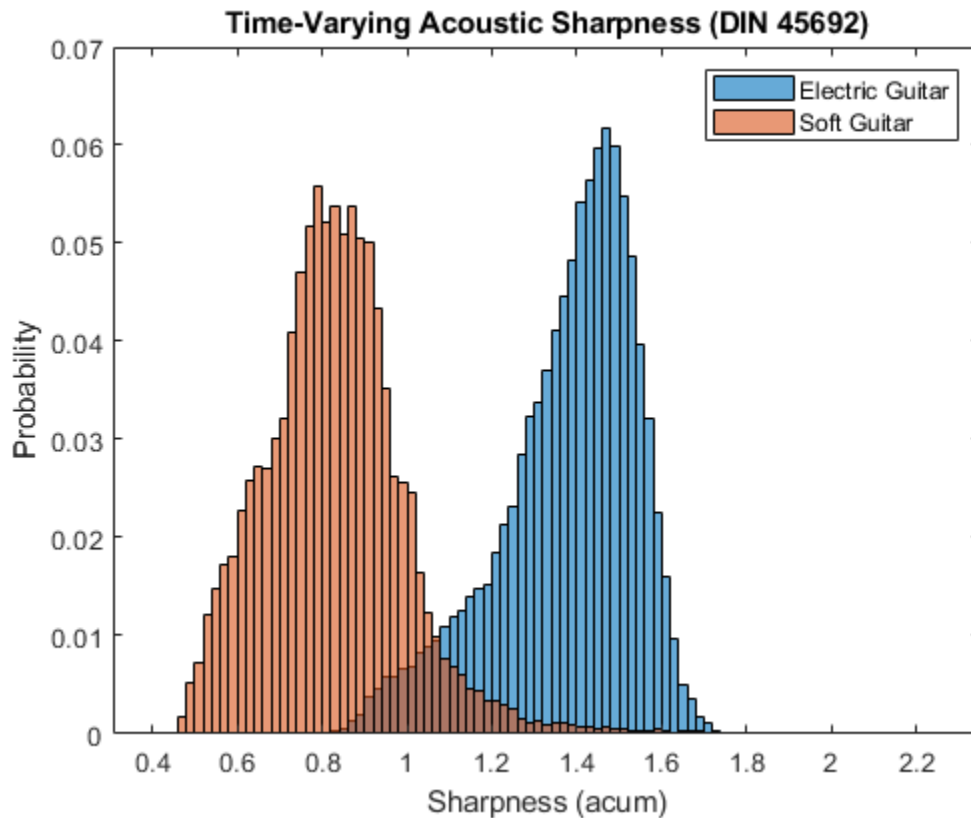
```
fs = 44.1e3;
rockGuitar = audioread('RockGuitar-16-44p1-stereo-72secs.wav');
softGuitar = audioread('SoftGuitar-44p1_mono-10mins.ogg');
rockGuitar = mean(rockGuitar,2);
softGuitar = softGuitar(1:numel(rockGuitar));
```

Calculate the time-varying sharpness for both the rock guitar and soft guitar.

```
rGSharpness = acousticSharpness(rockGuitar,fs,'TimeVarying',true);
sGSharpness = acousticSharpness(softGuitar,fs,'TimeVarying',true);
```

Plot the probability distribution based on the observed sharpness of the rock guitar and the soft guitar.

```
histogram(rGSharpness,'Normalization','probability')
hold on
histogram(sGSharpness,'Normalization','probability')
legend('Electric Guitar','Soft Guitar')
xlabel('Sharpness (acum)')
ylabel('Probability')
title('Time-Varying Acoustic Sharpness (DIN 45692)')
```



Measure Acoustic Sharpness from Sound Pressure Level

Read in an audio file.

```
[audioIn,fs] = audioread('Turbine-16-44p1-mono-22secs.wav');
```

To calculate sound pressure levels from an audio signal, first create an `splMeter` object. Call the `splMeter` object with the audio input.

```
spl = splMeter("SampleRate",fs,"Bandwidth","1/3 octave",...
    "FrequencyWeighting","Z-weighting","OctaveFilterOrder",6);
```

```
splMeasurement = spl(audioIn);
```

Compute the mean SPL level, skipping the first 0.2 seconds. Only keep the bands from 25 Hz to 12.5 kHz (the first 28 bands).

```
SPLIn = mean(splMeasurement(ceil(0.2*fs):end,1:28));
```

To determine the acoustic sharpness of the audio signal, call `acousticSharpness` using the sound pressure level input.

```
sharpness = acousticSharpness(SPLIn)
```

```
sharpness = 1.1020
```

Input Arguments

audioIn — Audio input

column vector | 2-column matrix

Audio input, specified as a column vector (mono) or matrix with two columns (stereo). Sharpness is computed for each channel (column) independently.

Data Types: `single` | `double`

fs — Sample rate (Hz)

positive scalar

Sample rate in Hz, specified as a positive scalar. The recommended sample rate for new recordings is 48 kHz.

Note The minimum acceptable sample rate is 8 kHz.

Data Types: `single` | `double`

calibrationFactor — Microphone calibration factor

$\sqrt{8}$ | positive scalar

Microphone calibration factor, specified as a positive scalar. The default calibration factor corresponds to a full-scale 1 kHz sine wave with a sound pressure level of 100 dB (SPL). To compute the calibration factor specific to your system, use the `calibrateMicrophone` function.

Data Types: `single` | `double`

SPLIn — Sound pressure level (dB)

`1-by-28-by-C`

Sound pressure level (SPL) in dB, specified as a `1-by-28-by-C` array. 28 corresponds to one-third-octave bands between 25 Hz and 12.5 kHz. *C* is the number of channels.

Data Types: `single` | `double`

specificLoudnessIn — Specific loudness (sones/Bark)

`T-by-240-by-C`

Specific loudness in sones/Bark, specified as a `T-by-240-by-C` array, where:

- *T* is 1 for stationary signals or one per 2 ms for time-varying signals.
- 240 is the number of Bark bins in the domain for specific loudness. The Bark bins are `0.1:0.1:24`.
- *C* is the number of channels.

You can use the `acousticLoudness` function to calculate `specificLoudnessIn` using this syntax:

```
[~,specificLoudnessIn] = acousticLoudness(audioIn,fs);
```

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `acousticSharpness(audioIn,fs,'Weighting','von Bismarck')`

Weighting — Frequency weighting

`'DIN 45692'` (default) | `'Aures'` | `'von Bismarck'`

Frequency weighting, specified as `'DIN 45692'`, `'Aures'`, or `'von Bismarck'`. By design, the `'Aures'` frequency weighting method is more sensitive to amplitude levels and proper calibration. For details, see “Algorithms” on page 2-627.

Data Types: `char` | `string`

SoundField — Sound field

`'free'` (default) | `'diffuse'`

Sound field of audio recording, specified as `'free'` or `'diffuse'`.

Data Types: `char` | `string`

PressureReference — Reference pressure (Pa)

`20e-6` (default) | positive scalar

Reference pressure for dB calculation in pascals, specified as a positive scalar. The default value, 20 micropascals, is the common value for air.

Data Types: `single` | `double`

TimeVarying — Input is time-varying

`false` (default) | `true`

Input is time-varying, specified as `true` or `false`. If `TimeVarying` is set to `true`, acoustic sharpness is calculated in 2 ms intervals.

Data Types: `logical`

Output Arguments

sharpness — Acoustic sharpness (acum)

`scalar` | `vector` | `matrix`

Acoustic sharpness in acum, returned as a scalar, vector, or matrix. Sharpness is computed according to DIN 45692 and ISO 532-1.

Data Types: `single` | `double`

Algorithms

Acoustic sharpness is a measurement derived from acoustic loudness. The acoustic loudness algorithm is described in [1] and implemented in the `acousticLoudness` function. The acoustic sharpness calculation is described in [2]. The algorithm for acoustic sharpness is outlined as follows.

$$\text{sharpness} = k \left(\frac{\int_{z=0}^{24} N(z) g(z) z \, dz}{\int_{z=0}^{24} N(z) \, dz} \right)$$

Where N' is the specific loudness in sones/Bark. The function $g(z)$ and the scaling factor k depend on the specified `Weighting` method:

'DIN 45692': k is set such that a 1 kHz reference tone results in a 1 acum sharpness measurement, and

$$\begin{aligned} g(z) &= 1 && \text{for } z \leq 15.8 \text{ Bark} \\ g(z) &= 0.15e^{0.42(z - 15.8)} + 0.85 && \text{for } z > 15.8 \text{ Bark} \end{aligned}$$

'von Bismark': k is set to 0.11, and

$$\begin{aligned} g(z) &= 1 && \text{for } z \leq 15 \text{ Bark} \\ g(z) &= 0.2e^{0.308(z - 15)} + 0.8 && \text{for } z > 15 \text{ Bark} \end{aligned}$$

'Aures': k is set to 0.11, and

$$g(z) = 0.078 \left(\frac{e^{0.171z}}{z} \right) \left(\frac{N}{\ln(0.05N + 1)} \right)$$

where

$$N = \int_{z=0}^{24} N'(z) dz$$

References

- [1] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [2] DIN 45692:2009. "Measurement Technique for the Simulation of the Auditory Sensation of Sharpness." *German Institute for Standardization*.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

splMeter | acousticLoudness | calibrateMicrophone | sone2phon | phon2sone | acousticFluctuation | acousticRoughness

Topics

"Effect of Soundproofing on Perceived Noise Levels"

Introduced in R2020a

detectSpeech

Detect boundaries of speech in audio signal

Syntax

```
idx = detectSpeech(audioIn,fs)
idx = detectSpeech(audioIn,fs,Name,Value)
[idx,thresholds] = detectSpeech( ___ )
detectSpeech( ___ )
```

Description

`idx = detectSpeech(audioIn,fs)` returns indices of `audioIn` that correspond to the boundaries of speech signals.

`idx = detectSpeech(audioIn,fs,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Example:

```
detectSpeech(audioIn,fs,'Window',hann(512,'periodic'),'OverlapLength',256)
detects speech using a 512-point periodic Hann window with 256-point overlap.
```

`[idx,thresholds] = detectSpeech(___)` also returns the thresholds used to compute the boundaries of speech.

`detectSpeech(___)` with no output arguments displays a plot of the detected speech regions in the input signal.

Examples

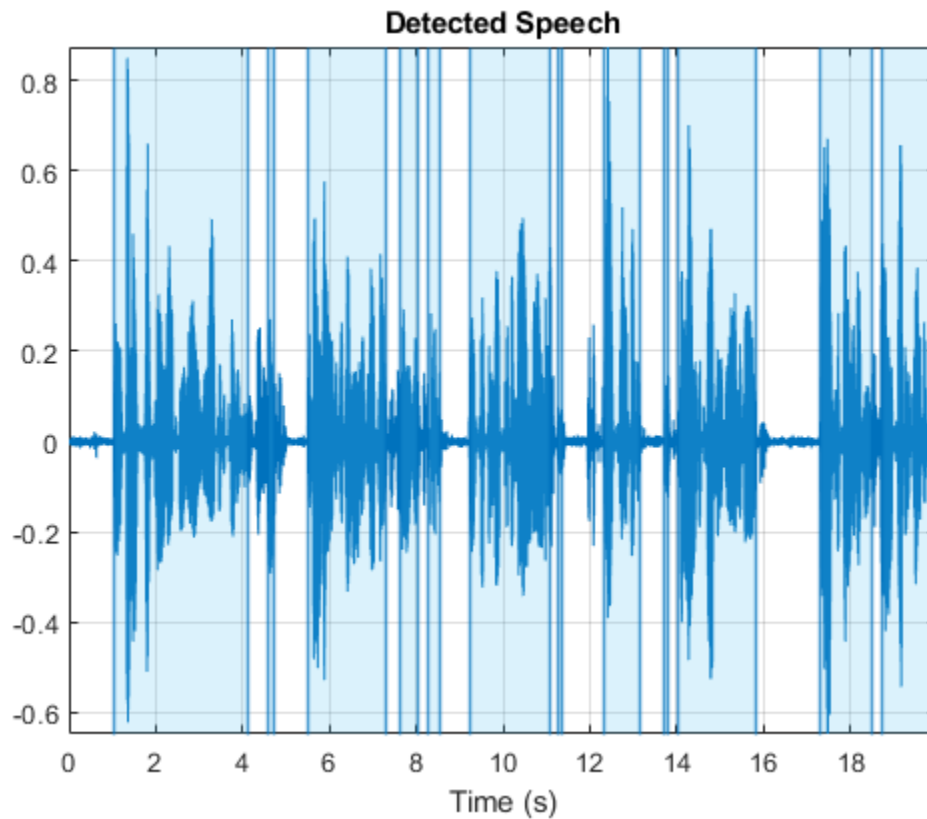
Plot Detected Regions of Speech

Read in an audio signal. Clip the audio signal to 20 seconds.

```
[audioIn,fs] = audioread('Rainbow-16-8-mono-114secs.wav');
audioIn = audioIn(1:20*fs);
```

Call `detectSpeech`. Specify no output arguments to display a plot of the detected speech regions.

```
detectSpeech(audioIn,fs);
```



The `detectSpeech` function uses a thresholding algorithm based on energy and spectral spread per analysis frame. You can modify the `Window`, `OverlapLength`, and `MergeDistance` to fine-tune the algorithm for your specific needs.

```

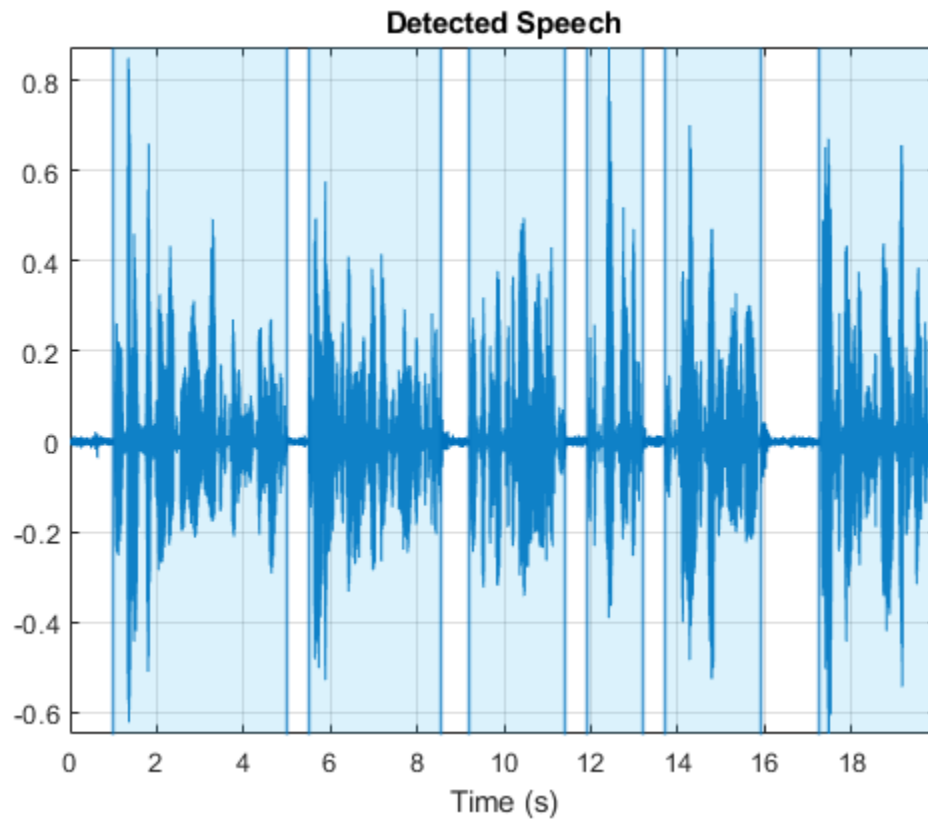
windowDuration = 0.074  ; % seconds
numWindowSamples = round(windowDuration*fs);
win = hamming(numWindowSamples,'periodic');

percentOverlap = 35  ;
overlap = round(numWindowSamples*percentOverlap/100);

mergeDuration = 0.44  ;
mergeDist = round(mergeDuration*fs);

detectSpeech(audioIn,fs,"Window",win,"OverlapLength",overlap,"MergeDistance",mergeDist)

```



Reuse Decision Thresholds

Read in an audio file containing speech. Split the audio signal into a first half and a second half.

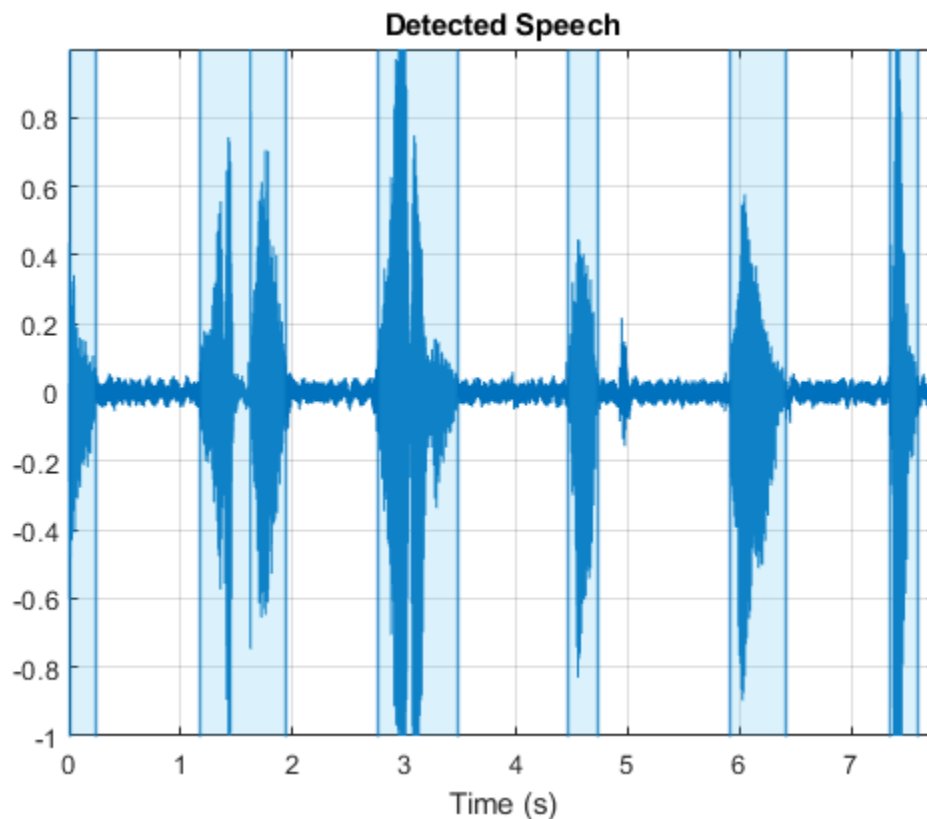
```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
firstHalf = audioIn(1:floor(numel(audioIn)/2));
secondHalf = audioIn(numel(firstHalf):end);
```

Call `detectSpeech` on the first half of the audio signal. Specify two output arguments to return the indices corresponding to regions of detected speech and the thresholds used for the decision.

```
[speechIndices,thresholds] = detectSpeech(firstHalf,fs);
```

Call `detectSpeech` on the second half with no output arguments to plot the regions of detected speech. Specify the thresholds determined from the previous call to `detectSpeech`.

```
detectSpeech(secondHalf,fs,'Thresholds',thresholds)
```



Working with Large Data Sets

Reusing speech detection thresholds provides significant computational efficiency when you work with large data sets, or when you deploy a deep learning or machine learning pipeline for real-time inference. Download and extract the data set [1] on page 2-0 .

```
url = 'https://storage.googleapis.com/download.tensorflow.org/data/speech_commands_v0.01.tar.gz'

downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,'google_speech');

if ~exist(datasetFolder,'dir')
    disp('Downloading data set (1.9 GB) ...')
    untar(url,datasetFolder)
end
```

Create an audio datastore to point to the recordings. Use the folder names as labels.

```
ads = audioDatastore(datasetFolder,'IncludeSubfolders',true,'LabelSource','foldernames');
```

Reduce the data set by 95% for the purposes of this example.

```
ads = splitEachLabel(ads,0.05,'Exclude','_background_noise');
```

Create two datastores: one for training and one for testing.

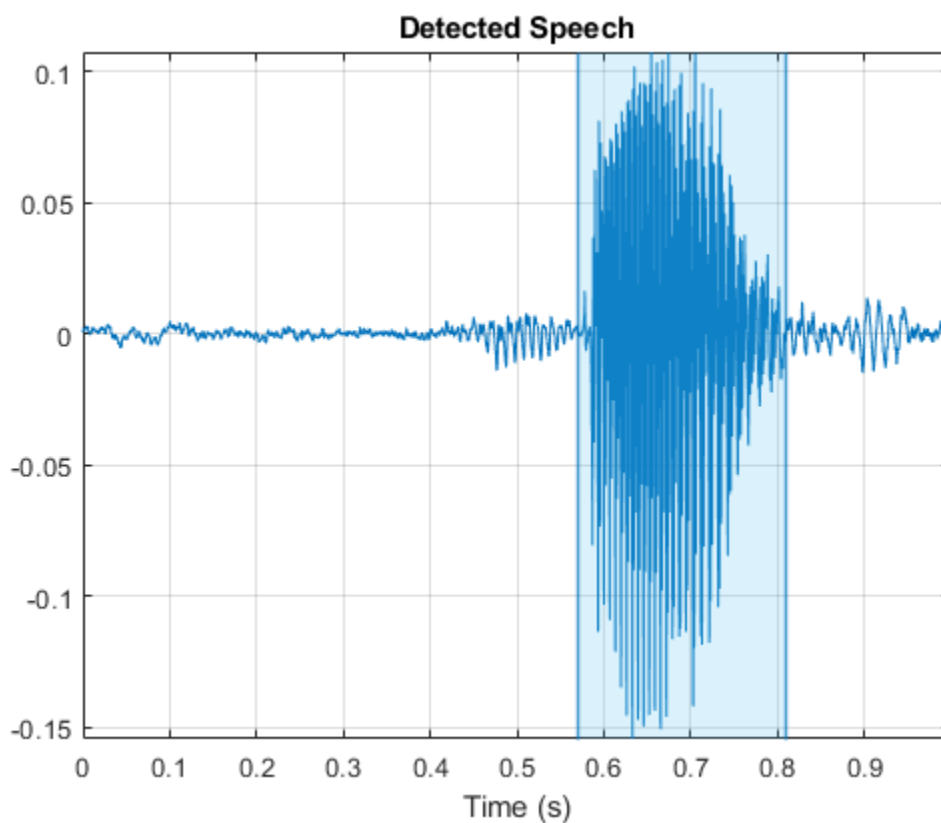
```
[adsTrain,adsTest] = splitEachLabel(ads,0.8);
```

Compute the average thresholds over the training data set.

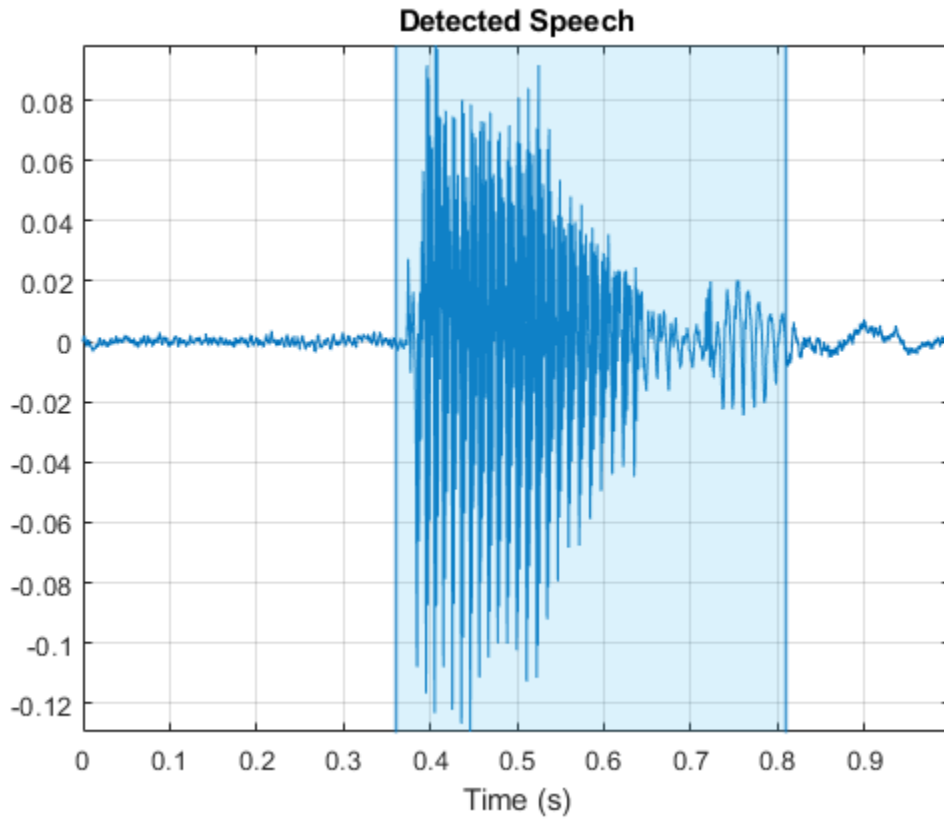
```
thresholds = zeros(numel(adsTrain.Files),2);
for ii = 1:numel(adsTrain.Files)
    [audioIn,adsInfo] = read(adsTrain);
    [~,thresholds(ii,:)] = detectSpeech(audioIn,adsInfo.SampleRate);
end
thresholdAverage = mean(thresholds,1);
```

Use the precomputed thresholds to detect speech regions on files from the test data set. Plot the detected region for three files.

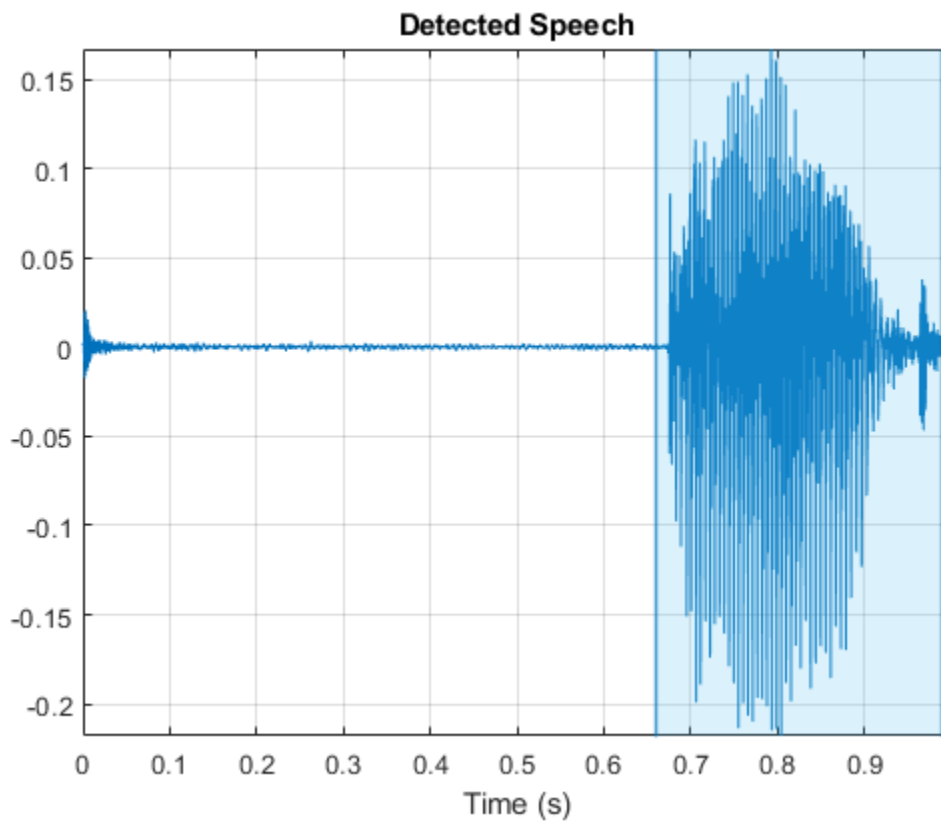
```
[audioIn,adsInfo] = read(adsTest);
detectSpeech(audioIn,adsInfo.SampleRate,'Thresholds',thresholdAverage);
```



```
[audioIn,adsInfo] = read(adsTest);
detectSpeech(audioIn,adsInfo.SampleRate,'Thresholds',thresholdAverage);
```



```
[audioIn,adsInfo] = read(adsTest);  
detectSpeech(audioIn,adsInfo.SampleRate,'Thresholds',thresholdAverage);
```

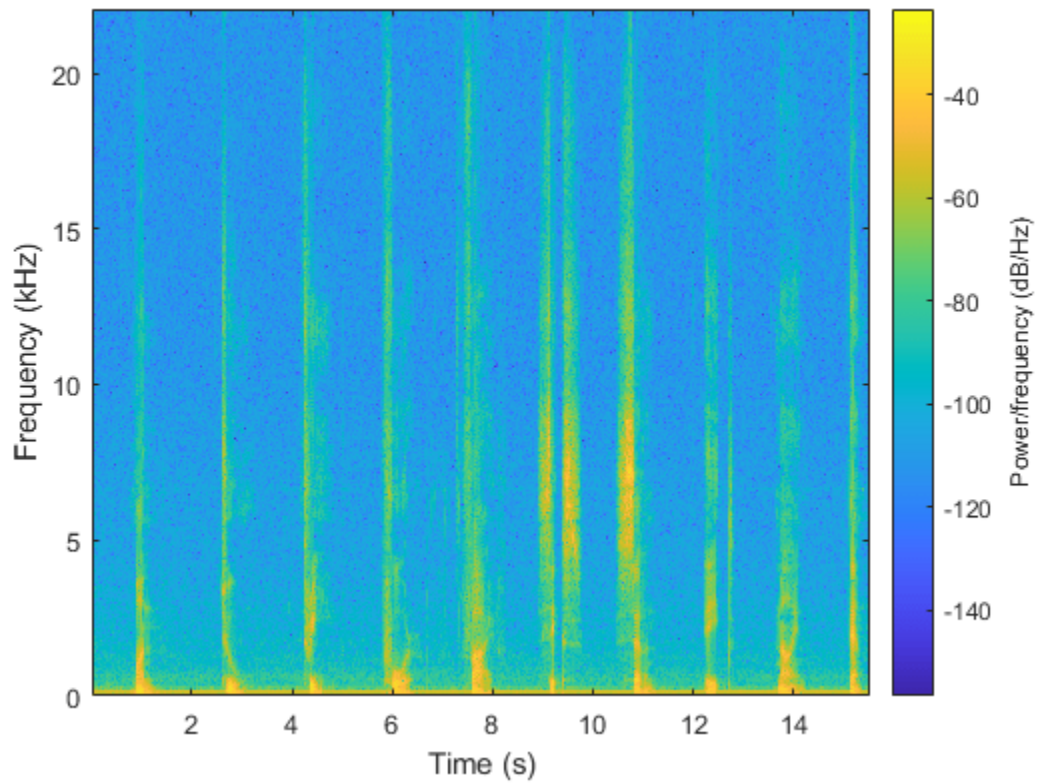
References

[1] Warden, Pete. "Speech Commands: A Public Dataset for Single Word Speech Recognition." Distributed by TensorFlow. Creative Commons Attribution 4.0 License.

Remove Silent Regions from Speech Signal

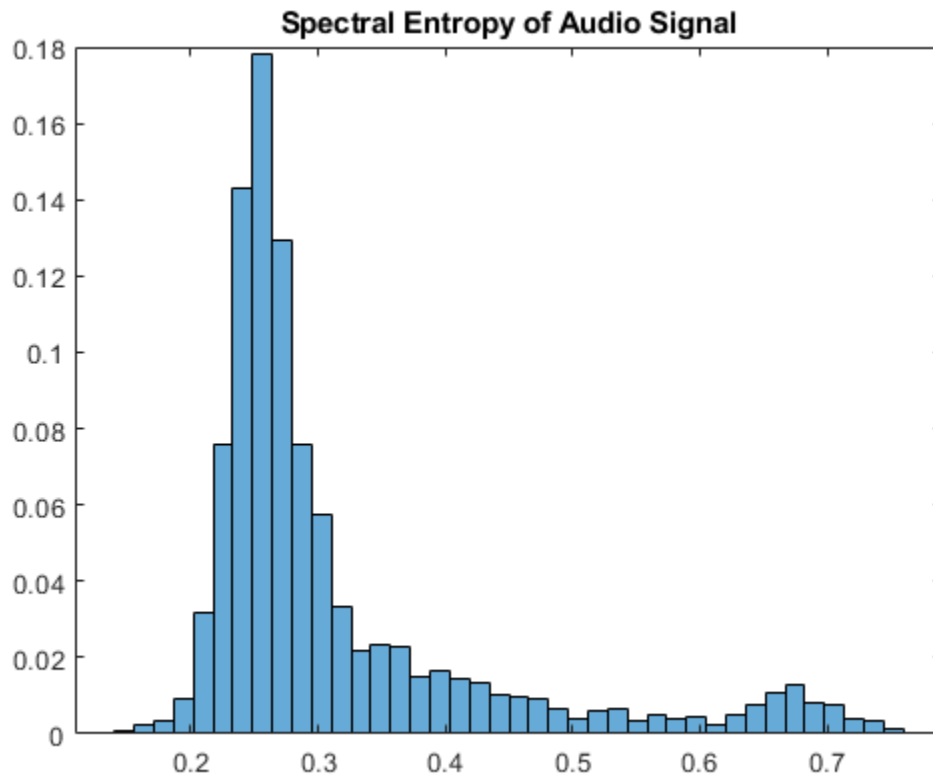
Read in an audio file and listen to it. Plot the spectrogram.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');  
sound(audioIn,fs)  
spectrogram(audioIn,hann(1024,'periodic'),512,1024,fs,'yaxis')
```



For machine learning applications, you often want to extract features from an audio signal. Call the `spectralEntropy` function on the audio signal, then plot the histogram to display the distribution of spectral entropy.

```
entropy = spectralEntropy(audioIn,fs);  
  
numBins = 40;  
histogram(entropy,numBins,'Normalization','probability')  
title('Spectral Entropy of Audio Signal')
```



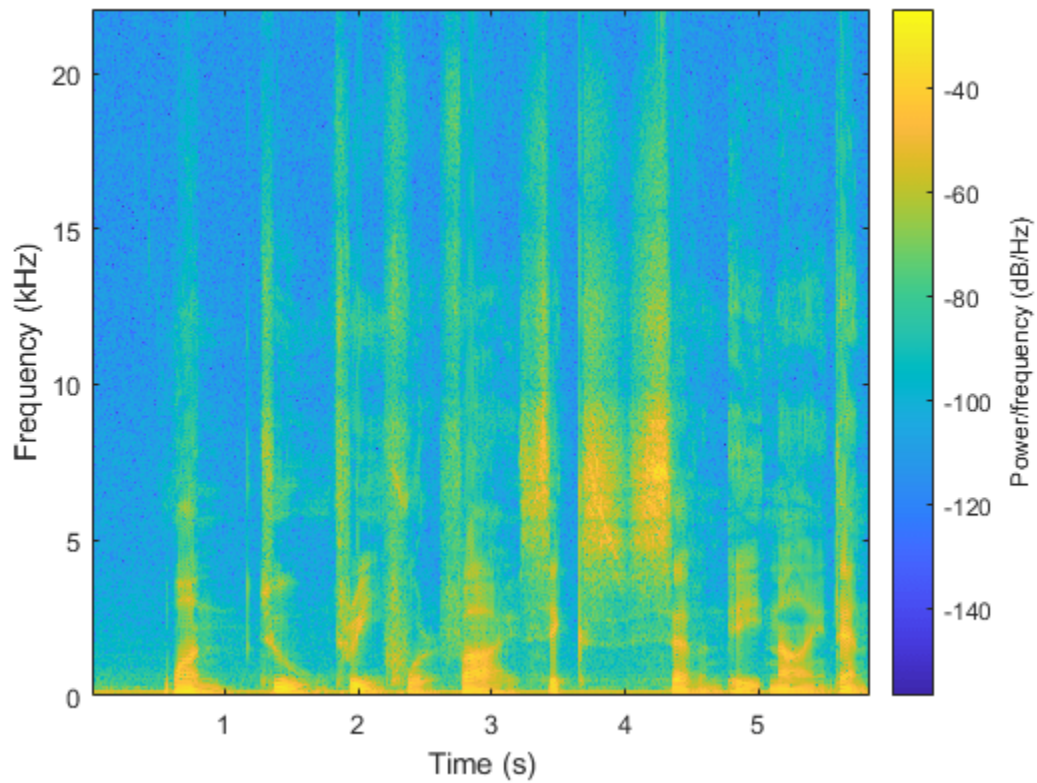
Depending on your application, you might want to extract spectral entropy from only the regions of speech. The resulting statistics are more characteristic of the speaker and less characteristic of the channel. Call `detectSpeech` on the audio signal and then create a new signal that contains only the regions of detected speech.

```
speechIndices = detectSpeech(audioIn, fs);
speechSignal = [];
for ii = 1:size(speechIndices,1)
    speechSignal = [speechSignal; audioIn(speechIndices(ii,1):speechIndices(ii,2))];
end
```

Listen to the speech signal and plot the spectrogram.

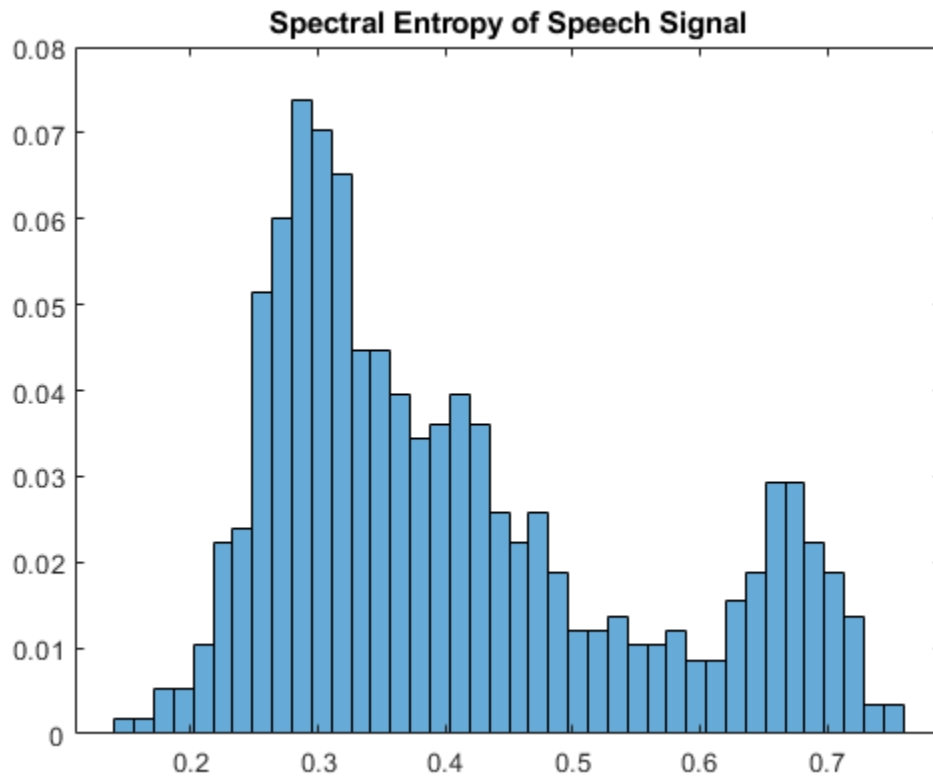
```
sound(speechSignal, fs)
```

```
spectrogram(speechSignal, hann(1024, 'periodic'), 512, 1024, fs, 'yaxis')
```



Call the `spectralEntropy` function on the speech signal and then plot the histogram to display the distribution of spectral entropy.

```
entropy = spectralEntropy(speechSignal,fs);  
  
histogram(entropy,numBins,'Normalization','probability')  
title('Spectral Entropy of Speech Signal')
```



Input Arguments

audioIn — Audio input

column vector

Audio input, specified as a column vector.

Data Types: `single` | `double`

fs — Sample rate (Hz)

scalar

Sample rate in Hz, specified as a scalar.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `detectSpeech(audioIn,fs,'MergeDistance',100)`

Window — Window applied in time domain

`hann(round(0.03*fs), 'periodic')` (default) | vector

Window applied in the time domain, specified as the comma-separated pair consisting of 'Window' and a real vector. The number of elements in the vector must be in the range $[2, \text{size}(\text{audioIn}, 1)]$. The number of elements in the vector must also be greater than `OverlapLength`.

Data Types: `single` | `double`

OverlapLength — Number of samples overlapping between adjacent windows

`0` (default) | scalar in the range $[0, \text{numel}(\text{Window}) - 1]$

Number of samples overlapping between adjacent windows, specified as the comma-separated pair consisting of 'OverlapLength' and an integer in the range $[0, \text{size}(\text{Window}, 1)]$.

Data Types: `single` | `double`

MergeDistance — Number of samples over which to merge positive speech detection decisions

`numel(Window)*5` (default) | nonnegative scalar

Number of samples over which to merge positive speech detection decisions, specified as the comma-separated pair consisting of 'MergeDistance' and a nonnegative scalar.

Note The resolution for speech detection is given by the hop length, where the hop length is equal to $\text{numel}(\text{Window}) - \text{OverlapLength}$.

Data Types: `single` | `double`

Thresholds — Thresholds for decision

2-element vector

Thresholds for decision, specified as the comma-separated pair consisting of 'Thresholds' and a two-element vector.

- If you do not specify `Thresholds`, the `detectSpeech` function derives thresholds by using histograms of the features calculated over the current input frame.
- If you specify `Thresholds`, the `detectSpeech` function skips the derivation of new decision thresholds. Reusing speech decision thresholds provides significant computational efficiency when you work with large data sets, or when you deploy a deep learning or machine learning pipeline for real-time inference.

Data Types: `single` | `double`

Output Arguments**idx — Start and end indices of speech regions**

N -by-2 matrix

Start and end indices of speech regions, returned as an N -by-2 matrix. N corresponds to the number of individual speech regions detected. The first column corresponds to start indices of speech regions and the second column corresponds to end indices of speech regions.

Data Types: `single` | `double`

thresholds — Thresholds used for decision

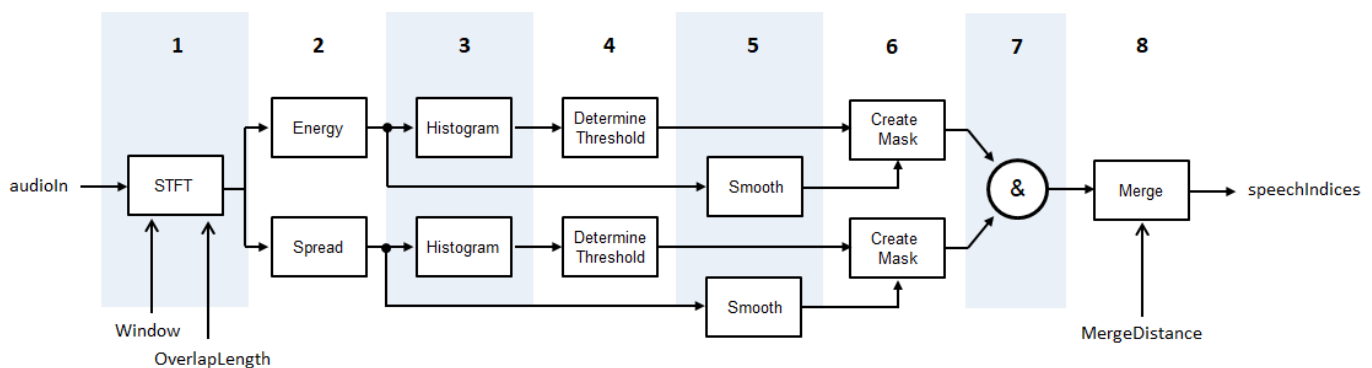
two-element vector

Thresholds used for decision, returned as a two-element vector. The thresholds are in the order [Energy Threshold, Spectral Spread Threshold].

Data Types: single | double

Algorithms

The detectSpeech algorithm is based on [1], although modified so that the statistics to threshold are short-term energy and spectral spread, instead of short-term energy and spectral centroid. The diagram and steps provide a high-level overview of the algorithm. For details, see [1].



- 1 The audio signal is converted to a time-frequency representation using the specified Window and OverlapLength.
- 2 The short-term energy and spectral spread is calculated for each frame. The spectral spread is calculated according to spectralSpread.
- 3 Histograms are created for both the short-term energy and spectral spread distributions.
- 4 For each histogram, a threshold is determined according to $T = \frac{W \times M_1 + M_2}{W + 1}$, where M_1 and M_2 are the first and second local maxima, respectively. W is set to 5.
- 5 Both the spectral spread and the short-term energy are smoothed across time by passing through successive five-element moving median filters.
- 6 Masks are created by comparing the short-term energy and spectral spread with their respective thresholds. To declare a frame as containing speech, a feature must be above its threshold.
- 7 The masks are combined. For a frame to be declared as speech, both the short-term energy and the spectral spread must be above their respective thresholds.
- 8 Regions declared as speech are merged if the distance between them is less than MergeDistance.

References

- [1] Giannakopoulos, Theodoros. "A Method for Silence Removal and Segmentation of Speech Signals, Implemented in MATLAB", (University of Athens, Athens, 2009).

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

This function fully supports GPU arrays. For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`spectralSpread` | `voiceActivityDetector`

Topics

“Keyword Spotting in Noise Using MFCC and LSTM Networks”

Introduced in R2020a

calibrateMicrophone

Calibration factor for microphone

Syntax

```
calibrationFactor = calibrateMicrophone(micRecording, fs, SPLreading)
calibrationFactor = calibrateMicrophone(micRecording, fs, SPLreading,
Name, Value)
```

Description

`calibrationFactor = calibrateMicrophone(micRecording, fs, SPLreading)` returns the calibration factor for the microphone used to create `micRecording`.

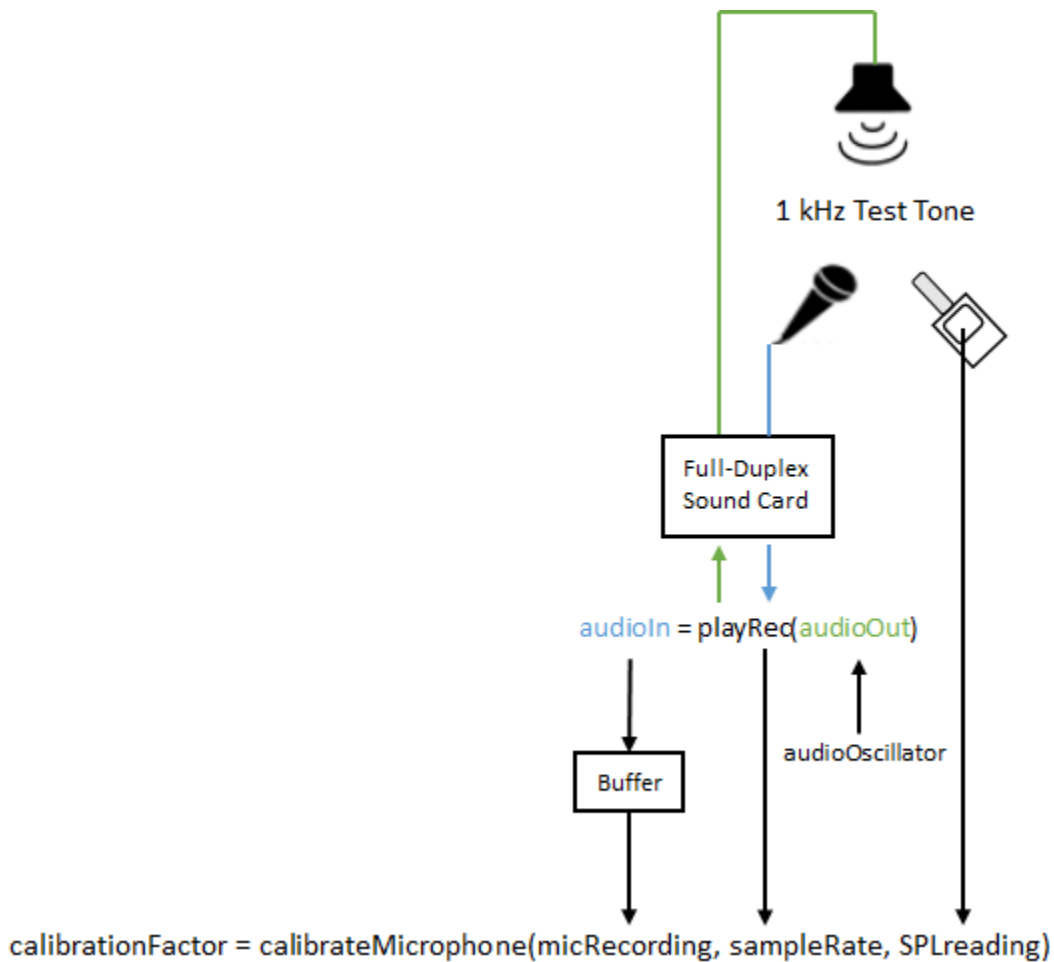
`calibrationFactor = calibrateMicrophone(micRecording, fs, SPLreading, Name, Value)` specifies options using one or more `Name, Value` pair arguments.

Example: `calibrationFactor = calibrateMicrophone(micRecording, fs, SPLreading, 'FrequencyWeighting', 'Z-weighting')` returns the calibration factor for an SPL reading that applies Z-weighting.

Examples

Determine Microphone Calibration Factor

This diagram depicts the setup used in the example:



To run this example, you must connect a microphone and loudspeaker to a full-duplex sound card, and use an SPL meter to determine the true loudness level.

Create an `audioOscillator` object to generate a 1 kHz sine wave at a sample rate of 48 kHz.

```
fs = 48e3;
osc = audioOscillator("sine", 1e3, "SampleRate", fs);
```

Create an `audioPlayerRecorder` object to write the sine wave to your loudspeaker and simultaneously read from your microphone.

```
playRec = audioPlayerRecorder(fs);
```

Create a `dsp.AsyncBuffer` object to store the audio recorded from your microphone. Specify the capacity of the buffer to hold 3 seconds worth of data.

```
dur = 3;
buff = dsp.AsyncBuffer(dur*fs);
```

In a loop, for three seconds:

- Generate a frame of a 1 kHz sinusoid.

- Write the frame to your loudspeaker and simultaneously read a frame from your microphone.
- Write the frame acquired from your microphone to the buffer.

While the loop runs, note the true SPL measurement as reported from your SPL meter. Once complete, read the contents of the buffer object.

```
numFrames = dur*(fs/osc.SamplesPerFrame);  
for ii = 1:numFrames  
    audioOut = osc();  
    audioIn = playRec(audioOut);  
    write(buff,audioIn);  
end  
release(playRec);
```

```
SPL = 78.2; % read from physical SPL meter
```

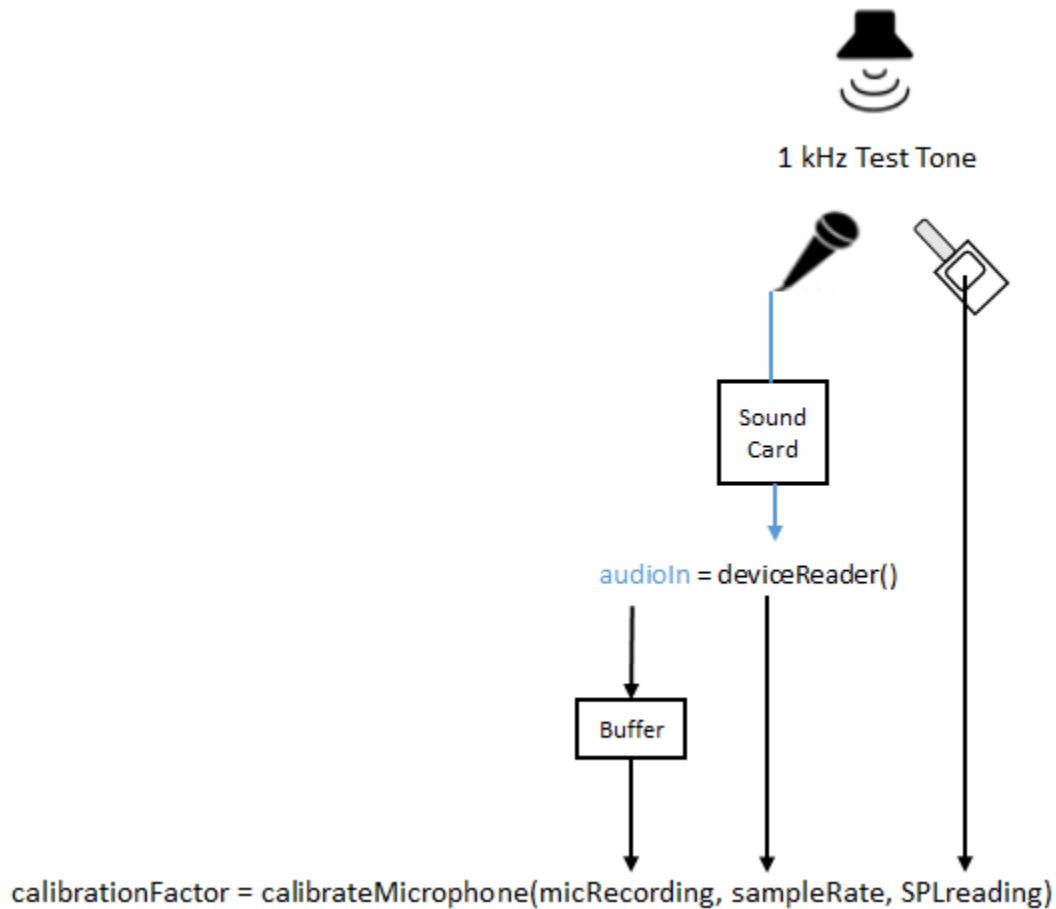
```
micRecording = read(buff);
```

Compute the calibration factor for the microphone.

```
calibrationFactor = calibrateMicrophone(micRecording,playRec.SampleRate,SPL);
```

Calibrate Microphone Using Externally Generated Calibration Tone

The diagram depicts the example setup and data flow.



To run this example, you must connect a microphone to your audio card, generate a 1 kHz tone using an external device, and use an SPL meter to determine the true loudness level.

Specify a 48 kHz sample rate for your audio device and a 3-second duration for acquiring audio. Create an `audioDeviceReader` object to read from your audio device.

```
fs = 48e3;
dur = 3;
```

```
deviceReader = audioDeviceReader(fs);
```

Create a `dsp.AsyncBuffer` object to store the streamed audio.

```
buff = dsp.AsyncBuffer(dur*fs);
```

Start the 1 kHz test tone using an external loudspeaker. Then, in a loop, read from your audio device and then write the data to the buffer. While the loop runs, note the true SPL measurement as reported from your SPL meter. Once complete, read the contents of the buffer object.

```
N = deviceReader.SamplesPerFrame;
while buff.NumUnreadSamples+N <= buff.Capacity
    audioIn = deviceReader();
    write(buff,audioIn);
end
```

```
release(deviceReader);
SPL = 77.7; % read from physical SPL meter
micRecording = read(buff);
Compute the calibration factor for the microphone.
calibrationFactor = calibrateMicrophone(micRecording,deviceReader.SampleRate,SPL);
```

Input Arguments

micRecording — Audio signal used to calibrate microphone

column vector | matrix

Audio signal used to calibrate microphone, specified as a column vector (mono) or matrix of independent channels (stereo). `micRecording` must be acquired from the microphone you want to calibrate. The recording should consist of a 1 kHz test tone.

Data Types: `single` | `double`

fs — Sample rate of microphone recording (Hz)

positive scalar

Sample rate of microphone recording in Hz, specified as a positive scalar. The recommended sample rate for new recordings is 48 kHz.

Data Types: `single` | `double`

SPLreading — Sound pressure level reported from physical meter (dB)

scalar | vector

Sound pressure level reported from meter in dB, specified as a scalar or vector. If `SPLreading` is specified as a vector, it must have the same number of elements as columns in `micRecording`.

Data Types: `single` | `double`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `calibrateMicrophone(micRecording, fs, SPLreading, 'PressureReference', 22)`

PressureReference — Reference pressure (Pa)

$20\text{e-}6$ (default) | positive scalar

Reference pressure for dB calculation in pascals, specified as a positive scalar. The default reference pressure (20 micropascals) is the common value for air.

Data Types: `single` | `double`

FrequencyWeighting — Frequency weighting used by physical meter

'A-weighting' (default) | 'C-weighting' | 'Z-weighting'

Frequency weighting used by physical meter, specified as 'A-weighting', 'C-weighting', or 'Z-weighting'.

Data Types: char | string

Output Arguments

calibrationFactor – Microphone calibration factor

scalar | row vector

Microphone calibration factor, returned as a scalar or row vector with the same number of elements as `SPLreading`.

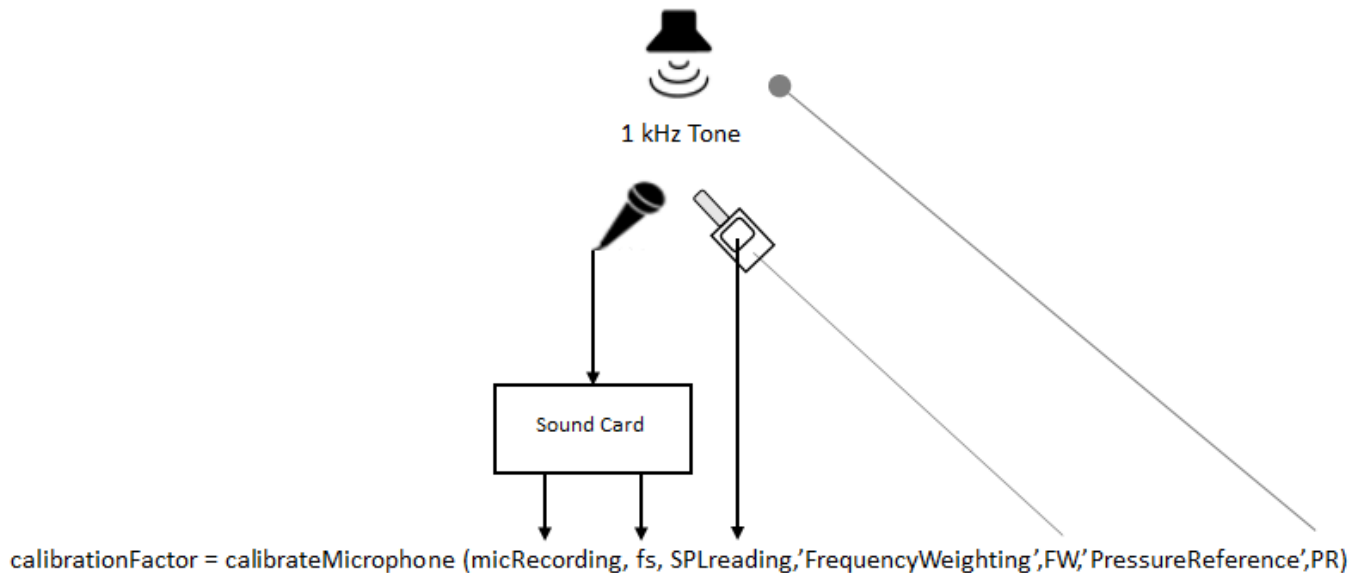
Data Types: single | double

Algorithms

To determine the calibration factor for a microphone, the `calibrateMicrophone` function uses:

- A calibration tone recorded from the microphone you want to calibrate.
- The sample rate used by your sound card for AD conversion.
- The known loudness, usually determined using a physical SPL meter.
- The frequency weighting used by your physical SPL meter.
- The atmospheric pressure at the recording location.

The diagram indicates a typical physical setup and the locations of required information.



The `calibrationFactor` is set according to the equation:

$$\text{CalibrationFactor} = \frac{10^{((\text{SPLreading} - k)/20)}}{\text{rms}(x)}$$

where x is the microphone recording passed through the weighting filter specified in the `FrequencyWeighting` argument. k is 1 pascal relative to the `PressureReference` calculated in dB:

$$k = 20\log_{10}\left(\frac{1}{\text{PressureReference}}\right).$$

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`splMeter` | `acousticLoudness` | `acousticSharpness` | `acousticFluctuation` | `acousticRoughness`

Introduced in R2020a

sone2phon

Convert from sone to phon

Syntax

```
phon = sone2phon(sone)
phon = sone2phon(sone, standard)
```

Description

`phon = sone2phon(sone)` converts `sone` to `phon`, according to ISO 532-1:2017(E).

`phon = sone2phon(sone, standard)` specifies the standard used to convert `sone` to `phon`.

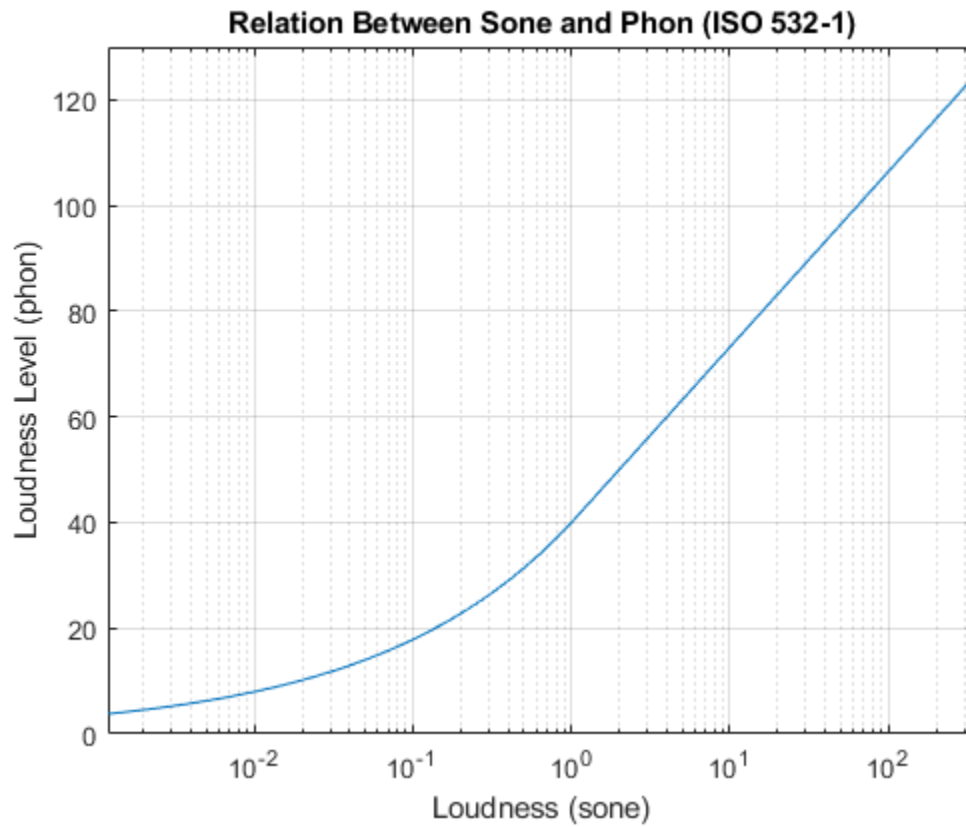
Examples

Convert Sone to Phon

Plot the relationship between loudness (sone) and loudness levels (phon), as specified in ISO 532-1.

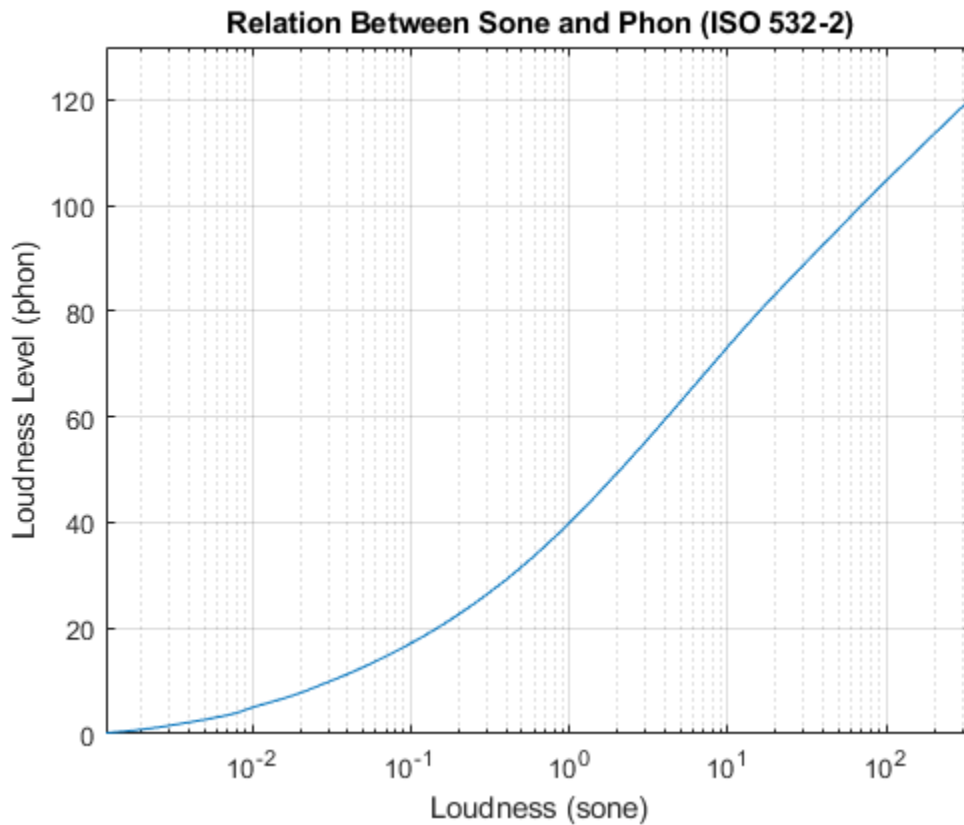
```
s = (0.51:0.01:1.8).^10;
p1 = sone2phon(s);

semilogx(s,p1)
xlabel('Loudness (sone)')
ylabel('Loudness Level (phon)')
title('Relation Between Sone and Phon (ISO 532-1)')
grid on
axis([0 s(end) 0 130])
```

Plot the relationship between loudness (sone) and loudness levels (phon), as specified in ISO 532-2.

```
p2 = sone2phon(s, 'ISO 532-2');  
  
semilogx(s,p2)  
xlabel('Loudness (sone)')  
ylabel('Loudness Level (phon)')  
title('Relation Between Sone and Phon (ISO 532-2)')  
grid on  
axis([0 s(end) 0 130])
```



Input Arguments

sone — Input loudness in sone

nonnegative scalar | vector of nonnegative values | matrix of nonnegative values | multidimensional array of nonnegative values

Input loudness in sone, specified as a scalar, vector, matrix, or multidimensional array of nonnegative values.

Data Types: `single` | `double`

standard — Reference standard for unit conversion

'ISO 532-1' (default) | 'ISO 532-2'

Reference standard for unit conversion, specified as 'ISO 532-1' or 'ISO 532-2'.

Data Types: `char` | `string`

Output Arguments

phon — Output loudness level in phon

scalar | vector | matrix | multidimensional array

Output loudness level in phon, returned as a scalar, vector, matrix, or multidimensional array the same size as `sone`.

Data Types: single | double

Algorithms

ISO 532-1: Zwicker Method

The Zwicker method of conversion from sone to phon is given by this equation in [1] on page 2-654:

$$phon = \begin{cases} 40(sone)^{0.35} & \text{if } sone < 1 \\ 40 + 10\log_2(sone) & \text{otherwise} \end{cases}$$

ISO 532-2: Moore-Glasberg Method

In the Moore-Glasberg method, conversion from sone to phon is prescribed according to this table (table 5 in [2] on page 2-654).

Loudness Level (phon)	Calculated Loudness (sone)
0.0	0.001
2.2	0.004
4.0	0.008
5.0	0.010
7.5	0.019
10.0	0.031
15.0	0.073
20.0	0.146
25.0	0.26
30.0	0.43
35.0	0.67
40.0	1.00
45.0	1.46
50.0	2.09
55.0	2.96
60.0	4.14
65.0	5.77
70.0	8.04
75.0	11.2
80.0	15.8
85.0	22.7
90.0	32.9
95.0	47.7
100.0	69.6
105.0	102.0

Loudness Level (phon)	Calculated Loudness (sone)
110.0	151.0
115.0	225.0
120.0	337.6

The `sone2phon` function uses interpolation for values not specified in the table.

References

- [1] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [2] ISO 532-2:2017(E). "Acoustics - Methods for calculating loudness - Part 2: Moore-Glasberg method." *International Organization for Standardization*.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`phon2sone` | `acousticLoudness`

Introduced in R2020a

phon2sone

Convert from phon to sone

Syntax

```
sone = phon2sone(phon)
sone = phon2sone(phon, standard)
```

Description

`sone = phon2sone(phon)` converts phon to sone, according to ISO 532-1:2017(E).

`sone = phon2sone(phon, standard)` specifies the standard used to convert phon to sone.

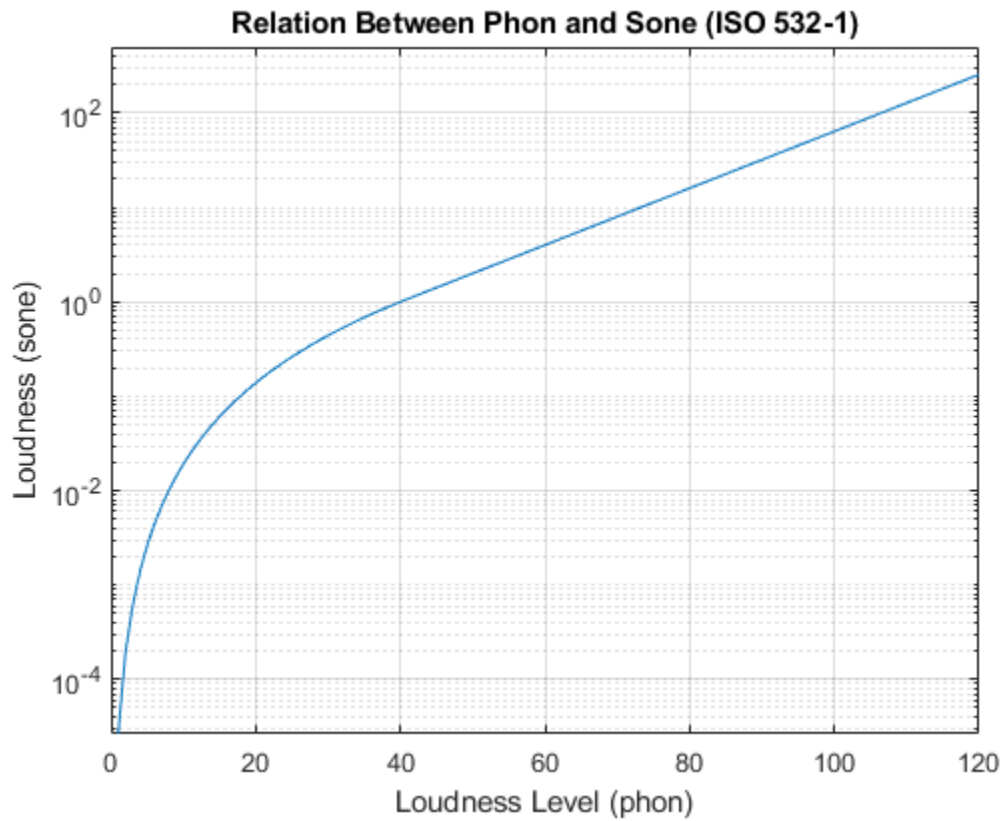
Examples

Convert Phon to Sone

Plot the relationship between loudness level (phon) and loudness (sone), as specified in ISO 532-1.

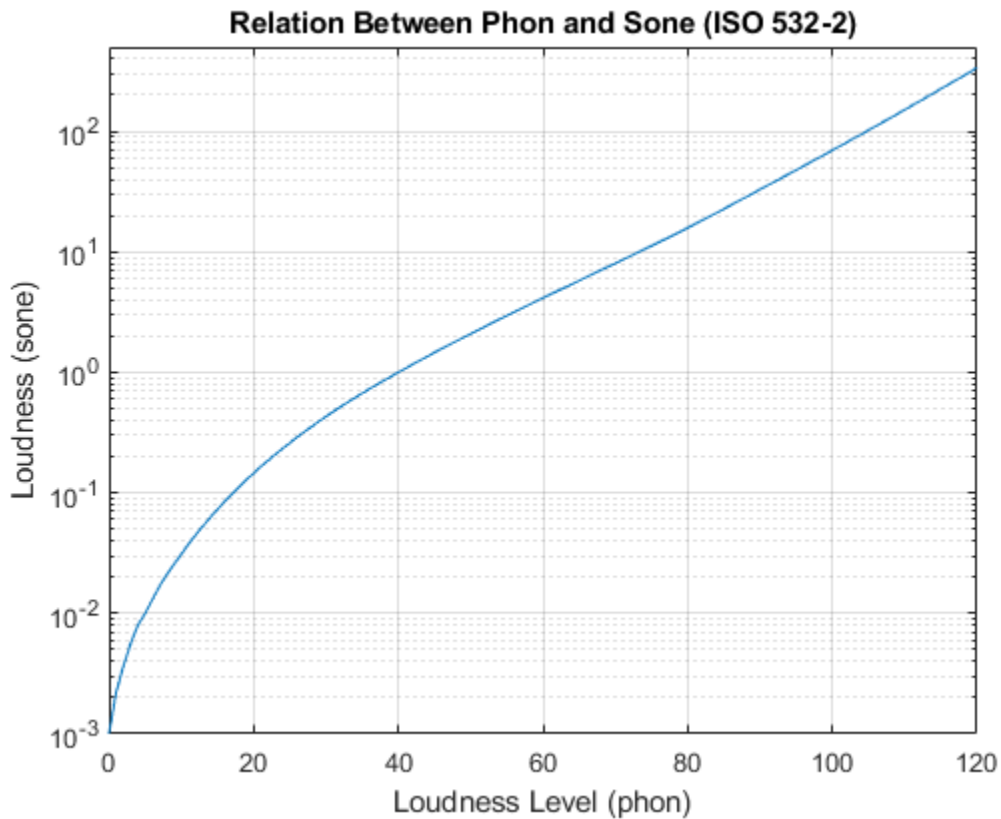
```
p = 0:120;
s1 = phon2sone(p);

semilogy(p,s1)
xlabel('Loudness Level (phon)')
ylabel('Loudness (sone)')
title('Relation Between Phon and Sone (ISO 532-1)')
grid on
axis([0 120 0 500])
```



Plot the relationship between loudness level (phon) and loudness (sone), as specified in ISO 532-2.

```
s2 = phon2sone(p, 'ISO 532-2');  
  
semilogy(p, s2)  
xlabel('Loudness Level (phon)')  
ylabel('Loudness (sone)')  
title('Relation Between Phon and Sone (ISO 532-2)')  
grid on  
axis([0 120 0 500])
```



Input Arguments

phon — Loudness level in phon

nonnegative scalar | vector of nonnegative values | matrix of nonnegative values | multidimensional array of nonnegative values

Input loudness level in phon, specified as a scalar, vector, matrix, or multidimensional array of nonnegative values.

Data Types: `single` | `double`

standard — Reference standard for unit conversion

'ISO 532-1' (default) | 'ISO 532-2'

Reference standard for unit conversion, specified as 'ISO 532-1' or 'ISO 532-2'.

Data Types: `char` | `string`

Output Arguments

sone — Output loudness in sone

scalar | vector | matrix | multidimensional array

Output loudness in sone, returned as a scalar, vector, matrix, or multidimensional array the same size as `phon`.

Data Types: single | double

Algorithms

ISO 532-1: Zwicker Method

The Zwicker method of conversion from phon to sone is given by [1] on page 2-659:

$$sone = \begin{cases} \left(\frac{phon}{40}\right)^{1/0.35} & \text{if } phon < 40 \\ 2\left(\frac{phon - 40}{10}\right) & \text{otherwise} \end{cases}$$

ISO 532-2: Moore-Glasberg Method

In the Moore-Glasberg method, conversion from phon to sone is prescribed according to this table (table 5 in [2] on page 2-659).

Loudness Level (phon)	Calculated Loudness (sone)
0.0	0.001
2.2	0.004
4.0	0.008
5.0	0.010
7.5	0.019
10.0	0.031
15.0	0.073
20.0	0.146
25.0	0.26
30.0	0.43
35.0	0.67
40.0	1.00
45.0	1.46
50.0	2.09
55.0	2.96
60.0	4.14
65.0	5.77
70.0	8.04
75.0	11.2
80.0	15.8
85.0	22.7
90.0	32.9
95.0	47.7
100.0	69.6

Loudness Level (phon)	Calculated Loudness (sone)
105.0	102.0
110.0	151.0
115.0	225.0
120.0	337.6

The `phon2sone` function uses interpolation for values not specified in the table.

References

- [1] ISO 532-1:2017(E). "Acoustics - Methods for calculating loudness - Part 1: Zwicker method." *International Organization for Standardization*.
- [2] ISO 532-2:2017(E). "Acoustics - Methods for calculating loudness - Part 2: Moore-Glasberg method." *International Organization for Standardization*.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

`sone2phon` | `acousticLoudness`

Introduced in R2020a

System Objects

audioTimeScaler

Apply time scaling to streaming audio

Description

The `audioTimeScaler` object performs audio time scale modification (TSM) independently across each input channel.

To modify the time scale of streaming audio:

- 1 Create the `audioTimeScaler` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
aTS = audioTimeScaler
aTS = audioTimeScaler(speedupFactor)
aTS = audioTimeScaler( ____, 'Name', Value)
```

Description

`aTS = audioTimeScaler` creates an object, `aTS`, that performs audio time scale modification independently across each input channel over time.

`aTS = audioTimeScaler(speedupFactor)` sets the `SpeedupFactor` property to `speedupFactor`.

`aTS = audioTimeScaler(____, 'Name', Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `aTS = audioTimeScaler(1.2, 'Window', sqrt(hann(1024, 'periodic'))), 'OverlapLength', 768)` creates an object, `aTS`, that increases the tempo of audio by 1.2 times its original speed using a periodic 1024-point Hann window and a 768-point overlap.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see [System Design in MATLAB Using System Objects](#).

SpeedupFactor — Speedup factor

1.1 (default) | positive real scalar

Speedup factor, specified as a positive real scalar.

Tunable: Yes

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

InputDomain — Domain of input signal

"Time" (default) | "Frequency"

Domain of the input signal, specified as "Time" or "Frequency".

Data Types: char | string

Window — Analysis window

sqrt(hann(512, 'periodic')) (default) | real vector

Analysis window, specified as a real vector.

Note If using audioTimeScaler with frequency-domain input, you must specify Window as the same window used to transform audioIn to the frequency domain.

Data Types: single | double

OverlapLength — Overlap length of adjacent analysis windows

384 (default) | nonnegative integer

Overlap length of adjacent analysis windows, specified as a nonnegative integer.

Note If using audioTimeScaler with frequency-domain input, you must specify OverlapLength as the same overlap length used to transform audioIn to a time-frequency representation.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

FFTLength — FFT length

[] (default) | positive scalar integer

FFT length, specified as a positive integer. The default, [], means that the FFT length is equal to the number of rows in the input signal.

Dependencies

To enable this property, set InputDomain to 'Time'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

LockPhase — Apply identity phase locking

false (default) | true

Apply identity phase locking, specified as true or false.

Data Types: logical

Usage

Syntax

```
audioOut = aTS(audioIn)
```

Description

`audioOut = aTS(audioIn)` applies time-scale modification to the input, `audioIn`, and returns the time-scaled output, `audioOut`.

Input Arguments

audioIn — Input audio

column vector | matrix

Input audio, specified as a column vector or matrix. How `audioTimeScaler` interprets `audioIn` depends on the `InputDomain` property.

- If `InputDomain` is set to "Time", `audioIn` must be a real N -by-1 column vector or N -by- C matrix. The number of rows, N , must be equal to or less than the hop length (`size(audioIn,1) <= numel(Window) - OverlapLength`). Columns of a matrix are interpreted as individual channels.
- If `InputDomain` is set to "Frequency", specify `audioIn` as a real or complex $NFFT$ -by-1 column vector or $NFFT$ -by- C matrix. The number of rows, $NFFT$, is the number of points in the DFT calculation, and is set on the first call to the audio time scaler. $NFFT$ must be greater than or equal to the window length (`size(audioIn,1) >= numel(Window)`). Columns of a matrix are interpreted as individual channels.

Data Types: `single` | `double`

Complex Number Support: Yes

Output Arguments

audioOut — Time-stretched audio

column vector | matrix

Time-stretched audio, returned as a column vector or matrix.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Common to All System Objects

`step` Run System object algorithm

`release` Release resources and allow changes to System object property values and input characteristics

reset Reset internal states of System object

Examples


Apply Time Scale Modification to Streaming Audio

To minimize artifacts caused by windowing, create a square root Hann window capable of perfect reconstruction. Use `iscola` to verify the design.

```
win = sqrt(hann(1024, 'periodic'));
overlapLength = 896;
iscola(win, overlapLength)
```

```
ans = logical
     1
```

Create an `audioTimeScaler` with a speedup factor of 1.5. Change the value of `alpha` to hear the effect of the speedup factor.

```
alpha = 1.5  ;
aTS = audioTimeScaler( ...
    'SpeedupFactor', alpha, ...
    'Window', win, ...
    'OverlapLength', overlapLength);
```

Create a `dsp.AudioFileReader` object to read frames from an audio file. The length of frames input to the audio time scaler must be less than or equal to the analysis hop length defined in `audioTimeScaler`. To minimize buffering, set the samples per frame of the file reader to the analysis hop length.

```
hopLength = numel(aTS.Window) - overlapLength;
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav', ...
    'SamplesPerFrame', hopLength);
```

Create an `audioDeviceWriter` to write frames to your audio device. Use the same sample rate as the file reader.

```
deviceWriter = audioDeviceWriter('SampleRate', fileReader.SampleRate);
```

In an audio stream loop, read a frame the file, apply time scale modification, and then write a frame to the device.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = aTS(audioIn);
    deviceWriter(audioOut);
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(aTS)
```

Process Frequency-Domain Input

Create a window capable of perfect reconstruction. Use `iscola` to verify the design.

```
win = kbdwin(512);
overlapLength = 256;
iscola(win,overlapLength)

ans = logical
     1
```

Create an `audioTimeScaler` with a speedup factor of 0.8. Set `InputDomain` to "Frequency" and specify the window and overlap length used to transform time-domain audio to the frequency domain. Set `LockPhase` to `true` to increase the fidelity in the time-scaled output.

```
alpha = 0.8;
timeScaleModification = audioTimeScaler( ...
    "SpeedupFactor",alpha, ...
    "InputDomain","Frequency", ...
    "Window",win, ...
    "OverlapLength",overlapLength, ...
    "LockPhase",true);
```

Create a `dsp.AudioFileReader` object to read frames from an audio file. Create a `dsp.STFT` object to perform a short-time Fourier transform on streaming audio. Specify the same window and overlap length you used to create the `audioTimeScaler`. Create an `audioDeviceWriter` object to write frames to your audio device.

```
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3','SamplesPerFrame',numel(win))
shortTimeFourierTransform = dsp.STFT('Window',win,'OverlapLength',overlapLength,'FFTLength',numel(win))
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

In an audio stream loop:

- 1 Read a frame from the file.
- 2 Input the frame to the STFT. The `dsp.STFT` object performs buffering.
- 3 Apply time scale modification.
- 4 Write the modified audio to your audio device.

```
while ~isDone(fileReader)
    x = fileReader();
    X = shortTimeFourierTransform(x);
    y = timeScaleModification(X);
    deviceWriter(y);
end
```

As a best practice, release your objects once done.

```
release(fileReader)
release(shortTimeFourierTransform)
release(timeScaleModification)
release(deviceWriter)
```


Algorithms

`audioTimeScaler` uses the same phase vocoder algorithm as `stretchAudio` and is based on the descriptions in [1] and [2].

References

- [1] Driedger, Johnathan, and Meinard Müller. "A Review of Time-Scale Modification of Music Signals." *Applied Sciences*. Vol. 6, Issue 2, 2016.
- [2] Driedger, Johnathan. "Time-Scale Modification Algorithms for Music Audio Signals." Master's thesis, Saarland University, 2011.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

`shiftPitch` | `stretchAudio` | `audioDataAugmenter`

Introduced in R2019b

parameterTuner

Tune object parameters while streaming

Syntax

```
H = parameterTuner(obj)
```

Description

H = parameterTuner(obj) creates a parameter tuning UI and returns a figure handle, H.

Examples

Tune Parameters of Multiple Objects

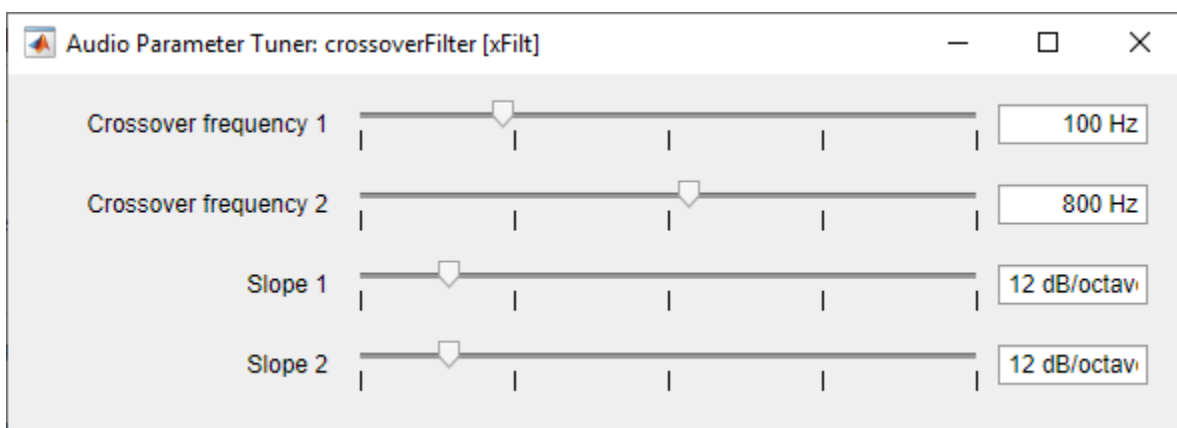
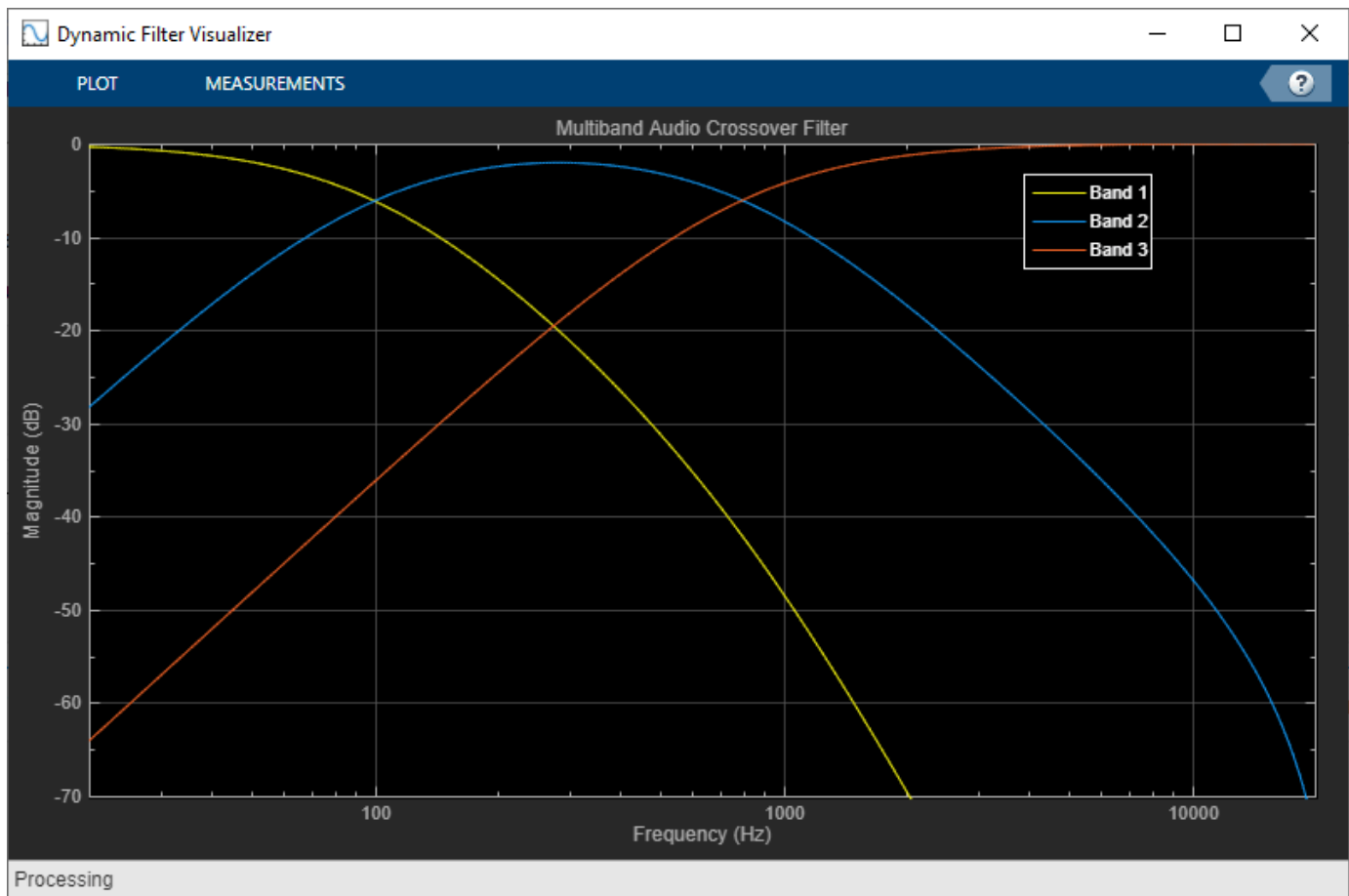
parameterTuner enables you to graphically tune parameters of multiple objects. In this example, you use a crossover filter to split a signal into multiple subbands and then apply different effects to the subbands.

Create a dsp.AudioFileReader to read in audio frame-by-frame. Create an audioDeviceWriter to write audio to your sound card.

```
fileReader = dsp.AudioFileReader('FunkyDrums-48-stereo-25secs.mp3', ...  
                                'PlayCount',2);  
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

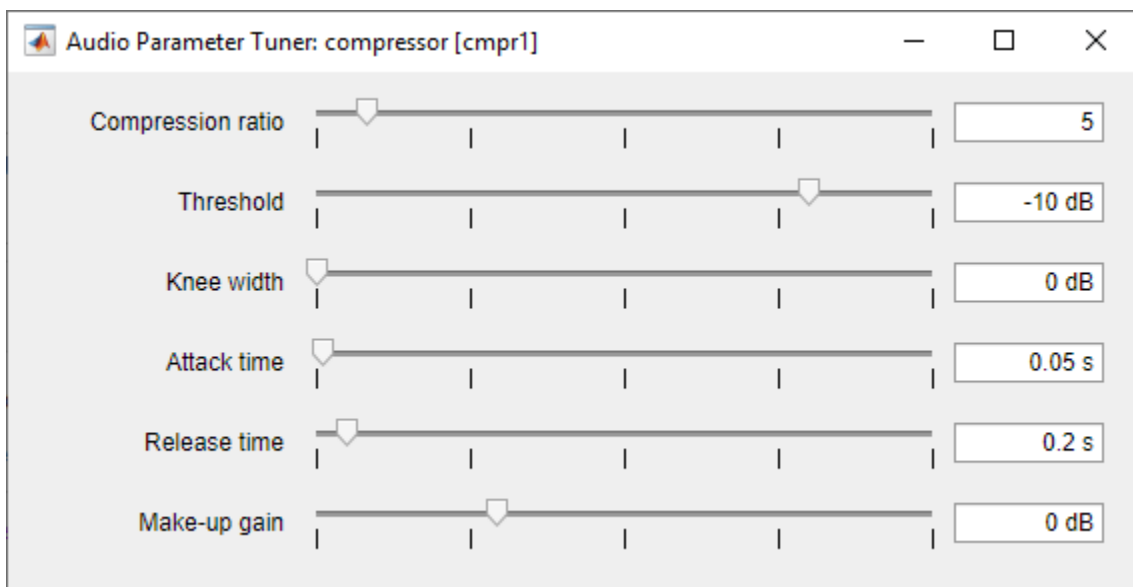
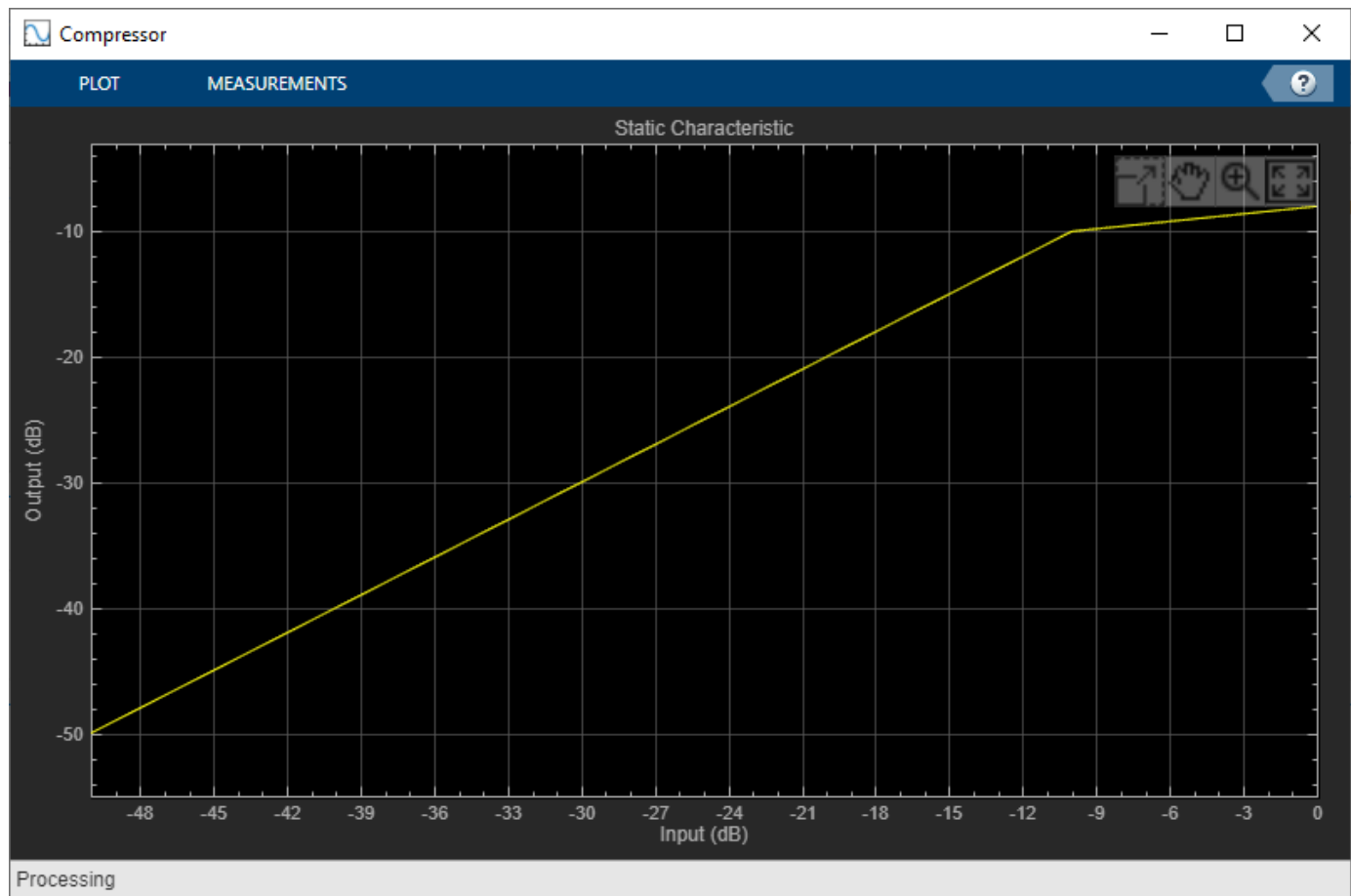
Create a crossoverFilter with two crossovers to split the audio into three bands. Call visualize to plot the frequency responses of the filters. Call parameterTuner to open a UI to tune the crossover frequencies while streaming.

```
xFilt = crossoverFilter('SampleRate',fileReader.SampleRate,'NumCrossovers',2);  
visualize(xFilt)  
parameterTuner(xFilt)
```

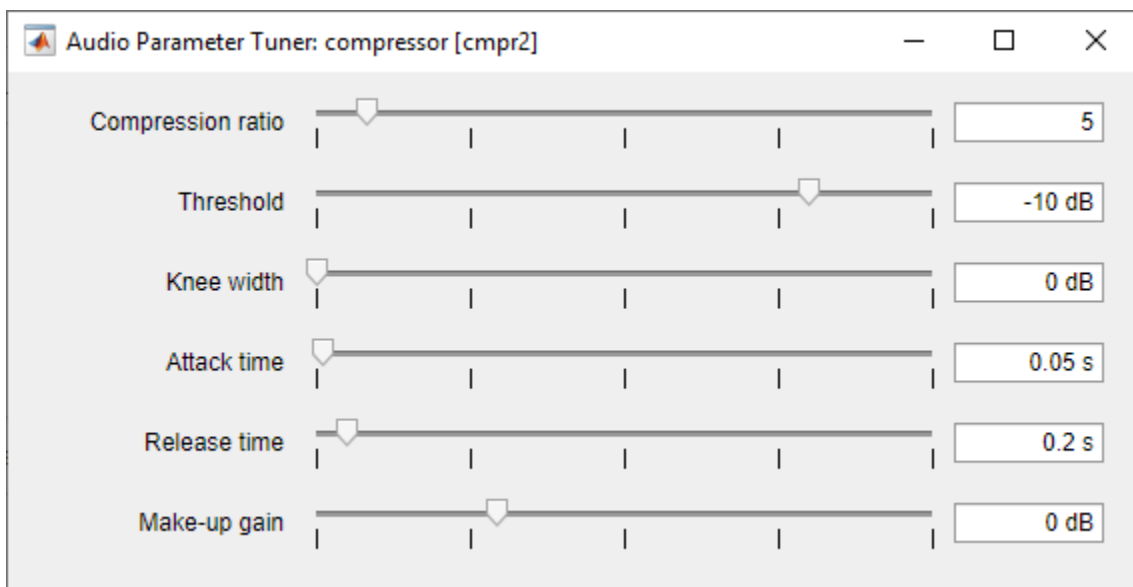
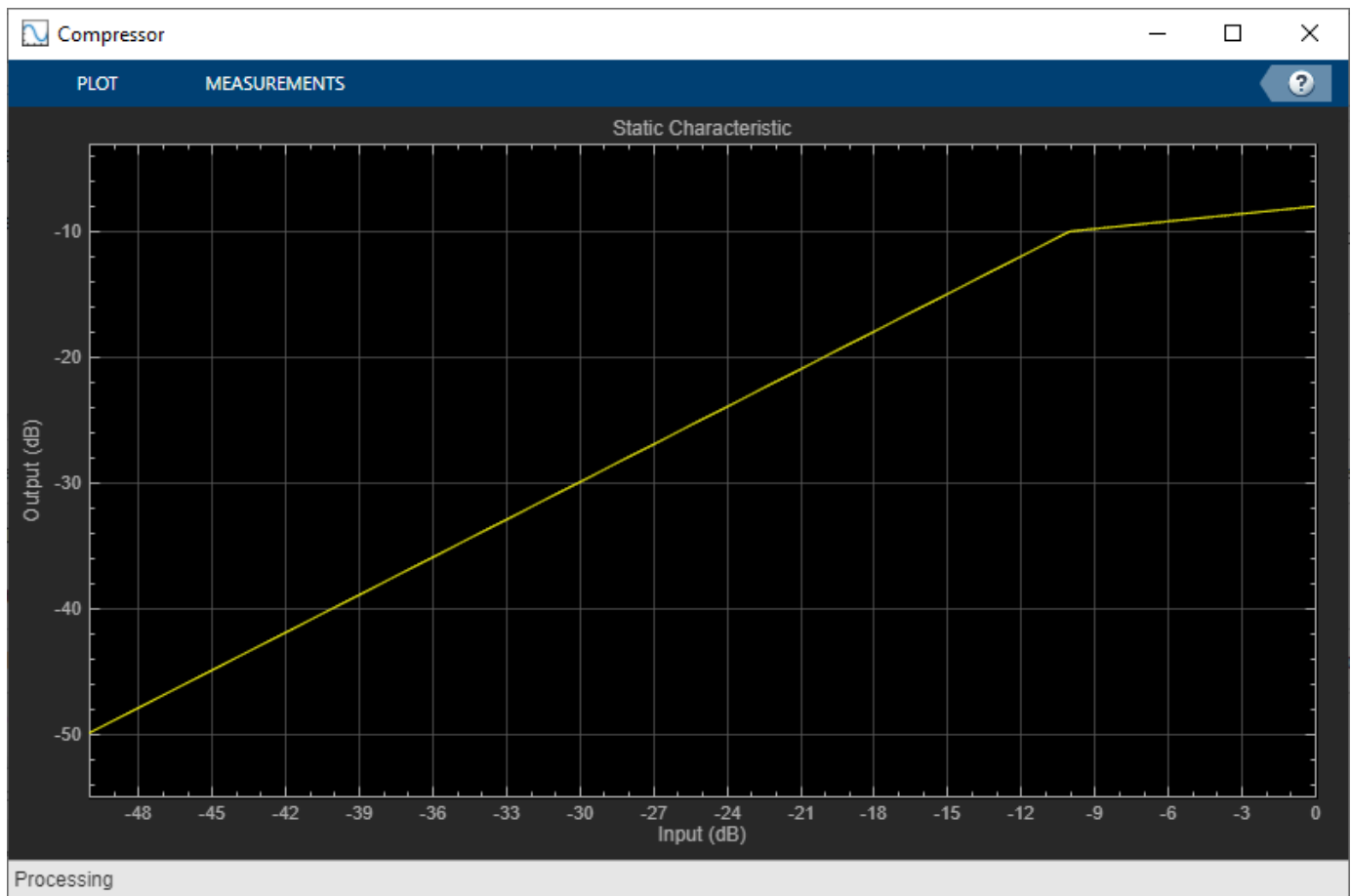


Create two compressor objects to apply dynamic range compression on two of the subbands. Call `visualize` to plot the static characteristic of both of the compressors. Call `parameterTuner` to open UIs to tune the static characteristics.

```
cmpr1 = compressor('SampleRate',fileReader.SampleRate);
visualize(cmpr1)
parameterTuner(cmpr1)
```



```
cmpr2 = compressor('SampleRate',fileReader.SampleRate);
visualize(cmpr2)
parameterTuner(cmpr2)
```



Create an `audiopluginexample.Chorus` to apply a chorus effect to one of the bands. Call `parameterTuner` to open a UI to tune the chorus plugin parameters.

```
chorus = audiopluginexample.Chorus;  
setSampleRate(chorus, fileReader.SampleRate);  
parameterTuner(chorus)
```

In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Split the audio into three bands using the crossover filter.
- 3 Apply dynamic range compression to the first and second bands.
- 4 Apply a chorus effect to the third band.
- 5 Sum the audio bands.
- 6 Write the frame of audio to your audio device for listening.

```
while ~isDone(fileReader)  
    audioIn = fileReader();  
  
    [b1,b2,b3] = xFilt(audioIn);  
  
    b1 = cmpr1(b1);  
    b2 = cmpr2(b2);  
    b3 = process(chorus,b3);  
  
    audioOut = b1+b2+b3;  
  
    deviceWriter(audioOut);  
  
    drawnow limitrate % Process parameterTuner callbacks  
end
```

As a best practice, release your objects once done.

```
release(fileReader)  
release(deviceWriter)
```

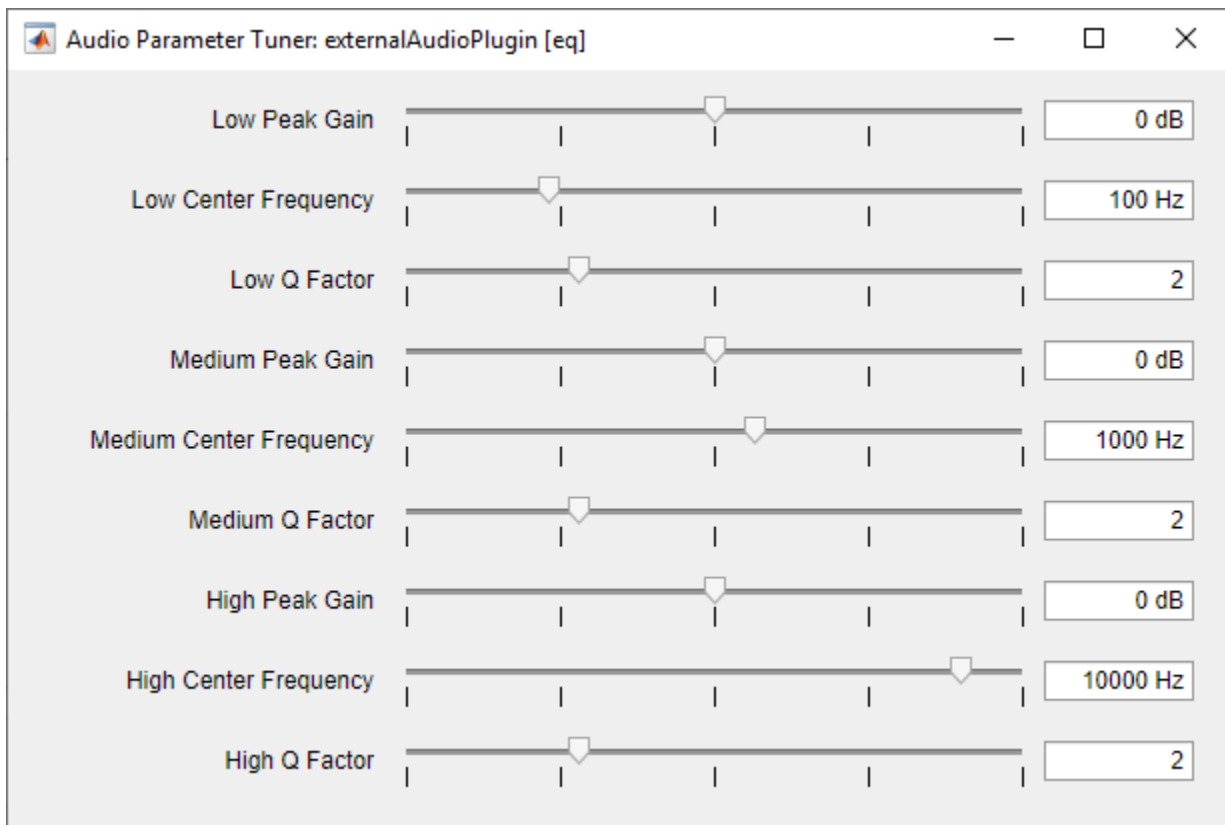
Tune Hosted Audio Plugin Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Use `loadAudioPlugin` to load an equalizer plugin. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
fileReader = dsp.AudioFileReader('FunkyDrums-48-stereo-25secs.mp3');  
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);  
  
pluginPath = fullfile(matlabroot,'toolbox/audio/samples/ParametricEqualizer.dll');  
eq = loadAudioPlugin(pluginPath);  
setSampleRate(eq,fileReader.SampleRate);
```

Call `parameterTuner` to open a UI to tune parameters of the equalizer while streaming.

```
parameterTuner(eq)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply equalization.
- 3 Write the frame of audio to your audio device for listening.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = process(eq,audioIn);
    deviceWriter(audioOut);

    drawnow limitrate % Process parameterTuner callbacks
end
```

As a best practice, release your objects once done.

```
release(fileReader)
release(deviceWriter)
```

Tune MATLAB Audio Plugin Parameters

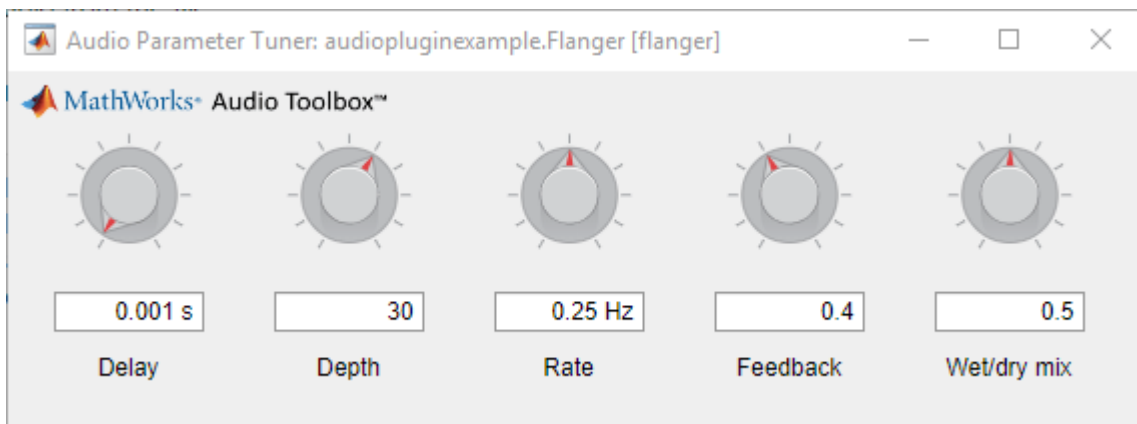
Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create an `audiopluginexample.Flanger` to process the audio data and set the sample rate.

```
fileReader = dsp.AudioFileReader('RockGuitar-16-96-stereo-72secs.flac');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

```
flanger = audiopluginexample.Flanger;
setSampleRate(flanger,fileReader.SampleRate);
```

Call `parameterTuner` to open a UI to tune parameters of the flanger while streaming.

```
parameterTuner(flanger)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply flanging.
- 3 Write the frame of audio to your audio device for listening.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = process(flanger,audioIn);
    deviceWriter(audioOut);

    drawnow limitrate % Process parameterTuner callbacks
end
```

As a best practice, release your objects once done.

```
release(fileReader)
release(deviceWriter)
```

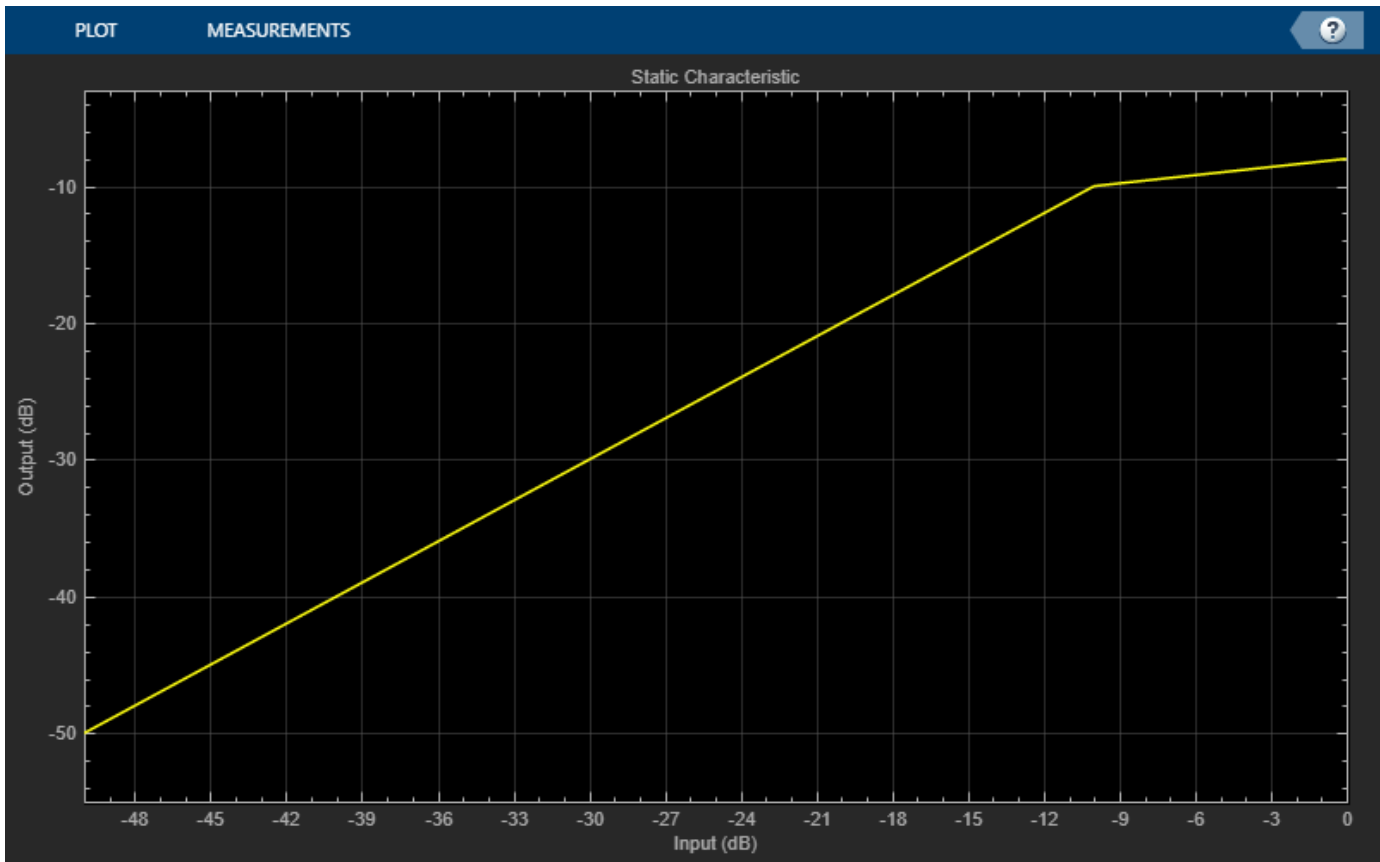
Tune Compressor Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create a compressor to process the audio data. Call `visualize` to plot the static characteristic of the compressor.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```



```
dRC = compressor('SampleRate',fileReader.SampleRate);
visualize(dRC)
```

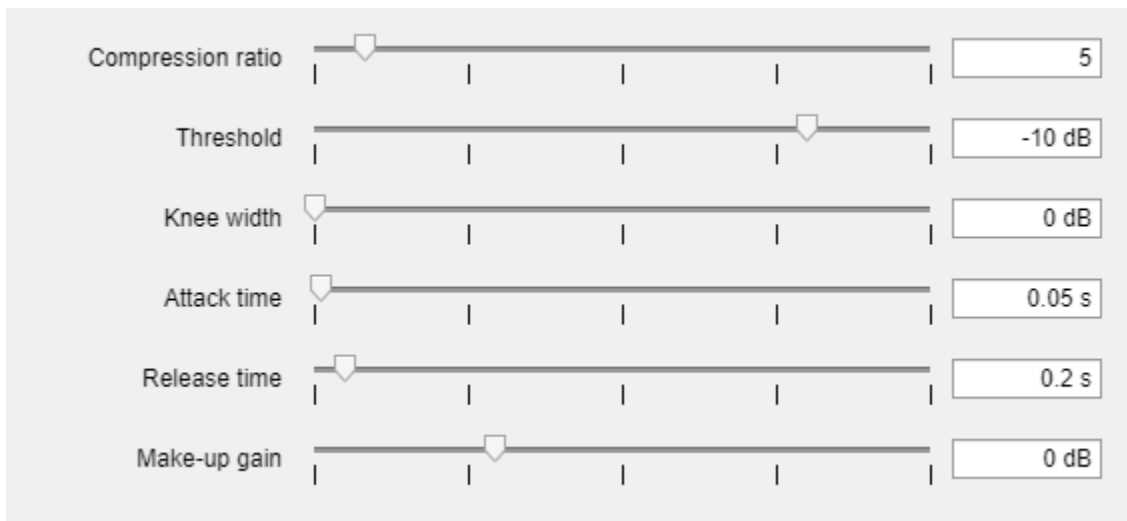


Create a timescope to visualize the original and processed audio.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanSource','property',...
    'TimeSpan',1, ...
    'BufferLength',fileReader.SampleRate*4, ...
    'YLimits',[-1,1], ...
    'TimeSpanOvverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2,1], ...
    'NumInputPorts',2, ...
    'Title','Original vs. Compressed Audio (top) and Compressor Gain in dB (bottom)');
scope.ActiveDisplay = 2;
scope.YLimits = [-4,0];
scope.YLabel = 'Gain (dB)';
```

Call parameterTuner to open a UI to tune parameters of the compressor while streaming.

```
parameterTuner(dRC)
```



In an audio stream loop:

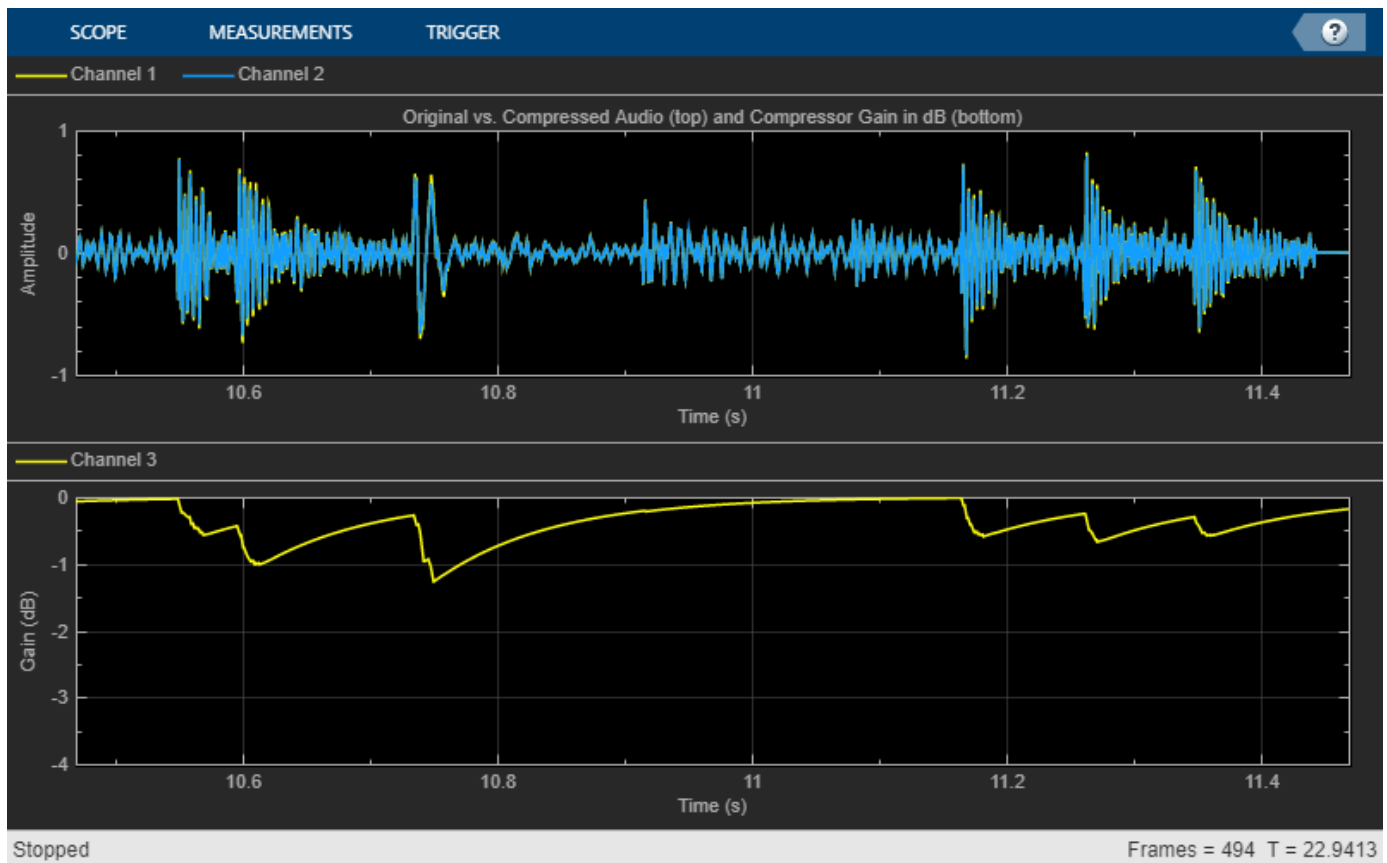
- 1 Read in a frame of audio from the file.
- 2 Apply dynamic range compression.
- 3 Write the frame of audio to your audio device for listening.
- 4 Visualize the original audio, the processed audio, and the gain applied.

While streaming, tune parameters of the dynamic range compressor and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    [audioOut,g] = dRC(audioIn);
    deviceWriter(audioOut);
    scope([audioIn(:,1),audioOut(:,1)],g(:,1));
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(dRC)
release(scope)
```



Input Arguments

obj — Object to tune

audioPlugin object | compressor | expander | limiter | noiseGate | octaveFilter | crossoverFilter | multibandParametricEQ | graphicEQ | audioOscillator | wavetableSynthesizer | reverberator | shelvingFilter

Object to tune, specified as an object that inherits from `audioPlugin` or one of the following Audio Toolbox objects:

- `compressor`
- `expander`
- `limiter`
- `noiseGate`
- `octaveFilter`
- `crossoverFilter`
- `multibandParametricEQ`
- `graphicEQ`
- `audioOscillator`
- `wavetableSynthesizer`

- reverberator
- shelvingFilter

Output Arguments

H — Target figure

Figure object

Target figure, returned as a Figure object.

See Also

Audio Test Bench | `audioPlugin`

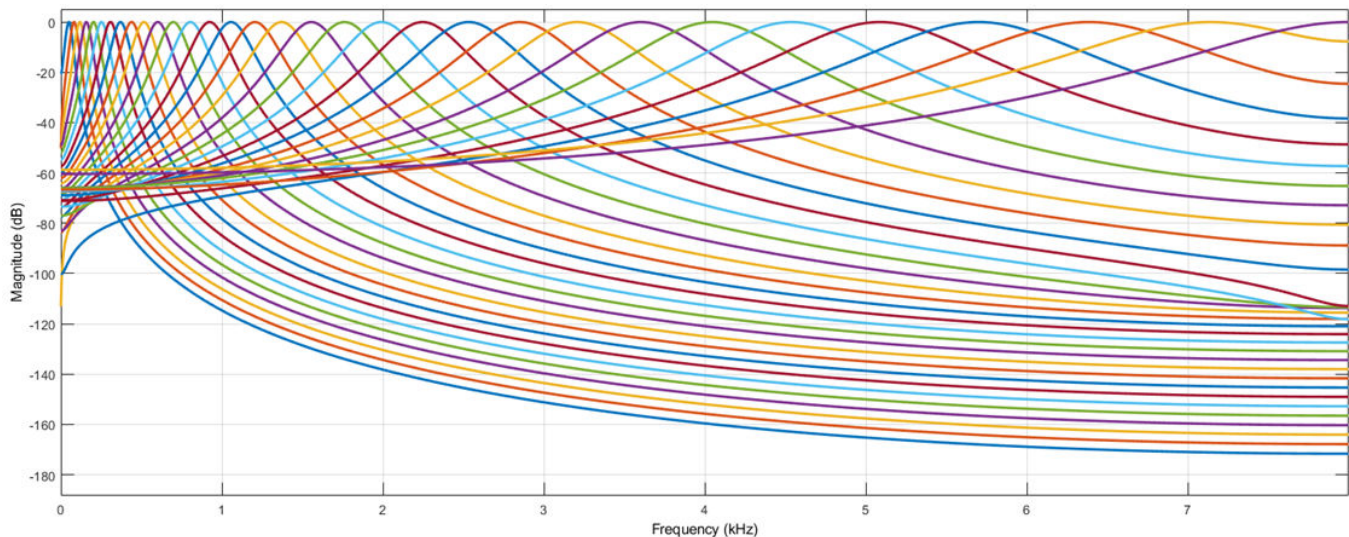
Introduced in R2019a

gammatoneFilterBank

Gammatone filter bank

Description

`gammatoneFilterBank` decomposes a signal by passing it through a bank of gammatone filters equally spaced on the ERB scale. Gammatone filter banks were designed to model the human auditory system.



To model the human auditory system:

- 1 Create the `gammatoneFilterBank` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
gammaFiltBank = gammatoneFilterBank
gammaFiltBank = gammatoneFilterBank(range)
gammaFiltBank = gammatoneFilterBank(range,numFiltS)
gammaFiltBank = gammatoneFilterBank(range,numFiltS,fs)
gammaFiltBank = gammatoneFilterBank( ___,Name,Value)
```

Description

`gammaFiltBank = gammatoneFilterBank` returns a gammatone filter bank. The object filters data independently across each input channel over time.

`gammaFiltBank = gammatoneFilterBank(range)` sets the `Range` property to `range`.

`gammaFiltBank = gammatoneFilterBank(range,numFilts)` sets the `NumFilters` property to `numFilts`.

`gammaFiltBank = gammatoneFilterBank(range,numFilts,fs)` sets the `SampleRate` property to `fs`.

`gammaFiltBank = gammatoneFilterBank(____,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `gammaFiltBank = gammatoneFilterBank([62.5,12e3], 'SampleRate', 24e3)` creates a gammatone filter bank, `gammaFiltBank`, with bandpass filters placed between 62.5 Hz and 12 kHz. `gammaFiltBank` operates at a sample rate of 24 kHz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

FrequencyRange — Frequency range of filter bank (Hz)

[50 8000] (default) | two-element row vector of monotonically increasing values

Frequency range of the filter bank in Hz, specified as a two-element row vector of monotonically increasing values.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

NumFilters — Number of filters

32 (default) | positive integer scalar

Number of filters in the filter bank, specified as a positive integer scalar.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

SampleRate — Input sample rate (Hz)

16000 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
audioOut = gammaFiltBank(audioIn)
```

Description

`audioOut = gammaFiltBank(audioIn)` applies the gammatone filter bank on the input and returns the filtered output.

Input Arguments

audioIn — Audio input to filter bank

scalar | vector | matrix

Audio input to the filter bank, specified as a scalar, vector, or matrix. If specified as a matrix, the columns are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from filter bank

scalar | vector | matrix | 3-D array

Audio output from the filter bank, returned as a scalar, vector, matrix, or 3-D array. The shape of `audioOut` depends on the shape of `audioIn` and `NumFilters`. If `audioIn` is an M -by- N matrix, then `audioOut` is returned as an M -by-`NumFilters`-by- N array. If N is 1, then `audioOut` is returned as a matrix.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to `gammatoneFilterBank`

<code>fvtool</code>	Visualize filter bank
<code>freqz</code>	Compute frequency response
<code>getCenterFrequencies</code>	Center frequencies of filters
<code>getBandwidths</code>	Get filter bandwidths
<code>coeffs</code>	Get filter coefficients
<code>info</code>	Get filter information

Common to All System Objects

<code>step</code>	Run System object algorithm
<code>release</code>	Release resources and allow changes to System object property values and input characteristics

reset Reset internal states of System object

Examples

Apply Gammatone Filter Bank

Create a default gammatone filter bank for a 16 kHz sample rate.

```
fs = 16e3;  
gammaFiltBank = gammatoneFilterBank('SampleRate', fs)
```

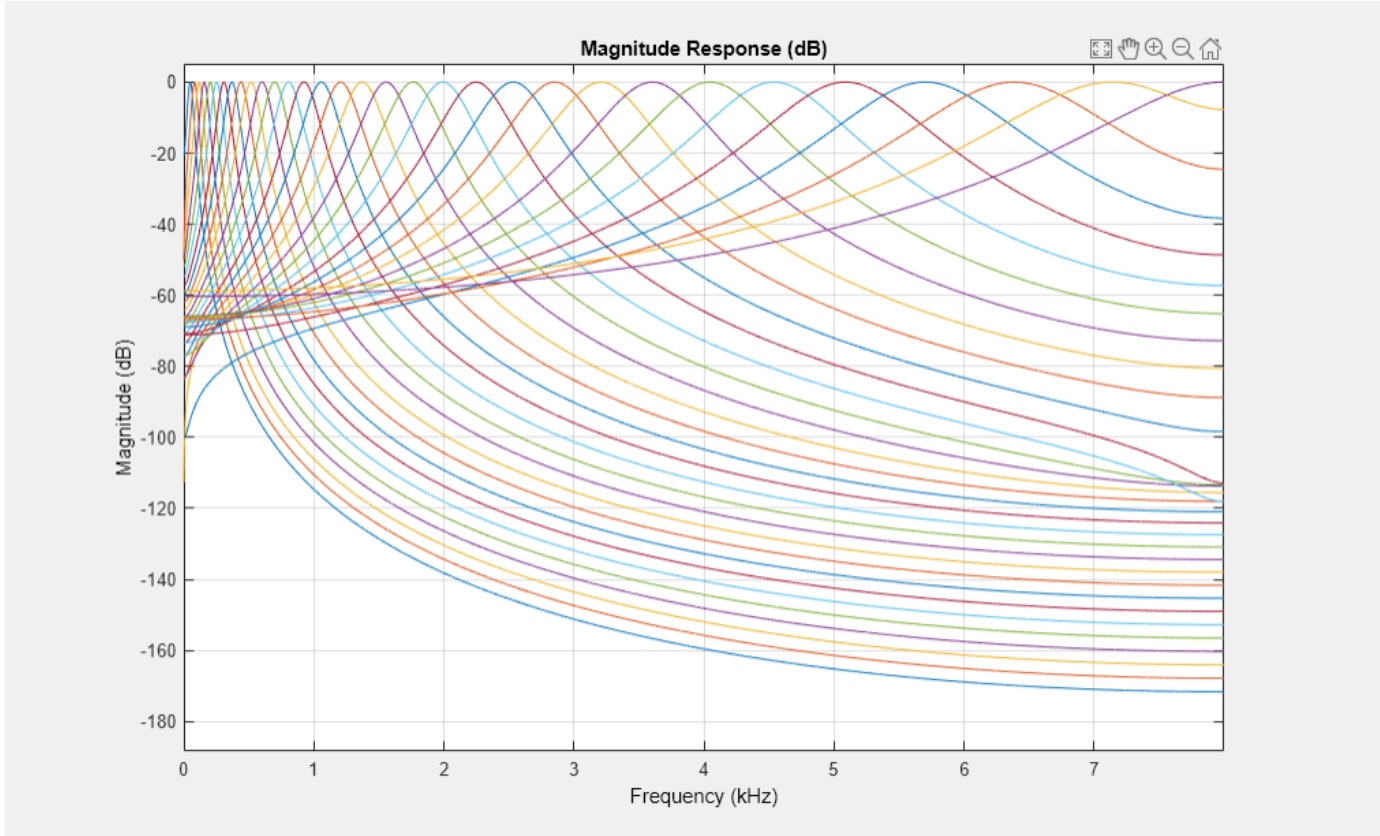
```
gammaFiltBank =
```

```
gammatoneFilterBank with properties:
```

```
FrequencyRange: [50 8000]  
NumFilters: 32  
SampleRate: 16000
```

Use `fvtool` to visualize the response of the filter bank.

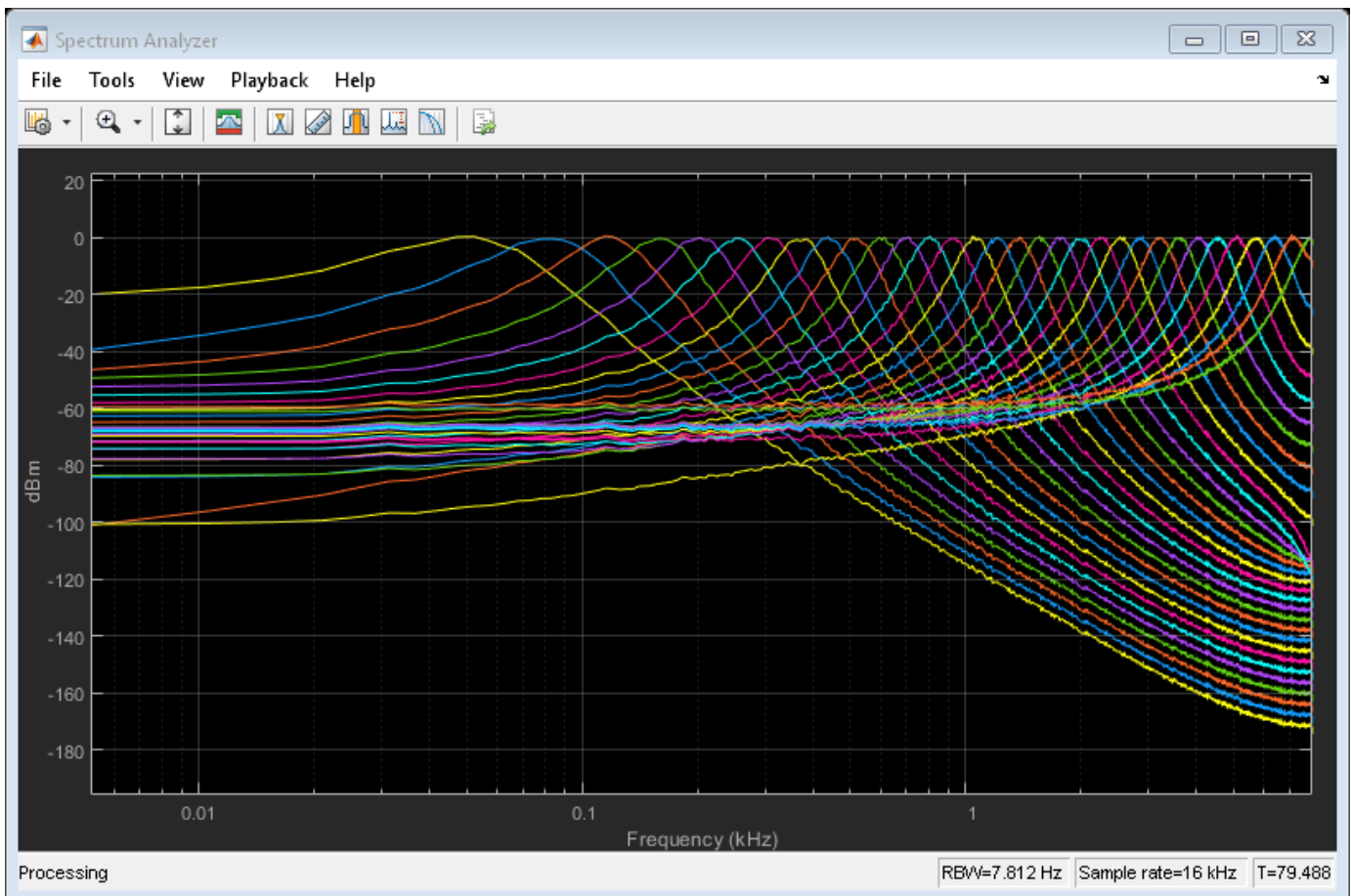
```
fvtool(gammaFiltBank)
```



Process white Gaussian noise through the filter bank. Use a spectrum analyzer to view the spectrum of the filter outputs.

```
sa = dsp.SpectrumAnalyzer('SampleRate',16e3,...
    'PlotAsTwoSidedSpectrum',false,...
    'FrequencyScale','log',...
    'SpectralAverages',100);

for i = 1:5000
    x = randn(256,1);
    y = gammaFiltBank(x);
    sa(y);
end
```



Analysis and Synthesis

This example illustrates a nonoptimal but simple approach to analysis and synthesis using `gammatoneFilterBank`.

Read in an audio file and listen to its contents.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
sound(audioIn,fs)
```

Create a default `gammatoneFilterBank`. The default frequency range of the filter bank is 50 to 8000 Hz. Frequencies outside of this range are attenuated in the reconstructed signal.

```
gammaFiltBank = gammatoneFilterBank('SampleRate', fs)
```

```
gammaFiltBank =  
    gammatoneFilterBank with properties:
```

```
    FrequencyRange: [50 8000]  
    NumFilters: 32  
    SampleRate: 44100
```

Pass the audio signal through the `gammatone` filter bank. The output is 32 channels, where the number of channels is set by the `NumFilters` property of the `gammatoneFilterBank`.

```
audioOut = gammaFiltBank(audioIn);
```

```
[N,numChannels] = size(audioOut)
```

```
N = 685056
```

```
numChannels = 32
```

To reconstruct the original signal, sum the channels. Listen to the result.

```
reconstructedSignal = sum(audioOut,2);  
sound(reconstructedSignal, fs)
```

The `gammatone` filter bank introduced various group delays for the output channels, which results in poor reconstruction. To compensate for the group delay, remove the beginning delay from the individual channels and zero-pad the ends of the channels. Use `info` to get the group delays. Listen to the group delay-compensated reconstruction.

```
infoStruct = info(gammaFiltBank);  
groupDelay = round(infoStruct.GroupDelays); % round for simplicity  
audioPadded = [audioOut; zeros(max(groupDelay), gammaFiltBank.NumFilters)];
```

```
for i = 1:gammaFiltBank.NumFilters  
    audioOut(:,i) = audioPadded(groupDelay(i)+1:N+groupDelay(i),i);  
end
```

```
reconstructedSignal = sum(audioOut,2);  
sound(reconstructedSignal, fs)
```

Create Gammatone Spectrogram

Read in an audio signal and convert it to mono for easy visualization.

```
[audio, fs] = audioread('WaveGuideLoopOne-24-96-stereo-10secs.aif');  
audio = mean(audio,2);
```

Create a `gammatoneFilterBank` with 64 filters that span the range 62.5 to 20,000 Hz. Pass the audio signal through the filter bank.

```
gammaFiltBank = gammatoneFilterBank('SampleRate',fs, ...
                                   'NumFilters',64, ...
                                   'FrequencyRange',[62.5,20e3]);
```

```
audioOut = gammaFiltBank(audio);
```

Calculate the energy-per-band using 50 ms windows with 25 ms overlap. Use `dsp.AsyncBuffer` to divide the signals into overlapped windows and then to log the RMS value of each window for each channel.

```
samplesPerFrame = round(0.05*fs);
samplesOverlap = round(0.025*fs);
```

```
buff = dsp.AsyncBuffer(numel(audio));
write(buff, audioOut.^2);
```

```
sink = dsp.AsyncBuffer(numel(audio));
```

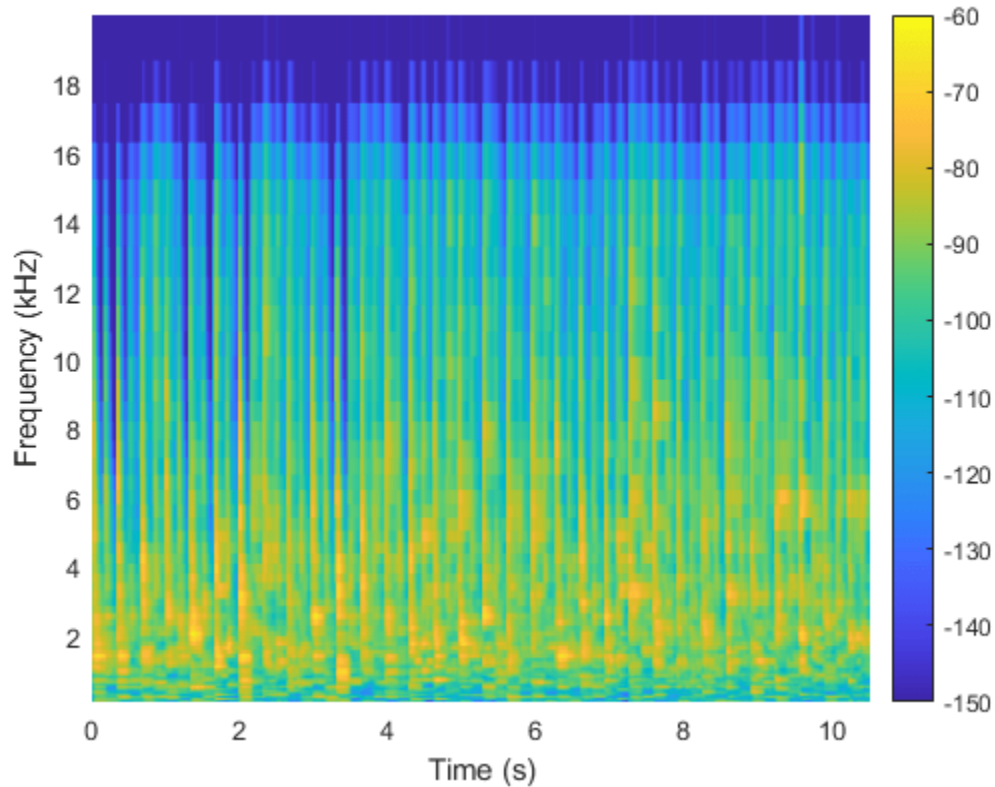
```
while buff.NumUnreadSamples > 0
    currentFrame = read(buff, samplesPerFrame, samplesOverlap);
    write(sink, mean(currentFrame, 1));
end
```

Convert the energy values to dB. Plot the energy-per-band over time.

```
gammatoneSpec = read(sink);
D = 20*log10(gammatoneSpec');
```

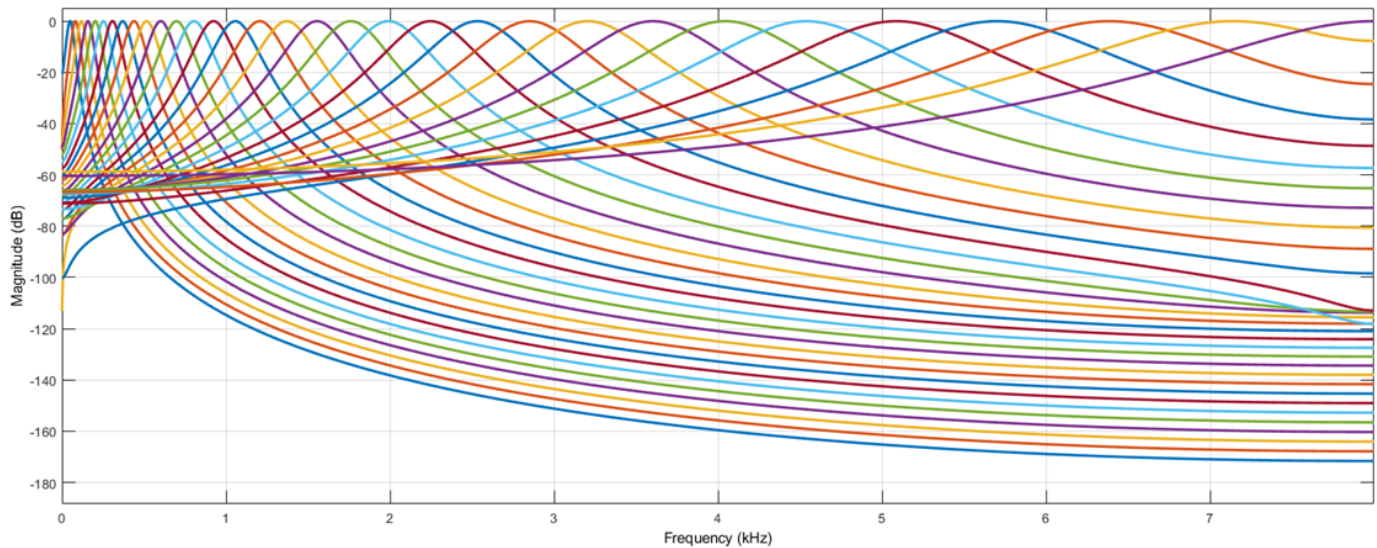
```
timeVector = ((samplesPerFrame-samplesOverlap)/fs)*(0:size(D,2)-1);
cf = getCenterFrequencies(gammaFiltBank)./1e3;
```

```
surf(timeVector, cf, D, 'EdgeColor', 'none')
axis([timeVector(1) timeVector(end) cf(1) cf(end)])
view([0 90])
caxis([-150, -60])
colorbar
xlabel('Time (s)')
ylabel('Frequency (kHz)')
```



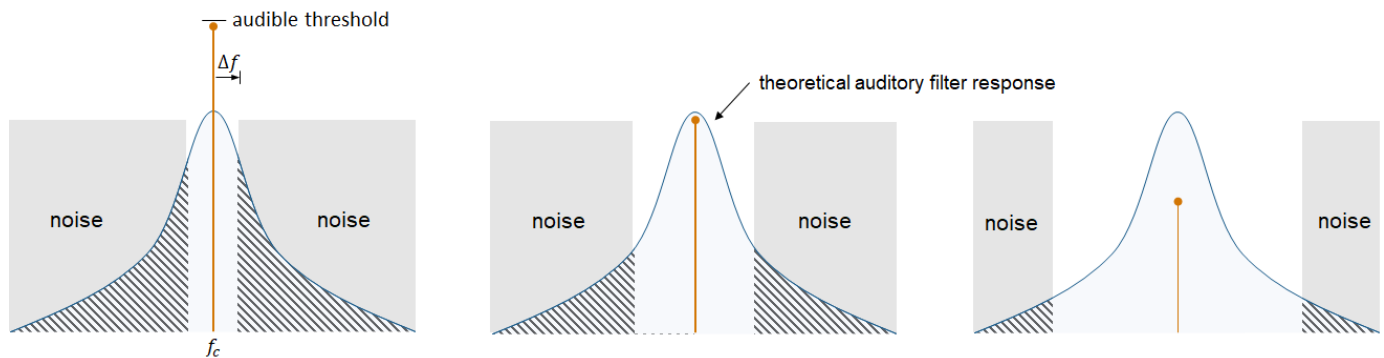
Algorithms

A gammatone filter bank is often used as the front end of a cochlea simulation, which transforms complex sounds into a multichannel activity pattern like that observed in the auditory nerve.[2] The `gammatoneFilterBank` follows the algorithm described in [1]. The algorithm is an implementation of an idea proposed in [2]. The design of the gammatone filter bank can be described in two parts: the filter shape (gammatone) and the frequency scale. The equivalent rectangular bandwidth (ERB) scale defines the relative spacing and bandwidth of the gammatone filters. The derivation of the ERB scale also provides an estimate of the auditory filter response which closely resembles the gammatone filter.

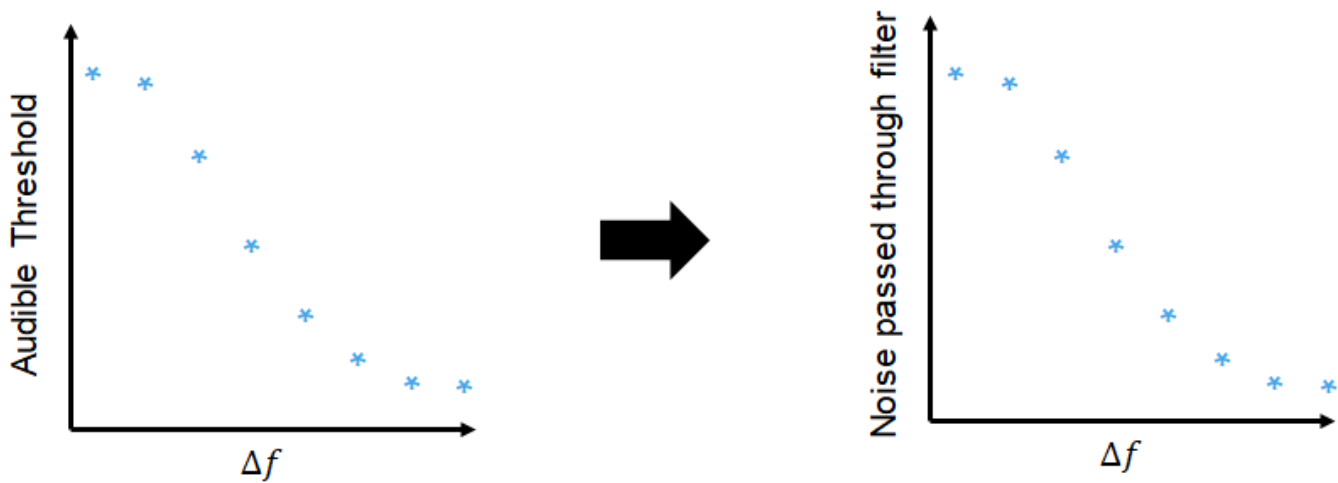


Frequency Scale

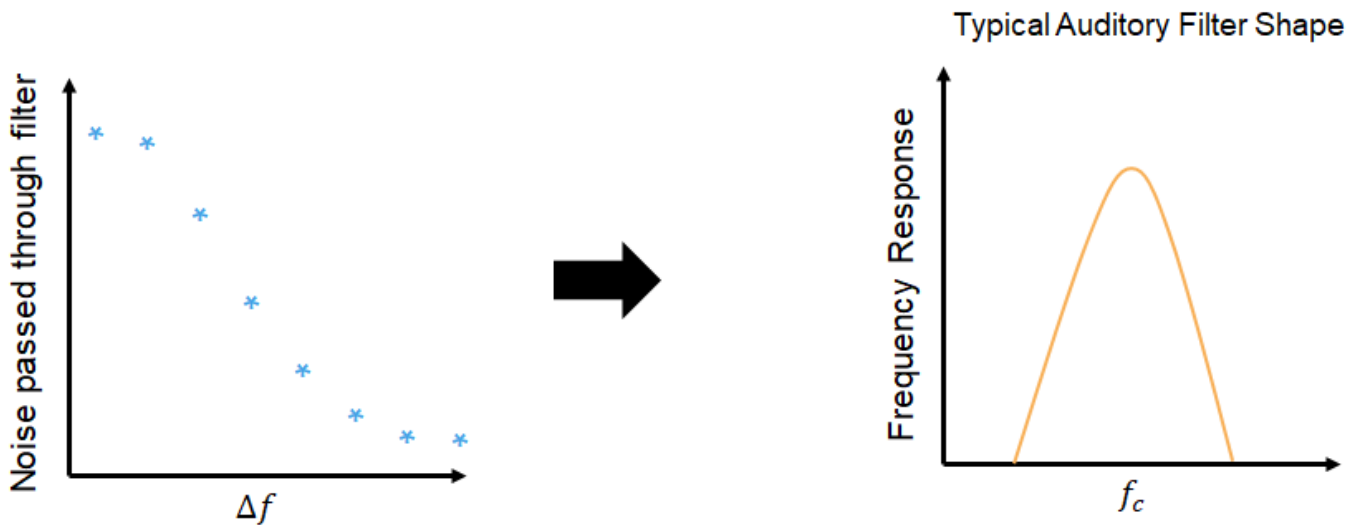
The ERB scale was determined using the notched-noise masking method. This method involves a listening test wherein notched noise is centered on a tone. The power of the tone is tuned, and the audible threshold (the power required for the tone to be heard) is recorded. The experiment is repeated for different notch widths and center frequencies.



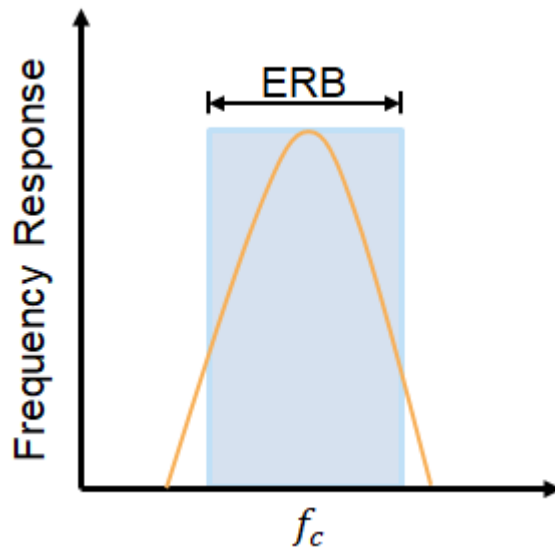
The notched-noise method assumes the audible threshold corresponds to a constant signal-to-masker ratio at the output of the theoretical auditory filter. That is, the ratio of the power of the f_c tone and the shaded area is constant. Therefore, the relationship between the audible threshold and $2\Delta f$ (the notch bandwidth) is linearly related to the relationship between the noise passed through the filter and $2\Delta f$.



The derivative of the function relating Δf to the noise passed through the filter estimates the auditory filter shape. Because Δf has an inverse relationship with the noise power passed through the filter, the derivative of the function must be multiplied by -1. The resulting auditory filter shape is usually approximated as a roex filter.



The equivalent rectangular bandwidth of the auditory filter is defined as the width of a rectangular filter required to pass the same noise power as the auditory filter.



[4] defines ERB as a function of center frequency for young listeners with normal hearing and a moderate noise level:

$$\text{ERB} = 24.7(0.00437f_c + 1)$$

The ERB scale (ERBs) is an extension of the relationship between ERB and center frequency, derived by integrating the reciprocal of the ERB function:

$$\text{ERBs} = 21.4\log_{10}(0.00437f + 1)$$

To design a gammatone filter bank, [2] suggests distributing the center frequencies of the filters in proportion to their bandwidth. To accomplish this, `gammatoneFilterBank` defines the center frequencies as linearly spaced on the ERB scale, covering the specified frequency range with the desired number of filters. You can specify the frequency range and desired number of filters using the `FrequencyRange` and `NumFilters` properties.

Gammatone Filter

The gammatone filter was introduced in [3]. The continuous impulse response is:

$$g(t) = at^{n-1}e^{-2\pi bt}\cos(2\pi f_c t + \phi)$$

where

- a -- amplitude factor
- t -- time in seconds
- n -- filter order (set to four to model human hearing)
- f_c -- center frequency
- b -- bandwidth, set to $1.019 \cdot \text{hz2erb}(f_c)$.
- ϕ -- phase factor

The gammatone filter is similar to the roex filter derived from the notched-noise experiment. `gammatoneFilterBank` implements the digital filter as a cascade of four second-order sections, as described in [1].

References

- [1] Slaney, Malcolm. "An Efficient Implementation of the Patterson-Holdsworth Auditory Filter Bank." Apple Computer Technical Report 35, 1993.
- [2] Patterson, R. D., K. Robinson, J. Holdsworth, D. McKeown, C. Zhang, and M. Allerhand. "Complex Sounds and Auditory Images." *Auditory Physiology and Perception*. 1992, pp. 429-446.
- [3] Aertsen, A. M. H. J., and P. I. M. Johannesma. "Spectro-temporal Receptive Fields of Auditory Neurons in the Grassfrog." *Biological Cybernetics*. Vol. 38, Issue 4, 1980, pp. 223-234.
- [4] Glasberg, Brian R., and Brian C. J. Moore. "Derivation of Auditory Filter Shapes from Notched-Noise Data." *Hearing Research*. Vol. 47. Issue 1-2, 1990, pp. 103 -138.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

`octaveFilterBank` | `crossoverFilter`

Introduced in R2019a

coeffs

Get filter coefficients

Syntax

```
[B,A] = coeffs(obj)
```

Description

`[B,A] = coeffs(obj)` returns the coefficients of the filters created by `obj`.

Examples

Get graphicEQ Coefficients

Create a `graphicEQ` and then call `coeffs` to get its coefficients. The coefficients are returned as second-order sections. The dimensions of `B` are 3-by-($M * EQOrder / 2$), where M is the number of bandpass equalizers. The dimensions of `A` are 2-by-($M * EQOrder / 2$).

```
fs = 44.1e3;
x = 0.1*randn(fs*5,1);
equalizer = graphicEQ('SampleRate',fs, ...
                    'Gains',[-10,-10,10,10,-10,-10,10,10,-10,-10], ...
                    'EQOrder',2);
```

```
[B,A] = coeffs(equalizer);
```

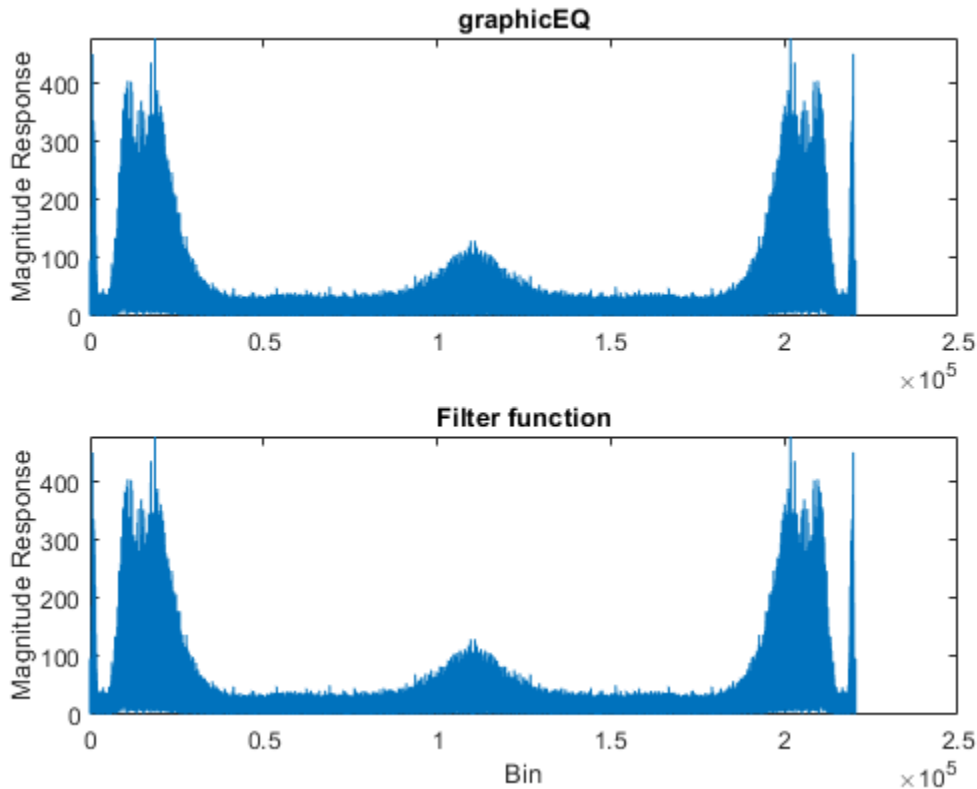
Compare the output of the filter function using coefficients `B` and `A` with the output of `graphicEQ`.

```
y = x;
for section = 1:equalizer.EQOrder/2
    for i = 1:numel(equalizer.Gains)
        y = filter(B(:,i*section),A(:,i*section),y);
    end
end
audioOut_filter = y;

audioOut = equalizer(x);

subplot(2,1,1)
plot(abs(fft(audioOut)))
title('graphicEQ')
ylabel('Magnitude Response')

subplot(2,1,2)
plot(abs(fft(audioOut_filter)))
title('Filter function')
xlabel('Bin')
ylabel('Magnitude Response')
```



Get gammatoneFilterBank Coefficients

Create the default `gammatoneFilterBank`, and then call `coeffs` to get its coefficients. Each gammatone filter is an eighth-order IIR filter composed of a cascade of four second-order sections. The size of `B` is 4-by-3-by-NumFilters. The size of `A` is 4-by-2-by-NumFilters.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

```
gammaFiltBank = gammatoneFilterBank('SampleRate',fs);
```

```
[B,A] = coeffs(gammaFiltBank);
```

Compare the output of the `filter` function using coefficients `B` and `A` with the output of `gammaFiltBank`. For simplicity, compare output from channel eight only.

```
channelToCompare = 8;
```

```
y1 = filter(B(1,:,channelToCompare),[1,A(1,:,channelToCompare)],audioIn);
```

```
y2 = filter(B(2,:,channelToCompare),[1,A(2,:,channelToCompare)],y1);
```

```
y3 = filter(B(3,:,channelToCompare),[1,A(3,:,channelToCompare)],y2);
```

```
audioOut_filter = filter(B(4,:,channelToCompare),[1,A(4,:,channelToCompare)],y3);
```

```
audioOut = gammaFiltBank(audioIn);
```

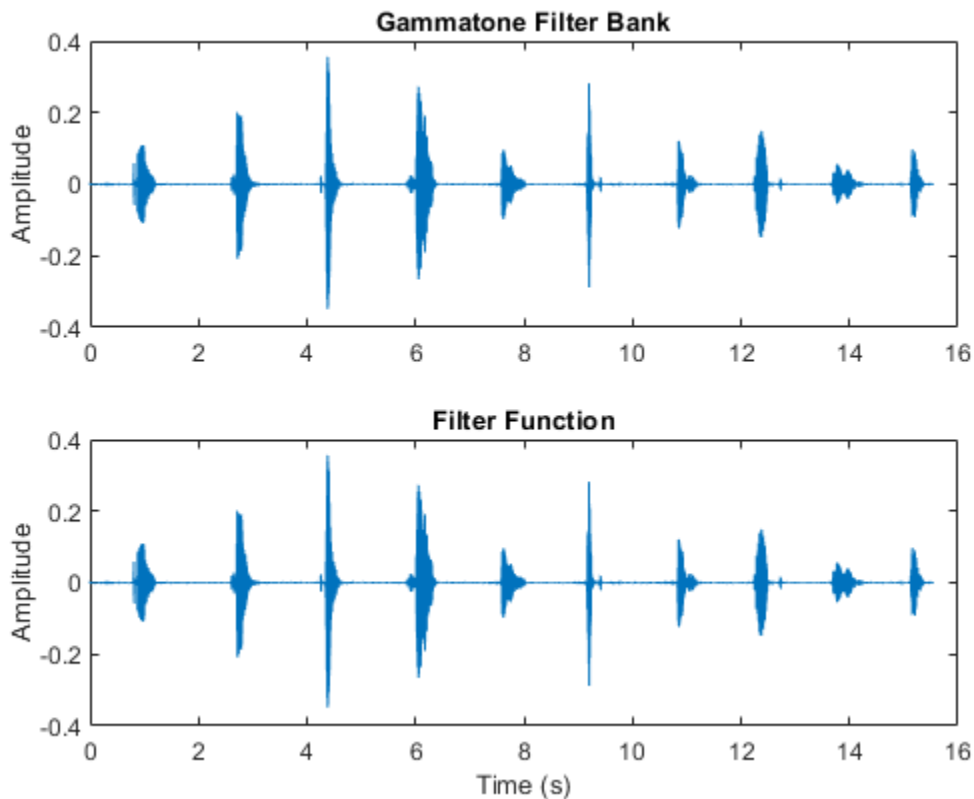
```
t = (0:(size(audioOut,1)-1))/fs;
```

```

subplot(2,1,1)
plot(t, audioOut(:, channelToCompare))
title('Gammatone Filter Bank')
ylabel('Amplitude')

subplot(2,1,2)
plot(t, audioOut_filter)
title('Filter Function')
xlabel('Time (s)')
ylabel('Amplitude')

```



Get octaveFilterBank Coefficients

Create the default `octaveFilterBank`, and then call `coeffs` to get its coefficients. The coefficients are returned as second-order sections. The dimensions of `B` and `A` are T -by-3-by- M , where T is the number of sections and M is the number of filters.

```

[audioIn, fs] = audioread('Counting-16-44p1-mono-15secs.wav');
octFiltBank = octaveFilterBank('SampleRate', fs);
[B, A] = coeffs(octFiltBank);

```

Compare the output of the filter function using coefficients `B` and `A` with the output of `octaveFilterBank`. For simplicity, compare output from channel five only.

```

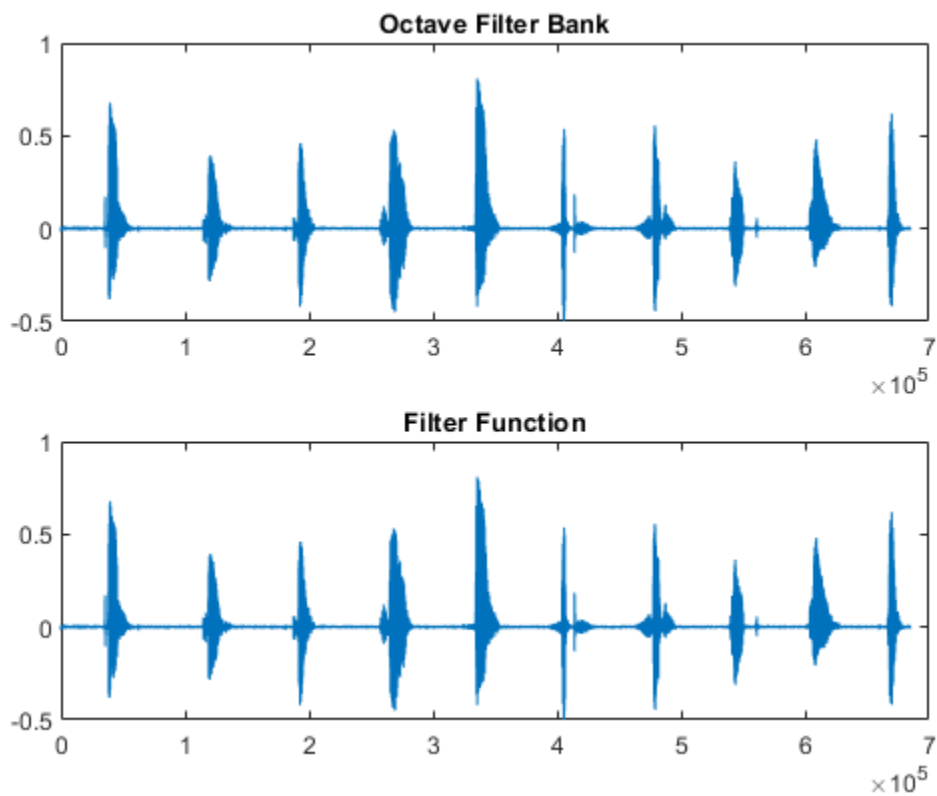
channelToCompare = 5;

audioOut_filter = filter(B(1,:,channelToCompare),A(1,:,channelToCompare),audioIn);
audioOut = octFiltBank(audioIn);

subplot(2,1,1)
plot(audioOut(:,channelToCompare))
title('Octave Filter Bank')

subplot(2,1,2)
plot(audioOut_filter)
title('Filter Function')

```



Input Arguments

obj — Object to get filter coefficients from

gammatoneFilterBank | octaveFilterBank | graphicEQ

Object to get filter coefficients from, specified as an object of gammatoneFilterBank, octaveFilterBank, graphicEQ, or shelvingFilter.

Output Arguments

B — Numerator filter coefficients

matrix | 3-D array

Numerator filter coefficients, returned as a 2-D matrix or 3-D array, depending on obj.

Data Types: `single` | `double`

A — Denominator filter coefficients

matrix | 3-D array

Numerator filter coefficients, returned as a 2-D matrix or 3-D array, depending on obj.

Data Types: `single` | `double`

Compatibility Considerations

SOS returned instead of FOS from octaveFilterBank

Behavior changed in R2020b

The `coeffs` function of `octaveFilterBank` now returns the filter in second-order sections (SOS) instead of fourth-order sections (FOS). This new format reflects an updated internal representation, which has been enhanced to remain stable at very low frequencies.

See Also

`gammatoneFilterBank` | `octaveFilterBank` | `graphicEQ`

Introduced in R2019a

freqz

Compute frequency response

Syntax

```
[H,f] = freqz(obj)
[H,f] = freqz(obj,ind)
[H,f] = freqz( ___,Name,Value)
freqz( ___ )
```

Description

`[H,f] = freqz(obj)` returns a matrix of complex frequency responses for each filter designed by `obj`.

`[H,f] = freqz(obj,ind)` returns the frequency response of filters with indices corresponding to the elements in vector `ind`.

`[H,f] = freqz(___,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

`freqz(___)` with no output arguments plots the frequency response of the filter bank.

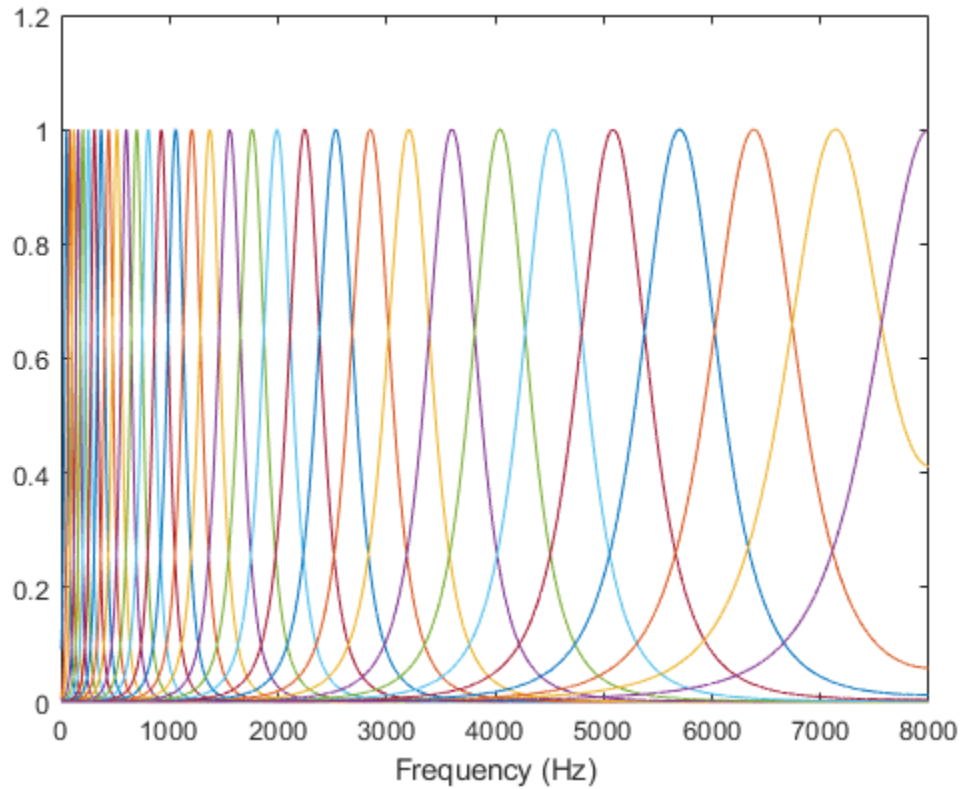
Examples

Frequency Response of `gammatoneFilterBank`

Create a `gammatoneFilterBank` object. Call `freqz` to get the complex frequency response, `H`, of the filter bank and a vector of frequencies, `f`, at which the response is calculated. Plot the magnitude frequency response of the filter bank.

```
gammaFiltBank = gammatoneFilterBank;
[H,f] = freqz(gammaFiltBank);

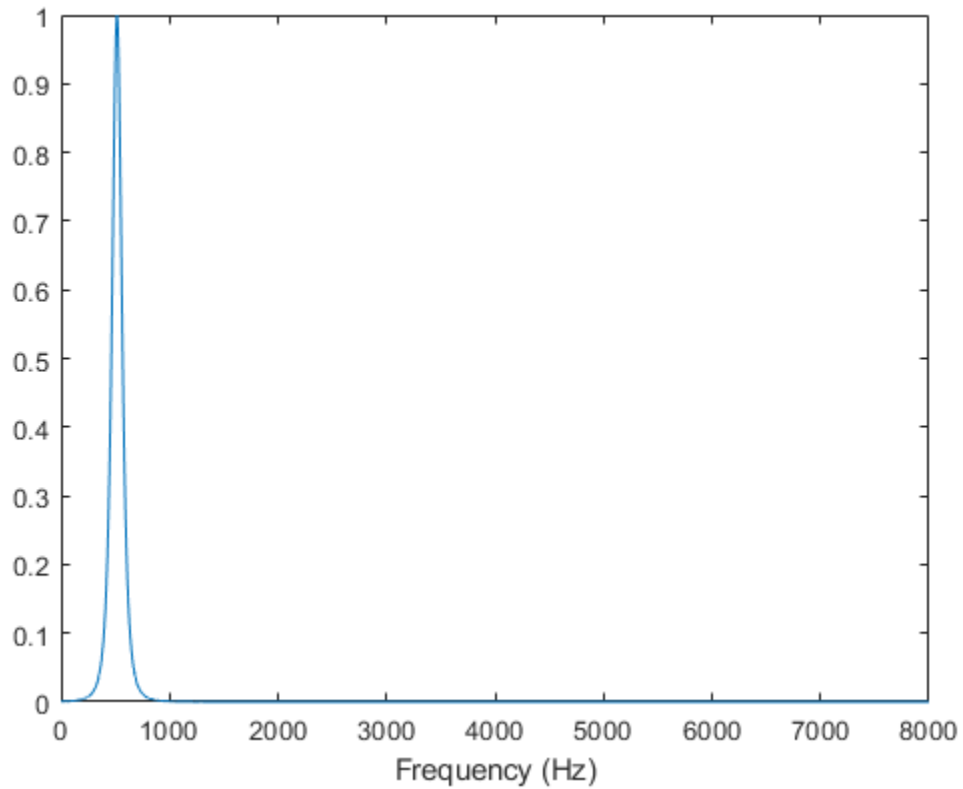
plot(f,abs(H))
xlabel('Frequency (Hz)')
```



To get the frequency response of a subset of filters in the filter bank, specify the second argument as a row vector of indices between one and the number of filters in the filter bank. Get the frequency response of the 10th filter in the filter bank and plot the magnitude frequency response.

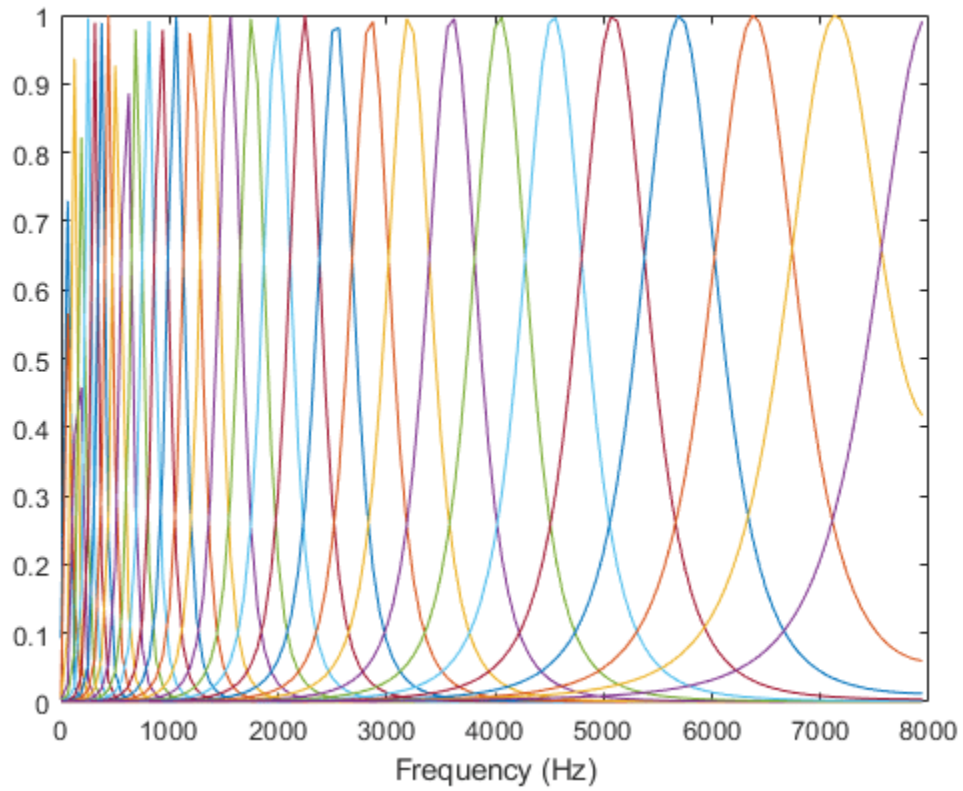
```
[H,f] = freqz(gammaFiltBank,10);
```

```
plot(f,abs(H))  
xlabel('Frequency (Hz)')
```



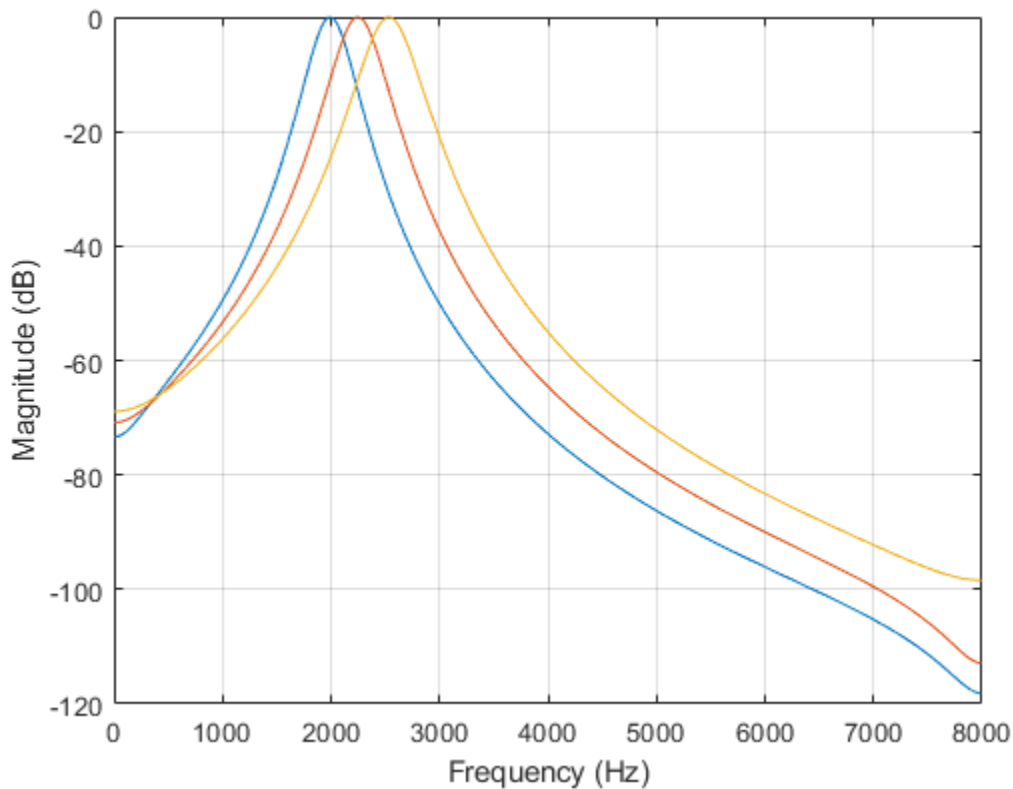
To specify the number of FFT points used to compute the frequency response, use the `NFFT` name-value pair. Specify that the frequency response is calculated using a 128-point FFT. Plot the magnitude frequency response.

```
[H,f] = freqz(gammaFiltBank, 'NFFT', 128);  
  
plot(f,abs(H))  
xlabel('Frequency (Hz)')
```

To visualize the magnitude frequency response only, call `freqz` without any output arguments. Plot the magnitude frequency response, in dB, of filters 20, 21, and 22 using a 1024-point DFT.

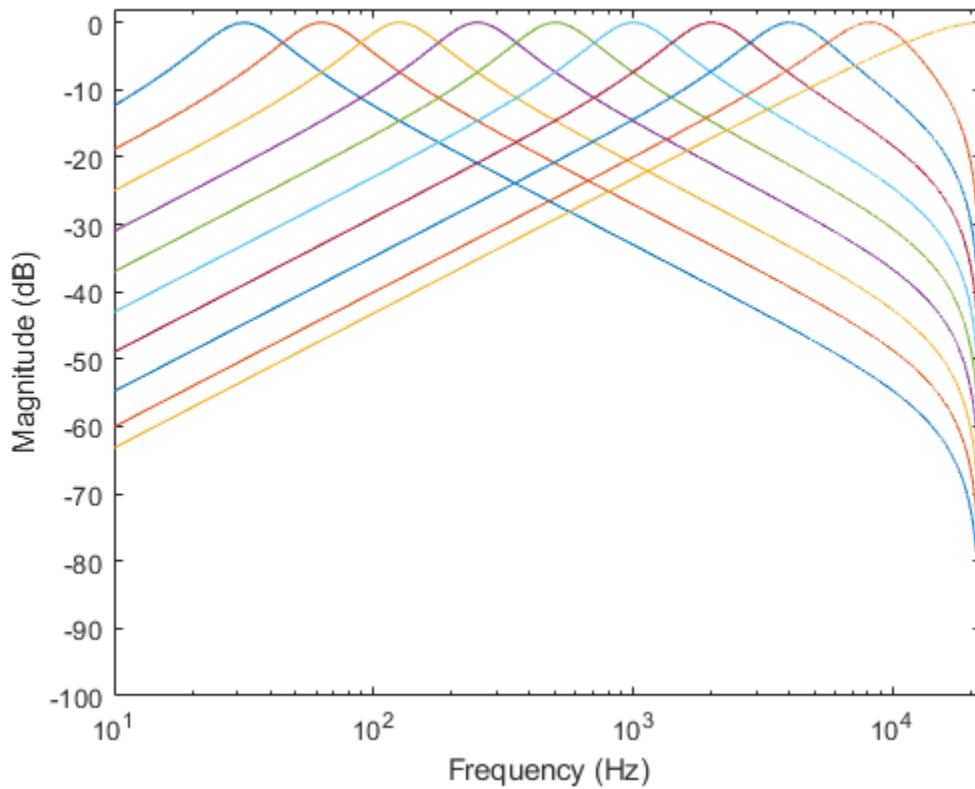
```
freqz(gammaFiltBank,[20,21,22], 'NFFT',1024)
```



Frequency Response of octaveFilterBank

Create an `octaveFilterBank` object. Call `freqz` to get the complex frequency response, `H`, of the filter bank and a vector of frequencies, `f`, at which the response is calculated. Plot the magnitude frequency response in dB.

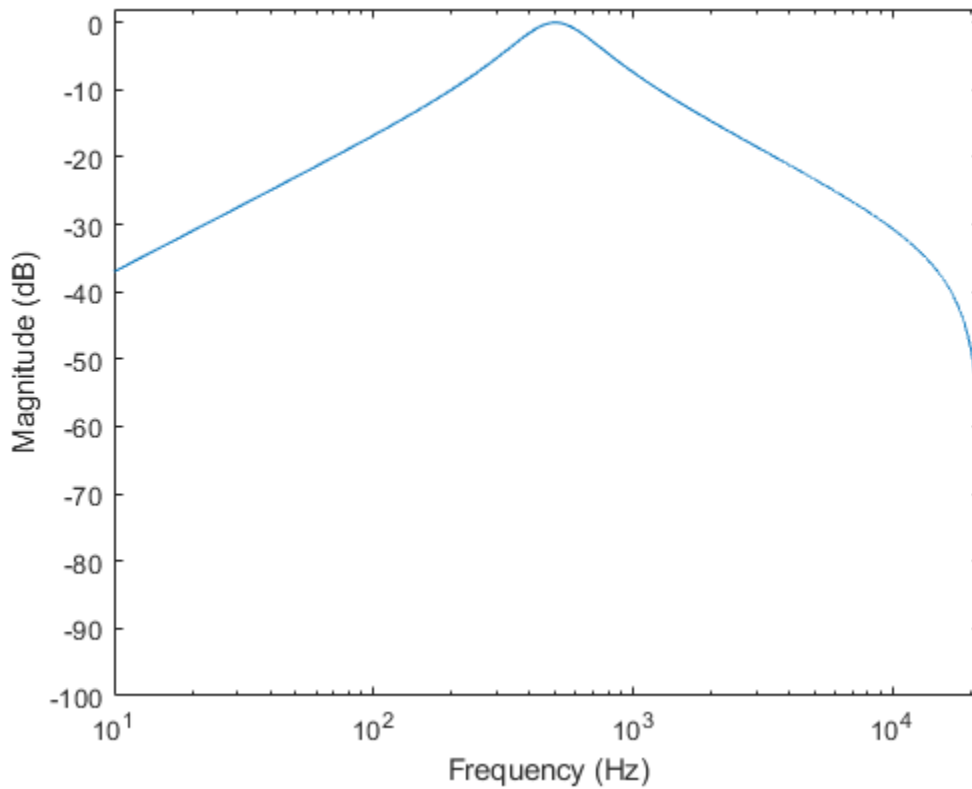
```
octFiltBank = octaveFilterBank;  
[H,f] = freqz(octFiltBank);  
  
plot(f,20*log10(abs(H)))  
xlabel('Frequency (Hz)')  
ylabel('Magnitude (dB)')  
set(gca,'XScale','log')  
axis([10 octFiltBank.SampleRate/2 -100 2])
```



To get the frequency response of a subset of filters in the filter bank, specify the second argument as a row vector of indices between one and the number of filters in the filter bank. Get the frequency response of the 5th filter in the filter bank and plot the magnitude frequency response in dB.

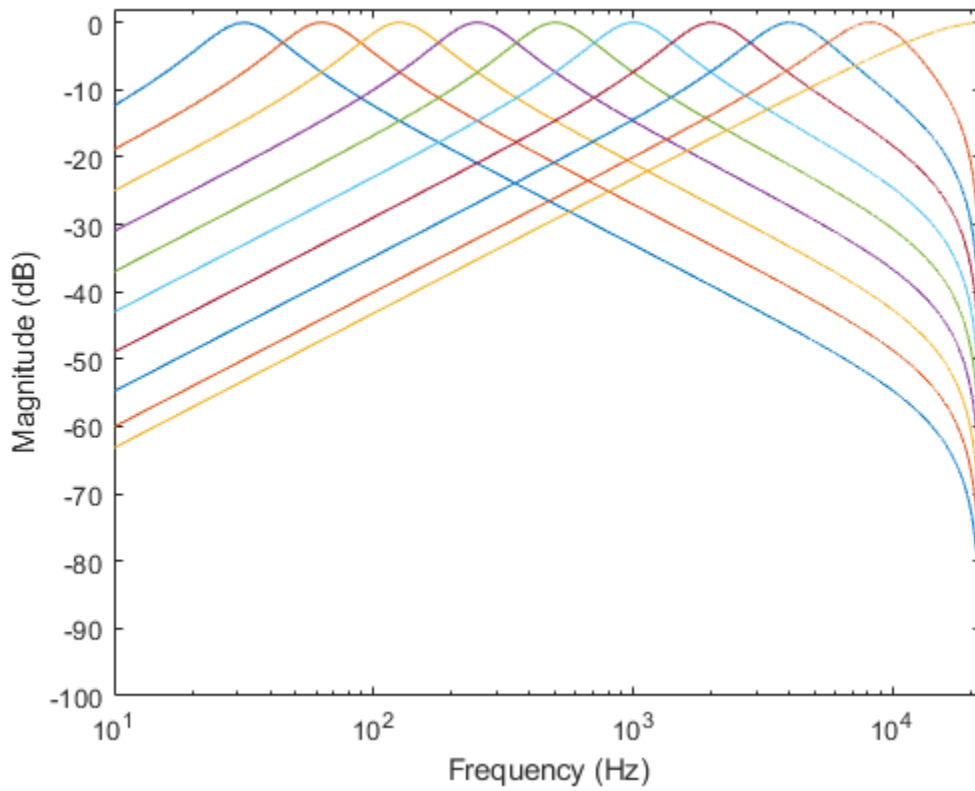
```
[H,f] = freqz(octFiltBank,5);

plot(f,20*log10(abs(H)))
xlabel('Frequency (Hz)')
ylabel('Magnitude (dB)')
set(gca,'XScale','log')
axis([10 octFiltBank.SampleRate/2 -100 2])
```



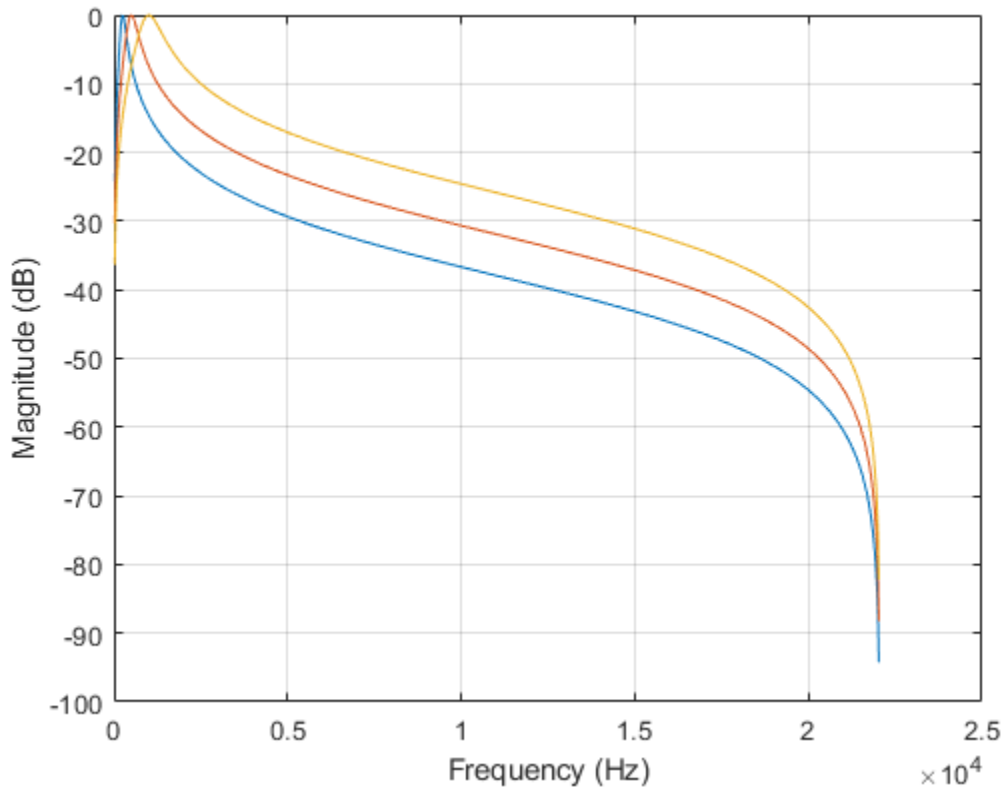
To specify the number of FFT points used to compute the frequency response, use the `NFFT` name-value pair. Specify that the frequency response is calculated using a 8192-point FFT. Plot the magnitude frequency response in dB.

```
[H,f] = freqz(octFiltBank, 'NFFT',8192);  
  
plot(f,20*log10(abs(H)))  
xlabel('Frequency (Hz)')  
ylabel('Magnitude (dB)')  
set(gca,'XScale','log')  
axis([10 octFiltBank.SampleRate/2 -100 2])
```



To visualize the magnitude frequency response only, call `freqz` without any output arguments. Plot the magnitude frequency response, in dB, of filters 4, 5, and 6 using a 1024-point DFT.

```
freqz(octFiltBank,[4,5,6], 'NFFT',1024)
```



Input Arguments

obj — Object to get filter frequency responses from

gammatoneFilterBank | octaveFilterBank

Object to get filter frequency responses from, specified as an object of `gammatoneFilterBank` or `octaveFilterBank`.

ind — Indices of filters to calculate frequency responses from

1:N (default) | row vector of integers with values in the range [1, N]

Indices of filters to calculate frequency responses from, specified as a row vector of integers with values in the range [1, N]. N is the total number of filters designed by `obj`.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'NFFT', 2048

NFFT — Number of DFT bins

8192 (default) | positive integer

Number of DFT bins, specified as a positive integer.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

H — Complex frequency response of each filter

matrix

Complex frequency response of each filter, returned as an M -by- N matrix. M is the number of DFT bins, specified by `NFFT`. N is the number of filters, which is either `length(ind)` or, if `ind` is not specified, the total number of filters in the filter bank.

Data Types: `double`

f — Frequencies at which response is computed (Hz)

column vector

Frequencies at which the response is computed in Hz, returned as a column vector.

Data Types: `double`

See Also

`gammatoneFilterBank` | `octaveFilterBank` | `fvtool`

Introduced in R2019a

fvtool

Visualize filter bank

Syntax

```
fvtool(obj)  
fvtool(obj,ind)  
fvtool( ____,Name,Value)
```

Description

`fvtool(obj)` visualizes the filters in the filter bank using the Filter Visualization Tool (FVTool).

`fvtool(obj,ind)` visualizes the filters corresponding to the elements in the vector `ind`.

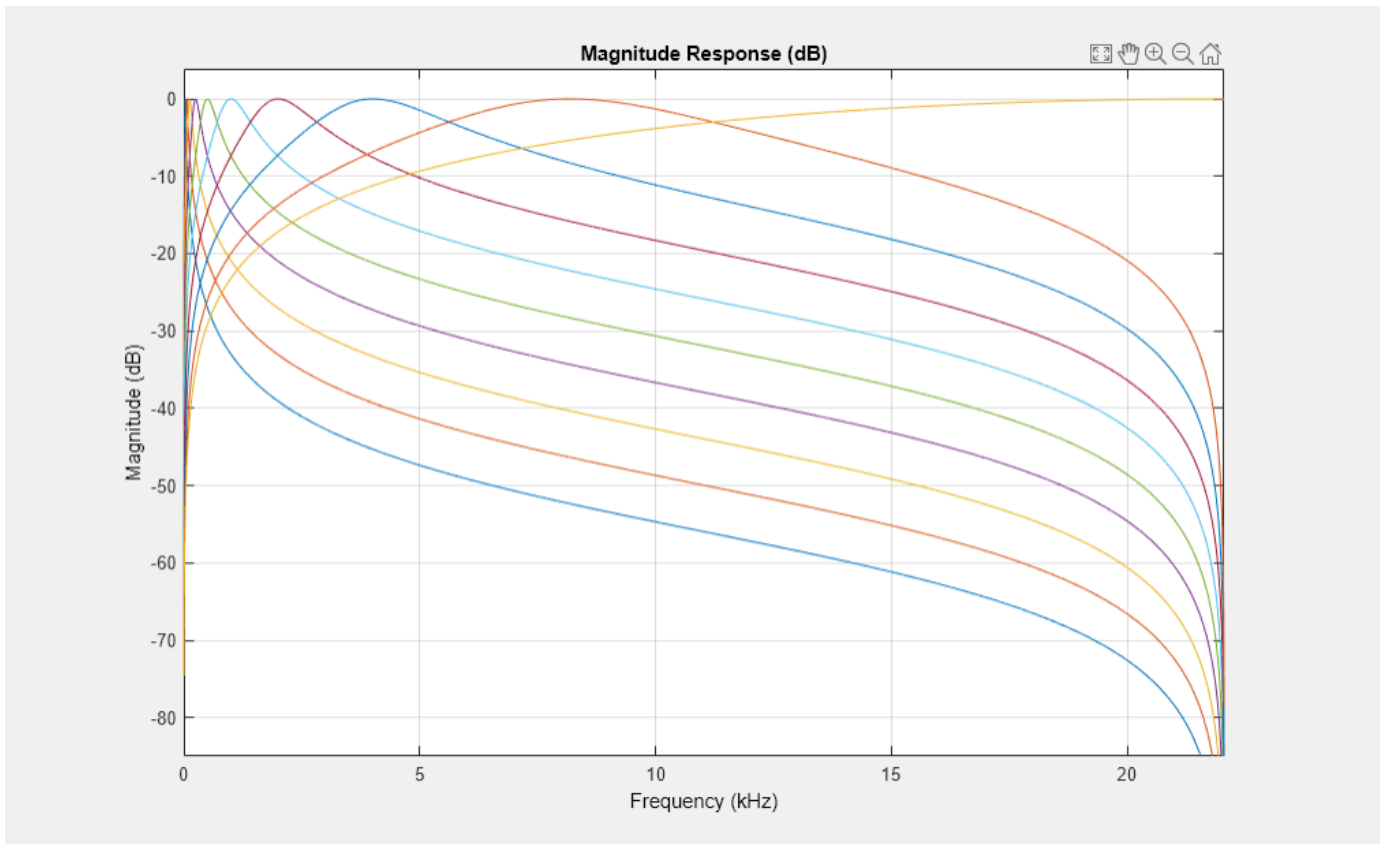
`fvtool(____,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Examples

View octaveFilterBank in FVTool

Create an `octaveFilterBank` object. Call `fvtool` to visualize the filter bank.

```
octFiltBank = octaveFilterBank;  
fvtool(octFiltBank)
```

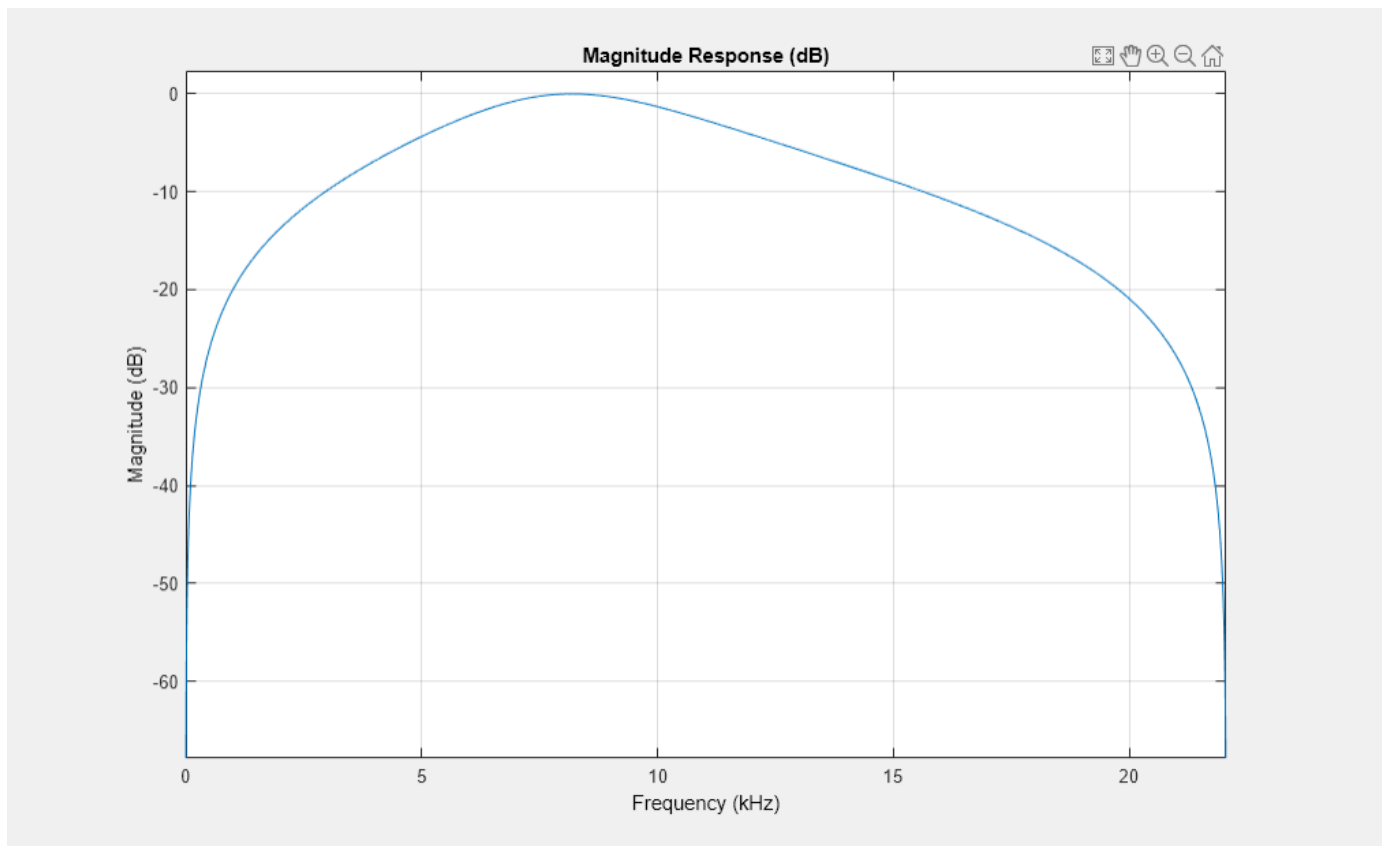
```
ans =
  Figure (filtervisualizationtool) with properties:
```

```
    Number: 1
    Name: 'Magnitude Response (dB)'
    Color: [0.9400 0.9400 0.9400]
    Position: [360 502 560 420]
    Units: 'pixels'
```

Use `get` to show all properties

To visualize a subset of filters in the filter bank, specify the second argument as a row vector of indices between one and the number of filters in the filter bank. If not specified, `fvtool` visualizes 1 to N filters of the filter bank, where N is the smallest of `octFiltBank.NumFilters` and 64. Visualize the ninth filter.

```
fvtool(octFiltBank,9)
```



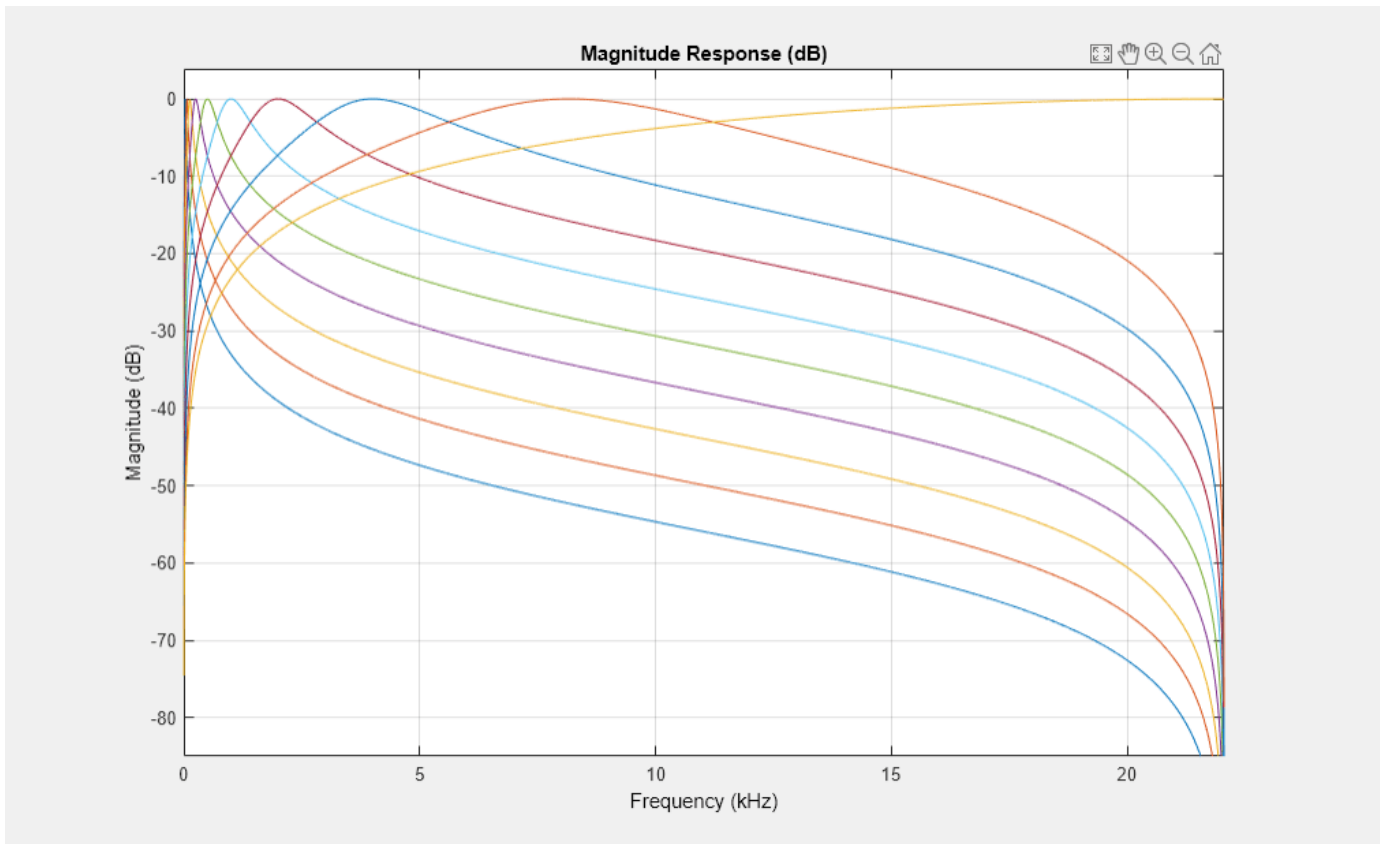
```
ans =
  Figure (filtervisualizationtool) with properties:

    Number: 2
    Name: 'Magnitude Response (dB)'
    Color: [0.9400 0.9400 0.9400]
    Position: [360 502 560 420]
    Units: 'pixels'
```

Use `get` to show all properties

To specify the number of FFT points used to compute the frequency response, use the `NFFT` name-value pair. Specify that the frequency response is calculated using a 8192-point FFT.

```
fvtool(octFiltBank, 'NFFT', 8192)
```



```
ans =
  Figure (filtervisualizationtool) with properties:
```

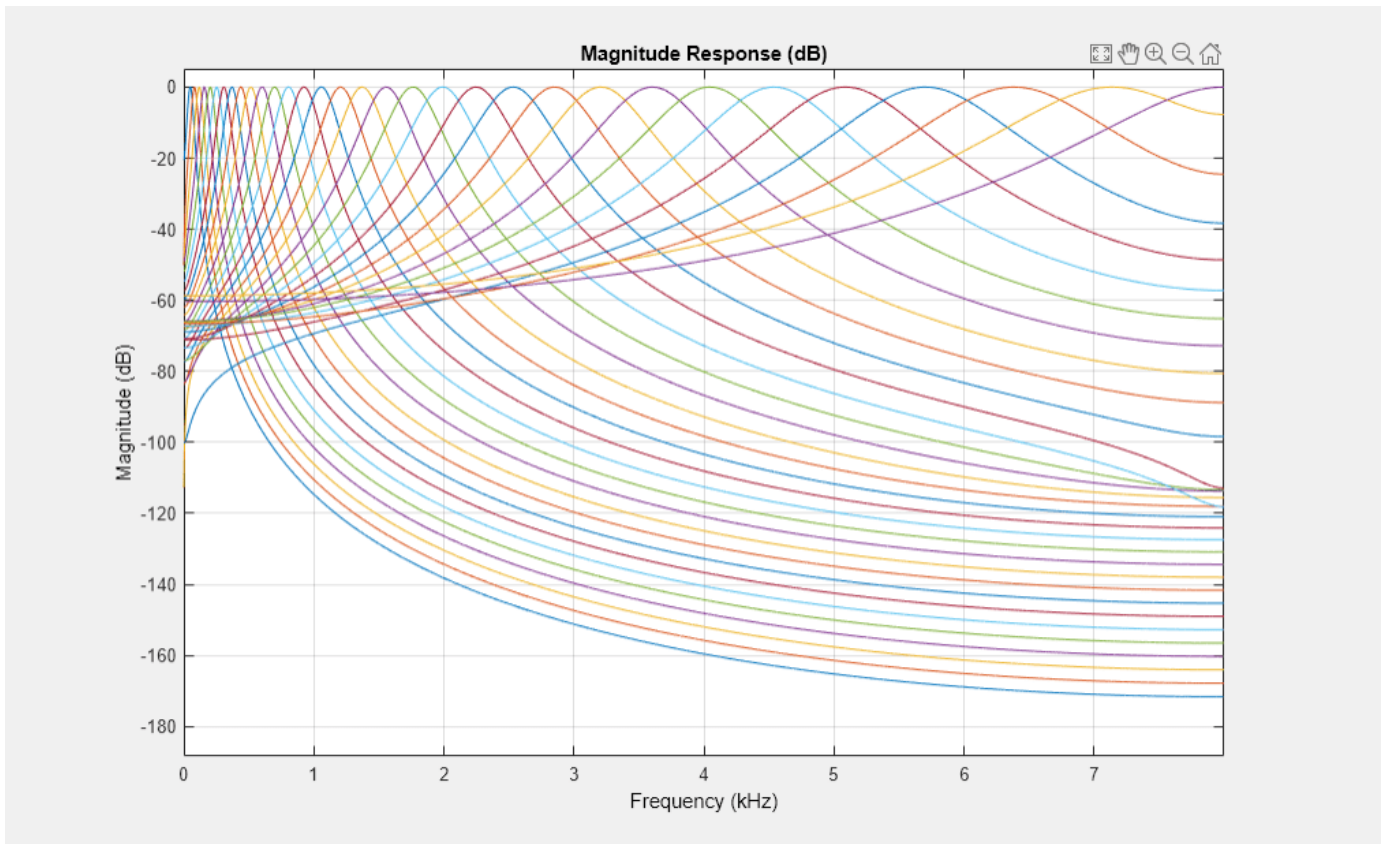
```
    Number: 3
    Name: 'Magnitude Response (dB)'
    Color: [0.9400 0.9400 0.9400]
    Position: [360 502 560 420]
    Units: 'pixels'
```

```
Use get to show all properties
```

View gammatoneFilterBank in FVTool

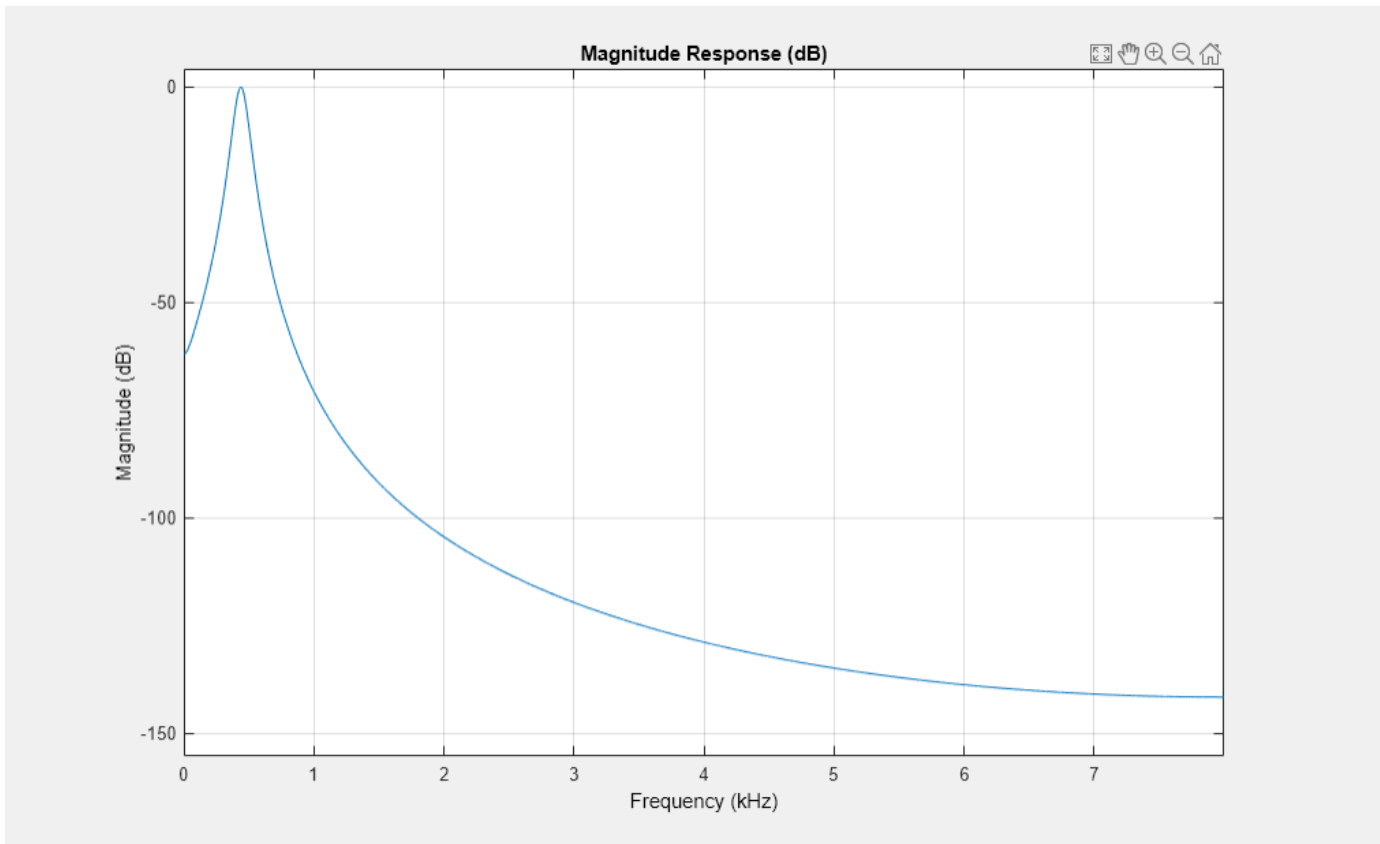
Create a `gammatoneFilterBank` object. Call `fvtool` to visualize the filter bank.

```
gammaFiltBank = gammatoneFilterBank;
fvtool(gammaFiltBank);
```



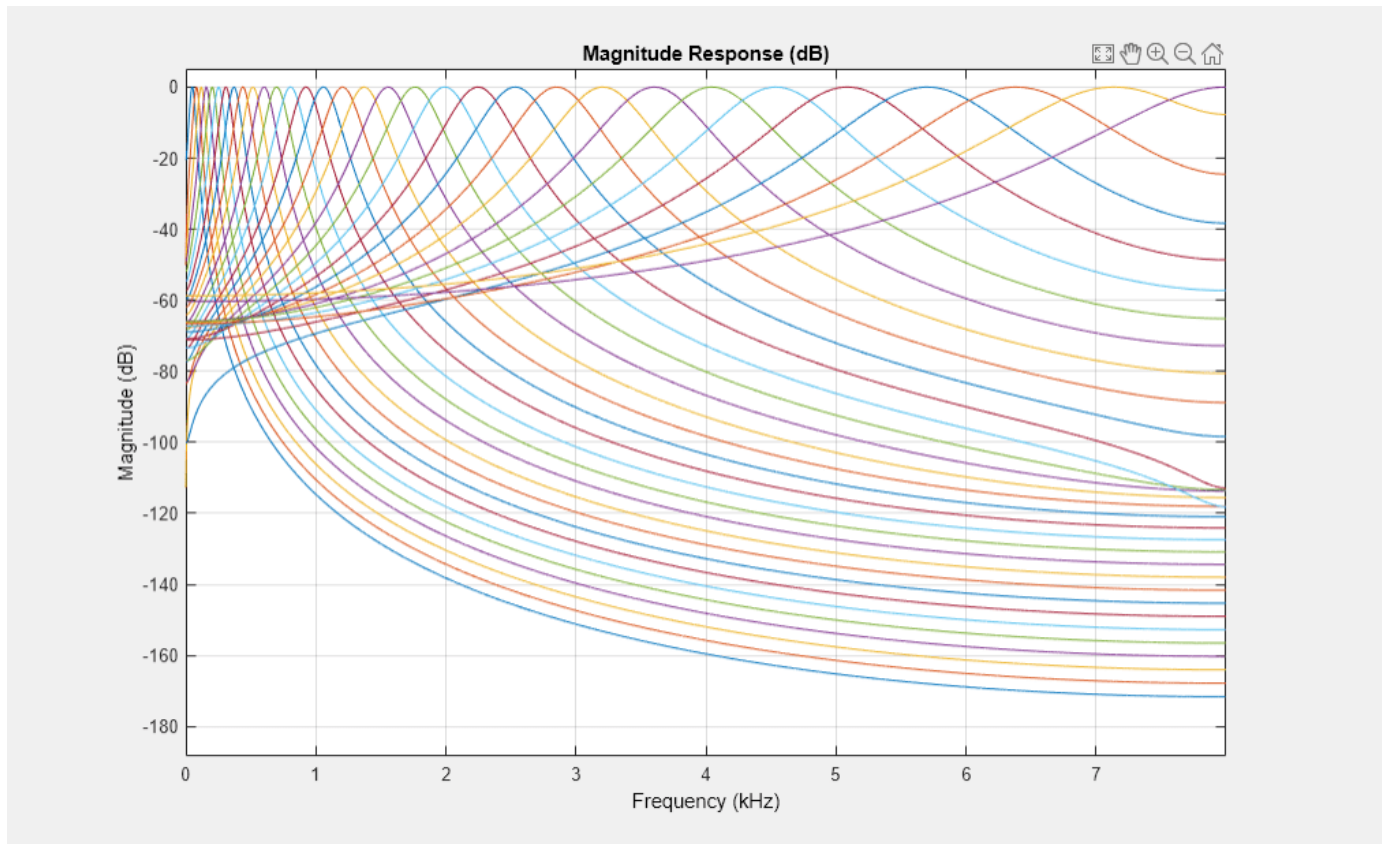
To visualize a subset of filters in the filter bank, specify the second argument as a row vector of indices between one and the number of filters in the filter bank. If not specified, `fvtool` visualizes 1 to N filters of the filter bank, where N is the smallest of `gammaFiltBank.NumFilters` and 64. Visualize the ninth filter.

```
fvtool(gammaFiltBank,9);
```



To specify the number of FFT points used to compute the frequency response, use the `NFFT` name-value pair. Specify that the frequency response is calculated using a 8192-point FFT.

```
fvtool(gammaFiltBank, 'NFFT', 8192);
```



Input Arguments

obj — Object to get filter frequency responses from

gammatoneFilterBank | octaveFilterBank

Object to get filter frequency responses from, specified as an object of `gammatoneFilterBank` or `octaveFilterBank`.

ind — Indices of filters to calculate frequency responses from

1:max(N,64) (default) | row vector of integers with values in the range [1, N]

Indices of filters to calculate frequency responses from, specified as a row vector of integers with values in the range [1, N]. N is the total number of filters designed by `obj`.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: 'NFFT',2048

NFFT — Number of DFT bins

8192 (default) | positive integer

Number of DFT bins, specified as a positive integer.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

See Also

gammatoneFilterBank | octaveFilterBank

Introduced in R2019a

getBandedgeFrequencies

Get filter bandedges

Syntax

```
bandEdges = getBandedgeFrequencies(obj)
[bandEdges,centerFrequencies] = getBandedgeFrequencies(obj)
```

Description

`bandEdges = getBandedgeFrequencies(obj)` returns the bandedge frequencies of the filters designed by `obj`. If there are M filters, then there are M center frequencies and $M+1$ band edge frequencies.

`[bandEdges,centerFrequencies] = getBandedgeFrequencies(obj)` returns the center frequencies of the filters designed by `obj`.

Examples

Get Bandedge Frequencies

Create a default octaveFilterBank object.

```
octFiltBank = octaveFilterBank;
```

Call `getBandedgeFrequencies` to return a vector of bandedge frequencies.

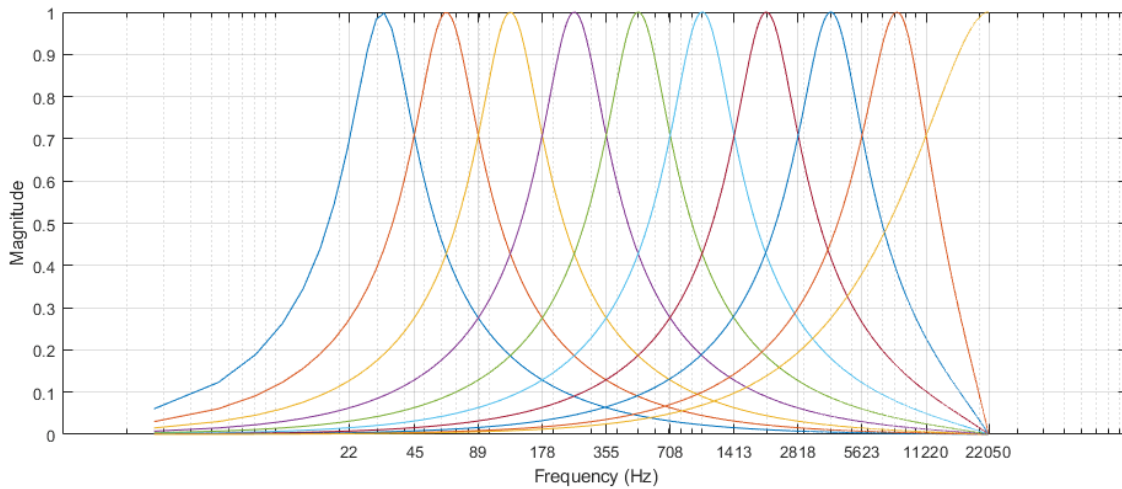
```
bE = getBandedgeFrequencies(octFiltBank)
```

```
bE = 1×11
104 ×
```

```
0.0022    0.0045    0.0089    0.0178    0.0355    0.0708    0.1413    0.2818    0.5623    1.1246
```

Call `freqz` to get the frequency response of the filter bank. Plot the magnitude frequency response. Use the bandedge frequencies to label the frequency axis.

```
[H,f] = freqz(octFiltBank);
semilogx(f,abs(H))
xticks(round(bE))
xlabel('Frequency (Hz)')
ylabel('Magnitude')
grid on
h = gcf;
set(h,'Position',[h.Position(1) h.Position(2) h.Position(3)*2 h.Position(4)])
```

Input Arguments

obj — Object to get filter information from

octaveFilterBank object

Object to get filter information from, specified as an object of octaveFilterBank.

Output Arguments

bandEdges — Bandedges of filters (Hz)

row vector

Bandedges of filters designed by obj in Hz, returned as a row vector.

Data Types: double | single

centerFrequencies — Center frequencies of filters (Hz)

row vector

Center frequencies of filters designed by obj in Hz, returned as a row vector.

Data Types: double | single

See Also

octaveFilterBank

Introduced in R2019a

getCenterFrequencies

Center frequencies of filters

Syntax

```
cf = getCenterFrequencies(obj)
```

Description

`cf = getCenterFrequencies(obj)` returns the center frequencies of the filters created by `obj`, in Hz.

Examples

Center Frequencies of `gammatoneFilterBank`

Create a `gammatoneFilterBank` and get the center frequencies of the filters in the filter bank.

```
gammaFiltBank = gammatoneFilterBank;
```

```
cf = getCenterFrequencies(gammaFiltBank)
```

```
cf = 1×32  
103 ×
```

```
0.0500 0.0822 0.1181 0.1581 0.2027 0.2525 0.3081 0.3700 0.4391 0.5
```

Center frequencies of a gammatone filter bank are spaced evenly on the ERB scale. Convert the center frequencies vector to the ERB scale and calculate the differences between center frequencies.

```
diff(hz2erb(cf))
```

```
ans = 1×31
```

```
1.0130 1.0130 1.0130 1.0130 1.0130 1.0130 1.0130 1.0130 1.0130 1.0
```

Center Frequencies of `octaveFilterBank`

Create an `octaveFilterBank` and get the center frequencies of the filters in the filter bank.

```
octFiltBank = octaveFilterBank;
```

```
cf = getCenterFrequencies(octFiltBank)
```

```
cf = 1×10  
104 ×
```

```
0.0032 0.0063 0.0126 0.0251 0.0501 0.1000 0.1995 0.3981 0.7943 1.5
```

Center frequencies of an octave filter bank are spaced evenly on a logarithmic scale. Convert the center frequencies vector to the log scale and calculate the differences between center frequencies.

```
diff(log10(cf))
```

```
ans = 1×9
```

```
0.3000 0.3000 0.3000 0.3000 0.3000 0.3000 0.3000 0.3000 0.3000
```

Get Center Frequencies of Octave Filter Bank Used in splMeter

Create an octave bandwidth splMeter and get the center frequencies of the octave filter bank. Round the center frequencies to two significant digits for display purposes.

```
SPL = splMeter('SampleRate',44100,'Bandwidth','1 octave');
cf = getCenterFrequencies(SPL);
round(cf,2,'significant')
```

```
ans = 1×10
```

```
32 63 130 250 500 1000 2000 4000
```

Input Arguments

obj — Object to get filter bank center frequencies from

gammatoneFilterBank | octaveFilterBank | splMeter

Object to get filter bank center frequencies from, specified as an object of gammatoneFilterBank, octaveFilterBank, or splMeter.

Output Arguments

cf — Filter bank center frequencies (Hz)

scalar | vector

Filter bank center frequencies in Hz, returned a scalar or vector.

See Also

gammatoneFilterBank | octaveFilterBank | splMeter

Introduced in R2019a

getBandwidths

Get filter bandwidths

Syntax

```
bw = getBandwidths(obj)
```

Description

`bw = getBandwidths(obj)` returns the bandwidths of the filters created by `obj`, in Hz.

Examples

Get Filter Bandwidths of `gammatoneFilterBank`

Create a default `gammatoneFilterBank`. Call `getBandwidths` to get the bandwidths of the filters, in Hz.

```
gammaFiltBank = gammatoneFilterBank;
```

```
bw = getBandwidths(gammaFiltBank)
```

```
bw = 1×32
```

```
    30.6688    34.2080    38.1555    42.5583    47.4691    52.9463    59.0554    65.8692    73.4690    81.9
```

Input Arguments

obj — Object to get filter bandwidth from

`gammatoneFilterBank`

Object to get filter bandwidth from, specified as an object of `gammatoneFilterBank`.

Output Arguments

bw — Filter bandwidths (Hz)

scalar | vector

Filter bandwidths in Hz, returned as a scalar or vector.

See Also

`gammatoneFilterBank`

Introduced in R2019a

getGroupDelays

Get group delays

Syntax

```
groupDelays = getGroupDelays(obj)  
[groupDelays,centerFrequencies] = getGroupDelays(obj)
```

Description

`groupDelays = getGroupDelays(obj)` returns the group delay of each filter at its center frequency.

`[groupDelays,centerFrequencies] = getGroupDelays(obj)` returns the center frequency of each filter.

Examples

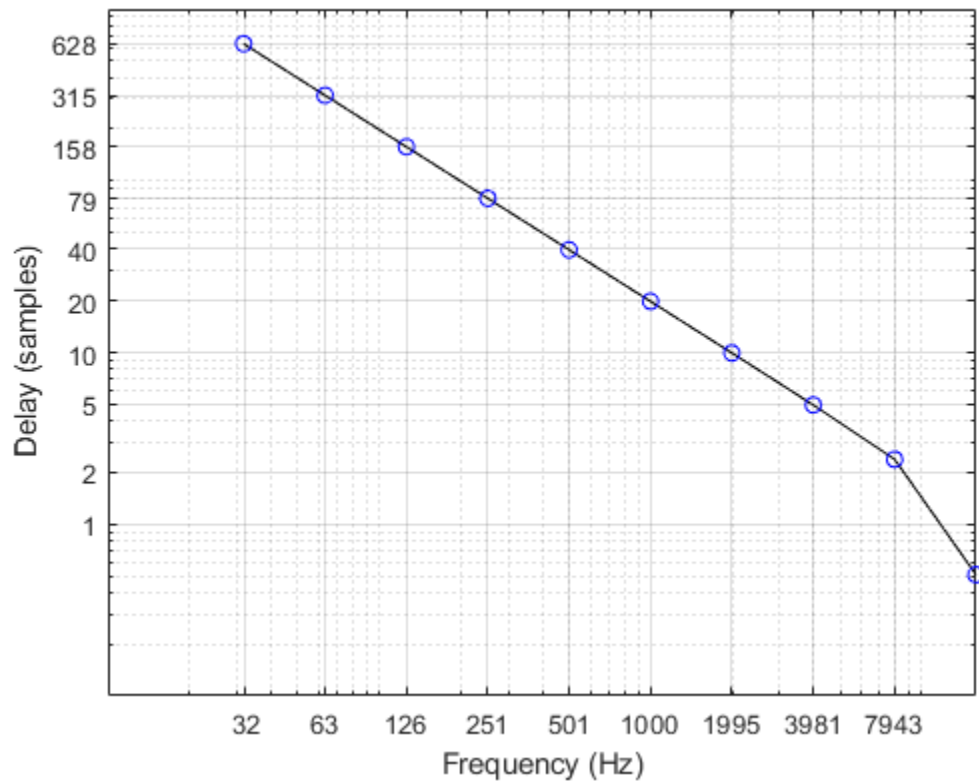
Get Group Delays

Create a default `octaveFilterBank` object. Call `getGroupDelays` to get the group delay of each octave filter at its center frequency.

```
octFiltBank = octaveFilterBank;  
[gd,cf] = getGroupDelays(octFiltBank);
```

Plot the group delay as a function of filter center frequency.

```
loglog(cf,gd,'k-',cf,gd,'bo')  
grid on  
xlabel('Frequency (Hz)')  
ylabel('Delay (samples)')  
xticks(round(cf))  
yticks(round(fliplr(gd)))
```



Input Arguments

obj – Object to get group delays from
`octaveFilterBank`

Object to get group delays from, specified as an object of `octaveFilterBank`.

Output Arguments

groupDelays – Group delays (samples)
 row vector

Group delay of each filter at its center frequency in samples, returned as a row vector.

centerFrequencies – Center frequencies of filters (Hz)
 row vector

Center frequencies of filters designed by `obj` in Hz, returned as a row vector.

Data Types: `double` | `single`

See Also

`octaveFilterBank`

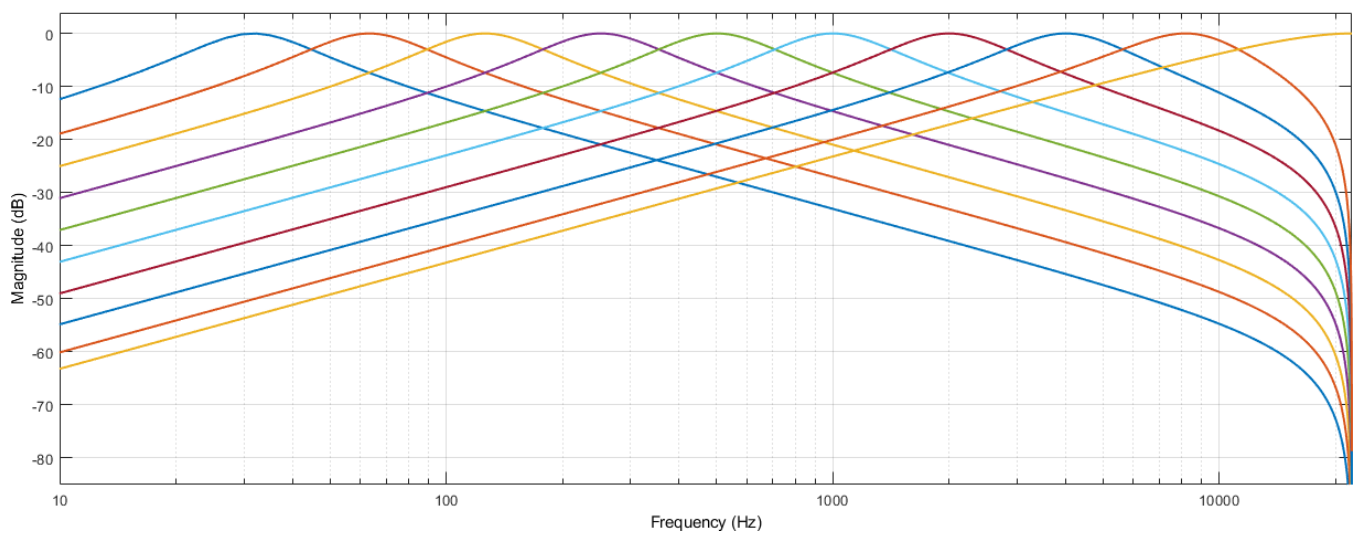
Introduced in R2019a

octaveFilterBank

Octave and fractional-octave filter bank

Description

`octaveFilterBank` decomposes a signal into octave or fractional-octave subbands. An octave band is a frequency band where the highest frequency is twice the lowest frequency. Octave-band and fractional octave-band filters are commonly used to mimic how humans perceive loudness.



To apply a bank of octave-band or fractional octave-band filters:

- 1 Create the `octaveFilterBank` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
octFiltBank = octaveFilterBank
octFiltBank = octaveFilterBank(bandwidth)
octFiltBank = octaveFilterBank(bandwidth, fs)
octFiltBank = octaveFilterBank( ___, Name, Value)
```

Description

`octFiltBank = octaveFilterBank` returns an octave filter bank. The object's filters data independently across each input channel over time.

`octFiltBank = octaveFilterBank(bandwidth)` sets the `Bandwidth` property to `bandwidth`.

`octFiltBank = octaveFilterBank(bandwidth, fs)` sets the `SampleRate` property to `fs`.

`octFiltBank = octaveFilterBank(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `octFiltBank = octaveFilterBank('1/2 octave', 'FrequencyRange', [62.5, 12000])` creates a $\frac{1}{2}$ octave-band filter bank, `octFiltBank`, with bandpass filters placed between 62.5 Hz and 12,000 Hz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

Bandwidth — Filter bandwidth (octave)

'1 octave' (default) | '2/3 octave' | '1/2 octave' | '1/3 octave' | '1/6 octave' | '1/12 octave' | '1/24 octave' | '1/48 octave'

Filter bandwidth in octaves, specified as '1 octave', '2/3 octave', '1/2 octave', '1/3 octave', '1/6 octave', '1/12 octave', '1/24 octave', or '1/48 octave'.

Tunable: No

Data Types: char | string

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: single | double

FrequencyRange — Frequency range of filter bank (Hz)

[22 22050] (default) | two-element row vector of positive monotonically increasing values

Frequency range of the filter bank in Hz, specified as a two-element row vector of positive monotonically increasing values. The filter bank center frequencies are placed according to the `Bandwidth`, `ReferenceFrequency`, and `OctaveRatioBase` properties. Filters that have a center frequency outside `FrequencyRange` are ignored.

Tunable: No

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

ReferenceFrequency — Reference frequency (Hz)

1000 (default) | positive integer scalar

Reference frequency of the filter bank in Hz, specified as a positive integer scalar. The reference frequency defines one of the center frequencies. All other center frequencies are set relative to the reference frequency.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

FilterOrder — Order of octave filters

2 (default) | even integer

Order of the octave filters, specified as an even integer. The filter order applies to each individual filter in the filter bank.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

OctaveRatioBase — Octave ratio base

10 (default) | 2

Octave ratio base, specified as 10 or 2. The octave ratio base determines the distribution of the center frequencies of the octave filters. The ANSI S1.11 standard recommends base 10. Base 2 is popular for music applications. Base 2 defines an octave as a factor of 2, and base 10 defines an octave as a factor of $10^{0.3}$.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

```
audioOut = octFiltBank(audioIn)
```

Description

`audioOut = octFiltBank(audioIn)` applies the octave filter bank on the input and returns the filtered output.

Input Arguments

audioIn — Audio input to octave filter bank

scalar | vector | matrix

Audio input to the octave filter bank, specified as a scalar, vector, or matrix. If specified as a matrix, the columns are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from octave filter bank

matrix | 3-D array

Audio output from octave filter bank, returned as a scalar, vector, matrix, or 3-D array. The shape of `audioOut` depends on the shape of `audioIn` and the number of filters in the filter bank. If M is the number of filters, and `audioIn` is an L -by- N matrix, then `audioOut` is returned as an L -by- M -by- N array. If N is 1, then `audioOut` is a matrix.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to octaveFilterBank

<code>coeffs</code>	Get filter coefficients
<code>freqz</code>	Compute frequency response
<code>fvtool</code>	Visualize filter bank
<code>getBandedgeFrequencies</code>	Get filter bandedges
<code>getCenterFrequencies</code>	Center frequencies of filters
<code>getGroupDelays</code>	Get group delays
<code>info</code>	Get filter information
<code>isStandardCompliant</code>	Verify octave filter bank is ANSI S1.11-2004 compliant

Common to All System Objects

<code>step</code>	Run System object algorithm
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object

Examples

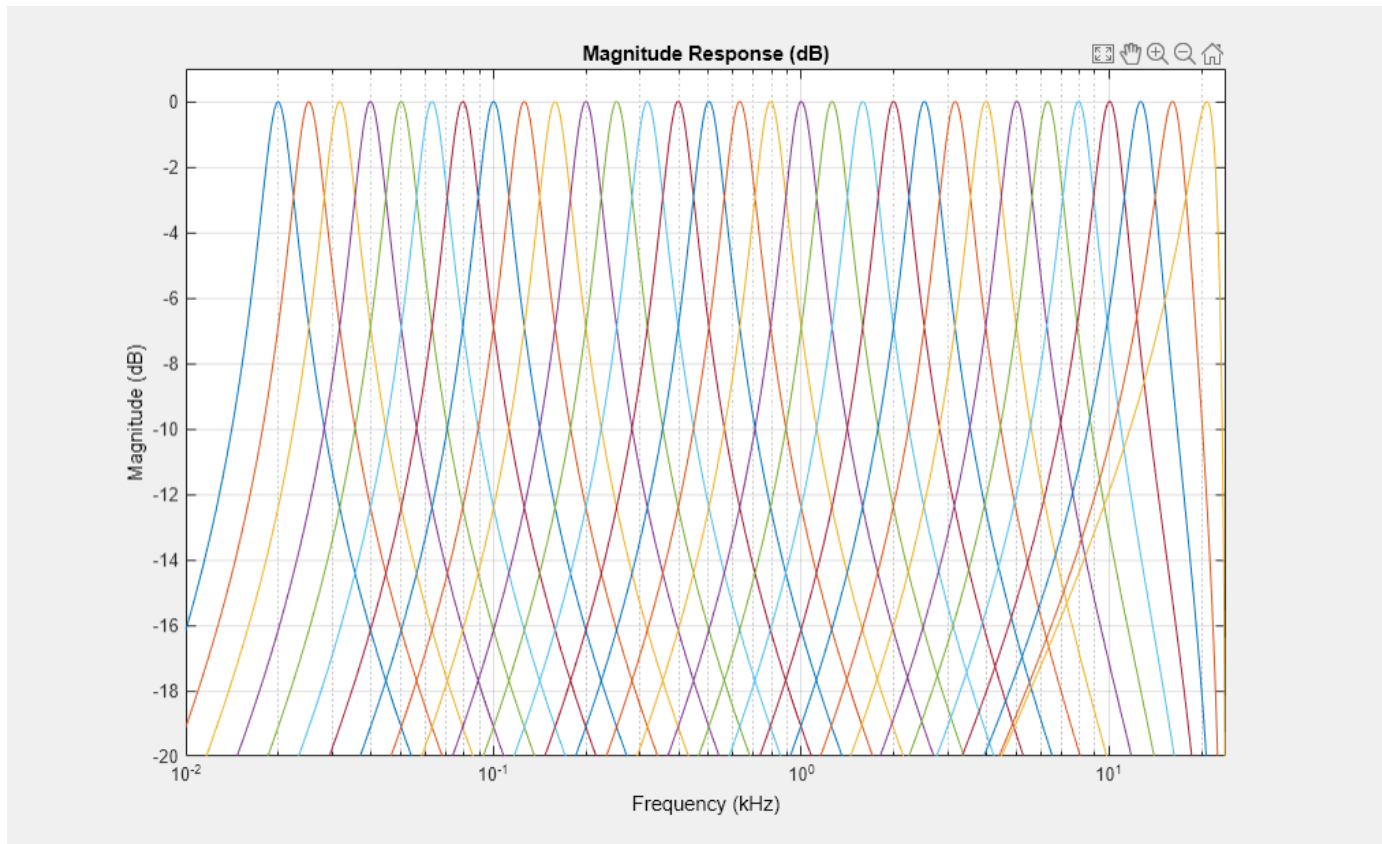
Apply Octave Filter Bank

Create a 1/3-octave filter bank for a signal sampled at 48 kHz. Set the frequency range to [18 22000] Hz.

```
octFilBank = octaveFilterBank('1/3 octave',48000, ...
    'FrequencyRange',[18 22000]);
```

Use `fvtool` to visualize the response of the filter bank. To get a high-resolution view on the lower frequencies, set the scale of the x-axis to `log` and `NFFT` to 2^{16} .

```
fvt = fvtool(octFilBank,'NFFT',2^16);
set(fvt,'FrequencyScale','log')
zoom(fvt,[.01 24 -20 1])
```



Display the filter bank center frequencies.

```
fc = getCenterFrequencies(octFilBank);
cf = string(size(fc));
for ii = find(fc<1000)
    cf(ii) = sprintf("%.0f Hz",round(fc(ii),2,"significant"));
end
for ii = find(fc>=1000)
    cf(ii) = sprintf("%.1f kHz",fc(ii)/1000);
end
disp(cf)
```

Columns 1 through 7

```
"20 Hz"    "25 Hz"    "32 Hz"    "40 Hz"    "50 Hz"    "63 Hz"    "79 Hz"
```

Columns 8 through 13

```
"100 Hz"   "130 Hz"   "160 Hz"   "200 Hz"   "250 Hz"   "320 Hz"
```

Columns 14 through 19

```
"400 Hz"   "500 Hz"   "630 Hz"   "790 Hz"   "1.0 kHz"   "1.3 kHz"
```

Columns 20 through 25

```
"1.6 kHz"   "2.0 kHz"   "2.5 kHz"   "3.2 kHz"   "4.0 kHz"   "5.0 kHz"
```

Columns 26 through 30

```
"6.3 kHz"    "7.9 kHz"    "10.0 kHz"   "12.6 kHz"   "15.8 kHz"
```

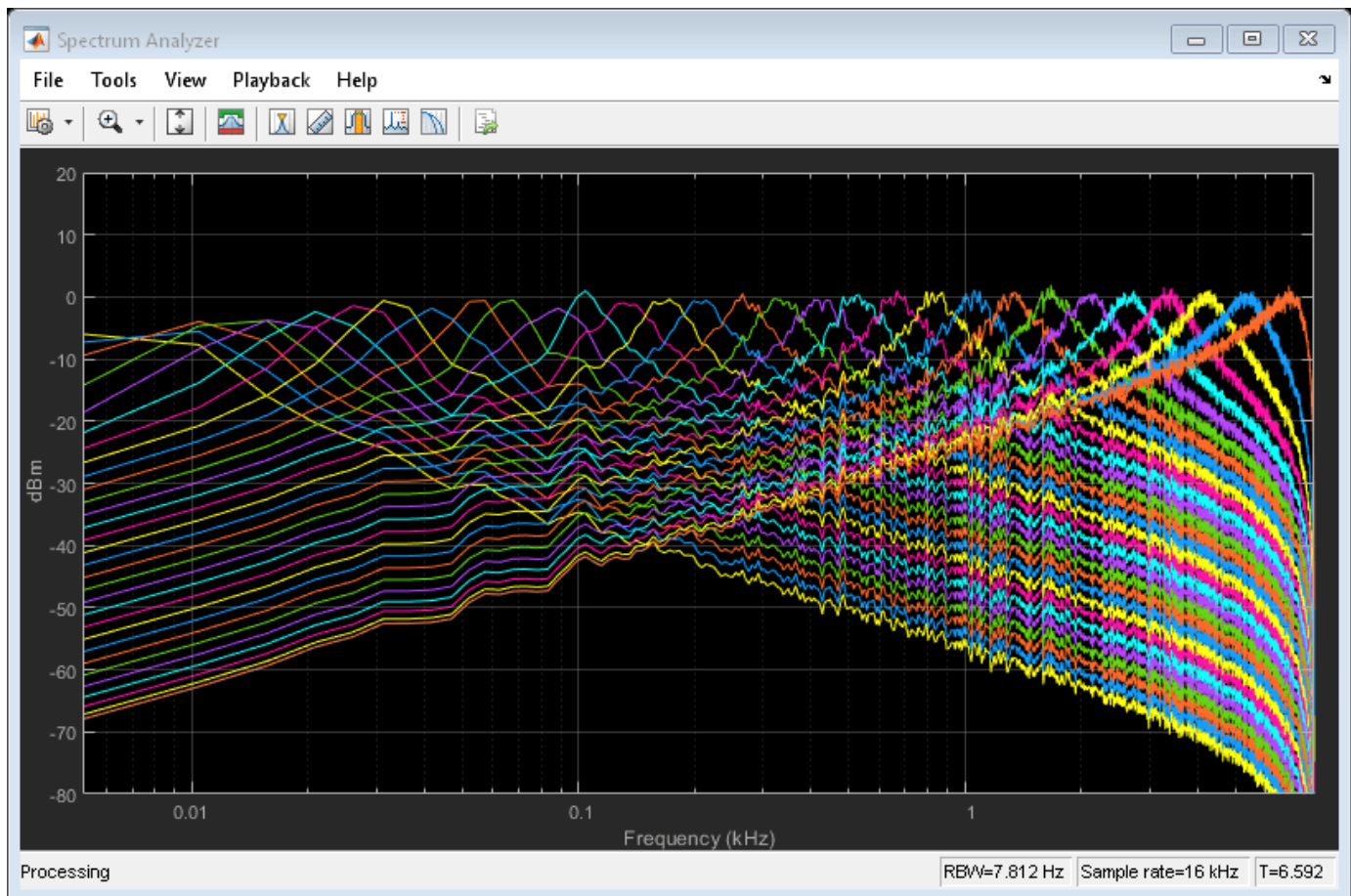
Column 31

```
"20.0 kHz"
```

Process white Gaussian noise through the filter bank. Use a spectrum analyzer to view the spectrum of the filter outputs.

```
sa = dsp.SpectrumAnalyzer('SampleRate',16e3,...
    'PlotAsTwoSidedSpectrum',false,...
    'FrequencyScale','log',...
    'SpectralAverages',100);

for index = 1:500
    x = randn(256,1);
    y = octFilBank(x);
    sa(y);
end
```



Analysis and Synthesis

The `octaveFilterBank` enables good reconstruction of a signal after analyzing or modifying its subbands.

Read in an audio file and listen to its contents.

```
[audioIn,fs] = audioread('Random0scThree-24-96-stereo-13secs.aif');  
sound(audioIn,fs)
```

Create a default `octaveFilterBank`. The default frequency range of the filter bank is 22 to 22,050 Hz. Frequencies outside of this range are attenuated in the reconstructed signal.

```
octFiltBank = octaveFilterBank('SampleRate',fs);
```

Pass the audio signal through the octave filter bank. The number of outputs depends on the `FrequencyRange`, `ReferenceFrequency`, `OctaveRatioBase`, and `Bandwidth` properties of the octave filter bank. Each channel of the input is passed through a filter bank independently and is returned as a separate page in the output.

```
audioOut = octFiltBank(audioIn);
```

```
[N,numFilters,numChannels] = size(audioOut)
```

```
N = 1265935
```

```
numFilters = 10
```

```
numChannels = 2
```

The octave filter bank introduces various group delays. To compensate for the group delay, remove the beginning delay from the individual filter outputs and zero-pad the ends of the signals so that they are all the same size. Use `getGroupDelays` to get the group delays. Listen to the group delay-compensated reconstruction.

```
groupDelay = round(getGroupDelays(octFiltBank)); % round for simplicity
```

```
audioPadded = [audioOut;zeros(max(groupDelay),numFilters,numChannels)];
```

```
for i = 1:numFilters
```

```
    audioOut(:,i,:) = audioPadded(groupDelay(i)+1:N+groupDelay(i),i,:);
```

```
end
```

To reconstruct the original signal, sum the outputs of the filter banks for each channel. Use `squeeze` to move the second channel from the third dimension to the second in the reconstructed signal.

```
reconstructedSignal = squeeze(sum(audioOut,2));  
sound(reconstructedSignal,fs)
```

Algorithms

The `octaveFilterBank` is implemented as a parallel structure of octave filters. Individual octave filters are designed as described by `octaveFilter`. By default, the octave filter bank center frequencies are placed as specified by the ANSI S1.11-2004 standard. You can modify the filter placements using the `Bandwidth`, `FrequencyRange`, `ReferenceFrequency`, and `OctaveRatioBase` properties.

References

- [1] Orfanidis, Sophocles J. *Introduction to Signal Processing*. Englewood Cliffs, NJ: Prentice Hall, 2010.
- [2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters*. ANSI S1.11-2004. Melville, NY: Acoustical Society of America, 2009.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

Octave Filter Bank | gammatoneFilterBank | octaveFilter | graphicEQ | splMeter

Topics

“Octave-Band and Fractional Octave-Band Filters”

Introduced in R2019a

isStandardCompliant

Verify octave filter bank is ANSI S1.11-2004 compliant

Syntax

```
[status,cf] = isStandardCompliant(ofb,ctype)
[statusall,cfref] = isStandardCompliant(ofb,ctype,'all')
```

Description

`[status,cf] = isStandardCompliant(ofb,ctype)` indicates whether each filter in `ofb` is compliant with the minimum and maximum attenuation specifications of the `ctype` design specified in the ANSI S1.11-2004 standard. The function also returns a vector of center frequencies.

`[statusall,cfref] = isStandardCompliant(ofb,ctype,'all')` returns a scalar that is true only if all the filters in the filter bank are compliant.

Examples

Verify Standard Compliance

Use `octaveFilterBank` to design an octave filter bank. Use `isStandardCompliant` to verify if the designed octave filter bank is compliant with the ANSI S1.11-2004 standard.

Create an `octaveFilterBank` object composed of 12th-order 1-octave filters.

Call `isStandardCompliant`, specifying the compliance class type as `'class 0'`. Display the compliance status and reference frequency for each filter.

```
ofb = octaveFilterBank('FilterOrder',12,'Bandwidth','1 octave');
[status,reffreq] = isStandardCompliant(ofb,'class 0')
```

```
status = 1x10 logical array
```

```
    1    1    1    1    1    1    1    1    1    1
```

```
reffreq = 1x10
104 ×
```

```
    0.0032    0.0063    0.0126    0.0251    0.0501    0.1000    0.1995    0.3981    0.7943    1.5886
```

Verify Octave Filter Bank Compliance

Use the `'all'` option to return compliance verification of the complete filter bank. The `'all'` option also returns the ANSI reference frequency against which the function checks the mask.


```
ofb = octaveFilterBank('FilterOrder',12,'Bandwidth','1/3 octave');
[status,reffreq] = isStandardCompliant(ofb,'class 0','all')
```

```
status = logical
        1
```

```
reffreq = 1000
```

Decrease the filter order to produce a noncompliant filter in the bank. Verify the last filter in the bank is noncompliant.

```
ofb = octaveFilterBank('FilterOrder',8);
status = isStandardCompliant(ofb,'class 1')
```

```
status = 1x10 logical array
```

```
    1    1    1    1    1    1    1    1    1    0
```

Use the 'all' option to verify noncompliance of the bank.

```
isStandardCompliant(ofb,'class 1','all')
```

```
ans = logical
      0
```

Input Arguments

ofb — Input octave filter bank

octaveFilterBank object

Input filter bank, specified as an octaveFilterBank object.

cctype — Compliance class type

'class 0' | 'class 1' | 'class 2'

Compliance class type to verify, specified as 'class 0', 'class 1', or 'class 2'. For more information on ANSI S1.11-2004 compliant filter classes, see “Octave-Band and Fractional Octave-Band Filters”.

Data Types: char | string

Output Arguments

status — Compliance status

vector

Compliance status, returned as a logical vector. The compliance status indicates whether each filter in the object ofb is compliant with the ANSI S1.11-2004 standard for cctype.

Data Types: logical

cf — Standard-compliant center frequencies

vector

Standard-compliant center frequencies, returned as a vector. The center frequencies are used to set the class attenuation limits.

statusall — Aggregate compliance status

scalar

Aggregate compliance status, returned as a logical scalar. `statusall` is true only if all the filters in the filter bank are compliant.

Data Types: `logical`

cfref — Standard-compliant reference frequency

scalar

Standard-compliant reference frequency, returned as a scalar. The reference frequency is used to set the class attenuation limits.

Tips

- To meet compliance, set the reference frequency of the octave filter bank to one of the values returned by the `getANSICenterFrequencies(octaveFilter)` method, increase the filter order, limit the frequency range, or increase the sample rate.

See Also

Introduced in R2021a

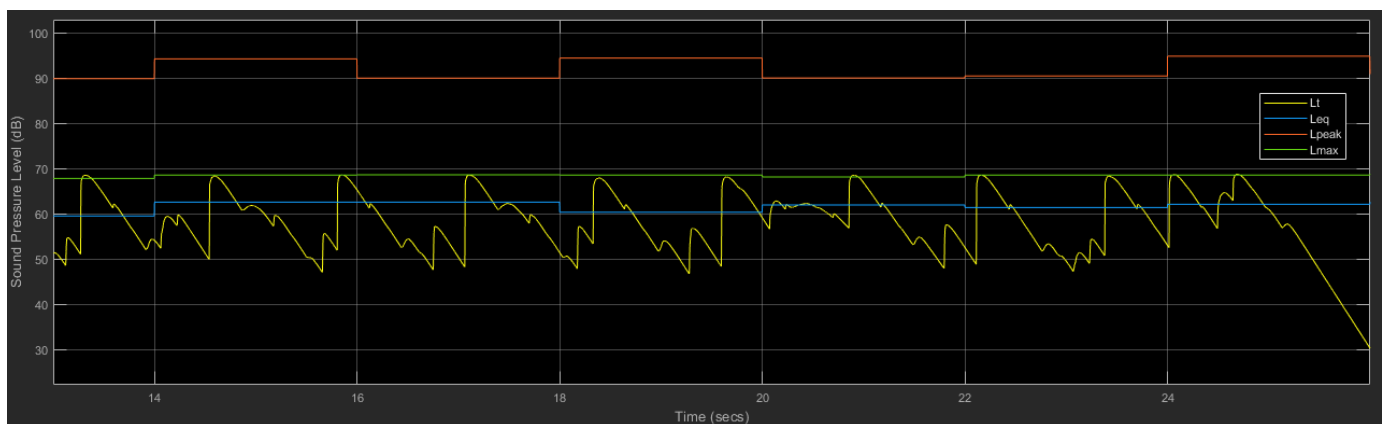
splMeter

Measure sound pressure level of audio signal

Description

The `splMeter` System object computes sound pressure level measurements. The object returns measurements for:

- frequency-weighted sound levels
- fast or slow time-weighted sound levels
- equivalent-continuous sound levels
- peak sound levels
- maximum sound levels



To implement SPL metering:

- 1 Create the `splMeter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
SPL = splMeter
SPL = splMeter(Name, Value)
```

Description

`SPL = splMeter` creates a System object, `SPL`, that performs SPL metering.

`SPL = splMeter(Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `SPL = splMeter('FrequencyWeighting', 'C-weighting', 'SampleRate', 12000)` creates a System object, `SPL`, that performs C-weighting and operates at 12 kHz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Bandwidth — Width of analysis bands

'Full band' (default) | '1 octave' | '2/3 octave' | '1/3 octave'

Width of analysis bands, specified as 'Full band', '1 octave', '2/3 octave', or '1/3 octave'. If `Bandwidth` is specified as 'Full band', the SPL meter returns one set of measurements for the whole frequency band. If `Bandwidth` is specified as '1 octave', '2/3 octave', or '1/3 octave', the SPL meter returns one set of measurements per octave or fractional-octave band.

Tunable: No

Data Types: char | string

FrequencyRange — Frequency range of filter bank (Hz)

[22 22050] (default) | two-element row vector of positive monotonically increasing values

Frequency range of the filter bank in Hz, specified as a two-element row vector of positive monotonically increasing values. Frequency bands centered above `SampleRate/2` are excluded.

Tunable: No

Dependencies

To enable this property, set `Bandwidth` to '1 octave', '2/3 octave', or '1/3 octave'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

OctaveFilterOrder — Order of octave filter

2 (default) | even integer

Order of the octave filter, specified as an even integer.

Tunable: No

Dependencies

To enable this property, set `Bandwidth` to '1 octave', '2/3 octave', or '1/3 octave'.

Data Types: single | double

FrequencyWeighting — Frequency weighting applied to input

'A-weighting' (default) | 'C-weighting' | 'Z-weighting' (no weighting)

Frequency weighting applied to input, specified as 'A-weighting', 'C-weighting', or 'Z-weighting', where Z-weighting corresponds to no weighting. The frequency weighting is designed and implemented using the `weightingFilter` System object.

Tunable: No

Data Types: `char` | `string`

TimeWeighting — Time weighting (s)

'Fast' (default) | 'Slow'

Time weighting, in seconds, for calculation of time-weighted sound level and maximum time-weighted sound level, specified as 'Fast' or 'Slow'. The `TimeWeighting` property is used to specify the coefficient of a lowpass filter.

- 'Fast' - 1/8
- 'Slow' - 1

Tunable: Yes

Data Types: `char` | `string`

PressureReference — Reference pressure for dB calculations (Pa)

2e-5 (default) | positive scalar

Reference pressure for dB calculations in Pa, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

TimeInterval — Time interval for reporting level measurements (s)

1 (default) | positive scalar

Time interval, in seconds, to report equivalent-continuous, peak, and maximum time-weighted sound levels, specified as a positive scalar integer.

Tunable: No

Data Types: `single` | `double`

CalibrationFactor — Calibration factor multiplied by input

1 (default) | positive finite scalar or vector

Scalar (mono input) or vector (multichannel input) calibration factor multiplied by input.

To set the calibration factor using a reference tone, use `calibrate`.

Tunable: No

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: No

Data Types: `single` | `double`

Usage

Syntax

```
[Lt,Leq,Lpeak,Lmax] = SPL(audioIn)
```

Description

`[Lt,Leq,Lpeak,Lmax] = SPL(audioIn)` returns measurement values for the time-weighted (`Lt`) sound level of the current input frame, `audioIn`. The object also returns the equivalent-continuous (`Leq`), peak (`Lpeak`), and maximum time-weighted (`Lmax`) sound levels of the input to your SPL meter.

Input Arguments

audioIn — Audio input to SPL meter

column vector | matrix

Audio input to the SPL meter, specified as a column vector or matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

Lt — Time-weighted sound level (dB)

column vector | matrix | 3-D array

Time-weighted sound level in dB, returned as a column vector, matrix, or 3-D array the same type as `audioIn`.

Size and interpretation of the outputs depend on what the `Bandwidth` property is set to:

- `'Full band'` (default) -- `Lt`, `Leq`, `Lpeak`, and `Lmax` are returned as column vectors or matrices the same size as `audioIn`.
- `'1 octave'`, `'2/3 octave'`, or `'1/3 octave'` -- `Lt`, `Leq`, `Lpeak`, and `Lmax` are returned as *L*-by-*B*-by-*C* arrays.
 - *L* -- Number of rows in `audioIn`
 - *B* -- Number of octave bands
 - *C* -- Number of columns in `audioIn`

Data Types: `single` | `double`

Leq — Equivalent-continuous sound level (dB)

column vector | matrix | 3-D array

Equivalent-continuous sound level in dB, returned as a column vector, matrix, or 3-D array the same type as `audioIn`.

Size and interpretation of the outputs depend on what the `Bandwidth` property is set to:

- 'Full band' (default) -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as column vectors or matrices the same size as `audioIn`.
- '1 octave', '2/3 octave', or '1/3 octave' -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as L -by- B -by- C arrays.
 - L -- Number of rows in `audioIn`
 - B -- Number of octave bands
 - C -- Number of columns in `audioIn`

Data Types: `single` | `double`

Lpeak — Peak sound level (dB)

column vector | matrix | 3-D array

Peak sound level in dB, returned as a column vector, matrix, or 3-D array the same type as `audioIn`.

Size and interpretation of the outputs depend on what the Bandwidth property is set to:

- 'Full band' (default) -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as column vectors or matrices the same size as `audioIn`.
- '1 octave', '2/3 octave', or '1/3 octave' -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as L -by- B -by- C arrays.
 - L -- Number of rows in `audioIn`
 - B -- Number of octave bands
 - C -- Number of columns in `audioIn`

Data Types: `single` | `double`

Lmax — Maximum time-weighted sound level (dB)

column vector | matrix | 3-D array

Maximum time-weighted sound level in dB, returned as a column vector, matrix, or 3-D array the same type as `audioIn`.

Size and interpretation of the outputs depend on what the Bandwidth property is set to:

- 'Full band' (default) -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as column vectors or matrices the same size as `audioIn`.
- '1 octave', '2/3 octave', or '1/3 octave' -- L_t , L_{eq} , L_{peak} , and L_{max} are returned as L -by- B -by- C arrays.
 - L -- Number of rows in `audioIn`
 - B -- Number of octave bands
 - C -- Number of columns in `audioIn`

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to splMeter

```
calibrate           Calibrate meter using calibration tone with known level  
getCenterFrequencies  Center frequencies of filters
```

Common to All System Objects

```
step      Run System object algorithm  
release   Release resources and allow changes to System object property values and input  
          characteristics  
reset     Reset internal states of System object
```

Examples

Measure SPL of Audio Signal

Use the `splMeter` System object™ to measure the A-weighted sound pressure level of a streaming audio signal. Specify a two second time-interval for reporting and a fast time-weighting. Visualize the SPL measurements using the `timescope` object.

Create a `dsp.AudioFileReader` object to read in an audio file frame by frame. Create an `audioDeviceWriter` object to listen to the audio signal. Create a `timescope` object to visualize SPL measurements. Create an `splMeter` to measure the sound pressure level of the audio file. Use the default calibration factor of 1.

```
source = dsp.AudioFileReader('Ambiance-16-44p1-mono-12secs.wav');  
fs = source.SampleRate;  
  
player = audioDeviceWriter('SampleRate',fs);  
  
scope = timescope('SampleRate',fs, ...  
    'TimeSpanOverrunAction','Scroll', ...  
    'TimeSpanSource','Property','TimeSpan',3,'ShowGrid',true, ...  
    'YLimits',[20 110],'AxesScaling','Auto', ...  
    'ShowLegend',true,'BufferLength',4*3*fs, ...  
    'ChannelNames', ...  
    {'Lt_AF','Leq_A','Lpeak_A','Lmax_AF'}, ...  
    'Name','Sound Pressure Level Meter');  
  
SPL = splMeter('TimeWeighting','Fast', ...  
    'FrequencyWeighting','A-weighting', ...  
    'SampleRate',fs, ...  
    'TimeInterval',2);
```

In an audio stream loop:

- 1 Read in the audio signal frame.
- 2 Play the audio signal to your output device.
- 3 Call the SPL meter to return the time-weighted, equivalent-continuous, peak, and maximum time-weighted sound levels in dB.
- 4 Display the sound levels using the scope.

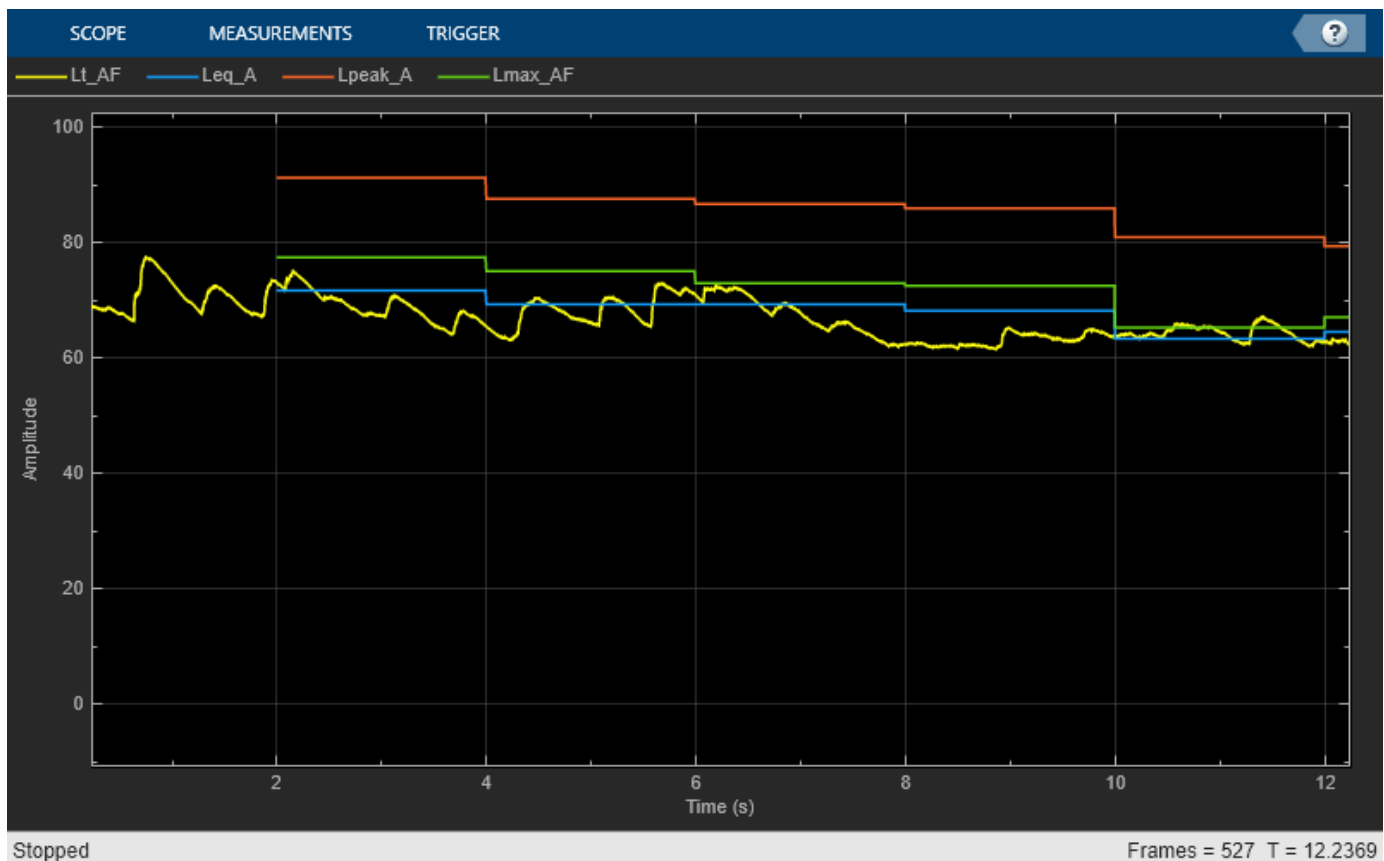
As a best practice, release your objects once complete.

```

while ~isDone(source)
    x = source();
    player(x);
    [Lt,Leq,Lpeak,Lmax] = SPL(x);
    scope([Lt,Leq,Lpeak,Lmax])
end

release(source)
release(player)
release(SPL)
release(scope)

```



Octave SPL Metering

The `splMeter` enables you to monitor sound pressure level for octave and fractional-octave bands. In this example, you monitor the equivalent-continuous sound pressure level of 1/3-octave bands.

Create a `dsp.AudioFileReader` object to read in an audio file frame by frame. Create an `audioDeviceWriter` object so you can listen to the audio signal. Create an `splMeter` to measure the octave sound pressure level of the audio file. Use the default calibration factor of 1. Create a `dsp.ArrayPlot` object to visualize the equivalent-continuous SPL for each octave band.

```
source = dsp.AudioFileReader('JetAirplane-16-11p025-mono-16secs.wav');
fs = source.SampleRate;

player = audioDeviceWriter('SampleRate',fs);

SPL = splMeter( ...
    'Bandwidth','1/3 octave', ...
    'SampleRate',fs);
centerFrequencies = getCenterFrequencies(SPL);

scope = dsp.ArrayPlot(...
    'XDataMode','Custom', ...
    'CustomXData',centerFrequencies, ...
    'XLabel','Octave Band Center Frequencies (Hz)', ...
    'YLabel','Equivalent-Continuous Sound Level (dB)', ...
    'YLimits',[20 90], ...
    'ShowGrid',true, ...
    'Name','Sound Pressure Level Meter');
```

In an audio stream loop:

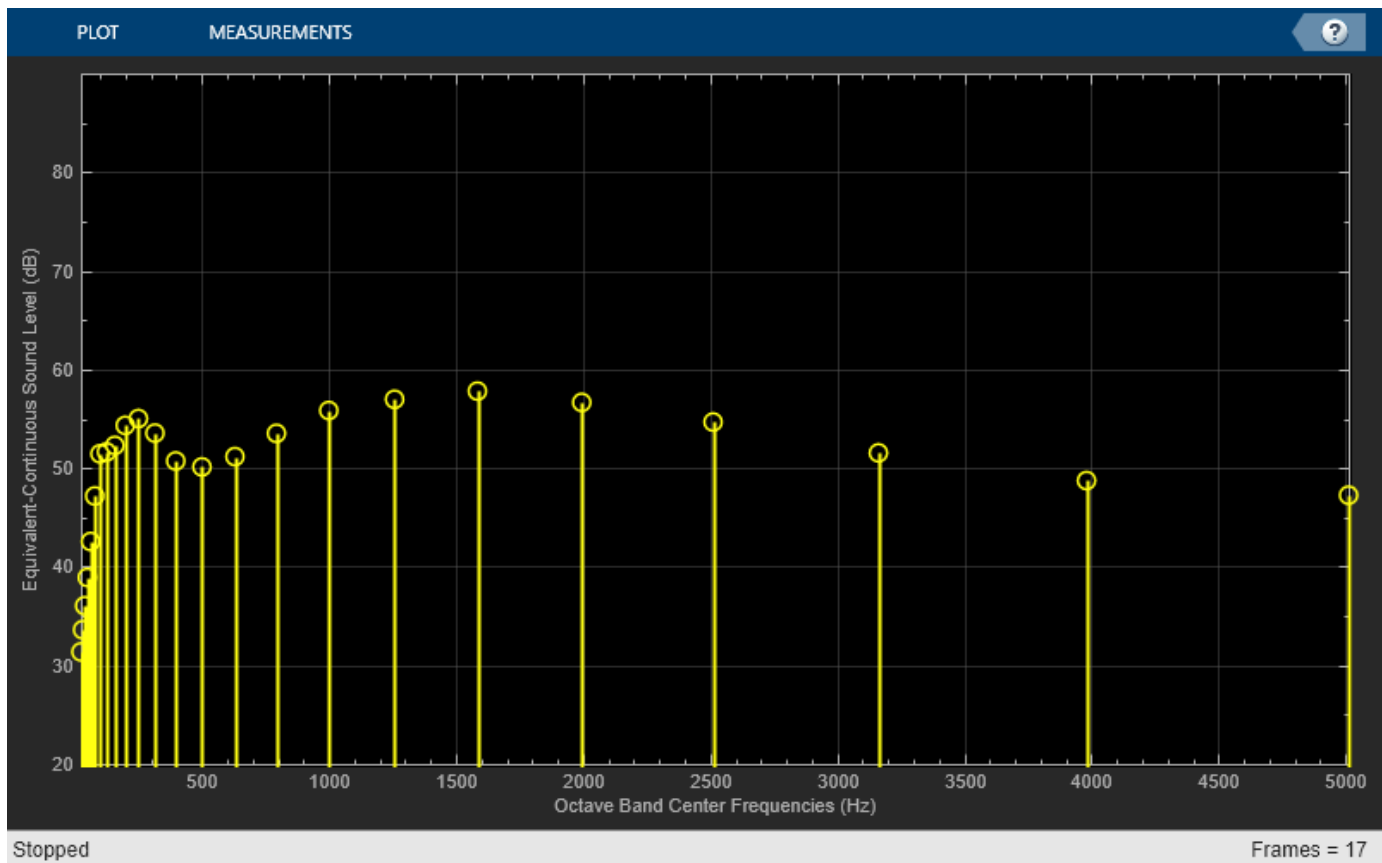
- 1 Read in the audio signal frame.
- 2 Play the audio signal to your output device.
- 3 Call the SPL meter to return the equivalent-continuous sound pressure level in dB.
- 4 Display the sound levels using the scope. Update the scope only when the equivalent-continuous sound pressure level has changed.

As a best practice, release your objects once complete.

```
LeqPrevious = zeros(size(centerFrequencies));
while ~isDone(source)
    x = source();
    player(x);
    [~,Leq] = SPL(x);

    for i = 1:size(Leq,1)
        if LeqPrevious ~= Leq(i,:)
            scope(Leq(i,:))
            LeqPrevious = Leq(i,:);
        end
    end
end

release(source)
release(player)
release(SPL)
release(scope)
```



Algorithms

Sound pressure level calculations follow the algorithms described in [1]. You can specify property values to conform to standards [2] and [3].

Calibration

To account for environmental and input device effects in SPL measurements, the audio input is multiplied by a calibration factor:

$$x = \text{audioIn} \times \text{CalibrationFactor}$$

The `CalibrationFactor` property can be set directly, or by using the `calibrate` function, which compares a known level with acquired data. The known level is determined using a physical calibrator.

Frequency Weighting

A-, C-, or Z-frequency weighting is applied. The frequency weighting is implemented using the `weightingFilter` System object.

Analysis Bands

If you specify the `Bandwidth` property as '1 octave', '2/3 octave' or '1/3 octave', then the SPL calculations are applied to each octave or fractional-octave band. These analysis bands are determined after frequency weighting.

Time-Weighted Sound Level

Time-weighted sound level is defined as the ratio of the time-weighted root mean squared sound pressure to the reference sound pressure, converted to dB. That is,

$$L_t = 10 \log_{10} \left\{ \frac{(1/\tau) \int_s^t y(\xi)^2 e^{-(t-\xi)/\tau} d\xi}{p_0^2} \right\}$$

$$= 10 \log_{10} \left\{ \frac{h(y^2)}{p_0^2} \right\}$$

$h(y^2)$ can be interpreted as the convolution of y^2 with a filter with impulse response $(1/\tau)e^{-t/\tau}$. y is the output of the frequency-weighting filter. The impulse response corresponds to a lowpass filter of the form $H(s) = \frac{1/\tau}{s + 1/\tau}$. Using impulse invariance, the discrete filter can be interpreted as,

$$H(z) = \frac{1/(\tau \times fs)}{1 - e^{-1/(\tau \times fs)} z^{-1}}$$

- τ is specified by the time-weighting coefficient as 0.125 (if `TimeWeighting` is set to 'Fast') or 1 (if `TimeWeighting` is set to 'Slow').
- fs is the sample rate specified by the `SampleRate` property.

Equivalent-Continuous Sound Level

Equivalent-continuous sound level is also called time-average sound level. It is defined as the ratio of root mean squared sound pressure to the reference sound pressure, converted to dB. That is,

$$L_{eq} = 10 \log_{10} \left\{ \frac{(1/T) \int_1^{t_2} y^2 dt}{p_0^2} \right\}$$

$$= 20 \log_{10}(\text{rms}(y)/p_0)$$

where

- y is the output of the frequency-weighting filter.
- p_0 is the reference sound pressure, specified by the `PressureReference` property.

Peak Sound Level

Peak sound level is defined as the ratio of peak sound pressure to the reference sound pressure, converted to dB. That is,

$$L_{peak} = 20 \log_{10}(\max(|y|)/p_0)$$

where

- y is the output of the frequency-weighting filter.
- p_0 is the reference sound pressure, specified by the `PressureReference` property.

Max Time-Weighted Sound Level

Maximum time-weighted sound level is defined as the greatest time-weighted sound level within a stated time interval.

References

- [1] Harris, Cyril M. *Handbook of Acoustical Measurements and Noise Control*. 3rd ed. American Institute of Physics, 1998.
- [2] International Electrotechnical Commission. *Electroacoustics - Sound level meters - Part 1: Specifications*. IEC 61672-1:2013.
- [3] American National Standards Institute. *ANSI S1.4: Specification for Sound Level Meters*. 1983.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

`LoudnessMeter` | `Loudness Meter` | `integratedLoudness`

Topics

“Sound Pressure Measurement of Octave Frequency Bands”

Introduced in R2018a

calibrate

Calibrate meter using calibration tone with known level

Syntax

```
calibrate(SPL,micRecording,SPLreading)
```

Description

`calibrate(SPL,micRecording,SPLreading)` sets the `CalibrationFactor` property of the `splMeter` object. The calibration factor is based on the computed sound pressure level (SPL) of `micRecording` and the known `SPLreading`.

To calibrate, first set the `SampleRate` property of the `splMeter` object to match the `micRecording`, and the `PressureReference` and `FrequencyWeighting` properties to match the values from the physical SPL meter.

Input Arguments

SPL — splMeter System object

object

`splMeter` System object to be calibrated.

micRecording — Audio signal used to calibrate microphone

column vector

Audio signal used to calibrate microphone, specified as a column vector. `micRecording` must be acquired from the microphone you want to calibrate. The recording should consist of a 1 kHz test tone.

Data Types: `single` | `double`

SPLreading — Sound pressure level reported from physical meter (dB)

scalar

Sound pressure level (SPL) reported from physical meter in dB, specified as a scalar.

Data Types: `single` | `double`

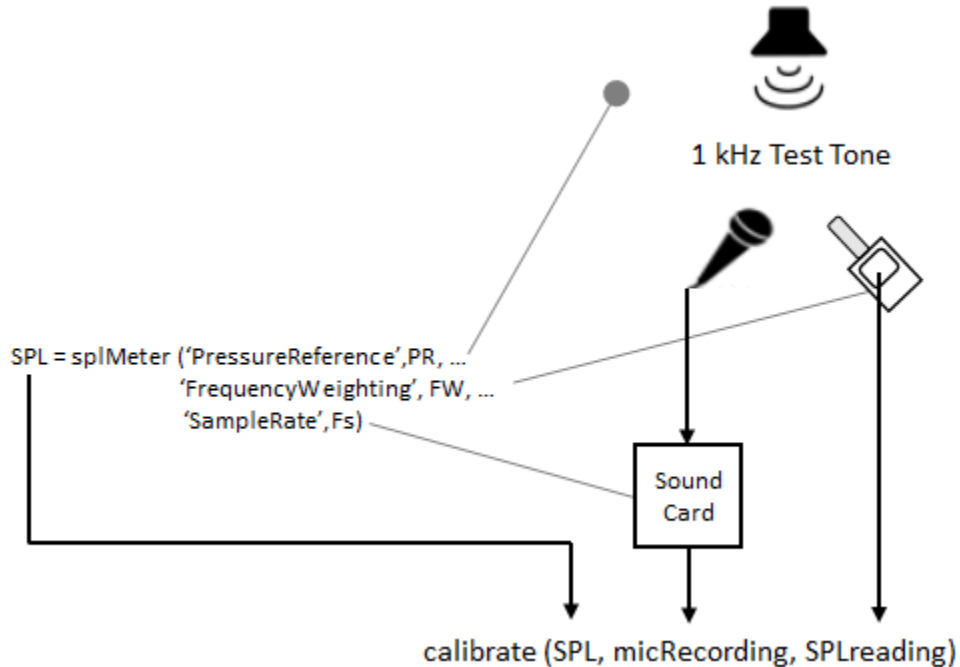
Algorithms

To set the `CalibrationFactor` property on an `splMeter` object, the `calibrate` function uses:

- A calibration tone recorded from the microphone you want to calibrate
- The sample rate used by your sound card for AD conversion.
- The known loudness, usually determined using a physical SPL meter.
- The frequency weighting used by your physical SPL meter.

- The atmospheric pressure at the recording location.

The diagram indicates a typical physical setup and the locations of required information.



The `CalibrationFactor` property is set according to the equation:

$$\text{CalibrationFactor} = \frac{10^{((\text{SPLreading}-k)/20)}}{\text{rms}(x)}$$

where x is the microphone recording passed through the weighting filter specified by the `FrequencyWeighting` property of the `splMeter` object. k is 1 pascal relative to the reference pressure calculated in dB:

$$k = 20\log_{10}\left(\frac{1}{\text{PressureReference}}\right).$$

See Also

`splMeter` | `calibrateMicrophone`

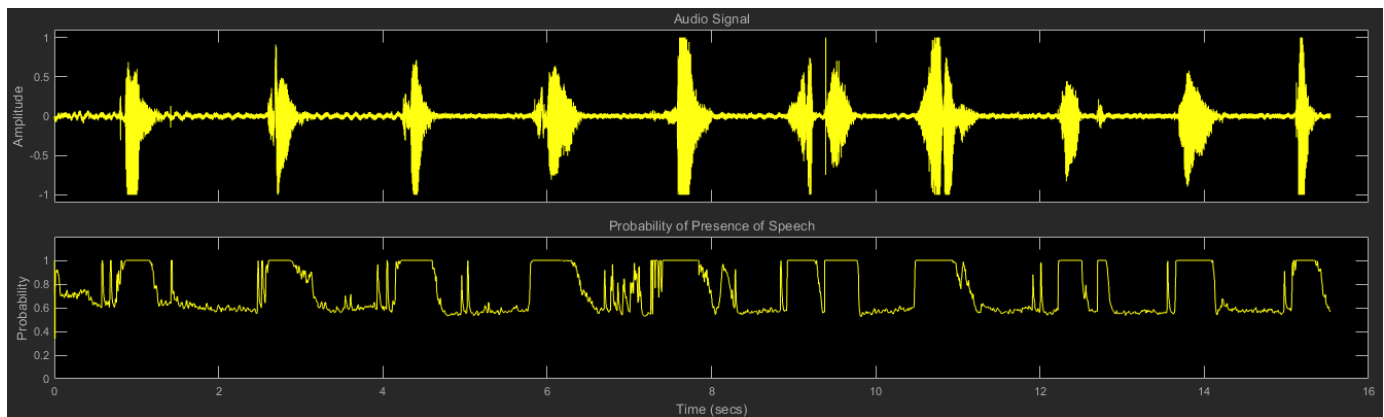
Introduced in R2018a

voiceActivityDetector

Detect presence of speech in audio signal

Description

The `voiceActivityDetector` System object detects the presence of speech in an audio segment. You can also use the `voiceActivityDetector` System object to output an estimate of the noise variance per frequency bin.



To detect the presence of speech:

- 1 Create the `voiceActivityDetector` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
VAD = voiceActivityDetector
VAD = voiceActivityDetector(Name,Value)
```

Description

`VAD = voiceActivityDetector` creates a System object, `VAD`, that detects the presence of speech independently across each input channel.

`VAD = voiceActivityDetector(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `VAD = voiceActivityDetector('InputDomain','Frequency')` creates a System object, `VAD`, that accepts frequency-domain input.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

InputDomain — Domain of input signal

'Time' (default) | 'Frequency'

Domain of the input signal, specified as 'Time' or 'Frequency'.

Tunable: No

Data Types: char | string

FFTLength — FFT length

[] (default) | positive scalar

FFT length, specified as a positive scalar. The default is [], which means that the `FFTLength` is equal to the number of rows of the input.

Tunable: No

Dependencies

To enable this property, set `InputDomain` to 'Time'.

Data Types: single | double

Window — Window function for FFT

'Hann' (default) | 'Chebyshev' | 'Flat Top' | 'Hamming' | 'Kaiser' | 'Rectangular'

Time-domain window function applied before calculating the discrete-time Fourier transform (DTFT), specified as 'Hann', 'Rectangular', 'Flat Top', 'Hamming', 'Chebyshev', or 'Kaiser'.

The window function is designed using the algorithms of the following functions:

- Hann -- hann
- Chebyshev -- chebwin
- Flat Top -- flattopwin
- Hamming -- hamming
- Kaiser -- kaiser

Tunable: No

Dependencies

To enable this property, set `InputDomain` to 'Time'.

Data Types: char | string

SidelobeAttenuation — Sidelobe attenuation of window (dB)

60 (default) | real positive scalar

Sidelobe attenuation of the window in dB, specified as a real positive scalar.

Tunable: No**Dependencies**

To enable this property, set `InputDomain` to 'Time' and `Window` to 'Chebyshev' or 'Kaiser'.

Data Types: single | double

SilenceToSpeechProbability — Probability of transition from a frame of silence to a frame of speech

0.2 (default) | scalar in the range [0,1]

Probability of transition from a frame of silence to a frame of speech, specified as a scalar in the range [0,1].

Tunable: Yes

Data Types: single | double

SpeechToSilenceProbability — Probability of transition from a frame of speech to a frame of silence

0.1 (default) | scalar in the range [0,1]

Probability of transition from a frame of speech to a frame of silence, specified as a scalar in the range [0,1].

Tunable: Yes

Data Types: single | double

Usage**Syntax**

```
[probability,noiseEstimate] = VAD(audioIn)
```

Description

`[probability,noiseEstimate] = VAD(audioIn)` applies a voice activity detector on the input, `audioIn`, and returns the probability that speech is present. It also returns the estimated noise variance per frequency bin.

Input Arguments**audioIn — Audio input to voice activity detector**

scalar | vector | matrix

Audio input to the voice activity detector, specified as a scalar, vector, or matrix. If `audioIn` is a matrix, the columns are treated as independent audio channels.

The size of the audio input is locked after the first call to the `voiceActivityDetector` object. To change the size of `audioIn`, call `release` on the object.

If `InputDomain` is set to 'Time', `audioIn` must be real-valued. If `InputDomain` is set to 'Frequency', `audioIn` can be real-valued or complex-valued.

Data Types: `single` | `double`
Complex Number Support: Yes

Output Arguments

probability — Probability that speech is present

scalar | row vector

Probability that speech is present, returned as a scalar or row vector with the same number of columns as `audioIn`.

Data Types: `single` | `double`

noiseEstimate — Estimate of noise variance per frequency bin

column vector | matrix

Estimate of the noise variance per frequency bin, returned as a column vector or matrix with the same number of columns as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm

Examples

Detect Voice Activity

Use the default `voiceActivityDetector` System object™ to detect the presence of speech in a streaming audio signal.

Create an audio file reader to stream an audio file for processing. Define parameters to chunk the audio signal into 10 ms non-overlapping frames.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');  
fs = fileReader.SampleRate;  
fileReader.SamplesPerFrame = ceil(10e-3*fs);
```

Create a default voiceActivityDetector System object to detect the presence of speech in the audio file.

```
VAD = voiceActivityDetector;
```

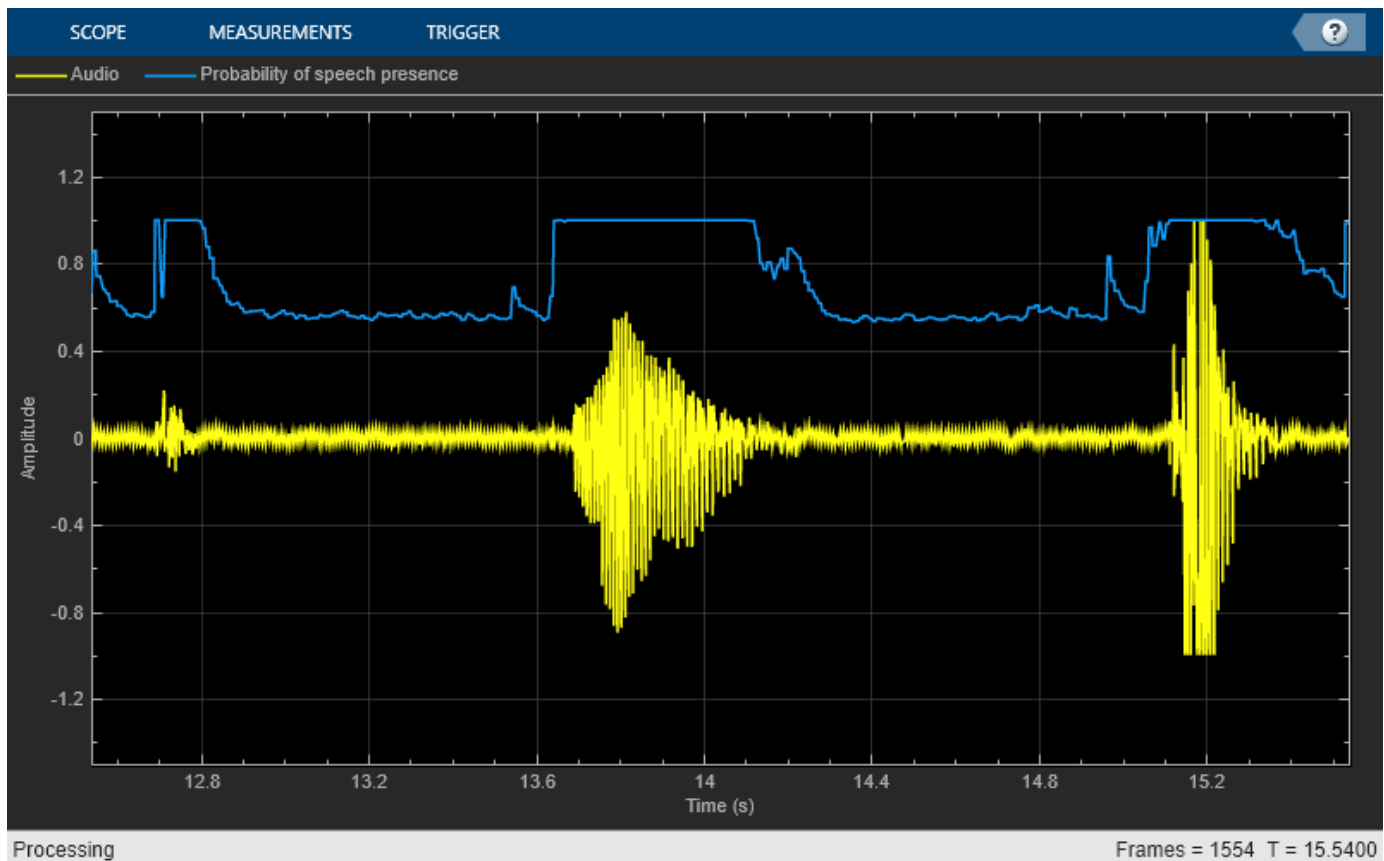
Create a scope to plot the audio signal and corresponding probability of speech presence as detected by the voice activity detector. Create an audio device writer to play the audio through your sound card.

```
scope = timescope( ...  
    'NumInputPorts',2, ...  
    'SampleRate',fs, ...  
    'TimeSpanSource','Property','TimeSpan',3, ...  
    'BufferLength',3*fs, ...  
    'YLimits',[-1.5 1.5], ...  
    'TimeSpanOverrunAction','Scroll', ...  
    'ShowLegend',true, ...  
    'ChannelNames',{'Audio','Probability of speech presence'});  
deviceWriter = audioDeviceWriter('SampleRate',fs);
```

In an audio stream loop:

- 1 Read from the audio file.
- 2 Calculate the probability of speech presence.
- 3 Visualize the audio signal and speech presence probability.
- 4 Play the audio signal through your sound card.

```
while ~isDone(fileReader)  
    audioIn = fileReader();  
    probability = VAD(audioIn);  
    scope(audioIn,probability*ones(fileReader.SamplesPerFrame,1))  
    deviceWriter(audioIn);  
end
```



Detect Voice Activity Using Overlapped Frames

Use a voice activity detector to detect the presence of speech in an audio signal. Plot the probability of speech presence along with the audio samples.

Create a `dsp.AudioFileReader` System object™ to read a speech file.

```
afr = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
fs = afr.SampleRate;
```

Chunk the audio into 20 ms frames with 75% overlap between successive frames. Convert the frame time in seconds to samples. Determine the hop size (the increment of new samples). In the audio file reader, set the samples per frame to the hop size. Create a default `dsp.AsyncBuffer` object to manage overlapping between audio frames.

```
frameSize = ceil(20e-3*fs);
overlapSize = ceil(0.75*frameSize);
hopSize = frameSize - overlapSize;
afr.SamplesPerFrame = hopSize;
```

```
inputBuffer = dsp.AsyncBuffer('Capacity',frameSize);
```

Create a `voiceActivityDetector` System object. Specify an FFT length of 1024.

```
VAD = voiceActivityDetector('FFTLength',1024);
```

Create a scope to plot the audio signal and corresponding probability of speech presence as detected by the voice activity detector. Create an `audioDeviceWriter` System object to play audio through your sound card.

```
scope = timescope('NumInputPorts',2, ...  
    'SampleRate',fs, ...  
    'TimeSpanSource','Property','TimeSpan',3, ...  
    'BufferLength',3*fs, ...  
    'YLimits',[-1.5,1.5], ...  
    'TimeSpanOverrunAction','Scroll', ...  
    'ShowLegend',true, ...  
    'ChannelNames',{'Audio','Probability of speech presence'});
```

```
player = audioDeviceWriter('SampleRate',fs);
```

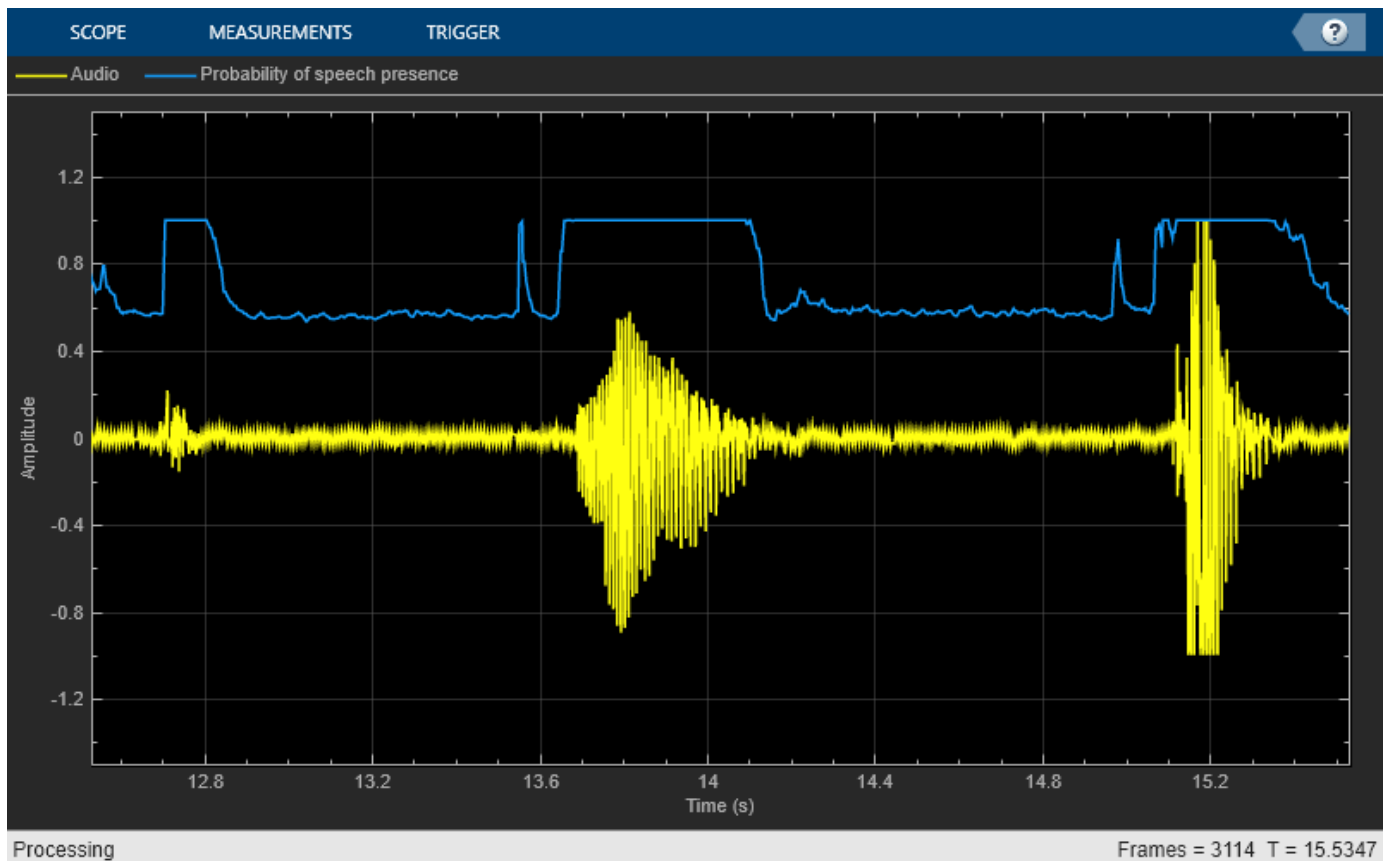
Initialize a vector to hold the probability values.

```
pHold = ones(hopSize,1);
```

In an audio stream loop:

- 1 Read a hop worth of samples from the audio file and save the samples into the buffer.
- 2 Read a frame from the buffer with specified overlap from the previous frame.
- 3 Call the voice activity detector to get the probability of speech for the frame under analysis.
- 4 Set the last element of the probability vector to the new probability decision. Visualize the audio and speech presence probability using the time scope.
- 5 Play the audio through your sound card.
- 6 Set the probability vector to the most recent result for plotting in the next loop.

```
while ~isDone(afr)  
    x = afr();  
    n = write(inputBuffer,x);  
  
    overlappedInput = read(inputBuffer,frameSize,overlapSize);  
  
    p = VAD(overlappedInput);  
  
    pHold(end) = p;  
    scope(x,pHold)  
  
    player(x);  
  
    pHold(:) = p;  
end
```



Release the player once the audio finishes playing.

```
release(player)
```

Frequency-Domain Voice Activity Detection and Cepstral Feature Extraction

Many feature extraction techniques operate on the frequency domain. Converting an audio signal to the frequency domain only once is efficient. In this example, you convert a streaming audio signal to the frequency domain and feed that signal into a voice activity detector. If speech is present, mel-frequency cepstral coefficients (MFCC) features are extracted from the frequency-domain signal using the `cepstralFeatureExtractor` System object™.

Create a `dsp.AudioFileReader` System object to read from an audio file.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
fs = fileReader.SampleRate;
```

Process the audio in 30 ms frames with a 10 ms hop. Create a default `dsp.AsyncBuffer` object to manage overlap between audio frames.

```
samplesPerFrame = ceil(0.03*fs);
samplesPerHop = ceil(0.01*fs);
samplesPerOverlap = samplesPerFrame - samplesPerHop;
```

```
fileReader.SamplesPerFrame = samplesPerHop;  
buffer = dsp.AsyncBuffer;
```

Create a `voiceActivityDetector` System object and a `cepstralFeatureExtractor` System object. Specify that they operate in the frequency domain. Create a `dsp.SignalSink` to log the extracted cepstral features.

```
VAD = voiceActivityDetector('InputDomain','Frequency');  
cepFeatures = cepstralFeatureExtractor('InputDomain','Frequency','SampleRate',fs,'LogEnergy','Repe  
sink = dsp.SignalSink;
```

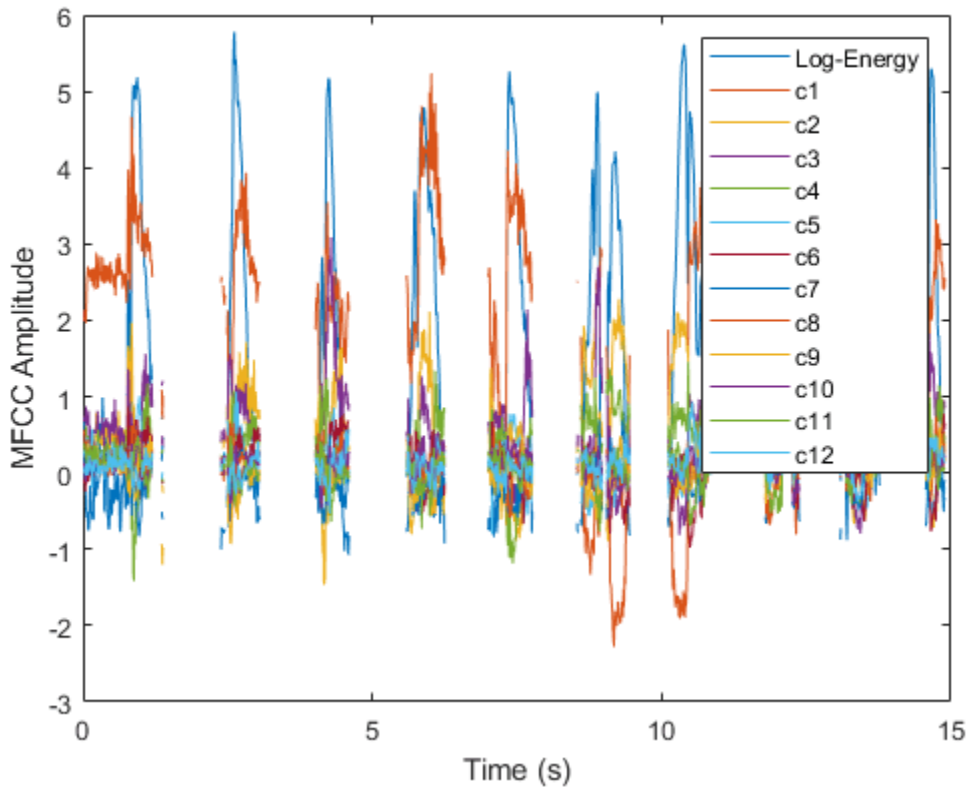
In an audio stream loop:

- 1 Read one hop's of samples from the audio file and save the samples into the buffer.
- 2 Read a frame from the buffer with specified overlap from the previous frame.
- 3 Call the voice activity detector to get the probability of speech for the frame under analysis.
- 4 If the frame under analysis has a probability of speech greater than 0.75, extract cepstral features and log the features using the signal sink. If the frame under analysis has a probability of speech less than 0.75, write a vector of NaNs to the sink.

```
threshold = 0.75;  
nanVector = nan(1,13);  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buffer,audioIn);  
  
    overlappedAudio = read(buffer,samplesPerFrame,samplesPerOverlap);  
    X = fft(overlappedAudio,2048);  
  
    probabilityOfSpeech = VAD(X);  
    if probabilityOfSpeech > threshold  
        xFeatures = cepFeatures(X);  
        sink(xFeatures')  
    else  
        sink(nanVector)  
    end  
end
```

Visualize the cepstral coefficients over time.

```
timeVector = linspace(0,15,size(sink.Buffer,1));  
plot(timeVector,sink.Buffer)  
xlabel('Time (s)')  
ylabel('MFCC Amplitude')  
legend('Log-Energy','c1','c2','c3','c4','c5','c6','c7','c8','c9','c10','c11','c12')
```

Determine Pitch Contour of Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio frame-by-frame.

```
fileReader = dsp.AudioFileReader("SingingAMajor-16-mono-18secs.ogg");
```

Create a `voiceActivityDetector` object to detect the presence of voice in streaming audio.

```
VAD = voiceActivityDetector;
```

While there are unread samples, read from the file and determine the probability that the frame contains voice activity. If the frame contains voice activity, call `pitch` to estimate the fundamental frequency of the audio frame. If the frame does not contain voice activity, declare the fundamental frequency as `NaN`.

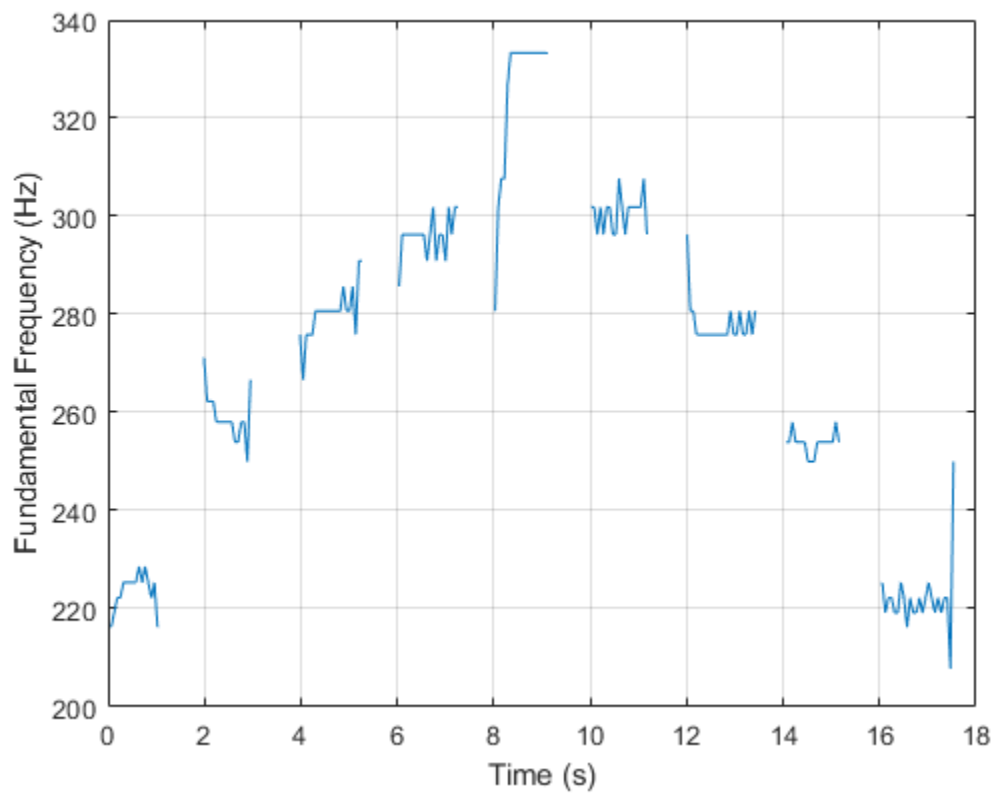
```
f0 = [];
while ~isDone(fileReader)
    x = fileReader();

    if VAD(x) > 0.99
        decision = pitch(x,fileReader.SampleRate, ...
            WindowLength=size(x,1), ...
            OverlapLength=0, ...
            Range=[200,340]);
    else
```

```
        decision = NaN;  
    end  
    f0 = [f0;decision];  
end
```

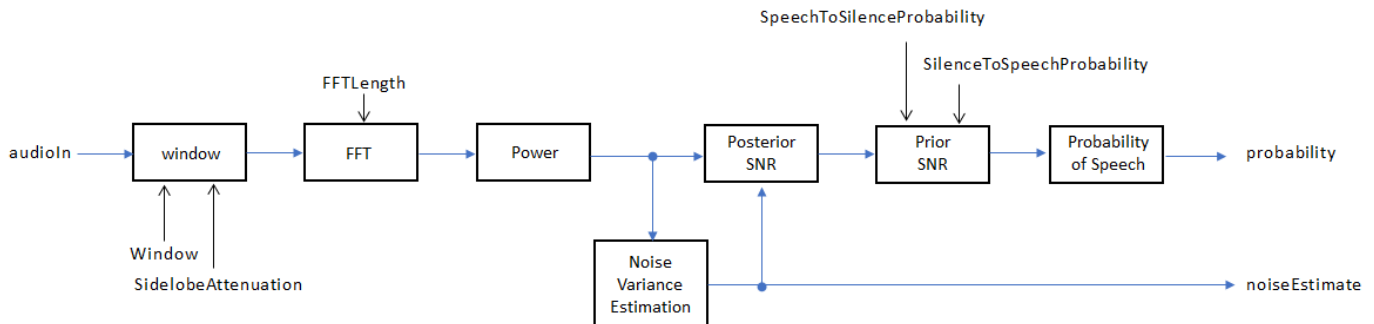
Plot the detected pitch contour over time.

```
t = linspace(0,(length(f0)*fileReader.SamplesPerFrame)/fileReader.SampleRate,length(f0));  
plot(t,f0)  
ylabel("Fundamental Frequency (Hz)")  
xlabel("Time (s)")  
grid on
```



Algorithms

The voiceActivityDetector implements the algorithm described in [1].



If `InputDomain` is specified as 'Time', the input signal is windowed and then converted to the frequency domain according to the `Window`, `SidelobeAttenuation`, and `FFTLenght` properties. If `InputDomain` is specified as frequency, the input is assumed to be a windowed discrete time Fourier transform (DTFT) of an audio signal. The signal is then converted to the power domain. Noise variance is estimated according to [2]. The posterior and prior SNR are estimated according to the Minimum Mean-Square Error (MMSE) formula described in [3]. A log likelihood ratio test and Hidden Markov Model (HMM)-based hang-over scheme determine the probability that the current frame contains speech, according to [1].

References

- [1] Sohn, Jongseo., Nam Soo Kim, and Wonyong Sung. "A Statistical Model-Based Voice Activity Detection." *Signal Processing Letters IEEE*. Vol. 6, No. 1, 1999.
- [2] Martin, R. "Noise Power Spectral Density Estimation Based on Optimal Smoothing and Minimum Statistics." *IEEE Transactions on Speech and Audio Processing*. Vol. 9, No. 5, 2001, pp. 504-512.
- [3] Ephraim, Y., and D. Malah. "Speech Enhancement Using a Minimum Mean-Square Error Short-Time Spectral Amplitude Estimator." *IEEE Transactions on Acoustics, Speech, and Signal Processing*. Vol. 32, No. 6, 1984, pp. 1109-1121.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

`audioFeatureExtractor` | `mfcc` | `pitch` | `cepstralFeatureExtractor` | Voice Activity Detector

Introduced in R2018a

cepstralFeatureExtractor

Extract cepstral features from audio segment

Description

The `cepstralFeatureExtractor` System object extracts cepstral features from an audio segment. Cepstral features are commonly used to characterize speech and music signals.

To extract cepstral features:

- 1 Create the `cepstralFeatureExtractor` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
cepFeatures = cepstralFeatureExtractor  
cepFeatures = cepstralFeatureExtractor(Name,Value)
```

Description

`cepFeatures = cepstralFeatureExtractor` creates a System object, `cepFeatures`, that calculates cepstral features independently across each input channel. Columns of the input are treated as individual channels.

`cepFeatures = cepstralFeatureExtractor(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `cepFeatures = cepstralFeatureExtractor('InputDomain','Frequency','SampleRate',fs,'LogEnergy','Replace')` accepts a signal in the frequency domain, sampled at `fs` Hz. The first element of the coefficients vector is replaced by the log energy value.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see [System Design in MATLAB Using System Objects](#).

FilterBank — Type of filter bank

'Mel' (default) | 'Gammatone'

Type of filter bank, specified as either 'Mel' or 'Gammatone'. When `FilterBank` is set to `Mel`, the object computes the mel frequency cepstral coefficients (MFCC). When `FilterBank` is set to `Gammatone`, the object computes the gammatone cepstral coefficients (GTCC).

Data Types: `char` | `string`

InputDomain — Domain of input signal

'Time' (default) | 'Frequency'

Domain of the input signal, specified as either 'Time' or 'Frequency'.

Data Types: `char` | `string`

NumCoeffs — Number of coefficients to return

13 (default) | positive integer

Number of coefficients to return, specified as an integer in the range $[2, v]$, where v is the number of valid passbands. The number of valid passbands depends on the type of filter bank:

- `Mel` -- The number of valid passbands is defined as $\text{sum}(\text{BandEdges} \leq \text{floor}(\text{SampleRate}/2)) - 2$.
- `Gammatone` -- The number of valid passbands is defined as $\text{ceil}(\text{hz2erb}(\text{FrequencyRange}(2)) - \text{hz2erb}(\text{FrequencyRange}(1)))$.

Data Types: `single` | `double`

Rectification — Nonlinear rectification type

'Log' (default) | 'Cubic-Root'

Nonlinear rectification type, specified as 'Log' or 'Cubic-Root'.

Data Types: `char` | `string`

FFTLength — FFT length

[] (default) | positive integer

FFT length, specified as a positive integer. The default, [], means that the FFT length is equal to the number of rows in the input signal.

Dependencies

To enable this property, set `InputDomain` to 'Time'.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

LogEnergy — Specify how the log energy is shown

'Append' (default) | 'Replace' | 'Ignore'

Specify how the log energy is shown in the coefficients vector output, specified as:

- 'Append' -- The object prepends the log energy to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$.
- 'Replace' -- The object replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is `NumCoeffs`.
- 'Ignore' -- The object does not calculate or return the log energy.

Data Types: `char` | `string`

SampleRate — Input sample rate (Hz)

16000 (default) | positive scalar

Input sample rate in Hz, specified as a real positive scalar.

Data Types: single | double

Advanced properties**BandEdges — Band edges of mel filter bank (Hz)**

row vector

Band edges of the filter bank in Hz, specified as a nonnegative monotonically increasing row vector in the range $[0, \infty)$. The maximum bandedge frequency can be any finite number. The number of bandedges must be in the range $[4, 80]$.

The default band edges are spaced linearly for the first ten and then logarithmically after. The default band edges are set as recommended by [1].

Dependencies

To enable this property, set `FilterBank` to `Mel`.

Data Types: single | double

FrequencyRange — Frequency range of gammatone filter bank (Hz)`[50 8000]` (default) | two-element row vector

Frequency range of the filter bank in Hz, specified as a positive, monotonically increasing two-element row vector. The maximum frequency can be any finite number. The center frequencies of the filter bank are equally spaced between `hz2erb(FrequencyRange(1))` and `hz2erb(FrequencyRange(2))` on the ERB scale.

Dependencies

To enable this property, set `FilterBank` to `Gammatone`.

Data Types: single | double

FilterBankDesignDomain — Domain for mel filter bank design`'Hz'` (default) | `'Bin'`

Domain for filter bank design, specified as either `'Hz'` or `'Bin'`. The filter bank is designed as overlapped triangles with band edges specified by the `BandEdges` property.

The `BandEdges` property is specified in Hz. When you set the design domain to:

- `'Hz'` -- Filter bank triangles are drawn in Hz and are mapped onto bins.

Here is an example that plots the filter bank in bins when the `FilterBankDesignDomain` is set to `'Hz'`:

```
[audioFile, fs] = audioread('NoisySpeech-16-22p5-mono-5secs.wav');
duration = round(0.02*fs); % 20 ms audio segment
audioSegment = audioFile(5500:5500+duration-1);
cepFeatures = cepstralFeatureExtractor('SampleRate', fs)

cepFeatures =
    cepstralFeatureExtractor with properties:
```

Properties

```
InputDomain: 'Time'  
NumCoeffs: 13  
FFTLength: []  
LogEnergy: 'Append'  
SampleRate: 22500
```

Advanced Properties

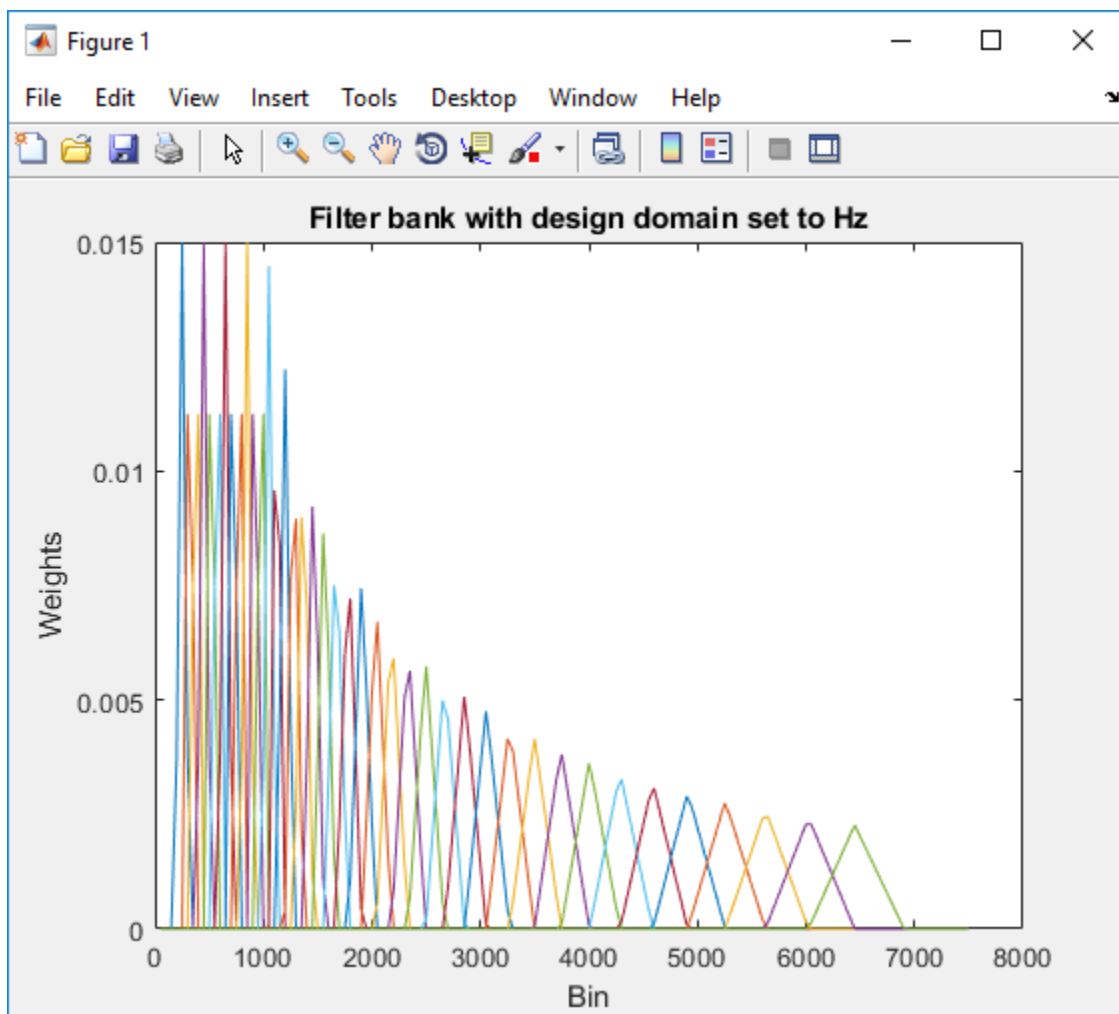
```
BandEdges: [1x42 double]  
FilterBankDesignDomain: 'Hz'  
FilterBankNormalization: 'Bandwidth'
```

Pass the audio segment as an input to the cepstral feature extractor algorithm to lock the object.

```
[coeffs,delta,deltaDelta] = cepFeatures(audioSegment);
```

Use the `getFilters` function to get the filter bank. Plot the filter bank.

```
[filterbank, freq] = getFilters(cepFeatures);  
plot(freq(1:150),filterbank(1:150,:))
```

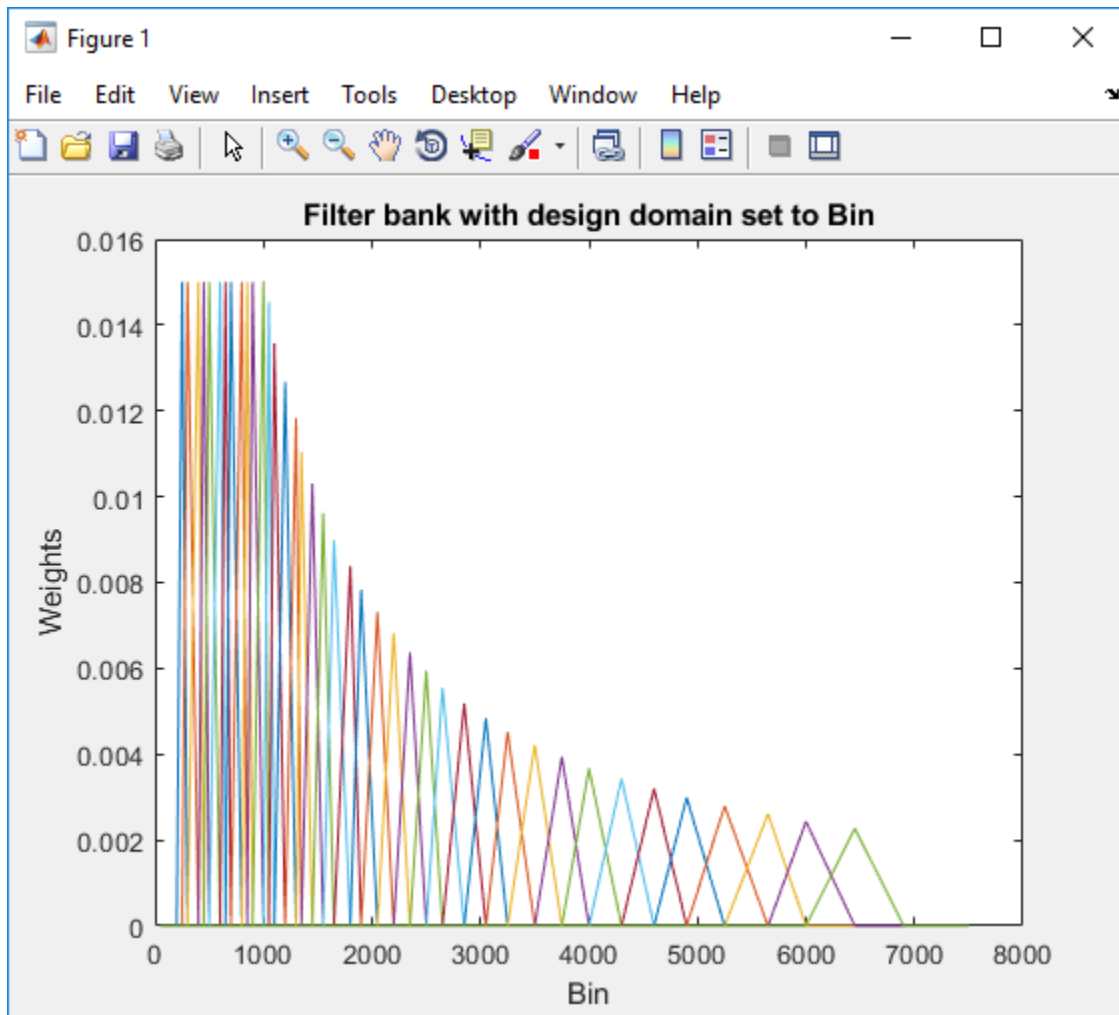


For details, see [1].

- 'Bin' -- The bandedge frequencies in 'Hz' are converted to bins. The filter bank triangles are drawn symmetrically in bins.

Change the FilterBankDesignDomain property to 'Bin':

```
release(cepFeatures);
cepFeatures.FilterBankDesignDomain = 'Bin';
[coeffs,delta,deltaDelta] = cepFeatures(audioSegment);
[filterbank, freq] = getFilters(cepFeatures);
plot(freq(1:150),filterbank(1:150,:))
```



For details, see [2].

Dependencies

To enable this property, set FilterBank to Mel.

Data Types: char | string

FilterBankNormalization — Normalize filter bank

'Bandwidth' (default) | 'Area' | 'None'

Normalization technique used on the weights of the filter bank, specified as:

- 'Bandwidth' -- The weights of each bandpass filter are normalized by the corresponding bandwidth of the filter.
- 'Area' -- The weights of each bandpass filter are normalized by the corresponding area of the bandpass filter.
- 'None' -- The weights of the filter are not normalized.

Data Types: char | string

Usage

Syntax

```
[coeffs,delta,deltaDelta] = cepFeatures(audioIn)
```

Description

[coeffs,delta,deltaDelta] = cepFeatures(audioIn) returns the cepstral coefficients, the log energy, the delta, and the delta-delta.

The log energy value prepends the coefficient vector or replaces the first element of the coefficients vector based on whether you set the LogEnergy property to 'Append' or 'Replace'. For details, see “coeffs” on page 3-0 .

Input Arguments

audioIn — Input signal

column vector | matrix

Input signal, specified as a column vector or matrix. If InputDomain is set to 'Time', specify audioIn as a real-valued frame of audio data. If InputDomain is set to 'Frequency', specify audioIn as a real- or complex-valued discrete Fourier transform. If specified as a matrix, the columns are treated as independent audio channels.

Data Types: single | double

Complex Number Support: Yes

Output Arguments

coeffs — Cepstral coefficients

column vector | matrix

Cepstral coefficients, returned as a column vector or a matrix. If the coefficients matrix is an N -by- M matrix, N is determined by the values you specify in NumCoeffs and LogEnergy properties. M equals the number of input audio channels.

When the LogEnergy property is set to:

- 'Append' -- The object prepends the log energy value to the coefficients vector. The length of the coefficients vector is $1 + \text{NumCoeffs}$. This is the default setting of the LogEnergy property.
- 'Replace' -- The object replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is NumCoeffs.

- 'Ignore' -- The object does not calculate or return the log energy.

Data Types: `single` | `double`

delta — Change in coefficients

column vector | matrix

Change in coefficients over consecutive calls to the algorithm, returned as a vector or a matrix. The `delta` array is of the same size and data type as the `coeffs` array.

In this example, `cepFeatures` is the cepstral feature extractor that accepts audio input signal sampled at 12 kHz. Stream in three segments of audio signal on three consecutive calls to the object algorithm. Return the cepstral coefficients of the filter bank and the corresponding `delta` values.

```
cepFeatures = cepstralFeatureExtractor('SampleRate',12000);  
[coeff1,delta1] = cepFeatures(audioIn);  
[coeff2,delta2] = cepFeatures(audioIn);  
[coeff3,delta3] = cepFeatures(audioIn);
```

`delta2` is computed as `coeff2-coeff1`, while `delta3` is computed as `coeff3-coeff2`. The initial array, `delta1`, is an array of zeros.

Data Types: `single` | `double`

deltaDelta — Change in delta values

column vector | matrix

Change in `delta` values over consecutive calls to the algorithm, returned as a vector or a matrix. The `deltaDelta` array is the same size and data type as the `coeffs` and `delta` arrays.

In this example, consecutive calls to the cepstral feature extractor algorithm return the `deltaDelta` values in addition to the coefficients and the `delta` values.

```
cepFeatures = cepstralFeatureExtractor('SampleRate',12000);  
[coeff1,delta1,deltaDelta1] = cepFeatures(audioIn);  
[coeff2,delta2,deltaDelta2] = cepFeatures(audioIn);  
[coeff3,delta3,deltaDelta3] = cepFeatures(audioIn);
```

`deltaDelta2` is computed as `delta2-delta1`, while `deltaDelta3` is computed as `delta3-delta2`. The initial array, `deltaDelta1`, is an array of zeros.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to cepstralFeatureExtractor

`getFilters` Get auditory filter bank

Common to All System Objects

`clone` Create duplicate System object

`isLocked` Determine if System object is in use

release Release resources and allow changes to System object property values and input characteristics
 reset Reset internal states of System object
 step Run System object algorithm

Examples

Get MFCC Data for Speech Segment

Extract the mel frequency cepstral coefficients and the log energy values of segments in a speech file. Return `delta`, the difference between current and the previous cepstral coefficients, and `deltaDelta`, the difference between the current and the previous `delta` values. The log energy value the object computes can prepend the coefficients vector or replace the first element of the coefficients vector. This is done based on whether you set the `LogEnergy` property of the `cepstralFeatureExtractor` object to 'Replace' or 'Append'.

Read an audio signal from 'Counting-16-44p1-mono-15secs.wav' file. Extract a 40 ms segment from the audio data. Create a `cepstralFeatureExtractor` object. The cepstral coefficients computed by the default object are the mel frequency coefficients. In addition, the object computes the log energy, delta, and delta-delta values of the audio segment.

```
[audioFile, fs] = audioread('Counting-16-44p1-mono-15secs.wav');
duration = round(0.04*fs); % 40 ms
audioSegment = audioFile(40000:40000+duration-1);
cepFeatures = cepstralFeatureExtractor('SampleRate',fs)
```

```
cepFeatures =
  cepstralFeatureExtractor with properties:
```

```
Properties
  FilterBank: 'Mel'
  InputDomain: 'Time'
  NumCoeffs: 13
  Rectification: 'Log'
  FFTLength: []
  LogEnergy: 'Append'
  SampleRate: 44100
```

```
Show all properties
```

The `LogEnergy` property is set to 'Append'. The first element in the coefficients vector is the log energy value and the remaining elements are the 13 cepstral coefficients computed by the object. The number of cepstral coefficients is determined by the value you specify in the `NumCoeffs` property.

```
[coeffs,delta,deltaDelta] = cepFeatures(audioSegment)
```

```
coeffs = 14x1
```

```
5.2999
-4.9406
3.6130
0.4397
-0.2280
-1.1068
```

```
0.6679
0.6367
-0.3869
0.6127
:

delta = 14x1

0
0
0
0
0
0
0
0
0
0
:

deltaDelta = 14x1

0
0
0
0
0
0
0
0
0
0
:
```

The initial values for the `delta` and `deltaDelta` arrays are always zero. Consider another 40 ms audio segment in the file and extract the cepstral features from this segment.

```
audioSegmentTwo = audioFile(5820:5820+duration-1);
[coeffsTwo,deltaTwo,deltaDeltaTwo] = cepFeatures(audioSegmentTwo)

coeffsTwo = 14x1

-0.1582
-15.9507
2.4295
0.2835
0.4345
0.4382
0.6040
0.4168
0.1846
0.2636
:
```

```
deltaTwo = 14x1
```

```
-5.4581
-11.0101
-1.1836
-0.1561
 0.6625
 1.5449
-0.0639
-0.2199
 0.5715
-0.3491
  :
```

```
deltaDeltaTwo = 14x1
```

```
-5.4581
-11.0101
-1.1836
-0.1561
 0.6625
 1.5449
-0.0639
-0.2199
 0.5715
-0.3491
  :
```

Verify that the difference between `coeffsTwo` and `coeffs` vectors equals `deltaTwo`.

```
isequal(coeffsTwo-coeffs,deltaTwo)
```

```
ans = logical
      1
```

Verify that the difference between `deltaTwo` and `delta` vectors equals `deltaDeltaTwo`.

```
isequal(deltaTwo-delta,deltaDeltaTwo)
```

```
ans = logical
      1
```

Frequency-Domain Voice Activity Detection and Cepstral Feature Extraction

Many feature extraction techniques operate on the frequency domain. Converting an audio signal to the frequency domain only once is efficient. In this example, you convert a streaming audio signal to the frequency domain and feed that signal into a voice activity detector. If speech is present, mel-frequency cepstral coefficients (MFCC) features are extracted from the frequency-domain signal using the `cepstralFeatureExtractor` System object™.

Create a `dsp.AudioFileReader` System object to read from an audio file.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');  
fs = fileReader.SampleRate;
```

Process the audio in 30 ms frames with a 10 ms hop. Create a default `dsp.AsyncBuffer` object to manage overlap between audio frames.

```
samplesPerFrame = ceil(0.03*fs);  
samplesPerHop = ceil(0.01*fs);  
samplesPerOverlap = samplesPerFrame - samplesPerHop;
```

```
fileReader.SamplesPerFrame = samplesPerHop;  
buffer = dsp.AsyncBuffer;
```

Create a `voiceActivityDetector` System object and a `cepstralFeatureExtractor` System object. Specify that they operate in the frequency domain. Create a `dsp.SignalSink` to log the extracted cepstral features.

```
VAD = voiceActivityDetector('InputDomain','Frequency');  
cepFeatures = cepstralFeatureExtractor('InputDomain','Frequency','SampleRate',fs,'LogEnergy','Repeatability');  
sink = dsp.SignalSink;
```

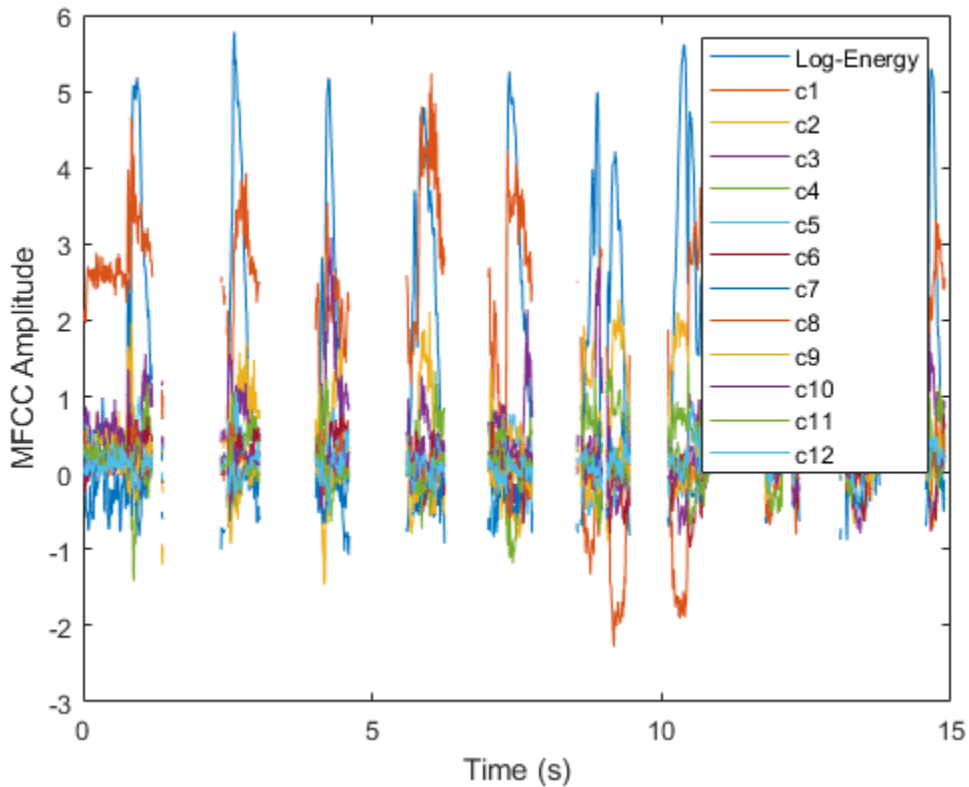
In an audio stream loop:

- 1 Read one hop's of samples from the audio file and save the samples into the buffer.
- 2 Read a frame from the `buffer` with specified overlap from the previous frame.
- 3 Call the voice activity detector to get the probability of speech for the frame under analysis.
- 4 If the frame under analysis has a probability of speech greater than 0.75, extract cepstral features and log the features using the signal sink. If the frame under analysis has a probability of speech less than 0.75, write a vector of NaNs to the sink.

```
threshold = 0.75;  
nanVector = nan(1,13);  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    write(buffer,audioIn);  
  
    overlappedAudio = read(buffer,samplesPerFrame,samplesPerOverlap);  
    X = fft(overlappedAudio,2048);  
  
    probabilityOfSpeech = VAD(X);  
    if probabilityOfSpeech > threshold  
        xFeatures = cepFeatures(X);  
        sink(xFeatures')  
    else  
        sink(nanVector)  
    end  
end
```

Visualize the cepstral coefficients over time.

```
timeVector = linspace(0,15,size(sink.Buffer,1));  
plot(timeVector,sink.Buffer)  
xlabel('Time (s)')  
ylabel('MFCC Amplitude')  
legend('Log-Energy','c1','c2','c3','c4','c5','c6','c7','c8','c9','c10','c11','c12')
```



Extract GTCC from Streaming Audio

Create a `dsp.AudioFileReader` object to read in audio data frame-by-frame. Create an `audioDeviceWriter` to write the audio to your sound card. Create a `dsp.ArrayPlot` to visualize the GTCC over time.

```
fileReader = dsp.AudioFileReader('Random0scThree-24-96-stereo-13secs.aif');
deviceWriter = audioDeviceWriter(fileReader.SampleRate);
scope = dsp.ArrayPlot;
```

Create a `cepstralFeatureExtractor` that extracts GTCC.

```
cepFeatures = cepstralFeatureExtractor('FilterBank','Gammatone', ...
    'SampleRate',fileReader.SampleRate);
```

In an audio stream loop:

- 1 Read in a frame of audio data.
- 2 Extract the GTCC from the frame of audio.
- 3 Visualize the GTCC.
- 4 Write the audio frame to your device.

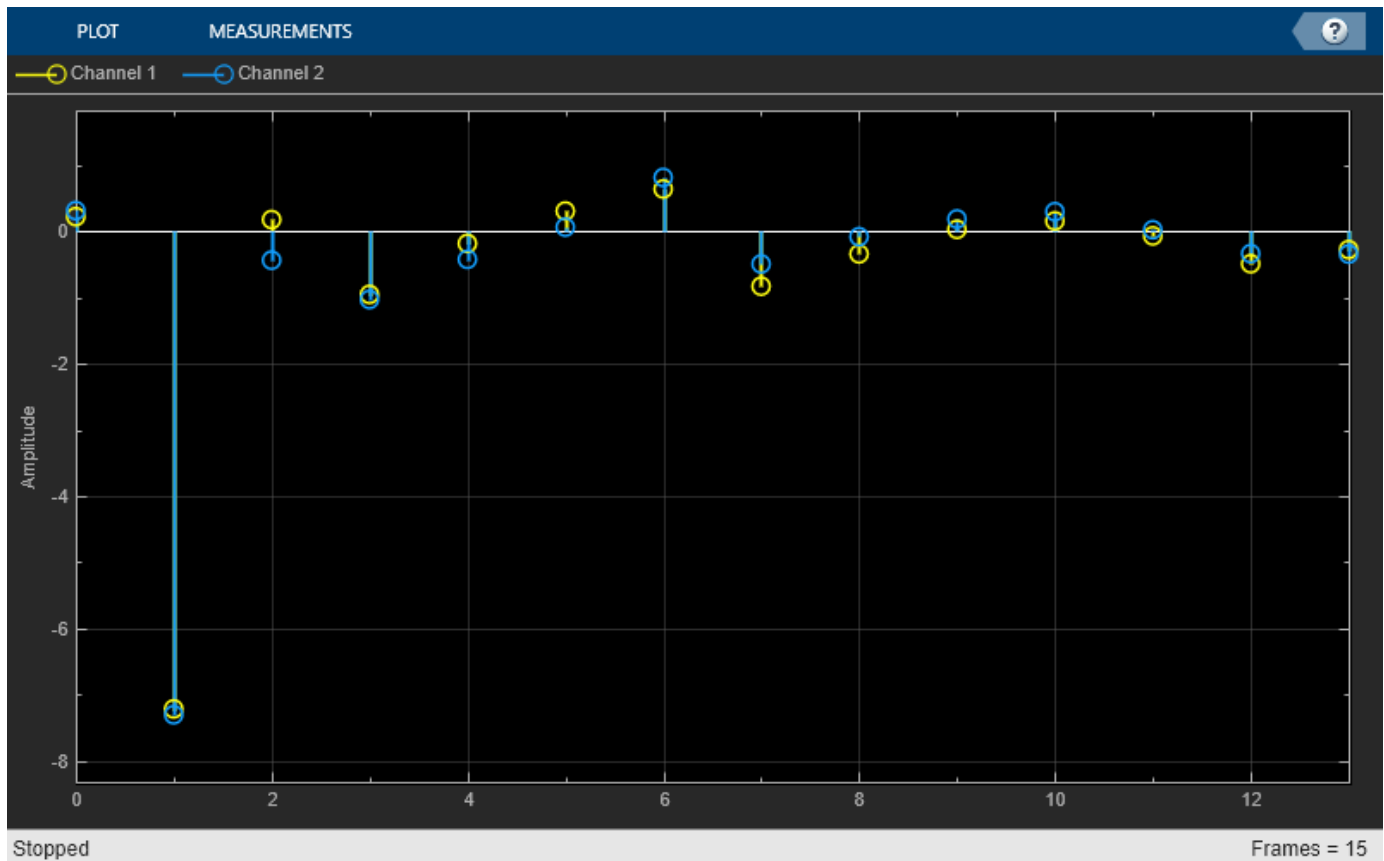
```
while ~isDone(fileReader)
    audioIn = fileReader();
```

```

        coeffs = cepFeatures(audioIn);
        scope(coeffs)
        deviceWriter(audioIn);
    end

    release(cepFeatures)
    release(scope)
    release(fileReader)

```

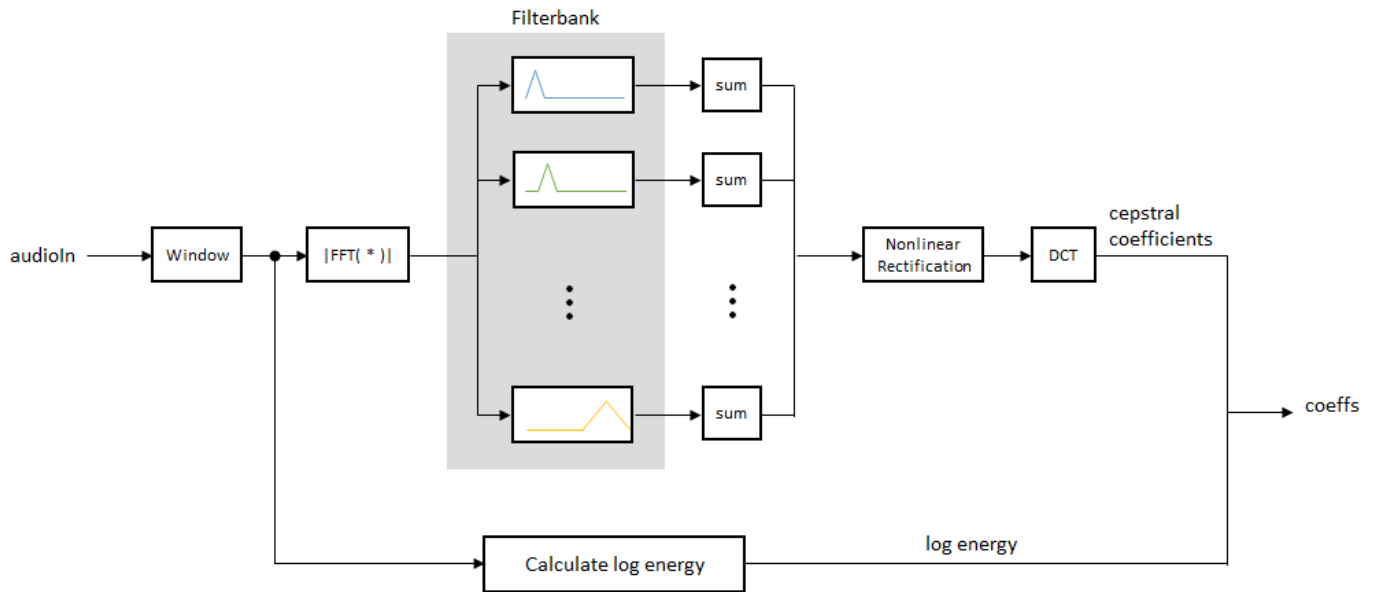


Algorithms

Auditory Cepstrum Coefficients

Auditory cepstrum coefficients are popular features extracted from speech signals for use in recognition tasks. In the source-filter model of speech, cepstral coefficients are understood to represent the filter (vocal tract). The vocal tract frequency response is relatively smooth, whereas the source of voiced speech can be modeled as an impulse train. As a result, the vocal tract can be estimated by the spectral envelope of a speech segment.

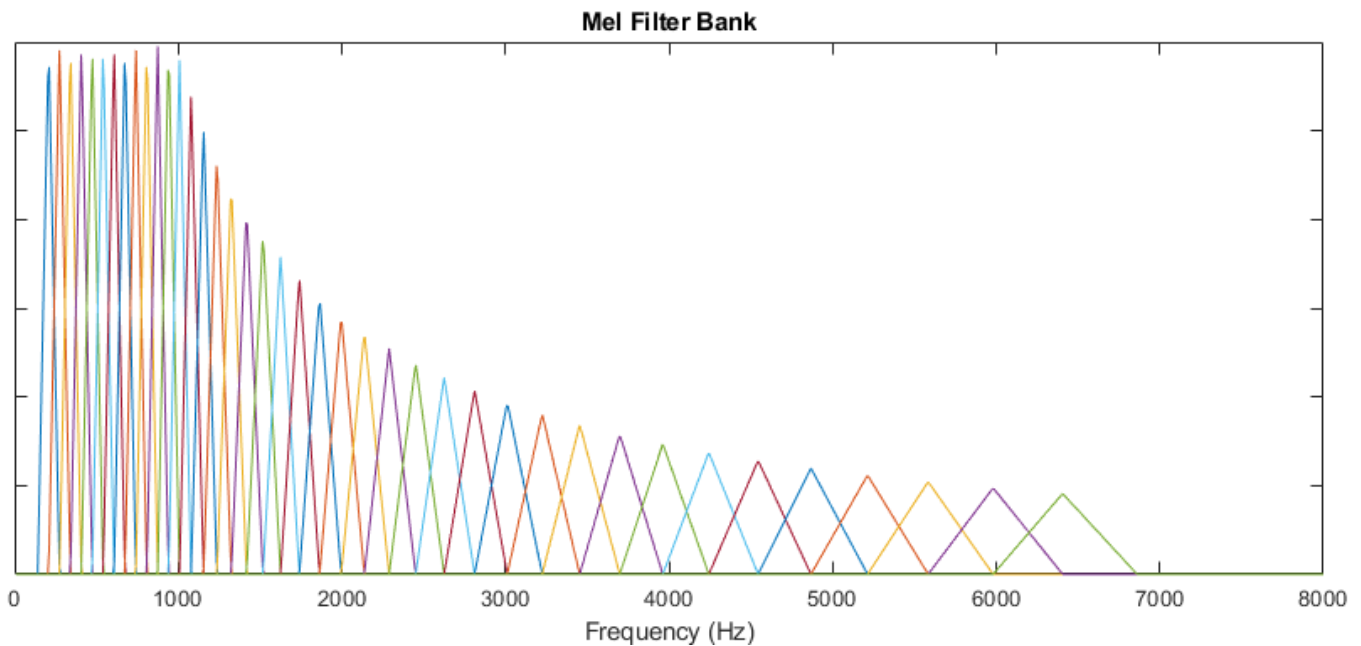
The motivating idea of cepstral coefficients is to compress information about the vocal tract (smoothed spectrum) into a small number of coefficients based on an understanding of the cochlea. Although there is no hard standard for calculating the coefficients, the basic steps are outlined by the diagram.



Two popular implementations of the filter bank are the mel filter bank and the gammatone filter bank.

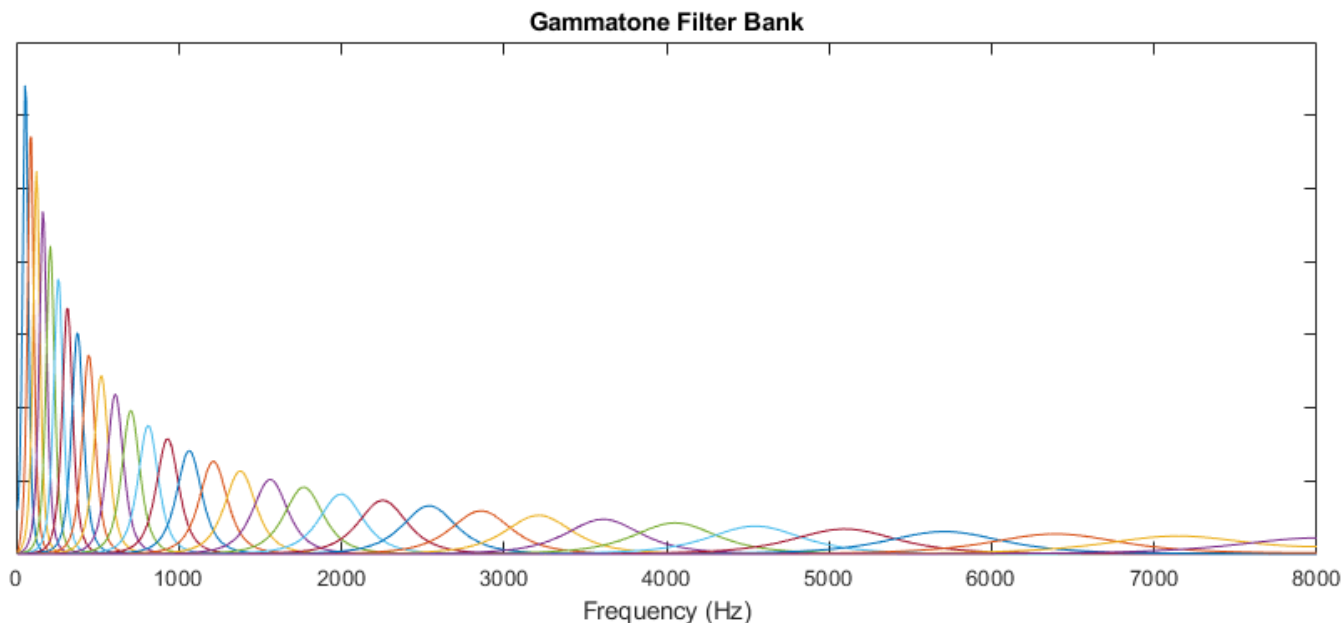
Mel Filter Bank

The default mel filter bank linearly spaces the first 10 triangular filters and logarithmically spaces the remaining filters.



Gammatone Filter Bank

The default gammatone filter bank is composed of gammatone filters spaced linearly on the ERB scale between 50 and 8000 Hz. The filter bank is designed by `gammatoneFilterBank`.



Log Energy

If the input (x) is a time-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(x^2))$$

If the input (x) is a frequency-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(|x|^2)/\text{FFTLength})$$

Compatibility Considerations

cepstralFeatureExtractor will be removed

Not recommended starting in R2020b

`cepstralFeatureExtractor` will be removed. Use the `mfcc` and `gtcc` functions to compute the same features for batch signals. For time-critical processing, use a combination of `designAuditoryFilterBank`, `cepstralCoefficients`, and `audioDelta` functions to compute the same features. If you are extracting multiple audio features, use the `audioFeatureExtractor` object.

References

- [1] Auditory Toolbox. <https://engineering.purdue.edu/~malcolm/interval/1998-010/AuditoryToolboxTechReport.pdf>
- [2] ETSI ES 201 108 V1.1.3 (2003-09). https://www.etsi.org/deliver/etsi_es/201100_201199/201108/01.01.03_60/es_201108v010103p.pdf

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

[mfcc](#) | [gtcc](#) | [gammatoneFilterBank](#) | [pitch](#) | [Cepstral Feature Extractor](#) | [voiceActivityDetector](#) | [Voice Activity Detector](#)

Topics

“Speaker Identification Using Pitch and MFCC”

Introduced in R2018a

getFilters

Get auditory filter bank

Syntax

```
[filterbank, freq] = getFilters(cepFeatures)
```

Description

[filterbank, freq] = getFilters(cepFeatures) returns the filter bank and the corresponding frequency bins in Hz. Each column of the filter bank corresponds to a single bandpass filter. The filter bank is undefined until the object is locked.

Examples

Get Auditory Filter Bank

The auditory filter bank contains a set of bandpass filters. The getFilters function returns the auditory filter bank and the corresponding frequency bins.

Read an audio signal from 'SpeechDFT-16-8-mono-5secs.wav' file. Extract a 40 ms segment from the audio data. Create a cepstralFeatureExtractor System object™ that accepts a time-domain audio input signal sampled at 8 kHz.

```
[audioFile, fs] = audioread('SpeechDFT-16-8-mono-5secs.wav');  
duration = round(0.04*fs); % 40 ms  
audioSegment = audioFile(5500:5500+duration-1);  
cepFeatures = cepstralFeatureExtractor('SampleRate', fs)
```

```
cepFeatures =  
cepstralFeatureExtractor with properties:
```

```
Properties  
FilterBank: 'Mel'  
InputDomain: 'Time'  
NumCoeffs: 13  
Rectification: 'Log'  
FFTLength: []  
LogEnergy: 'Append'  
SampleRate: 8000
```

```
Show all properties
```

Pass the 40 ms audio segment as an input to the cepstralFeatureExtractor algorithm. The algorithm computes the mel frequency coefficients, log energy, delta, and delta-delta values of the audio segment.

```
[coeffs, delta, deltaDelta] = cepFeatures(audioSegment);
```

Input Arguments

cepFeatures — Input cepstral feature extractor System object

cepstralFeatureExtractor System object

Input cepstral feature extractor, specified as a cepstralFeatureExtractor System object. To use the getFilters function, the object must be locked. The filter bank is defined only when the object is locked. The object is locked when you call the object algorithm.

Output Arguments

filterbank — Auditory filter bank

matrix

Filter bank used to calculate cepstral features, returned as a matrix. Each column of the matrix corresponds to a single bandpass filter in the filter bank. The number of columns in the matrix is given by $m - 2$, where m is the length of the vector you specify in the BandEdges property of the System object. The number of rows in the matrix corresponds to the FFT length. By default, the FFT length equals the number of rows in the input signal. You can also specify the FFT length through the FFTLength property of the System object.

Data Types: single | double

freq — Frequency bins corresponding to filter bank (Hz)

row vector

Frequency bins corresponding to the filter bank in Hz, returned as a row vector. The length of the vector equals the FFT length.

Data Types: single | double

See Also

cepstralFeatureExtractor

Introduced in R2018a

staticCharacteristic

Return static characteristic of dynamic range controller

Syntax

```
outputLevel = staticCharacteristic(dynamicRangeController)
outputLevel = staticCharacteristic(dynamicRangeController,inputRange)
```

Description

`outputLevel = staticCharacteristic(dynamicRangeController)` returns the static characteristic of the dynamic range control object.

`outputLevel = staticCharacteristic(dynamicRangeController,inputRange)` enables you to specify the input range.

Examples

Get Output Level From Static Characteristic

Create a limiter System object™. Get the output level of the static characteristic over a specified range.

```
dynamicRangeLimiter = limiter;
inputLevel = -15:1:-5
```

```
inputLevel = 1×11
```

```
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5
```

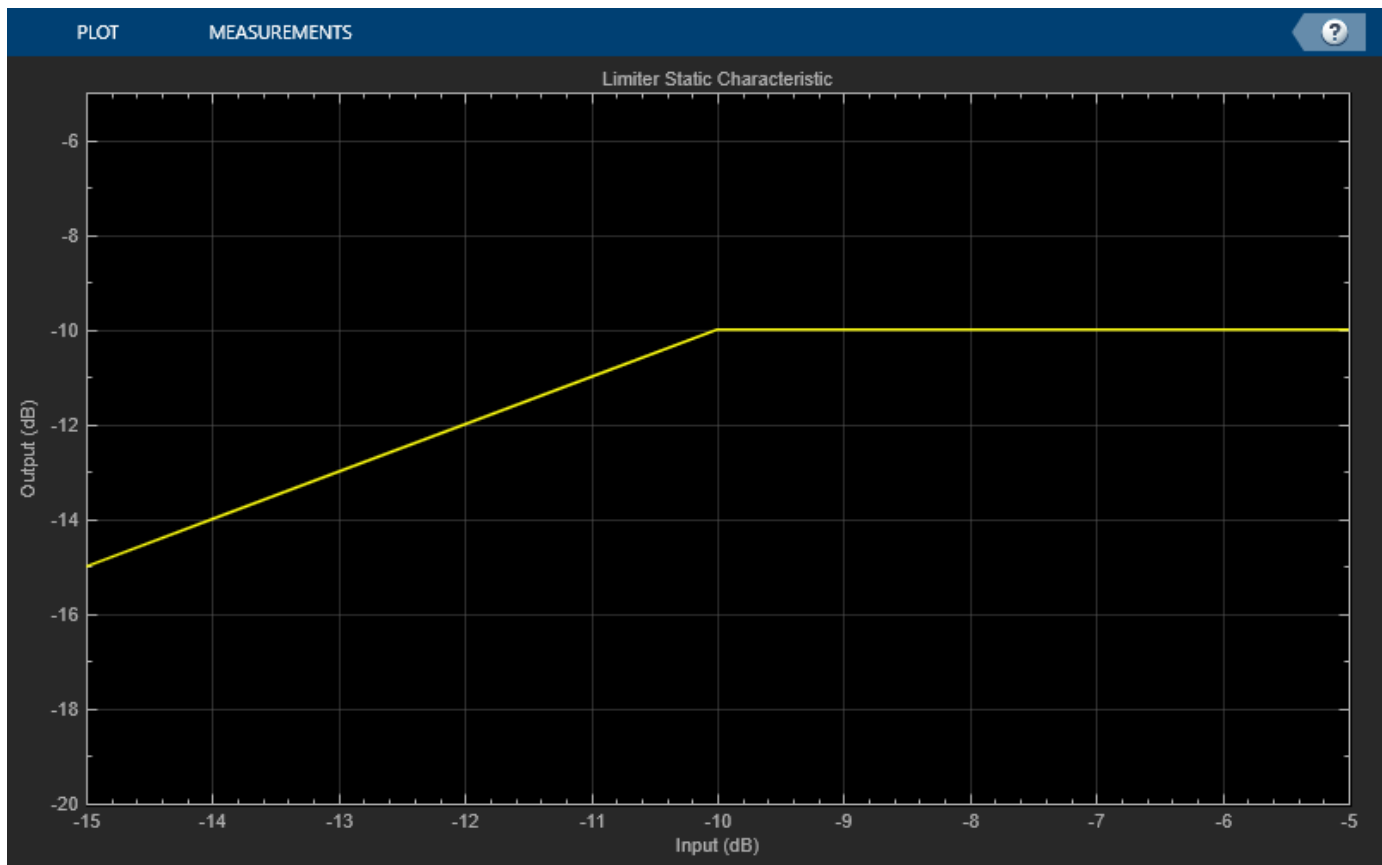
```
outputLevel = staticCharacteristic(dynamicRangeLimiter,inputLevel)
```

```
outputLevel = 1×11
```

```
-15 -14 -13 -12 -11 -10 -10 -10 -10 -10 -10
```

Plot the static characteristic. Modify the title to state that the object is a limiter.

```
hvsz = visualize(dynamicRangeLimiter,inputLevel);
hvsz.Title = "Limiter Static Characteristic";
```



Input Arguments

dynamicRangeController — Dynamic range control object
object

Dynamic range control object, specified as a compressor, expander, or limiter System object.

inputRange — Range to calculate static characteristic output
[-50:0.01:0] (default) | vector of monotonically increasing values

Range over which to calculate the output of the static characteristic, specified as a vector of monotonically increasing values expressed in dB. The default input range is [-50:0.01:0] dB.

Output Arguments

outputLevel — Output level (dB)
vector

Output level in dB, returned as a vector the same size as inputRange.

See Also

compressor | expander | limiter

Topics

“Dynamic Range Control”

Introduced in R2022a

visualize

Visualize static characteristic of dynamic range controller

Syntax

```
visualize(dynamicRangeController)
visualize(dynamicRangeController,inputRange)
hvsz = visualize( ___ )
```

Description

`visualize(dynamicRangeController)` plots the static characteristic of the dynamic range control object. The plot is updated automatically when properties of the object change.

`visualize(dynamicRangeController,inputRange)` enables you to specify the input range.

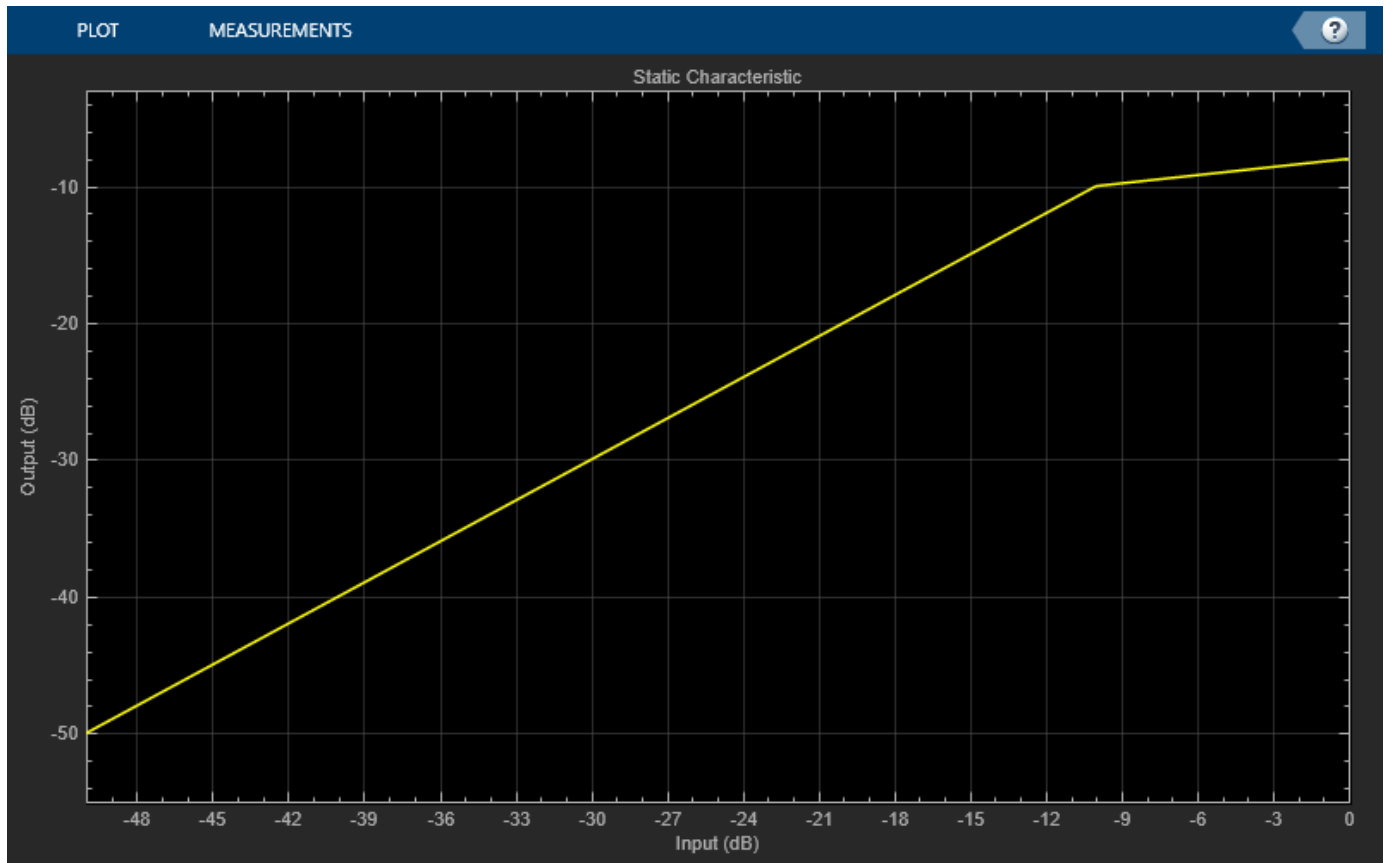
`hvsz = visualize(___)` returns a handle to the visualizer when called with any of the previous syntaxes.

Examples

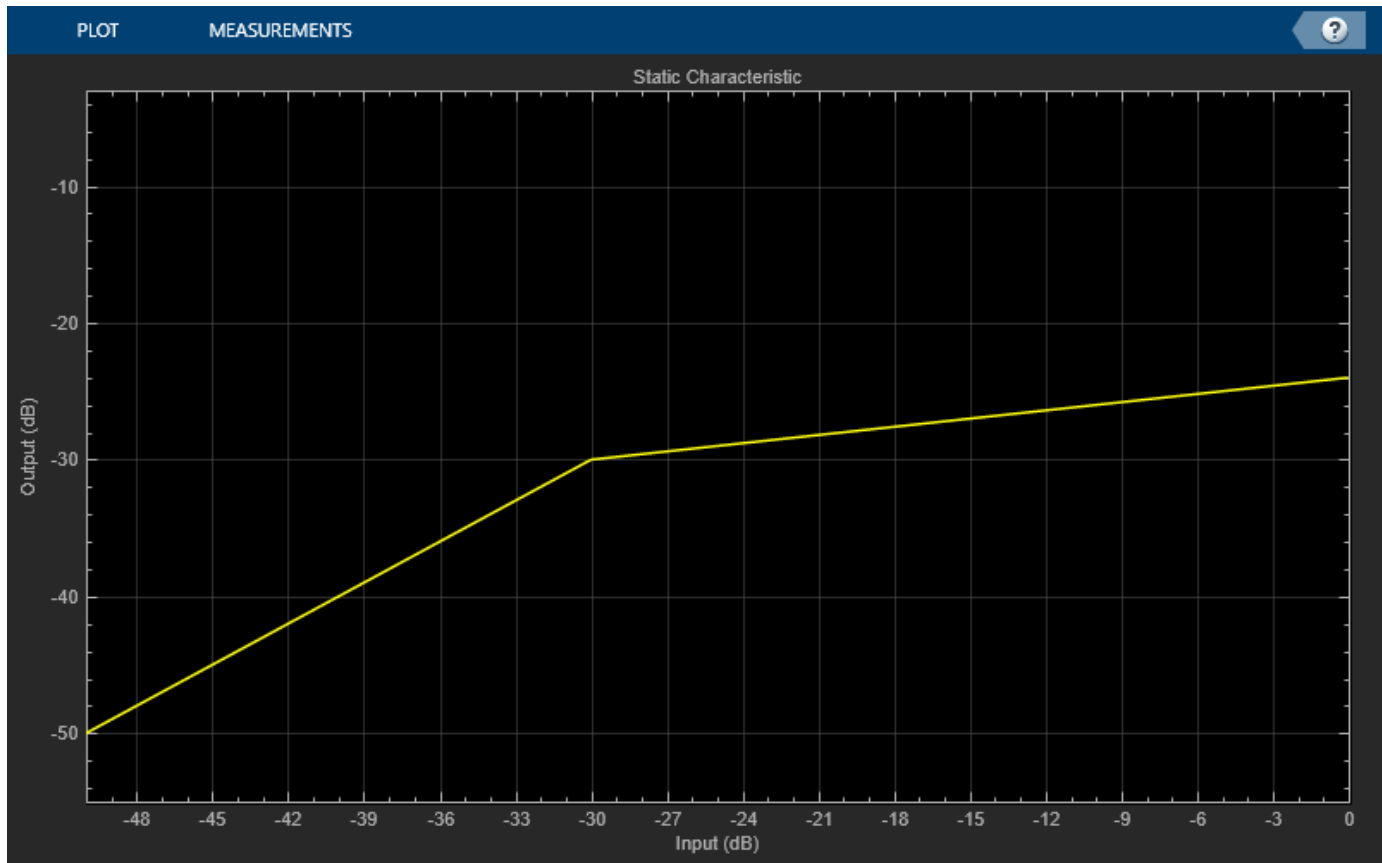
Plot Static Characteristic

Create a compressor System object™, and then plot the static characteristic.

```
dynamicRangeCompressor = compressor;
visualize(dynamicRangeCompressor)
```



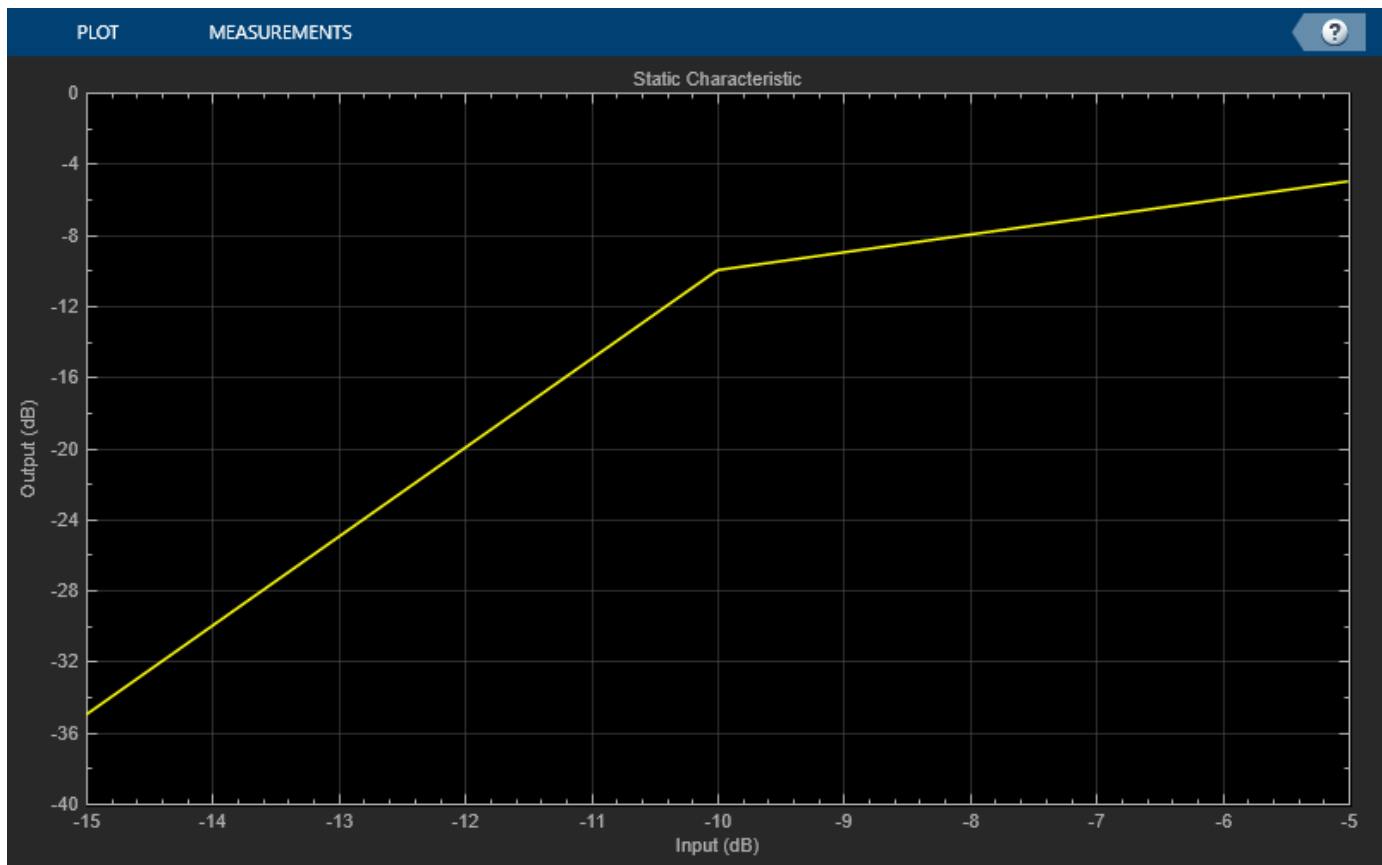
The static characteristic plot updates automatically if you modify a property of the object.
`dynamicRangeCompressor.Threshold = -30;`



Specify Range of Static Characteristic Plot

Create an expander System object™. Plot the static characteristic over the range -15 to -5, in 0.001 dB increments.

```
dynamicRangeExpander = expander;  
visualize(dynamicRangeExpander, -15:0.001:-5)
```



Get Output Level From Static Characteristic

Create a `limiter` System object™. Get the output level of the static characteristic over a specified range.

```
dynamicRangeLimiter = limiter;
inputLevel = -15:1:-5
```

```
inputLevel = 1x11
```

```
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5
```

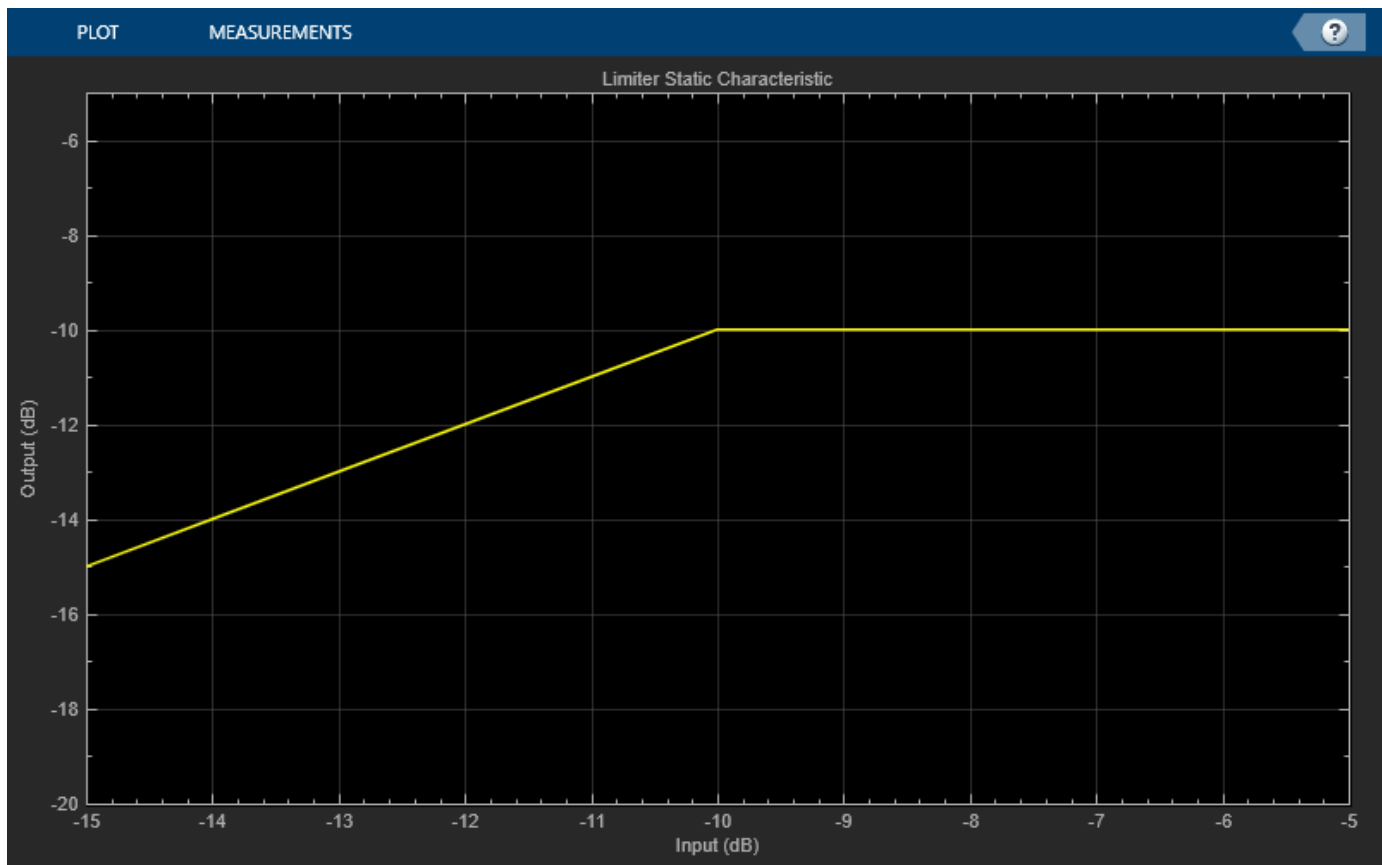
```
outputLevel = staticCharacteristic(dynamicRangeLimiter,inputLevel)
```

```
outputLevel = 1x11
```

```
-15 -14 -13 -12 -11 -10 -10 -10 -10 -10 -10
```

Plot the static characteristic. Modify the title to state that the object is a limiter.

```
hvsz = visualize(dynamicRangeLimiter,inputLevel);
hvsz.Title = "Limiter Static Characteristic";
```



Input Arguments

dynamicRangeController — Dynamic range control object
object

Dynamic range control object, specified as a compressor, expander, limiter, or noiseGate System object.

inputRange — Range to calculate static characteristic output
[-50:0.01:0] (default) | vector of monotonically increasing values

Range over which to calculate the output of the static characteristic, specified as a vector of monotonically increasing values expressed in dB. The default input range is [-50:0.01:0] dB.

Output Arguments

hvsz — Visualizer handle
dsp.ArrayPlot object

Visualizer handle, returned as a dsp.ArrayPlot object.

Compatibility Considerations

visualize object function outputs figure handles

Behavior changed in R2022a

In previous releases, calling the `visualize` function of the dynamic range control System objects with an output argument returned static characteristic data. Starting in R2022a, that syntax returns a figure handle instead. Use the new `staticCharacteristic` function to compute static dynamic range characteristics.

visualize plots static characteristics of noiseGate System objects in dB

Behavior changed in R2022a

In previous releases, the `visualize` function plotted the static characteristic of a `noiseGate` System object in linear units. Starting in R2022a, the function plots all static characteristics in dB.

See Also

`compressor` | `expander` | `limiter` | `noiseGate`

Topics

“Dynamic Range Control”

Introduced in R2016a

createAudioPluginClass

Create audio plugin class that implements functionality of System object

Syntax

```
createAudioPluginClass(obj)
createAudioPluginClass(obj,pluginName)
```

Description

`createAudioPluginClass(obj)` creates a System object plugin that implements the functionality of the Audio Toolbox System object, `obj`. The name of the created class is the System object variable name, `obj`, followed by 'Plugin', for example, `objPlugin`.

If the object is locked, the number of input and output channels of the plugin is equal to the number of channels of the object. Otherwise, the number of channels is equal to 2.

`createAudioPluginClass(obj,pluginName)` specifies the name of your created System object plugin class.

Example: `createAudioPluginClass(obj, 'coolEffect')` creates a System object plugin with class name 'coolEffect'.

Examples

Create an Audio Plugin Class From a System Object

Create a compressor object. Call `createAudioPluginClass` to create a System object™ plugin class that implements the functionality of the compressor object.

```
cmpr = compressor;
createAudioPluginClass(cmpr)
```

Specify Name of Created Plugin Class

Create an object of the reverberator System object™. Call `createAudioPluginClass` to create a System object™ plugin class that implements the functionality of the reverberator object, specifying the plugin class name as the second argument.

```
reverb = reverberator;
createAudioPluginClass(reverb, 'Garage');
```

Input Arguments

obj — System object to create plugin class from
Audio Toolbox System object

System object from which to create a plugin class.

pluginName — Name of created plugin class

character vector

Name of created plugin class, specified as a character vector with fewer than 64 elements.

Data Types: char

See Also

Objects

compressor | audioOscillator | crossoverFilter | expander | graphicEQ | limiter |
multibandParametricEQ | noiseGate | octaveFilter | reverberator |
wavetableSynthesizer | weightingFilter

Apps

Audio Test Bench

Functions

parameterTuner

Topics

“Audio Plugins in MATLAB”

“Export a MATLAB Plugin to a DAW”

Introduced in R2016a

getFilter

Return biquad filter object with design parameters set

Syntax

```
biquad = getFilter(obj)
```

Description

`biquad = getFilter(obj)` returns a `dsp.BiquadFilter` object, `biquad`. The `SOSMatrix` and `ScaleValues` properties of the biquad filter object are set as specified by the `obj` System object.

Use `getFilter` for the design capabilities of the `obj` System object and the processing capabilities of the `dsp.BiquadFilter` System object.

Examples

Get Biquad Filter for Octave Filter Design

Create an `octaveFilter` System object™. Call `getFilter` on your object to return a `dsp.BiquadFilter` object with design parameters specified by your `octaveFilter` System object.

```
octFilt = octaveFilter;
biquad = getFilter(octFilt)
```

```
biquad =
  dsp.SOSFilter with properties:
    Structure: 'Direct form II transposed'
  CoefficientSource: 'Property'
    Numerator: [3x3 double]
  Denominator: [3x3 double]
  HasScaleValues: false
```

```
Show all properties
```

Get Biquad Filter for Weighting Filter Design

Create a `weightingFilter` System object™.

```
weightFilt = weightingFilter;
```

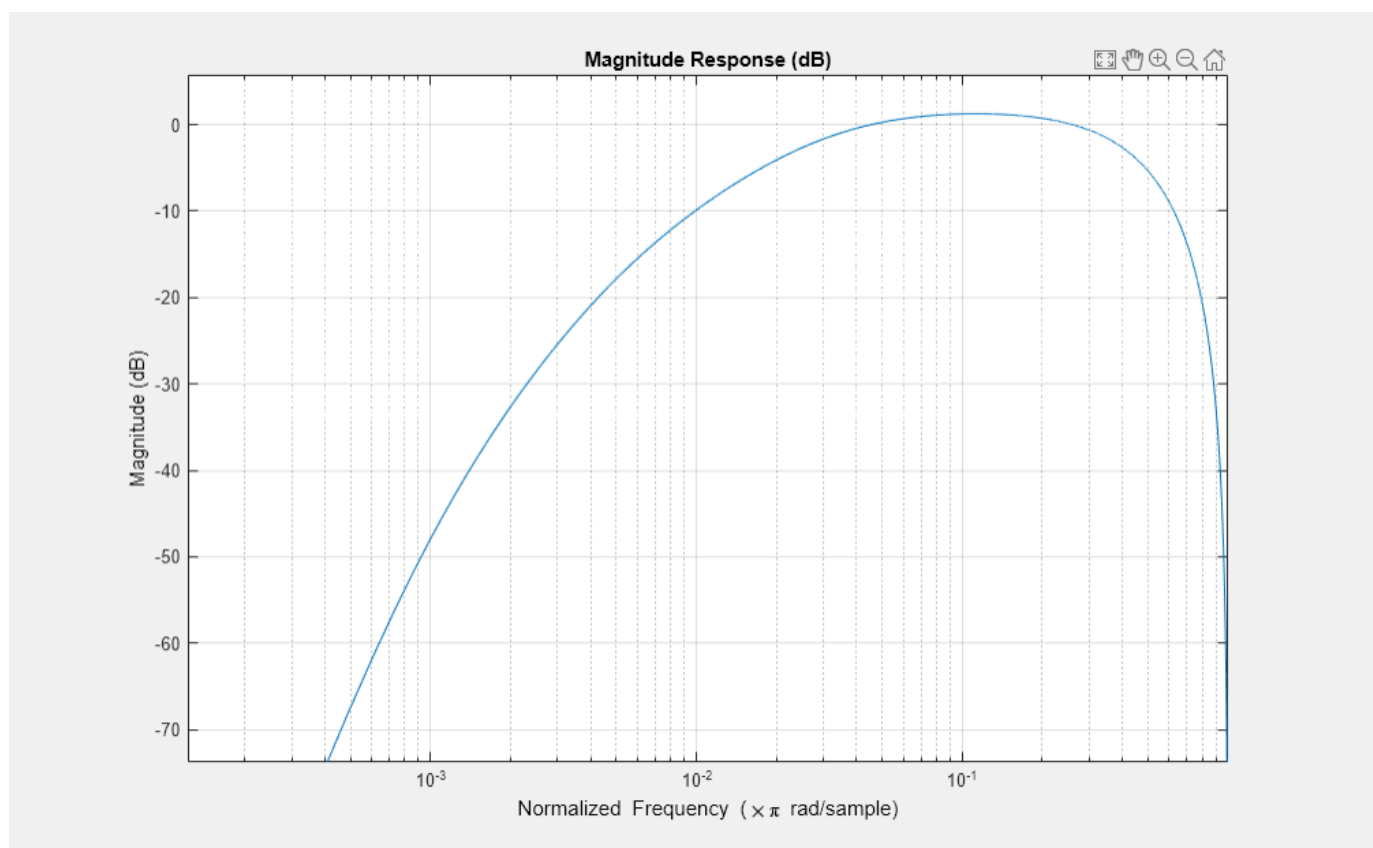
Call `getFilter` on your object to return a `dsp.BiquadFilter` object with design parameters specified by your `weightingFilter` System object. Use `fvtool` to visualize the biquad filter.

```
biquad = getFilter(weightFilt)
```

```
biquad =  
  dsp.SOSFilter with properties:  
  
    Structure: 'Direct form II transposed'  
  CoefficientSource: 'Property'  
    Numerator: [3x3 double]  
    Denominator: [3x3 double]  
  HasScaleValues: true  
    ScaleValues: [4x1 double]
```

Show all properties

```
fvtool(biquad, 'FrequencyScale', 'log')
```



Input Arguments

obj — System object to get filter from

System object

System object that you want to get a biquad filter object from.

Output Arguments

biquad — Object of `dsp.BiquadFilter`

object

`dsp.BiquadFilter` object.

See Also

`weightingFilter` | `octaveFilter` | `dsp.BiquadFilter`

Topics

“Audio Weighting Filters”

“Octave-Band and Fractional Octave-Band Filters”

“Sound Pressure Measurement of Octave Frequency Bands”

Introduced in R2016b

info

Get audio device information

Syntax

```
infoStruct = info(obj)
```

Description

`infoStruct = info(obj)` returns a structure, `infoStruct`, containing information about the System object, `obj`.

Examples

Get Input Audio Device Information

Create an object of the `audioDeviceReader` System object™ and then call `info` to return a structure containing information about the selected driver, device name, and the maximum number of input channels.

```
deviceReader = audioDeviceReader;  
info(deviceReader)
```

Get Output Audio Device Information

Create an object of the `audioDeviceWriter` System object™ and then call `info` to return a structure containing information about the selected driver, device name, and the maximum number of output channels.

```
deviceWriter = audioDeviceWriter;  
info(deviceWriter)
```

Get Audio I/O Device Information

Create an object of the `audioPlayerRecorder` System object™ and then call `info` to return a structure containing information about the selected driver, device name, and the maximum number of input and output channels.

```
playRec = audioPlayerRecorder;  
info(playRec)
```

Input Arguments

obj — System object to get information from

System object

System object to get information from.

Output Arguments

infoStruct — Struct containing object information

struct

Struct containing information about the System object, `obj`. Fields of the struct depend on the System object.

See Also

`audioDeviceWriter` | `audioDeviceReader` | `audioPlayerRecorder`

Introduced in R2016a

cost

Estimate implementation cost of audio System objects

Syntax

```
implementationCost = cost(audioObj)
```

Description

`implementationCost = cost(audioObj)` returns a structure, `implementationCost`, whose fields contain information about the computation cost of implementing the audio System object, `audioObj`.

Examples

Estimate Implementation Cost of Crossover Filter

Create a crossover filter with 2 crossovers with 48 dB/octave slopes. Call `cost` to get an estimate of the implementation cost.

```
crossFilt = crossoverFilter('NumCrossovers',2,'CrossoverSlopes',48);  
cost1 = cost(crossFilt)
```

```
cost1 = struct with fields:  
    NumCoefficients: 120  
    NumStates: 48  
    MultiplicationsPerInputSample: 120  
    AdditionsPerInputSample: 97
```

Reduce the crossover slopes for both crossovers to 12 dB/octave. Call `cost` to get an estimate of the new implementation cost.

```
crossFilt.CrossoverSlopes = 12;  
cost2 = cost(crossFilt)
```

```
cost2 = struct with fields:  
    NumCoefficients: 36  
    NumStates: 12  
    MultiplicationsPerInputSample: 36  
    AdditionsPerInputSample: 25
```

Input Arguments

audioObj — Audio System object

`crossoverFilter` object

Specify the input as a supported audio System object.

Data Types: object

Output Arguments

implementationCost — Estimate of implementation cost

struct

Estimate of the implementation cost of a filter, returned as struct:

Structure Field	Description
NumCoefficients	Number of filter coefficients (excluding coefficients with values 0, 1 or -1)
NumStates	Number of states
MultiplicationsPerInputSample	Number of multiplication per input sample
AdditionsPerInputSample	Number of additions per input sample

See Also

`crossoverFilter`

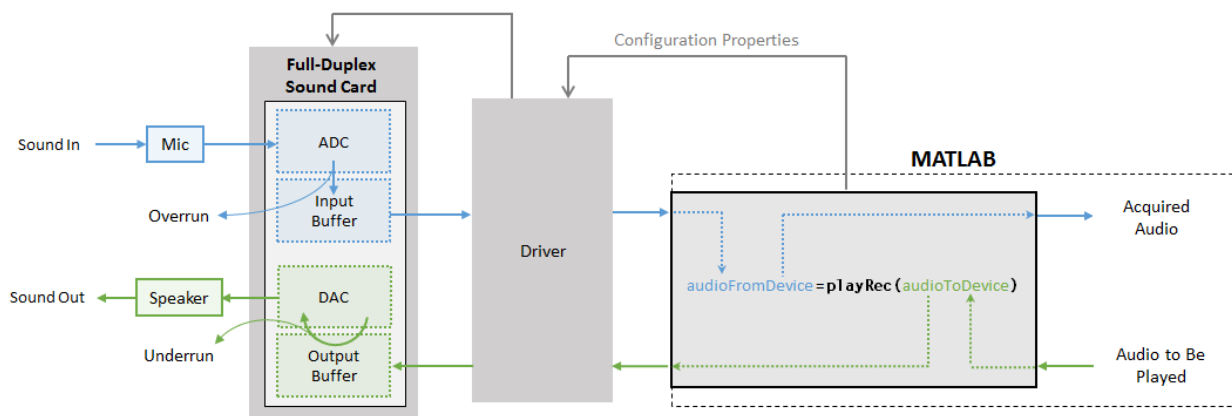
Introduced in R2016a

audioPlayerRecorder

Simultaneously play and record using an audio device

Description

The `audioPlayerRecorder` System object reads and writes audio samples using your computer's audio device. To use `audioPlayerRecorder`, you must have an audio device and driver capable of simultaneous playback and record.



See “Audio I/O: Buffering, Latency, and Throughput” for a detailed explanation of the data flow.

To simultaneously play and record:

- 1 Create the `audioPlayerRecorder` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
playRec = audioPlayerRecorder
playRec = audioPlayerRecorder(sampleRateValue)
playRec = audioPlayerRecorder( ___, Name, Value)
```

Description

`playRec = audioPlayerRecorder` returns a System object, `playRec`, that plays audio samples to an audio device and records samples from the same audio device, in real time.

`playRec = audioPlayerRecorder(sampleRateValue)` sets the `SampleRate` property to `sampleRateValue`.

`playRec = audioPlayerRecorder(____, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `playRec = audioPlayerRecorder(48000, 'BitDepth', '8-bit integer')` creates a System object, `playRec`, that operates at a 48 kHz sample rate and an 8-bit integer bit depth.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Device — Device used to play and record audio data

default audio device (default) | character vector | string

Device used to play and record audio data, specified as a character vector or string. The object supports only devices enabled for simultaneous playback and recording (full-duplex mode). Use `getAudioDevices` to list available devices.

Supported drivers for `audioPlayerRecorder` are platform-specific:

- Windows -- ASIO
- Mac -- CoreAudio
- Linux -- ALSA

Note The default audio device is the default device of your machine only if it supports full-duplex mode. If your machine's default audio device does not support full-duplex mode, `audioPlayerRecorder` specifies as the default device the first available device it detects that is capable of full-duplex mode. Use the `info` method to get the device name associated with your `audioPlayerRecorder` object.

Data Types: `char` | `string`

SampleRate — Sample rate used by device to record and play audio data (Hz)

44100 (default) | positive integer

Sample rate used by device to record and play audio data, in Hz, specified as a positive integer. The range of `SampleRate` depends on your audio hardware.

Data Types: `single` | `double`

BitDepth — Data type used by device

'16-bit integer' (default) | '8-bit integer' | '32-bit float' | '24-bit integer'

Data type used by device, specified as a character vector or string.

Data Types: char | string

SupportVariableSize — Support variable frame size

false (default) | true

Option to support variable frame size, specified as false or true.

- **false** -- If the `audioPlayerRecorder` object is locked, the input must have the same frame size at each call. The buffer size of your audio device is the same as the input frame size. If you are using the object on Windows, open the ASIO UI to set the sound card buffer to the frame size value.
- **true** -- If the `audioPlayerRecorder` object is locked, the input frame size can change at each call. The buffer size of your audio device is specified through the `BufferSize` property.

To minimize latency, set `SupportVariableSize` to false. If variable-size input is required by your audio system, set `SupportVariableSize` to true.

Data Types: logical

BufferSize — Buffer size of audio device

1024 (default) | positive integer

Buffer size of audio device, specified as a positive integer.

Note If you are using the object on a Windows machine, use `asioSettings` to set the sound card buffer size to the `BufferSize` value of your `audioPlayerRecorder` System object.

Dependencies

To enable this property, set `SupportVariableSize` to true.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

PlayerChannelMapping — Mapping between columns of played data and channels of device

[] (default) | scalar | vector

Mapping between columns of played data and channels of output device, specified as a scalar or as a vector of valid channel indices. The default value of this property is [], which means that the default channel mapping is used.

Note To ensure mono output on only one channel of a stereo device, use the default `PlayerChannelMapping` setting and provide a stereo signal where one channel is all zeros.

Example: `outputLeftOnly = [x(:,1) zeros(size(x,1),1)];`

Example: `outputRightOnly = [zeros(size(x,1),1) x(:,1)];`

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

RecorderChannelMapping — Mapping between channels of device and columns of recorded data

1 (default) | scalar | vector

Mapping between channels of your audio device and columns of recorded data, specified as a scalar or as a vector of valid channel indices. The default value is 1, which means that the first recording channel on the device is used to acquire data and is mapped to a single-column matrix.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

```
audioFromDevice = playRec(audioToDevice)
[audioFromDevice,numUnderrun] = playRec(audioToDevice)
[audioFromDevice,numUnderrun,numOverrun] = playRec(audioToDevice)
```

Description

`audioFromDevice = playRec(audioToDevice)` writes one frame of audio samples, `audioToDevice`, to the selected audio device, and returns one frame of audio, `audioFromDevice`.

`[audioFromDevice,numUnderrun] = playRec(audioToDevice)` returns the number of samples overrun since the last call to `playRec`.

`[audioFromDevice,numUnderrun,numOverrun] = playRec(audioToDevice)` returns the number of samples underrun since the last call to `playRec`.

Note: When you call the `audioPlayerRecorder` System object, the audio device specified by the `Device` property is locked. An audio device can be locked by only one `audioPlayerRecorder` at a time. To release the audio device, call `release` on the `audioPlayerRecorder` System object.

Input Arguments

audioToDevice — Audio to device

matrix

Audio signal to write to device, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `uint8`

Output Arguments

audioFromDevice — Audio from device

matrix

Audio signal read from device, returned as a matrix the same size and data type as `audioToDevice`.

Data Types: `single` | `double` | `int16` | `int32` | `uint8`

numUnderrun — Number of samples underrun

scalar

Number of samples by which the player queue was underrun since the last call to `playRec`. Underrun refers to output signal silence. Output signal silence occurs if the device buffer is empty when it is time for digital-to-analog conversion. This results when the processing loop in MATLAB does not supply samples at the rate the sound card demands.

Data Types: uint32

numOverrun — Number of samples overrun

scalar

Number of samples by which the recorder queue was overrun since the last call to `playRec`. Overrun refers to input signal drops. Input signal drops occur when the processing stage does not keep pace with the acquisition of samples.

Data Types: uint32

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to audioPlayerRecorder

`getAudioDevices` List available audio devices
`info` Get audio device information

Common to All System Objects

`clone` Create duplicate System object
`isLocked` Determine if System object is in use
`release` Release resources and allow changes to System object property values and input characteristics
`reset` Reset internal states of System object
`step` Run System object algorithm
`setup` One-time set up tasks for System objects

Examples**Synchronize Playback and Recording**

Synchronize playback and recording using a single audio device. If synchronization is lost, print information about samples dropped.

Create objects to read from and write to an audio file. Create an `audioPlayerRecorder` object to play an audio signal to your device and simultaneously record audio from your device.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav', ...  
    'SamplesPerFrame',512);  
fs = fileReader.SampleRate;  
  
fileWriter = dsp.AudioFileWriter('Counting-PlaybackRecorded.wav', ...  
    'SampleRate',fs);  
  
aPR = audioPlayerRecorder('SampleRate',fs);
```

In a frame-based loop:

- 1 Read an audio signal from your file.
- 2 Play the audio signal to your device and simultaneously record audio from your device. Use the optional `nUnderruns` and `nOverruns` output arguments to track any loss of synchronization.
- 3 Write your recorded audio to a file.

Once the loop is completed, release the objects to free devices and resources.

```
while ~isDone(fileReader)
    audioToPlay = fileReader();

    [audioRecorded,nUnderruns,nOverruns] = aPR(audioToPlay);

    fileWriter(audioRecorded)

    if nUnderruns > 0
        fprintf('Audio player queue was underrun by %d samples.\n',nUnderruns);
    end
    if nOverruns > 0
        fprintf('Audio recorder queue was overrun by %d samples.\n',nOverruns);
    end
end
```

```
Audio player queue was underrun by 512 samples.
```

```
release(fileReader)
release(fileWriter)
release(aPR)
```

Specify Nondefault Channel Mapping

The `audioPlayerRecorder` System object™ enables you to specify a nondefault mapping between the channels of your audio device and the data sent to and received from your audio device. To run this example, your audio device must have at least two channels and be capable of full-duplex mode.

Using Default Settings

Create an `audioPlayerRecorder` object with default settings. The `audioPlayerRecorder` is automatically configured to a compatible device and driver.

```
aPR = audioPlayerRecorder;
```

The `audioPlayerRecorder` combines reading from your device and writing to your device in a single call: `audioFromDevice = aPR(audioToDevice)`. Calling the `audioPlayerRecorder` with default settings:

- Maps columns of `audioToDevice` to output channels of your device
- Maps input channels of your device to columns of `audioFromDevice`

By default, `audioFromDevice` is a one-column matrix corresponding to channel 1 of your audio device. To view the maximum number of input and output channels of your device, use the `info` method.

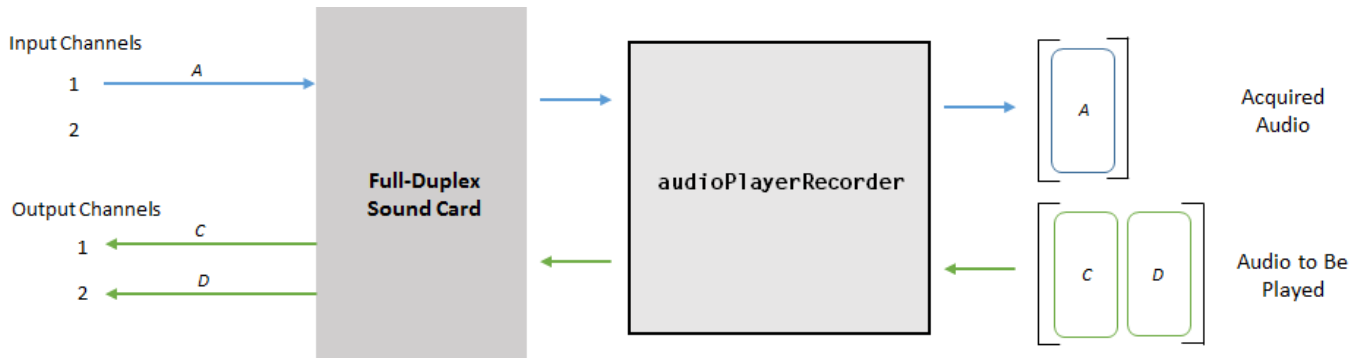
```
aPRInfo = info(aPR);
```

aPRInfo is returned as a structure with fields containing information about your selected driver, audio device, and the maximum number of input and output channels in your configuration.

Call the `audioPlayerRecorder` with a two-column matrix. By default, column 1 is mapped to output channel 1, and column 2 is mapped to output channel 2. The `audioPlayerRecorder` returns a one-column matrix with the same number of rows as the `audioToDevice` matrix.

```
highToneGenerator = audioOscillator('Frequency',600,'SamplesPerFrame',256);
lowToneGenerator = audioOscillator('Frequency',200,'SamplesPerFrame',256);
```

```
for i = 1:250
    C = highToneGenerator();
    D = lowToneGenerator();
    audioToDevice = [C,D];
    audioFromDevice = aPR(audioToDevice);
end
```



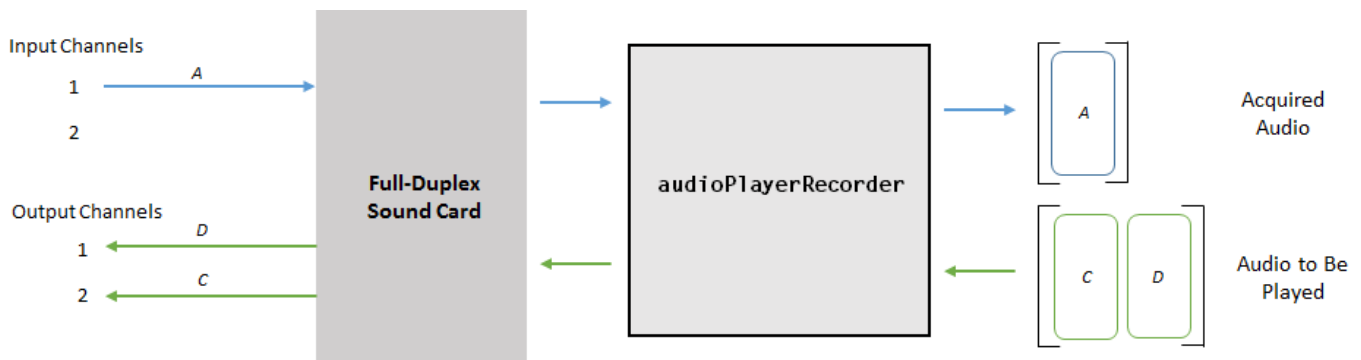
Nondefault Channel Mapping for Audio Output

Specify a nondefault channel mapping for your audio output. Specify that column 1 of `audioToDevice` maps to channel 2, and that column 2 of `audioToDevice` maps to channel 1. To modify the channel mapping, the `audioPlayerRecorder` object must be unlocked.

Run the `audioPlayerRecorder` object. If you are using headphones or stereo speakers, notice that the high frequency and low frequency tones have switched speakers.

```
release(aPR)
aPR.PlayerChannelMapping = [2,1];

for i = 1:250
    C = highToneGenerator();
    D = lowToneGenerator();
    audioToDevice = [C,D];
    audioFromDevice = aPR(audioToDevice);
end
```



Nondefault Channel Mapping for Audio Input

Specify a nondefault channel mapping for your audio input. Record data from only channel two of your device. In this case, channel 2 is mapped to a one-column matrix. Use `size` to verify that `audioFromDevice` is a 256-by-1 matrix.

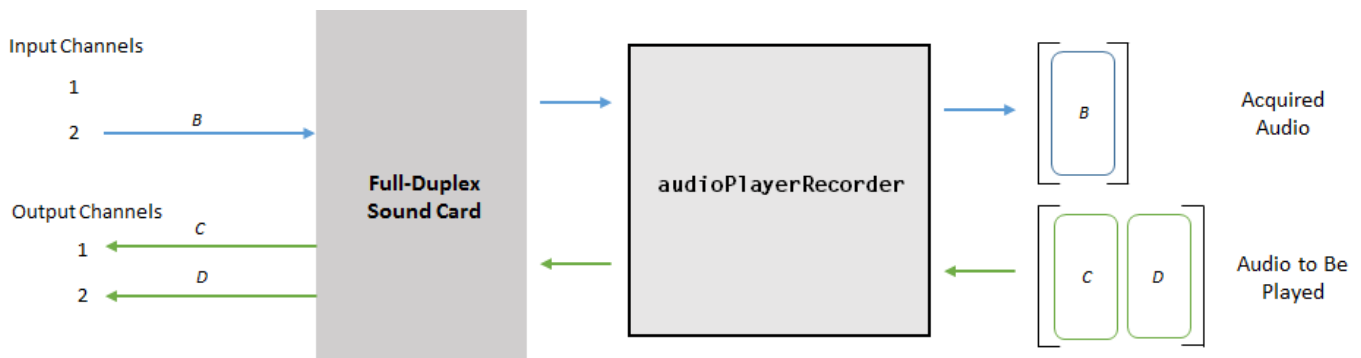
```
release(aPR)
aPR.RecorderChannelMapping = 2;

audioFromDevice = aPR(audioToDevice);

[rows,col] = size(audioFromDevice)
```

```
rows =
    256
```

```
col =
     1
```



As a best practice, release your audio device once complete.

release(aPR)

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- “System Objects in MATLAB Code Generation” (MATLAB Coder)
- The executable generated from this System object relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGo` function to package the code generated from this object and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

Functions

`asioSettings` | `getAudioDevices` | `audioDeviceWriter` | `audioDeviceReader` | `dsp.AudioFileReader`

Blocks

Audio Device Reader | Audio Device Writer

Topics

“Audio I/O: Buffering, Latency, and Throughput”
“Run Audio I/O Features Outside MATLAB and Simulink”
“Real-Time Audio in MATLAB”

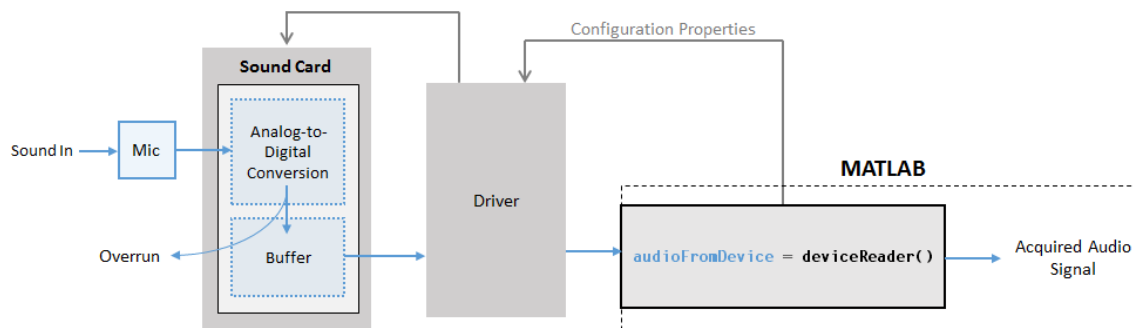
Introduced in R2017a

audioDeviceReader

Record from sound card

Description

The `audioDeviceReader` System object reads audio samples using your computer's audio input device.



See “Audio I/O: Buffering, Latency, and Throughput” for a detailed explanation of the audio device reader data flow.

The audio device reader specifies the driver, the device and its attributes, and the data type and size output from your System object.

To stream data from an audio device:

- 1 Create the `audioDeviceReader` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
deviceReader = audioDeviceReader
deviceReader = audioDeviceReader(sampleRateValue)
deviceReader = audioDeviceReader(sampleRateValue,sampPerFrameValue)
deviceReader = audioDeviceReader( ___,Name,Value)
```

Description

`deviceReader = audioDeviceReader` returns a System object, `deviceReader`, that reads audio samples using an audio input device in real time.

`deviceReader = audioDeviceReader(sampleRateValue)` sets the `SampleRate` property to `sampleRateValue`.

`deviceReader = audioDeviceReader(sampleRateValue, sampPerFrameValue)` sets the `SamplesPerFrame` property to `sampPerFrameValue`.

`deviceReader = audioDeviceReader(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `deviceReader = audioDeviceReader(16000, 'BitDepth', '8-bit integer')` creates a System object, `deviceReader`, that operates at a 16 kHz sample rate and an 8-bit integer bit depth.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

Driver — Driver used to access audio device (Windows only)

'DirectSound' (default) | 'ASIO' | 'WASAPI'

Driver used to access your audio device, specified as 'DirectSound', 'ASIO', or 'WASAPI'.

- ASIO drivers do not come pre-installed on Windows machines. To use the 'ASIO' driver option, install an ASIO driver outside of MATLAB.

Note If `Driver` is specified as 'ASIO', use `asioSettings` to set the sound card buffer size to the `SamplesPerFrame` value of your `audioDeviceReader` System object.

- WASAPI drivers are supported for exclusive-mode only.

ASIO and WASAPI drivers do not provide sample rate conversion. For ASIO and WASAPI drivers, set `SampleRate` to a sample rate supported by your audio device.

This property applies only on Windows machines. Linux machines always use the ALSA driver. Mac machines always use the CoreAudio driver.

Data Types: `char` | `string`

Device — Device used to acquire audio samples

default audio device (default) | character vector | string

Device used to acquire audio samples, specified as a character vector or string. Use `getAudioDevices` to list available devices for the selected driver.

Data Types: `char` | `string`

NumChannels — Number of input channels acquired by audio device

1 (default) | integer

Number of input channels acquired by audio device, specified as an integer. The range of NumChannels depends on your audio hardware.

Dependencies

To enable this property, set ChannelMappingSource to 'Auto'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

SamplesPerFrame — Frame size read from audio device

1024 (default) | integer

Frame size read from audio device, specified as a positive integer. SamplesPerFrame is also the size of your device buffer and the number of columns of the output matrix returned by your audioDeviceReader object.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

SampleRate — Sample rate used by device to acquire audio data (Hz)

44100 (default) | positive integer

Sample rate used by device to acquire audio data, in Hz, specified as a positive integer. The range of SampleRate depends on your audio hardware.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

BitDepth — Data type used by device to acquire audio data

'16-bit integer' (default) | '8-bit integer' | '32-bit float' | '24-bit integer'

Data type used by device to acquire audio data, specified as a character vector or string.

Data Types: char | string

ChannelMappingSource — Source of mapping between device channels and output matrix

'Auto' (default) | 'Property'

Source of mapping between the channels of your audio input device and columns of the output matrix, specified as 'Auto' or 'Property'.

- 'Auto' -- The default settings determine the mapping between device channels and output matrix. For example, suppose that your audio device has six channels available, and you set NumChannels to 6. The output from a call to your audio device reader is a six-column matrix. Column 1 corresponds to channel 1, column 2 corresponds to channel 2, and so on.
- 'Property' -- The ChannelMapping property determines the mapping between channels of your audio device and columns of the output matrix.

Data Types: char | string

ChannelMapping — Nondefault mapping between device channels and output matrix

[1:MaximumInputChannels] (default) | scalar | vector

Nondefault mapping between channels of your audio input device and columns of the output matrix, specified as a vector of valid channel indices. See “Specify Channel Mapping for audioDeviceReader” on page 3-150 for more information.

Dependencies

To enable this property, set ChannelMappingSource to 'Property'.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

OutputDataType — Data type of the output

`'double'` (default) | `'single'` | `'int32'` | `'int16'` | `'uint8'`

Data type of the output, specified as a character vector or string.

Note If `OutputDataType` is specified as `'double'` or `'single'`, the audio device reader outputs data in the range `[-1, 1]`. For other data types, the range is `[min, max]` of the specified data type.

Data Types: `char` | `string`

Usage**Syntax**

```
audioFromDevice = deviceReader()  
[audioFromDevice,numOverrun] = deviceReader()
```

Description

`audioFromDevice = deviceReader()` returns one frame of audio samples from the selected audio input device.

`[audioFromDevice,numOverrun] = deviceReader()` returns the number of samples by which the audio reader's queue was overrun since the last call to `deviceReader`.

Note: When you call the `audioDeviceReader` System object, the audio device specified by the `Device` property is locked. An audio device can be locked by only one `audioDeviceReader` at a time. To release the audio device, call `release` on your `audioDeviceReader` object.

Output Arguments**audioFromDevice — Audio from device**

matrix

Audio signal read from device, returned as a matrix. The specified number of channels and the `SamplesPerFrame` property determine the matrix size. The data type of the matrix depends on the `OutputDataType` property.

Data Types: `single` | `double` | `int16` | `int32` | `uint8`

numOverrun — Number of samples overrun

scalar

Number of samples by which the audio reader's queue was overrun since the last call to `deviceReader`.

Data Types: `uint32`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to audioDeviceReader

<code>getAudioDevices</code>	List available audio devices
<code>info</code>	Get audio device information

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm
<code>setup</code>	One-time set up tasks for System objects

Examples

Read from Microphone and Write to Audio File

Record 10 seconds of speech with a microphone and send the output to a WAV file.

Create an `audioDeviceReader` object with default settings. Call `setup` to reduce the computational load of initialization in an audio stream loop.

```
deviceReader = audioDeviceReader;
setup(deviceReader)
```

Create a `dsp.AudioFileWriter` System object. Specify the file name and type to write.

```
fileWriter = dsp.AudioFileWriter('mySpeech.wav', 'FileFormat', 'WAV');
```

Record 10 seconds of speech. In an audio stream loop, read an audio signal frame from the device, and write the audio signal frame to a specified file. The file saves to your current folder.

```
disp('Speak into microphone now.')
```

```
Speak into microphone now.
```

```
tic
while toc < 10
    acquiredAudio = deviceReader();
    fileWriter(acquiredAudio);
end
disp('Recording complete.')
```

```
Recording complete.
```

Release the audio device and close the output file.

```
release(deviceReader)
release(fileWriter)
```

Reduce Latency Due to Input Device Buffer

Latency due to the input device buffer is the time delay of acquiring one frame of data. In this example, you modify default properties of your `audioDeviceReader` object to reduce latency.

Create an `audioDeviceReader` object with default settings.

```
deviceReader = audioDeviceReader

deviceReader =
  audioDeviceReader with properties:

        Driver: 'DirectSound'
        Device: 'Default'
    NumChannels: 1
    SamplesPerFrame: 1024
        SampleRate: 44100

    Show all properties
```

Calculate the latency due to your device buffer.

```
fprintf('Latency due to device buffer: %f seconds.\n',deviceReader.SamplesPerFrame/deviceReader.SampleRate)

Latency due to device buffer: 0.023220 seconds.
```

Set the `SamplesPerFrame` property of your `audioDeviceReader` object to 64. Calculate the latency.

```
deviceReader.SamplesPerFrame = 64;
fprintf('Latency due to device buffer: %f seconds.\n',deviceReader.SamplesPerFrame/deviceReader.SampleRate)

Latency due to device buffer: 0.001451 seconds.
```

Set the `SampleRate` property of your `audioDeviceReader` System object to 96000. Calculate the latency.

```
deviceReader.SampleRate = 96000;
fprintf('Latency due to device buffer: %f seconds.\n',deviceReader.SamplesPerFrame/deviceReader.SampleRate)

Latency due to device buffer: 0.000667 seconds.
```

Determine and Decrease Overrun

Overrun refers to input signal drops, which occur when the audio stream loop does not keep pace with the device. Determine overrun of an audio stream loop, add an artificial computational load to the audio stream loop, and then modify properties of your `audioDeviceReader` object to decrease overrun. Your results depend on your computer.

Create an `audioDeviceReader` System object with `SamplesPerFrame` set to 256 and `SampleRate` set to 44100. Call `setup` to reduce the computational load of initialization in an audio stream loop.

```
deviceReader = audioDeviceReader( ...
    'SamplesPerFrame',256, ...
    'SampleRate',44100);
setup(deviceReader)
```

Create a `dsp.AudioFileWriter` object. Specify the file name and data type to write.

```
fileWriter = dsp.AudioFileWriter('mySpeech.wav', 'FileFormat', 'WAV');
```

Record 5 seconds of speech. In an audio stream loop, read an audio signal frame from your device, and write the audio signal frame to a specified file.

```
totalOverrun = 0;
disp('Speak into microphone now.')
```

Speak into microphone now.

```
tic
while toc < 5
    [input,numOverrun] = deviceReader();
    totalOverrun = totalOverrun + numOverrun;
    fileWriter(input);
end
fprintf('Recording complete.\n')
```

Recording complete.

```
fprintf('Total number of samples overrun: %d.\n',totalOverrun)
```

Total number of samples overrun: 0.

```
fprintf('Total seconds overrun: %d.\n',double(totalOverrun)/double(deviceReader.SampleRate))
```

Total seconds overrun: 0.

Release your `audioDeviceReader` and `dsp.AudioDeviceWriter` objects and zero your counter variable.

```
release(fileWriter)
release(deviceReader)
totalOverrun = 0;
```

Use `pause` to add an artificial computational load to your audio stream loop. The computational load causes the audio stream loop to go slower than the device, which causes acquired samples to be dropped.

```
disp('Speak into microphone now.')
```

Speak into microphone now.

```
tic
while toc < 5
    [input,numOverrun] = deviceReader();
    totalOverrun = totalOverrun + numOverrun;
    fileWriter(input);
    pause(0.01)
```

```
end
fprintf('Recording complete.\n')

Recording complete.

fprintf('Total number of samples overrun: %d.\n',totalOverrun)

Total number of samples overrun: 97536.

fprintf('Total seconds overrun: %d.\n',double(totalOverrun)/double(deviceReader.SampleRate))

Total seconds overrun: 2.211701e+00.
```

Release your `audioDeviceReader` and `dsp.AudioFileWriter` objects, and set the `SamplePerFrame` property to 512. The device buffer size increases so that the device now takes longer to acquire a frame of data. Set your counter variable to zero.

```
release(fileWriter)
release(deviceReader)
deviceReader.SamplesPerFrame = 512;
totalOverrun = 0;
```

Calculate the total overrun of the audio stream loop using your modified `SamplesPerFrame` property.

```
disp('Speak into microphone now.')

Speak into microphone now.

tic
while toc < 5
    [input,numOverrun] = deviceReader();
    totalOverrun = totalOverrun + numOverrun;
    fileWriter(input);
    pause(0.01)
end
fprintf('Recording complete.\n')

Recording complete.

fprintf('Total number of samples overrun: %d.\n',totalOverrun)

Total number of samples overrun: 0.

fprintf('Total seconds overrun: %f.\n',totalOverrun/deviceReader.SampleRate)

Total seconds overrun: 0.000000.
```

Specify Channel Mapping for `audioDeviceReader`

Specify nondefault channel mapping for an `audioDeviceReader` object. This example is hardware specific. It assumes that your computer has a default audio input device with two available channels.

Create an `audioDeviceReader` object with default settings.

```
deviceReader = audioDeviceReader;
```


The default number of channels is 1. Call your `audioDeviceReader` object like a function with no arguments to read one frame of data from your audio device. Verify that the output data matrix has one column.

```
x = deviceReader();
[frameLength,numChannels] = size(x)

frameLength = 1024
numChannels = 1
```

Use `info` to determine the maximum number of input channels available with your specified `Driver` and `Device` configuration.

```
info(deviceReader)

ans = struct with fields:
    Driver: 'DirectSound'
    DeviceName: 'Primary Sound Capture Driver'
    MaximumInputChannels: 2
```

Set `ChannelMappingSource` to `'Property'`. The `audioDeviceReader` object must be unlocked to change this property.

```
release(deviceReader)
deviceReader.ChannelMappingSource = 'Property'

deviceReader =
    audioDeviceReader with properties:
        Driver: 'DirectSound'
        Device: 'Default'
        SamplesPerFrame: 1024
        SampleRate: 44100

    Show all properties
```

By default, if `ChannelMappingSource` is set to `'Property'`, all available channels are mapped to the output. Call your `audioDeviceReader` object to read one frame of data from your audio device. Verify that the output data matrix has two columns.

```
x = deviceReader();
[frameLength,numChannels] = size(x)

frameLength = 1024
numChannels = 2
```

Use the `ChannelMapping` property to specify an alternative mapping between channels of your device and columns of the output matrix. Indicate the input channel number at an index corresponding to the output column. To change this property, first unlock the `audioDeviceReader` object.

```
release(deviceReader)
deviceReader.ChannelMapping = [2,1];
```

Now when you call your `audioDeviceReader`:

- Input channel 1 of your device maps to the second column of your output matrix.
- Input channel 2 of your device maps to the first column of your output matrix.

Acquire a specific channel from your input device.

```
deviceReader.ChannelMapping = 2;
```

If you call your `audioDeviceReader`, input channel 2 of your device maps to an output vector.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- “System Objects in MATLAB Code Generation” (MATLAB Coder)
- The executable generated from this System object relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGo` function to package the code generated from this object and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

Functions

`asioSettings` | `getAudioDevices` | `audioDeviceWriter` | `audioPlayerRecorder` | `dsp.AudioFileReader`

Blocks

Audio Device Reader

Topics

“Audio I/O: Buffering, Latency, and Throughput”
“Run Audio I/O Features Outside MATLAB and Simulink”
“Real-Time Audio in MATLAB”

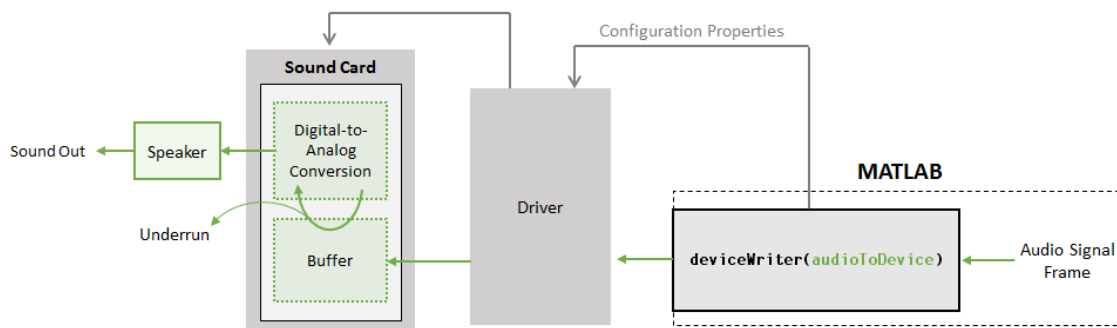
Introduced in R2016a

audioDeviceWriter

Play to sound card

Description

The `audioDeviceWriter` System object writes audio samples to an audio output device. Properties of the audio device writer specify the driver, the device, and device attributes such as sample rate, bit depth, and buffer size.



See “Audio I/O: Buffering, Latency, and Throughput” for a detailed explanation of the audio device writer data flow.

To stream data to an audio device:

- 1 Create the `audioDeviceWriter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
deviceWriter = audioDeviceWriter
deviceWriter = audioDeviceWriter(sampleRateValue)
deviceWriter = audioDeviceWriter( ___, Name, Value)
```

Description

`deviceWriter = audioDeviceWriter` returns a System object, `deviceWriter`, that writes audio samples to an audio output device in real time.

`deviceWriter = audioDeviceWriter(sampleRateValue)` sets the `SampleRate` property to `sampleRateValue`.

`deviceWriter = audioDeviceWriter(____, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `deviceWriter = audioDeviceWriter(48000, 'BitDepth', '8-bit integer')` creates a System object, `deviceWriter`, that operates at a 48 kHz sample rate and an 8-bit integer bit depth.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Driver — Driver used to access audio device (Windows only)

'DirectSound' (default) | 'ASIO' | 'WASAPI'

Driver used to access your audio device, specified as 'DirectSound', 'ASIO', or 'WASAPI'.

- ASIO drivers do not come pre-installed on Windows machines. To use the 'ASIO' driver option, install an ASIO driver outside of MATLAB.

Note If `Driver` is specified as 'ASIO', use `asioSettings` to set the sound card buffer size to the buffer size of your `audioDeviceWriter` System object.

- WASAPI drivers are supported for exclusive-mode only.

ASIO and WASAPI drivers do not provide sample rate conversion. For ASIO and WASAPI drivers, set `SampleRate` to a sample rate supported by your audio device.

This property applies only on Windows machines. Linux machines always use the ALSA driver. Mac machines always use the CoreAudio driver.

To specify nondefault `Driver` values, you must have an Audio Toolbox license. If the toolbox is not installed, specifying nondefault `Driver` values returns an error.

Data Types: `char` | `string`

Device — Device used to play audio samples

default audio device (default) | character vector | string scalar

Device used to play audio samples, specified as a character vector or string scalar. Use `getAudioDevices` to list available devices for the selected driver.

Data Types: `char` | `string`

SampleRate — Sample rate of signal sent to audio device (Hz)

44100 (default) | positive integer

Sample rate of signal sent to audio device, in Hz, specified as a positive integer. The range of `SampleRate` depends on your audio hardware.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

BitDepth — Data type used by the device

'16-bit integer' (default) | '8-bit integer' | '24-bit integer' | '32-bit float'

Data type used by the device, specified as a character vector or string scalar. Before performing digital-to-analog conversion, the input data is cast to a data type specified by `BitDepth`.

To specify a nondefault `BitDepth`, you must have an Audio Toolbox license. If the toolbox is not installed, specifying a nondefault `BitDepth` returns an error.

Data Types: char | string

SupportVariableSizeInput — Support variable frame size

false (default) | true

Option to support variable frame size, specified as `true` or `false`.

- `false` -- If the `audioDeviceWriter` object is locked, the input must have the same frame size at each call. The buffer size of your audio device is the same as the input frame size.
- `true` -- If the `audioDeviceWriter` object is locked, the input frame size can change at each call. The buffer size of your audio device is specified through the `BufferSize` property.

Data Types: char

BufferSize — Buffer size of audio device

4096 (default) | positive integer

Buffer size of audio device, specified as a positive integer.

Note If `Driver` is specified as 'ASIO', open the ASIO UI to set the sound card buffer size to the `BufferSize` value of your `audioDeviceWriter` System object.

Dependencies

To enable this property, set `SupportVariableSizeInput` to `true`.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

ChannelMappingSource — Source of mapping between input matrix and device channels

'Auto' (default) | 'Property'

Source of mapping between columns of input matrix and channels of audio output device, specified as 'Auto' or 'Property'.

- 'Auto' -- Default settings determine the mapping between columns of input matrix and channels of audio output device. For example, suppose that your input is a matrix with four columns, and your audio device has four channels available. Column 1 of your input data writes to channel 1 of your device, column 2 of your input data writes to channel 2 of your device, and so on.
- 'Property' -- The `ChannelMapping` property determines the mapping between columns of input matrix and channels of audio output device.

Data Types: char | string

ChannelMapping — Nondefault mapping between input matrix and device channels

[1:MaximumOutputChannels] (default) | scalar | vector

Nondefault mapping between columns of input matrix and channels of output device, specified as a scalar or vector of valid channel indices. See the “Specify Channel Mapping for `audioDeviceWriter`” on page 3-161 example for more information.

To selectively map between columns of the input matrix and your sound card's output channels, you must have an Audio Toolbox license. If the toolbox is not installed, specifying a nondefault `ChannelMapping` returns an error.

Note To ensure mono output on only one channel of a stereo device, use the default `ChannelMapping` setting and provide a stereo signal where one channel is all zeros.

Example: `outputLeftOnly = [x(:,1) zeros(size(x,1),1)];`

Example: `outputRightOnly = [zeros(size(x,1),1) x(:,1)];`

Dependencies

To enable this property, set `ChannelMappingSource` to 'Property'.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

```
numUnderrun = deviceWriter(audioToDevice)
```

Description

`numUnderrun = deviceWriter(audioToDevice)` writes one frame of audio samples, `audioToDevice`, to the selected audio device and returns the number of audio samples underrun since the last call to `deviceWriter`.

Note: When you call the `audioDeviceWriter` System object, the audio device specified by the `Device` property is locked. An audio device can be locked by only one `audioDeviceWriter` at a time. To release the audio device, call `release` on your `audioDeviceWriter` System object.

Input Arguments

audioToDevice – Audio to device

matrix

Audio signal to write to device, specified as a matrix. The columns of the matrix are treated as independent audio channels.

If `audioToDevice` is of data type 'double' or 'single', the audio device writer clips values outside the range [-1, 1]. For other data types, the allowed input range is [min, max] of the specified data type.

Data Types: `single` | `double` | `int16` | `int32` | `uint8`

Output Arguments

numUnderrun — Number of samples underrun

scalar

Number of samples by which the audio device writer queue was underrun since the last call to `deviceWriter`.

Data Types: `uint32`

Object Functions

To use an object function, specify the `System` object as the first input argument. For example, to release system resources of a `System` object named `obj`, use this syntax:

```
release(obj)
```

Specific to audioDeviceWriter

`getAudioDevices` List available audio devices
`info` Get audio device information

Common to All System Objects

`clone` Create duplicate `System` object
`isLocked` Determine if `System` object is in use
`release` Release resources and allow changes to `System` object property values and input characteristics
`reset` Reset internal states of `System` object
`step` Run `System` object algorithm
`setup` One-time set up tasks for `System` objects

Examples

Read from File and Write to Audio Device

Read an MP3 audio file and play it through your default audio output device.

Create a `dsp.AudioFileReader` object with default settings. Use the `audioinfo` function to return a structure containing information about the audio file.

```
fileReader = dsp.AudioFileReader('speech_dft.mp3');
fileInfo = audioinfo('speech_dft.mp3')

fileInfo = struct with fields:
    Filename: 'B:\matlab\toolbox\dsp\dsp\speech_dft.mp3'
    CompressionMethod: 'MP3'
    NumChannels: 1
    SampleRate: 22050
    TotalSamples: 112893
    Duration: 5.1199
    Title: []
    Comment: []
    Artist: []
```

```
BitRate: 64
```

Create an `audioDeviceWriter` object and specify the sample rate.

```
deviceWriter = audioDeviceWriter('SampleRate', fileInfo.SampleRate);
```

Call `setup` to reduce the computational load of initialization in an audio stream loop.

```
setup(deviceWriter, zeros(fileReader.SamplesPerFrame, ...  
    fileInfo.NumChannels))
```

Use the `info` function to obtain the characteristic information about the device writer.

```
info(deviceWriter)  
  
ans = struct with fields:  
    Driver: 'DirectSound'  
    DeviceName: 'Primary Sound Driver'  
    MaximumOutputChannels: 2
```

In an audio stream loop, read an audio signal frame from the file, and write the frame to your device.

```
while ~isDone(fileReader)  
    audioData = fileReader();  
    deviceWriter(audioData);  
end
```

Close the input file and release the device.

```
release(fileReader)  
release(deviceWriter)
```

Reduce Latency due to Output Device Buffer

Latency due to the output device buffer is the time delay of writing one frame of data. Modify default properties of your `audioDeviceWriter` System object™ to reduce latency due to device buffer size.

Create a `dsp.AudioFileReader` System object to read an audio file with default settings.

```
fileReader = dsp.AudioFileReader('speech_dft.mp3');
```

Create an `audioDeviceWriter` System object and specify the sample rate to match that of the audio file reader.

```
deviceWriter = audioDeviceWriter(...  
    'SampleRate', fileReader.SampleRate);
```

Calculate the latency due to your device buffer, in seconds.

```
bufferLatency = fileReader.SamplesPerFrame/deviceWriter.SampleRate %#ok  
  
bufferLatency = 0.0464
```

Set the `SamplesPerFrame` property of your `dsp.AudioFileReader` System object to 256. Calculate the buffer latency in seconds.


```
fileReader.SamplesPerFrame = 256;
bufferLatency = fileReader.SamplesPerFrame/deviceWriter.SampleRate

bufferLatency = 0.0116
```

Determine and Decrease Underrun

Underrun refers to output signal silence, which occurs when the audio stream loop does not keep pace with the output device. Determine the underrun of an audio stream loop, add artificial computational load to the audio stream loop, and then modify properties of your `audioDeviceWriter` object to decrease underrun. Your results depend on your computer.

Create a `dsp.AudioFileReader` object, and specify the file to read. Use the `audioinfo` function to return a structure containing information about the audio file.

```
fileReader = dsp.AudioFileReader('speech_dft.mp3');
fileInfo = audioinfo('speech_dft.mp3');
```

Create an `audioDeviceWriter` object. Use the `SampleRate` of the file reader as the `SampleRate` of the device writer. Call `setup` to reduce the computational load of initialization in an audio stream loop.

```
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
setup(deviceWriter,zeros(fileReader.SamplesPerFrame,...
    fileInfo.NumChannels))
```

Run your audio stream loop with input from file and output to device. Print the total samples underrun and the underrun in seconds.

```
totalUnderrun = 0;
while ~isDone(fileReader)
    input = fileReader();
    numUnderrun = deviceWriter(input);
    totalUnderrun = totalUnderrun + numUnderrun;
end
fprintf('Total samples underrun: %d.\n',totalUnderrun)

Total samples underrun: 0.

fprintf('Total seconds underrun: %d.\n',double(totalUnderrun)/double(deviceWriter.SampleRate))

Total seconds underrun: 0.
```

Release your `dsp.AudioFileReader` and `audioDeviceWriter` objects and set your counter variable to zero.

```
release(fileReader)
release(deviceWriter)
totalUnderrun = 0;
```

Use `pause` to mimic an algorithm that takes 0.075 seconds to process. The pause causes the audio stream loop to go slower than the device, which results in periods of silence in the output audio signal.

```
while ~isDone(fileReader)
    input = fileReader();
```

```
        numUnderrun = deviceWriter(input);
        totalUnderrun = totalUnderrun + numUnderrun;
        pause(0.075)
end
fprintf('Total samples underrun: %d.\n',totalUnderrun)

Total samples underrun: 68608.

fprintf('Total seconds underrun: %d.\n',double(totalUnderrun)/double(deviceWriter.SampleRate))

Total seconds underrun: 3.111474e+00.
```

Release your `audioDeviceReader` and `dsp.AudioFileWriter` and set the counter variable to zero.

```
release(fileReader)
release(deviceWriter)
totalUnderrun = 0;
```

Set the frame size of your audio stream loop to 2048. Because the `SupportVariableSizeInput` property of your `audioDeviceWriter` System object is set to `false`, the buffer size of your audio device is the same size as the input frame size. Increasing your device buffer size decreases underrun.

```
fileReader = dsp.AudioFileReader('speech_dft.mp3');
fileReader.SamplesPerFrame = 2048;
fileInfo = audioinfo('speech_dft.mp3');

deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
setup(deviceWriter,zeros(fileReader.SamplesPerFrame,fileInfo.NumChannels))
```

Calculate the total underrun.

```
while ~isDone(fileReader)
    input = fileReader();
    numUnderrun = deviceWriter(input);
    totalUnderrun = totalUnderrun + numUnderrun;
    pause(0.075)
end
fprintf('Total samples underrun: %d.\n',totalUnderrun)

Total samples underrun: 0.

fprintf('Total seconds underrun: %d.\n',double(totalUnderrun)/double(deviceWriter.SampleRate))

Total seconds underrun: 0.
```

The increased frame size reduces the total underrun of your audio stream loop. However, increasing the frame size also increases latency. Other approaches to reduce underrun include:

- Increasing the buffer size independent of input frame size. To increase buffer size independent of input frame size, you must first set `SupportVariableSizeInput` to `true`. This approach also increases latency.
- Decreasing the sample rate. Decreasing the sample rate reduces both latency and underrun at the cost of signal resolution.
- Choosing an optimal driver and device for your system.

Specify Channel Mapping for audioDeviceWriter

Specify nondefault channel mapping for an `audioDeviceWriter` object. This example is hardware specific. It assumes that your computer has a default audio output device with two available channels.

Create an `audioDeviceWriter` object with default settings.

```
deviceWriter = audioDeviceWriter;
```

By default, the `audioDeviceWriter` object writes the maximum number of channels available, corresponding to the columns of the input matrix. Use `info` to get the maximum number of channels of your device.

```
info(deviceWriter)

ans = struct with fields:
    Driver: 'DirectSound'
    DeviceName: 'Primary Sound Driver'
    MaximumOutputChannels: 2
```

If `deviceWriter` is called with one column of data, two channels are written to your audio output device. Both channels correspond to the one column of data.

Use the `audioOscillator` object to output a tone to your `audioDeviceWriter` object. Your object, `sineGenerator`, returns a vector when called.

```
sineGenerator = audioOscillator;
```

Write the sine tone to your audio device. If you are using headphones, you can hear the tone from both channels.

```
count = 0;
while count < 500
    sine = sineGenerator();
    deviceWriter(sine);
    count = count + 1;
end
```

If your `audioDeviceWriter` object is called with two columns of data, two channels are written to your audio output device. The first column corresponds to channel 1 of your audio output device, and the second column corresponds to channel 2 of your audio output device.

Write a two-column matrix to your audio output device. Column 1 corresponds to the sine tone, and column 2 corresponds to a static signal. If you are using headphones, you can hear the tone from one speaker and the static from the other speaker.

```
count = 0;
while count < 500
    sine = sineGenerator();
    static = randn(length(sine),1);
    deviceWriter([sine,static]);
    count = count + 1;
end
```

Specify alternative mappings between channels of your device and columns of the output matrix by indicating the output channel number at an index corresponding to the input column. Set `ChannelMappingSource` to `'Property'`. Indicate that the first column of your input data writes to channel 2 of your output device, and that the second column of your input data writes to channel 1 of your output device. To modify the channel mapping, you must first unlock the `audioDeviceReader` object.

```
release(deviceWriter)
deviceWriter.ChannelMappingSource = 'Property';
deviceWriter.ChannelMapping = [2,1];
```

Play your audio signals with reversed mapping. If you are using headphones, notice that the tone and static have switched speakers.

```
count = 0;
while count < 500
    sine = sineGenerator();
    static = randn(length(sine),1);
    deviceWriter([sine,static]);
    count = count + 1;
end
```

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- “System Objects in MATLAB Code Generation” (MATLAB Coder)
- The executable generated from this System object relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGO` function to package the code generated from this object and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

`asiosettings` | `getAudioDevices` | `Audio Device Writer` | `audioDeviceReader` | `audioPlayerRecorder` | `dsp.AudioFileWriter` | `dsp.AudioFileReader`

Topics

“Run Audio I/O Features Outside MATLAB and Simulink”
“Audio I/O: Buffering, Latency, and Throughput”
“Measure Audio Latency”
“Real-Time Audio in MATLAB”

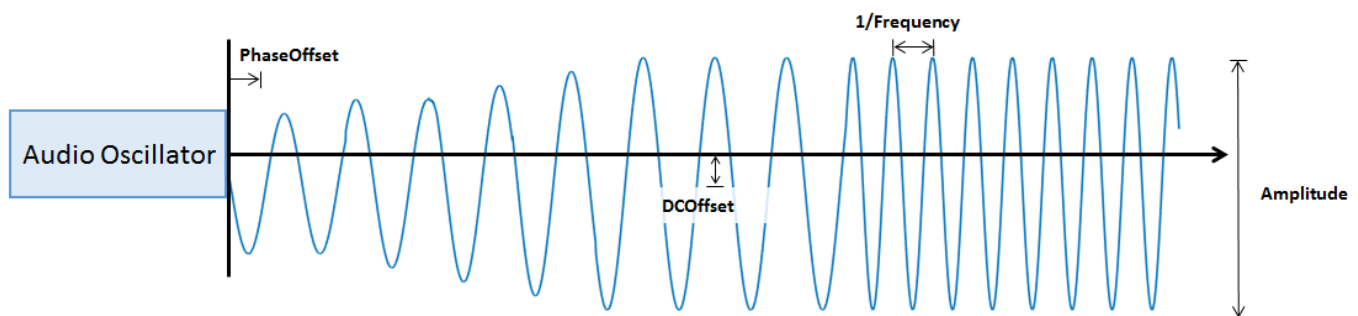
Introduced in R2016a

audioOscillator

Generate sine, square, and sawtooth waveforms

Description

The `audioOscillator` System object generates tunable waveforms. Typical uses include the generation of test signals for test benches, and the generation of control signals for audio effects. Properties of the `audioOscillator` System object specify the type of waveform generated.



To generate tunable waveforms:

- 1 Create the `audioOscillator` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
osc = audioOscillator
osc = audioOscillator(signalTypeValue)
osc = audioOscillator(signalTypeValue, frequencyValue)
osc = audioOscillator( ___, Name, Value)
```

Description

`osc = audioOscillator` creates an audio oscillator System object, `osc`, with default property values.

`osc = audioOscillator(signalTypeValue)` sets the `SignalType` property to `signalTypeValue`.

`osc = audioOscillator(signalTypeValue, frequencyValue)` sets the `Frequency` property to `frequencyValue`.

`osc = audioOscillator(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `osc = audioOscillator('SignalType','sine','Frequency',8000,'DCOffset',1)` creates a System object, `osc`, which generates 8 kHz sinusoids with a DC offset of one.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

SignalType — Type of generated waveform

'sine' (default) | 'square' | 'sawtooth'

Type of waveform generated by your `audioOscillator` object, specified as 'sine', 'square', or 'sawtooth'.

The waveforms are generated using the algorithms specified by the `sin`, `square`, and `sawtooth` functions.

Tunable: No

Data Types: char | string

Frequency — Frequency of generated waveform (Hz)

100 (default) | real scalar | vector of real scalars

Frequency of generated waveform in Hz, specified as a real scalar or vector of real scalars greater than or equal to 0.

- For sine waveforms, specify `Frequency` as a scalar or as a vector of length `NumTones`.
- For square waveforms, specify `Frequency` as a scalar.
- For sawtooth waveforms, specify `Frequency` as a scalar.

Tunable: Yes

Data Types: single | double

Amplitude — Amplitude of generated waveform

1 (default) | real scalar | vector of real scalars

Amplitude of generated waveform, specified as a real scalar or vector of real scalars greater than or equal to 0.

- For sine waveforms, specify `Amplitude` as a vector of length `NumTones`.
- For square waveforms, specify `Amplitude` as a scalar.
- For sawtooth waveforms, specify `Amplitude` as a scalar.

The generated waveform is multiplied by the value specified by `Amplitude` at the output, before `DCOffset` is applied.

Tunable: Yes

Data Types: `single` | `double`

PhaseOffset — Normalized phase offset of generated waveform

0 (default) | real scalar | vector of real scalars

Normalized phase offset of generated waveform, specified as a real scalar or vector of real scalars with values in the range [0, 1]. The range is a normalized 2π -radian interval.

- For sine waveforms, specify `PhaseOffset` as a vector of length `NumTones`.
- For square waveforms, specify `PhaseOffset` as a scalar.
- For sawtooth waveforms, specify `PhaseOffset` as a scalar.

Tunable: No

Data Types: `single` | `double`

DCOffset — Value added to each element of generated waveform

0 (default) | real scalar | vector of real scalars

Value added to each element of generated waveform, specified as a real scalar or vector of real scalars.

- For sine waveforms, specify `DCOffset` as a vector of length `NumTones`.
- For square waveforms, specify `DCOffset` as a scalar.
- For sawtooth waveforms, specify `DCOffset` as a scalar.

Tunable: Yes

Data Types: `single` | `double`

NumTones — Number of pure sine waveform tones

1 (default) | positive integer

Number of pure sine waveform tones summed and then generated by the audio oscillator.

Individual tones are generated based on values specified by `Frequency`, `Amplitude`, `PhaseOffset`, and `DCOffset`.

Tunable: No

Dependencies

To enable this property, set `SignalType` to `'sine'`.

Data Types: `single` | `double`

DutyCycle — Square waveform duty cycle

0.5 (default) | scalar in the range [0, 1]

Square waveform duty cycle, specified as a scalar in the range [0, 1].

Square waveform duty cycle is the percentage of one period in which the waveform is above the median amplitude. A `DutyCycle` of 1 or 0 is equivalent to a DC offset.

Tunable: Yes

Dependencies

To enable this property, set `SignalType` to 'square'.

Data Types: `single` | `double`

Width — Sawtooth width

1 (default) | scalar in the range [0, 1]

Sawtooth width, specified as a scalar in the range [0, 1].

Sawtooth width determines the point in a sawtooth waveform period at which the maximum occurs.

Tunable: Yes

Dependencies

To enable this property, set `SignalType` to 'sawtooth'.

Data Types: `single` | `double`

SamplesPerFrame — Number of samples per frame

512 (default) | positive integer

Number of samples per frame, specified as a positive integer in the range [1, 192000].

This property determines the vector length that your `audioOscillator` object outputs.

Tunable: Yes

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

SampleRate — Sample rate of generated waveform (Hz)

44100 (default) | positive scalar

Sample rate of generated waveform in Hz, specified as a positive scalar greater than twice the value specified by `Frequency`.

Tunable: Yes

Data Types: `single` | `double`

OutputDataType — Data type of generated waveform

'double' (default) | 'single'

Data type of generated waveform, specified as 'double' or 'single'.

Tunable: Yes

Data Types: `char` | `string`

Usage

Syntax

```
waveform = osc()
```

Description

`waveform = osc()` generates a waveform output, `waveform`. The type of waveform is specified by the algorithm and properties of the System object, `osc`.

Output Arguments

waveform — Waveform output from oscillator

column vector

Waveform output from the audio oscillator, returned as a column vector with length specified by the `SamplesPerFrame` property.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to audioOscillator

`createAudioPluginClass` Create audio plugin class that implements functionality of System object
`parameterTuner` Tune object parameters while streaming

MIDI

`configureMIDI` Configure MIDI connections between audio object and MIDI controller
`disconnectMIDI` Disconnect MIDI controls from audio object
`getMIDIConnections` Get MIDI connections of audio object

Common to All System Objects

`clone` Create duplicate System object
`isLocked` Determine if System object is in use
`release` Release resources and allow changes to System object property values and input characteristics
`reset` Reset internal states of System object
`step` Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the `audioOscillator` System object to user-facing parameters:

Property	Range	Mapping	Units
Frequency	[0.1, 20000]	log	Hz

Property	Range	Mapping	Units
Amplitude	[0, 10]	linear	no units
DCOffset	[-10, 10]	linear	no units
DutyCycle (available when you set SignalType to 'square')	[0, 1]	linear	no units
Width (available when you set SignalType to 'sawtooth')	[0, 1]	linear	no units

Examples

Generate Variable-Frequency Sine Wave

Use the `audioOscillator` to generate a variable-frequency sine wave.

Create an audio oscillator to generate a sine wave. Use the default settings.

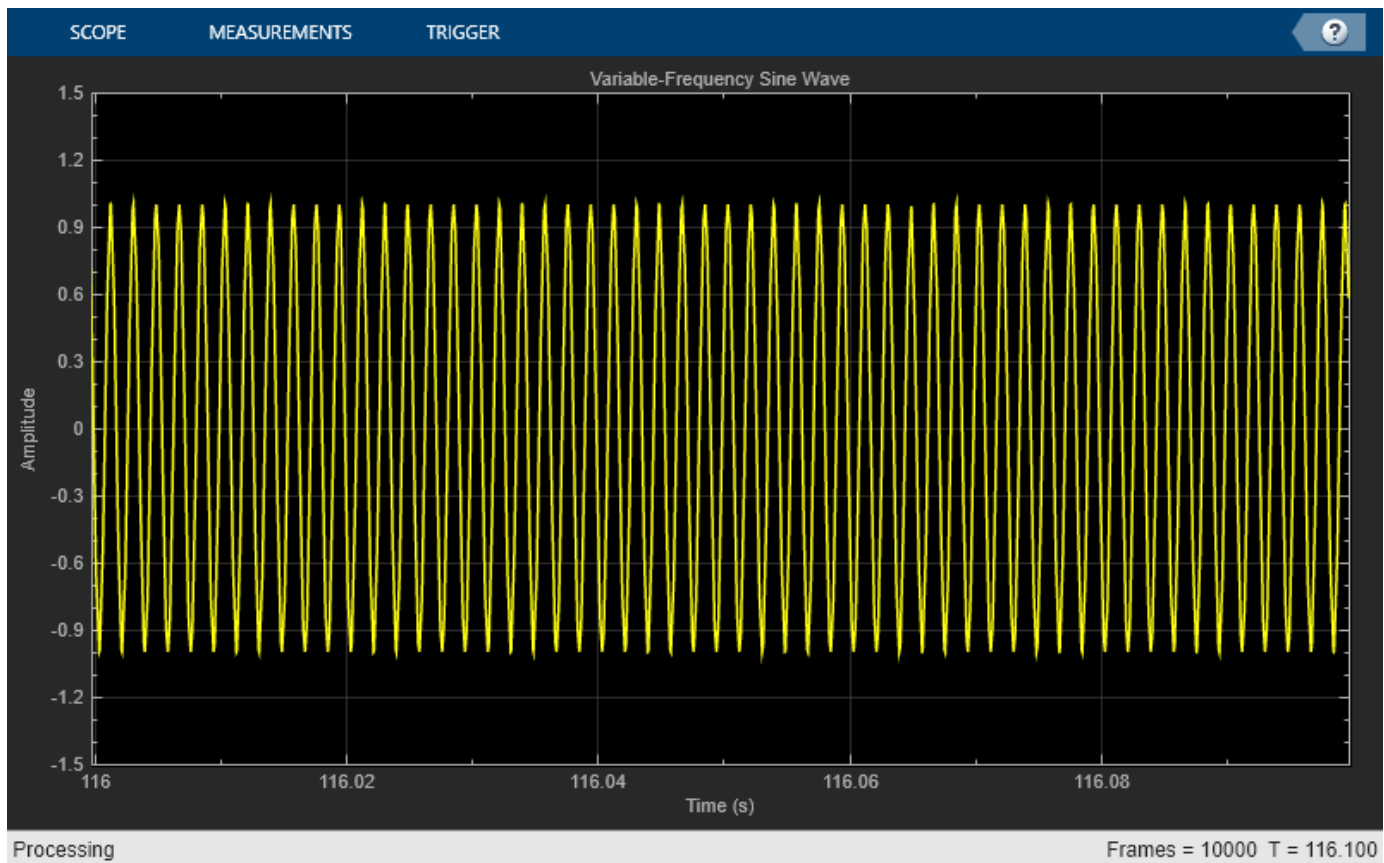
```
osc = audioOscillator;
```

Create a time scope to visualize the variable-frequency sine wave generated by the audio oscillator.

```
scope = timescope( ...
    'SampleRate',osc.SampleRate, ...
    'TimeSpanSource','Property','TimeSpan',0.1, ...
    'YLimits',[-1.5,1.5], ...
    'TimeSpanOvverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'Title','Variable-Frequency Sine Wave');
```

Place the audio oscillator in an audio stream loop. Increase the frequency of your sine wave in 50-Hz increments.

```
counter = 0;
while (counter < 1e4)
    counter = counter + 1;
    sineWave = osc();
    scope(sineWave);
    if mod(counter,1000)==0
        osc.Frequency = osc.Frequency + 50;
    end
end
```



Create a Melody by Tuning Oscillation Frequency

Tune the frequency of an audio oscillator at regularly spaced intervals to create a melody. Play the melody to your audio output device.

Create a structure to hold the frequency values of notes in a melody.

```
notes = struct('C4',261.63,'E4',329.63,'G4sharp',415.30,'A4',440,'B4',493.88, ...
    'C5',523.25,'D5',587.25,'D5sharp',622.25,'E5',659.25,'Silence',0);
```

Create `audioOscillator` and `audioDeviceWriter` objects. Use the default settings.

```
osc = audioOscillator;
aDW = audioDeviceWriter;
```

Create a vector with the initial melody of Fur Elise.

```
melody = [notes.Silence notes.Silence, ...
    notes.E5 notes.D5sharp notes.E5 notes.D5sharp notes.E5 notes.B4 ...
    notes.D5 notes.C5 notes.A4 notes.A4 notes.Silence ...
    notes.C4 notes.E4 notes.A4 notes.B4 notes.B4 notes.Silence ...
    notes.E4 notes.G4sharp notes.B4 notes.C5 notes.C5 notes.Silence];
```

Specify the note duration in seconds. In an audio stream loop, call your audio oscillator and write the sound to your audio device. Update the frequency of the audio oscillator in `noteDuration` time steps to follow the melody. As a best practice, release your objects once complete.

```
noteDuration = 0.3;

i = 1;
tic
while i < numel(melody)
    tone = osc();
    aDW(tone);
    if toc >= noteDuration
        i = i + 1;
        osc.Frequency = melody(i);
        tic
    end
end

release(osc)
release(aDW)
```

Control Cutoff Frequency of Lowpass Filter

Create a low-frequency oscillator (LFO) lowpass filter, using the `audioOscillator` as a control signal.

Create `dsp.AudioFileReader` and `audioDeviceWriter` System objects to read from an audio file and write to your audio device. Create a `biquadFilter` object to apply lowpass filtering to your audio signal.

```
fileReader = dsp.AudioFileReader('Filename','Engine-16-44p1-stereo-20sec.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
lowpassFilter = dsp.BiquadFilter( ...
    'SOSMatrixSource','Input port', ...
    'ScaleValuesInputPort',false);
```

Create an audio oscillator object. Your audio oscillator controls the cutoff frequency of the lowpass filter in an audio stream loop.

```
osc = audioOscillator('SignalType','sawtooth', ...
    'DCOffset',0.05, ...
    'Amplitude',0.03, ...
    'SamplesPerFrame',fileReader.SamplesPerFrame, ...
    'SampleRate',fileReader.SampleRate, ...
    'Frequency',5);
```

In a loop, filter the audio signal through the lowpass filter. Write the output signal to your audio device.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    ctrlSignal = osc();
    [B,A] = designVarSlopeFilter(48,ctrlSignal(end));
    audioOut = lowpassFilter(audioIn,B,A);
```

```
        deviceWriter(audioOut);  
end
```

As a best practice, release objects once complete.

```
release(osc)  
release(fileReader)  
release(deviceWriter)
```

For a more complete implementation of an LFO Filter, see `audiopluginexample.LFOFilter` in the “Audio Plugin Example Gallery”.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

`wavetableSynthesizer` | Audio Oscillator

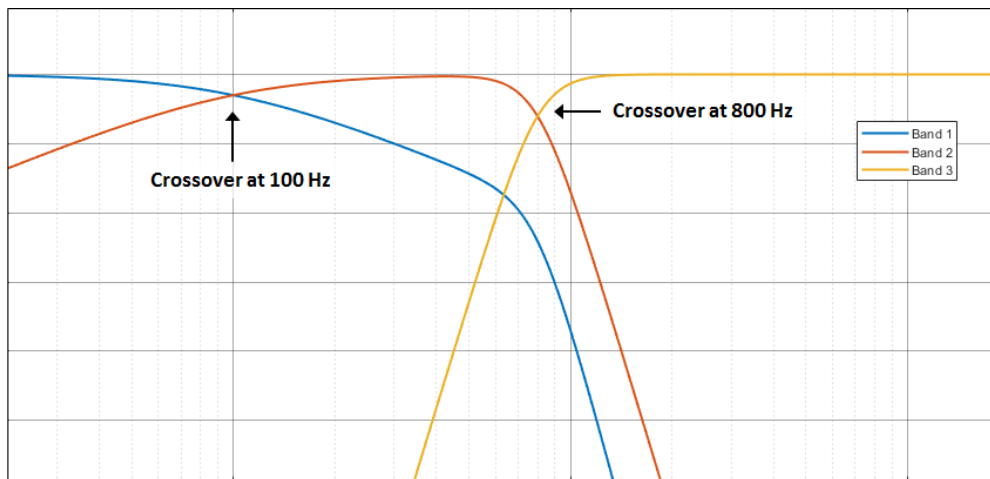
Introduced in R2016a

crossoverFilter

Audio crossover filter

Description

The `crossoverFilter` System object implements an audio crossover filter, which is used to split an audio signal into two or more frequency bands. Crossover filters are multiband filters whose overall magnitude frequency response is flat.



To implement an audio crossover filter:

- 1 Create the `crossoverFilter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
crossFilt = crossoverFilter
crossFilt = crossoverFilter(nCrossovers)
crossFilt = crossoverFilter(nCrossovers,xFrequencies)
crossFilt = crossoverFilter(nCrossovers,xFrequencies,xSlopes)
crossFilt = crossoverFilter(nCrossovers,xFrequencies,xSlopes,Fs)
crossFilt = crossoverFilter( ___,Name,Value)
```

Description

`crossFilt = crossoverFilter` creates a System object, `crossFilt`, that implements an audio crossover filter.

`crossFilt = crossoverFilter(nCrossovers)` sets the `NumCrossovers` property to `nCrossovers`.

`crossFilt = crossoverFilter(nCrossovers,xFrequencies)` sets the `CrossoverFrequencies` property to `xFrequencies`.

`crossFilt = crossoverFilter(nCrossovers,xFrequencies,xSlopes)` sets the `CrossoverSlopes` property to `xSlopes`.

`crossFilt = crossoverFilter(nCrossovers,xFrequencies,xSlopes,Fs)` sets the `SampleRate` property to `Fs`.

`crossFilt = crossoverFilter(___,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `crossFilt = crossoverFilter(2,'CrossoverFrequencies',[100,800],'CrossoverSlopes',[6,48])` creates a System object, `crossFilt`, with two crossovers located at 100 Hz and 800 Hz, and crossover slopes of 6 dB/octave and 48 dB/octave, respectively.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

NumCrossovers — Number of magnitude response band crossings

1 (default) | 2 | 3 | 4

Number of magnitude response band crossings, specified as a scalar integer in the range 1 to 4.

The number of bands output when implementing crossover filtering is one more than the `NumCrossovers` value.

Number of magnitude response band crossings	Number of bands output
1	two-band
2	three-band
3	four-band
4	five-band

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

CrossoverFrequencies — Crossover frequencies (Hz)

100 (default) | `scalar` | `vector`

Crossover frequencies in Hz, specified as a scalar or vector of real values of length `NumCrossovers`.

Crossover frequencies are the intersections of magnitude response bands of the individual two-band crossover filters used in the multiband crossover filter.

Tunable: Yes

Data Types: `single` | `double`

CrossoverSlopes — Crossover slopes (dB/octave)

12 (default) | `scalar` | `vector`

Crossover slopes in dB/octave, specified as a scalar or vector of real values in the range [6:6:48]. If a specified crossover slope is not inside the range, the slope is rounded to the nearest allowed value.

- If `CrossoverSlopes` is a scalar, all two-band component crossover slopes take that value.
- If `CrossoverSlopes` is a vector of length `NumCrossovers`, the respective two-band component crossover slopes take those values.

Crossover slopes are the slopes of individual bands at the associated crossover frequency, as specified in the two-band component crossover.

Tunable: Yes

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
[band1,...,bandN] = crossFilt(audioIn)
```

Description

`[band1,...,bandN] = crossFilt(audioIn)` applies a crossover filter on the input, `audioIn`, and returns the filtered output bands, `[band1,...,bandN]`, where `N = NumCrossovers + 1`.

Input Arguments

audioIn — Audio input to crossover filter

`matrix`

Audio input to the crossover filter, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

[band1, . . . , bandN] — Audio bands output from crossover filter

set of matrices

Audio bands output from the crossover filter, returned as a set of N bands. The NumCrossovers property determines the number of return arguments: $N = \text{NumCrossovers} + 1$. The size of each output argument is the same size as audioIn.

Data Types: single | double

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Specific to crossoverFilter

visualize	Visualize magnitude response of crossover filter
cost	Estimate implementation cost of audio System objects
createAudioPluginClass	Create audio plugin class that implements functionality of System object
parameterTuner	Tune object parameters while streaming

MIDI

configureMIDI	Configure MIDI connections between audio object and MIDI controller
disconnectMIDI	Disconnect MIDI controls from audio object
getMIDIConnections	Get MIDI connections of audio object

Common to All System Objects

clone	Create duplicate System object
isLocked	Determine if System object is in use
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
step	Run System object algorithm

The createAudioPluginClass and configureMIDI functions map tunable properties of the crossoverFilter System object to user-facing parameters:

Property	Range	Mapping	Unit
CrossoverFrequencies	[20, 20000]	linear	Hz
CrossoverSlopes	[6, 48]	linear	dB/octave

Examples

Pass Noise Signal Through Crossover Filter

Use the crossoverFilter object to split Gaussian noise into three separate frequency bands.

Create a 5 second noise signal that assumes a 24 kHz sample rate.

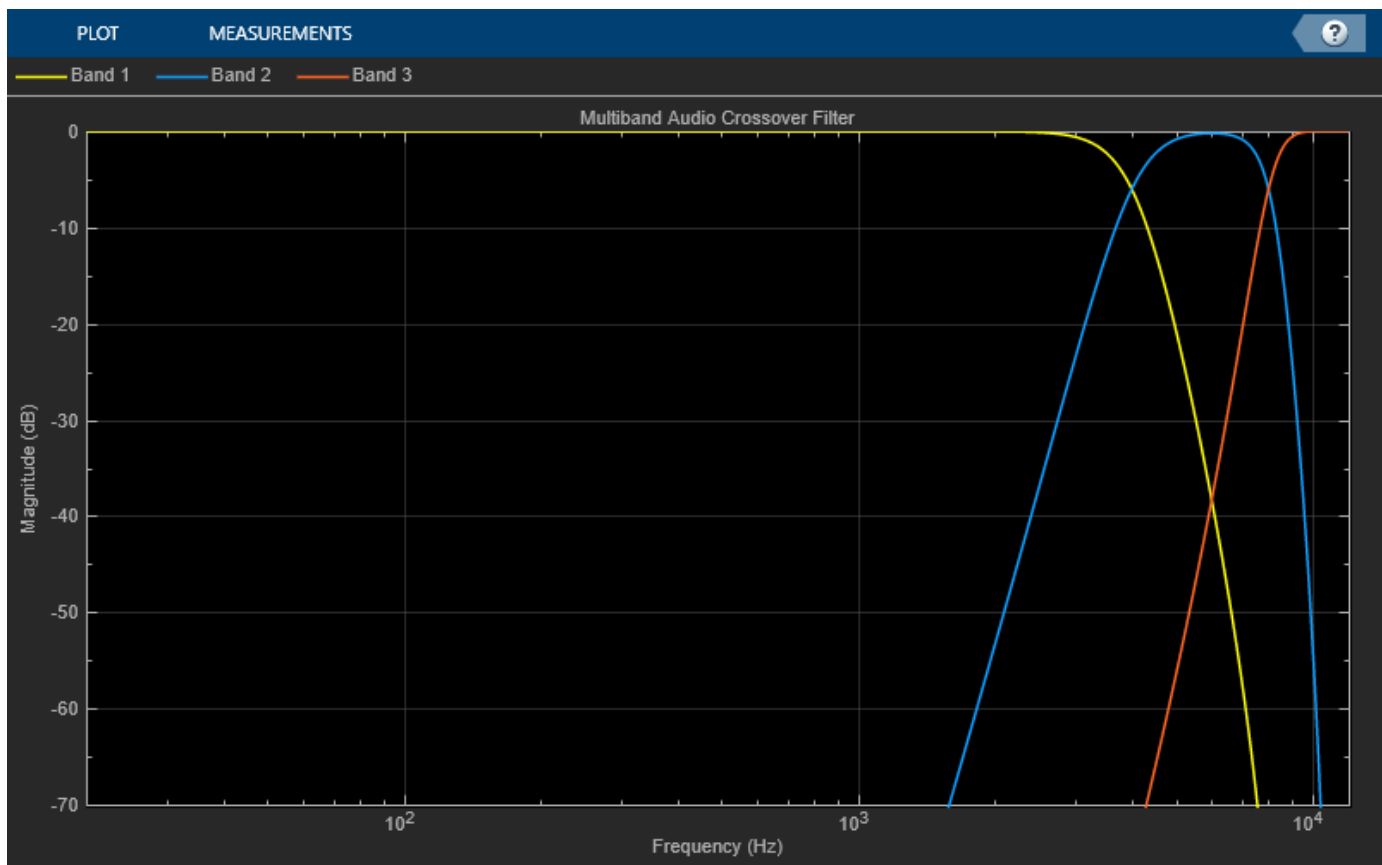
```
fs = 24e3;
noise = randn(fs*5,1);
```

Create a `crossoverFilter` object with 2 crossovers (3 bands), crossover frequencies at 4 kHz and 8 kHz, a slope of 48 dB/octave, and a sample rate of 24 kHz.

```
crossFilt = crossoverFilter( ...
    'NumCrossovers',2, ...
    'CrossoverFrequencies',[4000,8000], ...
    'CrossoverSlopes',48, ...
    'SampleRate',fs);
```

Visualize the magnitude response of your crossover filter object.

```
visualize(crossFilt)
```



Call your crossover filter like a function with the noise signal as the argument.

```
[y1,y2,y3] = crossFilt(noise);
```

Visualize the results using a spectrogram.

```
figure('Position',[100,100,800,700])
```

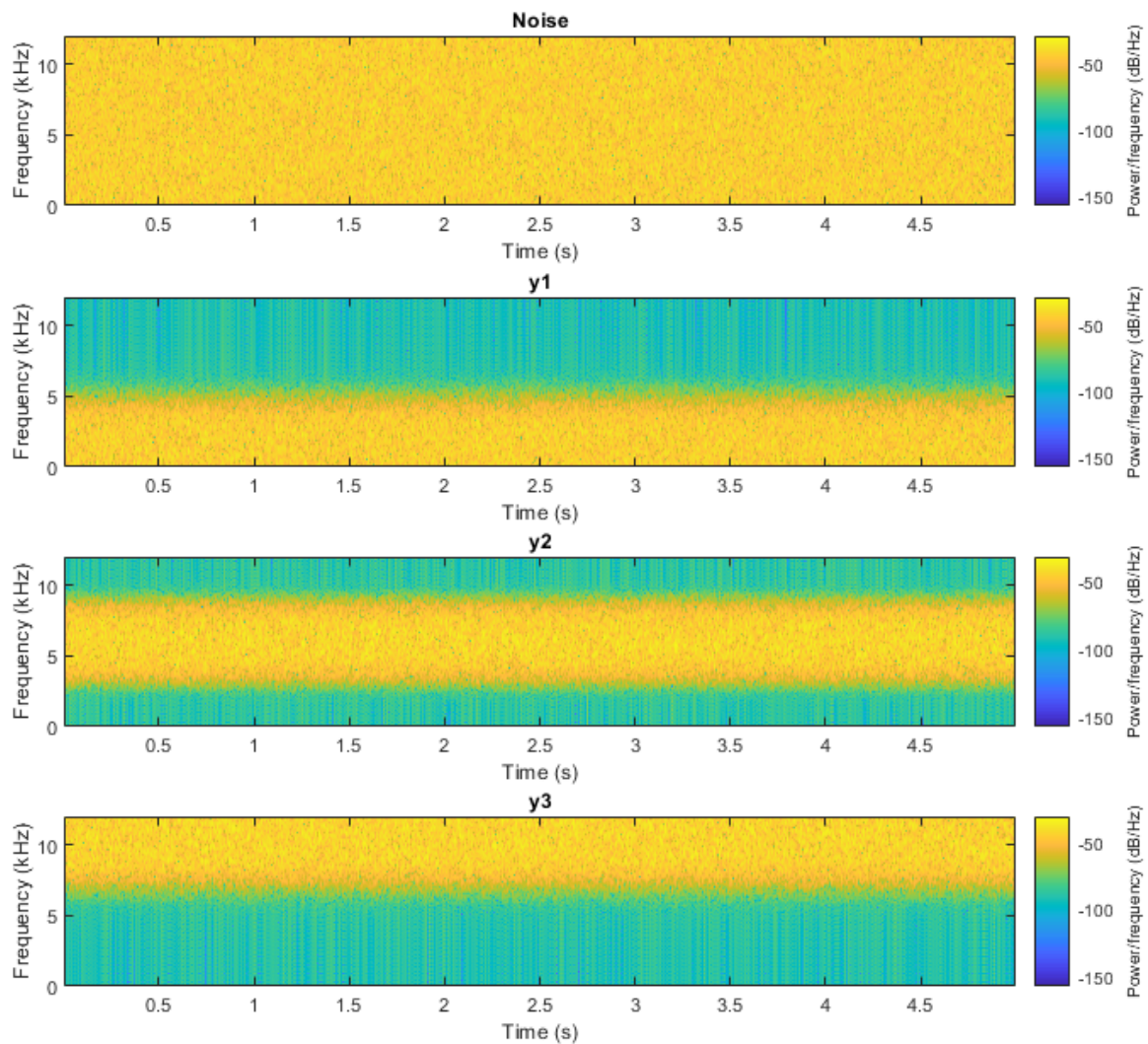
```
subplot(4,1,1)
```

```
spectrogram(noise,120,100,6000,fs,'yaxis')  
title('Noise')
```

```
subplot(4,1,2)  
spectrogram(y1,120,100,6000,fs,'yaxis')  
title('y1')
```

```
subplot(4,1,3)  
spectrogram(y2,120,100,6000,fs,'yaxis')  
title('y2')
```

```
subplot(4,1,4)  
spectrogram(y3,120,100,6000,fs,'yaxis')  
title('y3')
```



Split Audio Signal into Three Bands

Use the `crossoverFilter` object to split an audio signal into three frequency bands.

Create the `dsp.AudioFileReader` and `audioDeviceWriter` objects. Use the sample rate of the reader as the sample rate of the writer.

```
samplesPerFrame = 256;

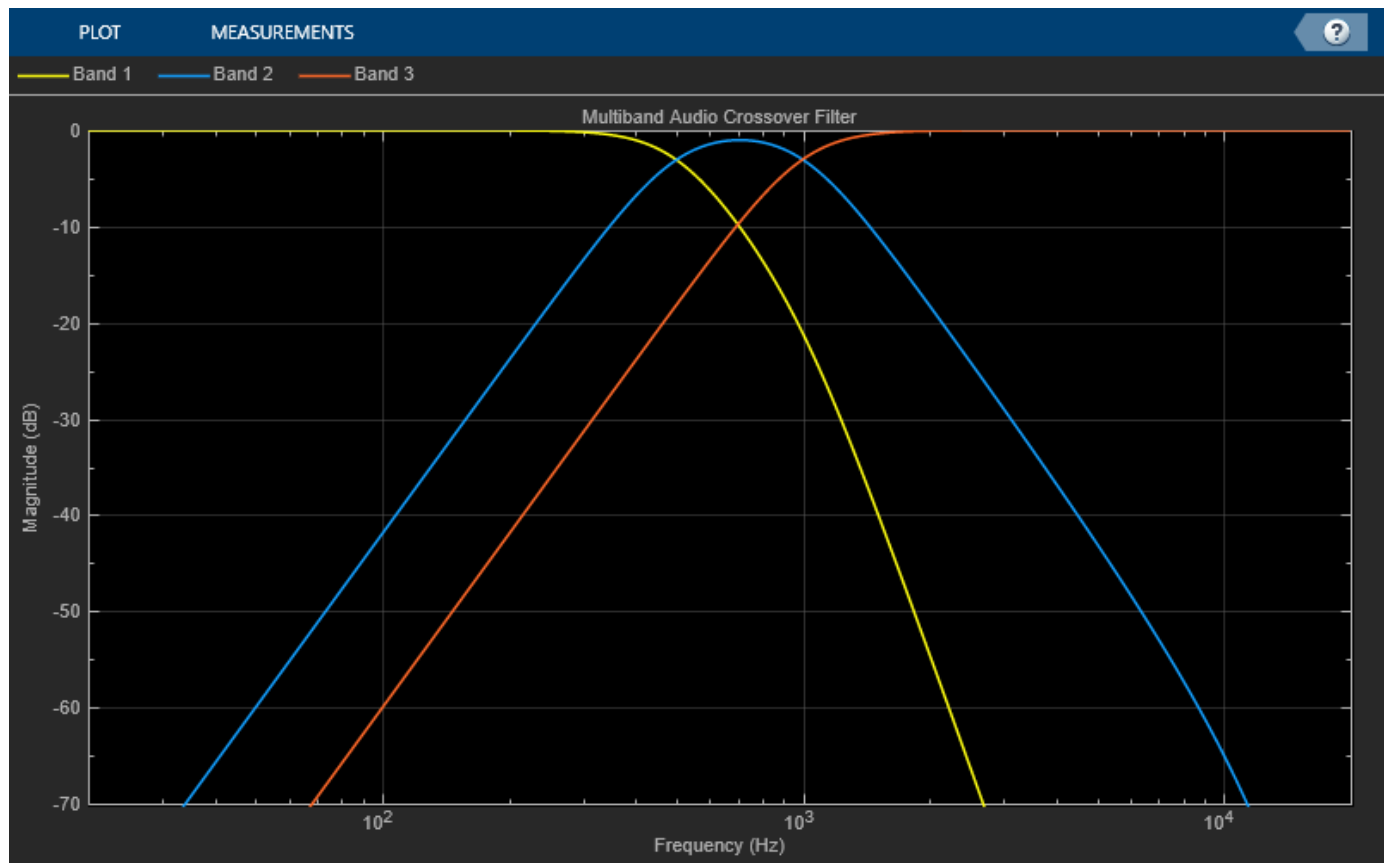
fileReader = dsp.AudioFileReader( ...
    'RockGuitar-16-44p1-stereo-72secs.wav', ...
    'SamplesPerFrame',samplesPerFrame);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);
```

Create a `crossoverFilter` object with 2 crossovers (3 bands), crossover frequencies at 500 Hz and 1 kHz, and a slope of 18 dB/octave. Use the sample rate of the reader as the sample rate of the crossover filter.

```
crossFilt = crossoverFilter( ...
    'NumCrossovers',2, ...
    'CrossoverFrequencies',[500,1000], ...
    'CrossoverSlopes',18, ...
    'SampleRate',fileReader.SampleRate);
```

Visualize the bands of the crossover filter.

```
visualize(crossFilt)
```



Get the cost of the crossover filter.

```
cost(crossFilt)

ans = struct with fields:
    NumCoefficients: 48
    NumStates: 18
    MultiplicationsPerInputSample: 48
    AdditionsPerInputSample: 37
```

Create a spectrum analyzer to visualize the effect of the crossover filter.

```
scope = dsp.SpectrumAnalyzer( ...
    'SampleRate',fileReader.SampleRate, ...
    'PlotAsTwoSidedSpectrum',false, ...
    'FrequencyScale','Log', ...
    'FrequencyResolutionMethod','WindowLength', ...
    'WindowLength',samplesPerFrame, ...
    'Title','Crossover Bands and Reconstructed Signal', ...
    'ShowLegend',true, ...
    'ChannelNames',{'Original Signal','Band 1','Band 2','Band 3','Sum'});
```

Play 10 seconds of the audio signal. Visualize the spectrum of the original audio, the crossover bands, and the reconstructed signal (sum of bands).

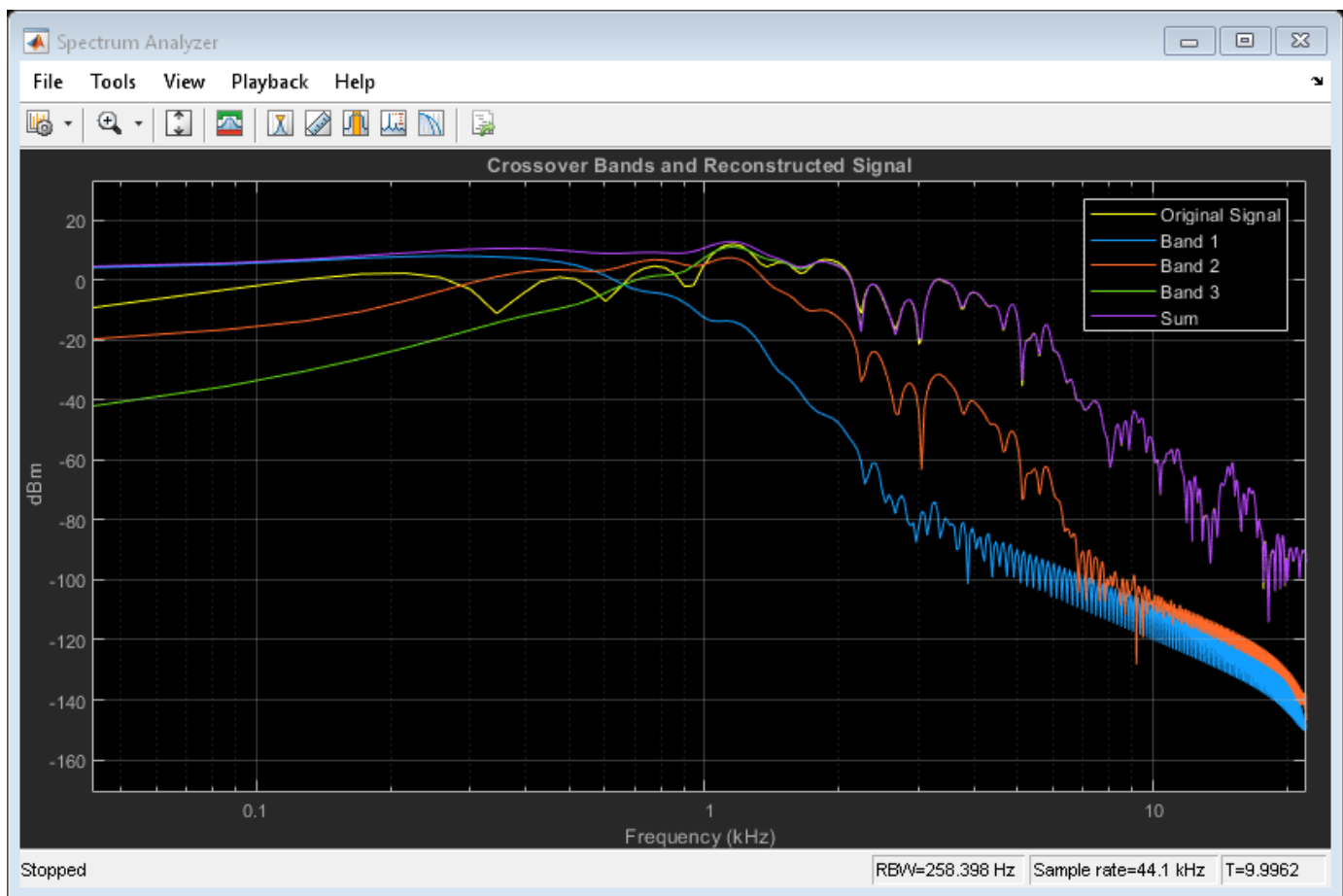
```
setup(scope,ones(samplesPerFrame,5))
count = 0;
```

```

while count < (fileReader.SampleRate/samplesPerFrame)*10
    originalSignal = fileReader();
    [band1,band2,band3] = crossFilt(originalSignal);
    sumOfBands = band1 + band2 + band3;
    scope([originalSignal(:,1), ...
           band1(:,1), ...
           band2(:,1), ...
           band3(:,1), ...
           sumOfBands(:,1)])
    deviceWriter(sumOfBands);
    count = count + 1;
end

release(fileReader)
release(crossFilt)
release(deviceWriter)
release(scope)

```



Apply Split-Band De-Essing

De-essing is the process of diminishing sibilant sounds in an audio signal. Sibilance refers to the *s*, *z*, and *sh* sounds in speech, which can be disproportionately emphasized during recording. *es* sounds

fall under the category of unvoiced speech with all consonants and have a higher frequency than voiced speech. In this example, you apply split-band de-essing to a speech signal by separating the signal into high and low frequencies, applying an expander to diminish the sibilant frequencies, and then remixing the channels.

Create a `dsp.AudioFileReader` object and an `audioDeviceWriter` object to read from a sound file and write to an audio device. Listen to the unprocessed signal. Then release the file reader and device writer.

```
fileReader = dsp.AudioFileReader( ...
    'Sibilance.wav');
deviceWriter = audioDeviceWriter;

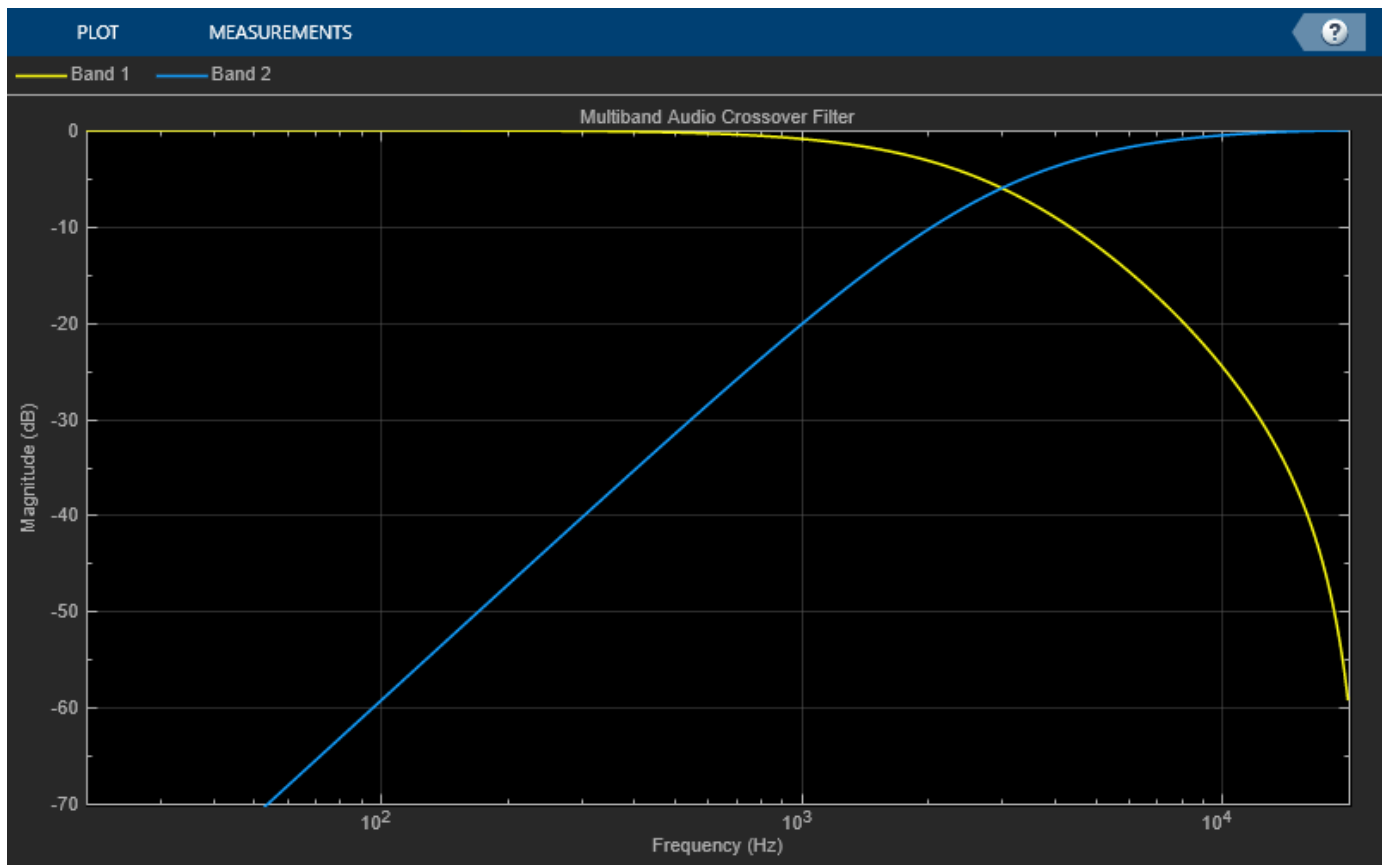
while ~isDone(fileReader)
    audioIn = fileReader();
    deviceWriter(audioIn);
end

release(deviceWriter)
release(fileReader)
```

Create an `expander` System object to de-ess the audio signal. Set the sample rate of the expander to the sample rate of the audio file. Create a two-band crossover filter with a crossover of 3000 Hz. Sibilance is usually found in this range. Set the crossover slope to 12. Plot the frequency response of the crossover filter to confirm your design visually.

```
dRExpander = expander( ...
    'Threshold',-50, ...
    'AttackTime',0.05, ...
    'ReleaseTime',0.05, ...
    'HoldTime',0.005, ...
    'SampleRate',fileReader.SampleRate);

crossFilt = crossoverFilter( ...
    'NumCrossovers',1, ...
    'CrossoverFrequencies',3000, ...
    'CrossoverSlopes',12);
visualize(crossFilt)
```



Create a timescope object to visualize the original and processed audio signals.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'TimeSpanSource','Property','TimeSpan',4, ...
    'BufferLength',fileReader.SampleRate*8, ...
    'YLimits',[-1 1], ...
    'ShowGrid',true, ...
    'ShowLegend',true, ...
    'ChannelNames',{'Original','Processed'});
```

In an audio stream loop:

- 1 Read in a frame of the audio file.
- 2 Split the audio signal into two bands.
- 3 Apply dynamic range expansion to the upper band.
- 4 Remix the channels.
- 5 Write the processed audio signal to your audio device for listening.
- 6 Visualize the processed and unprocessed signals on a time scope.

As a best practice, release your objects once done.

```
while ~isDone(fileReader)
    audioIn = fileReader();
```



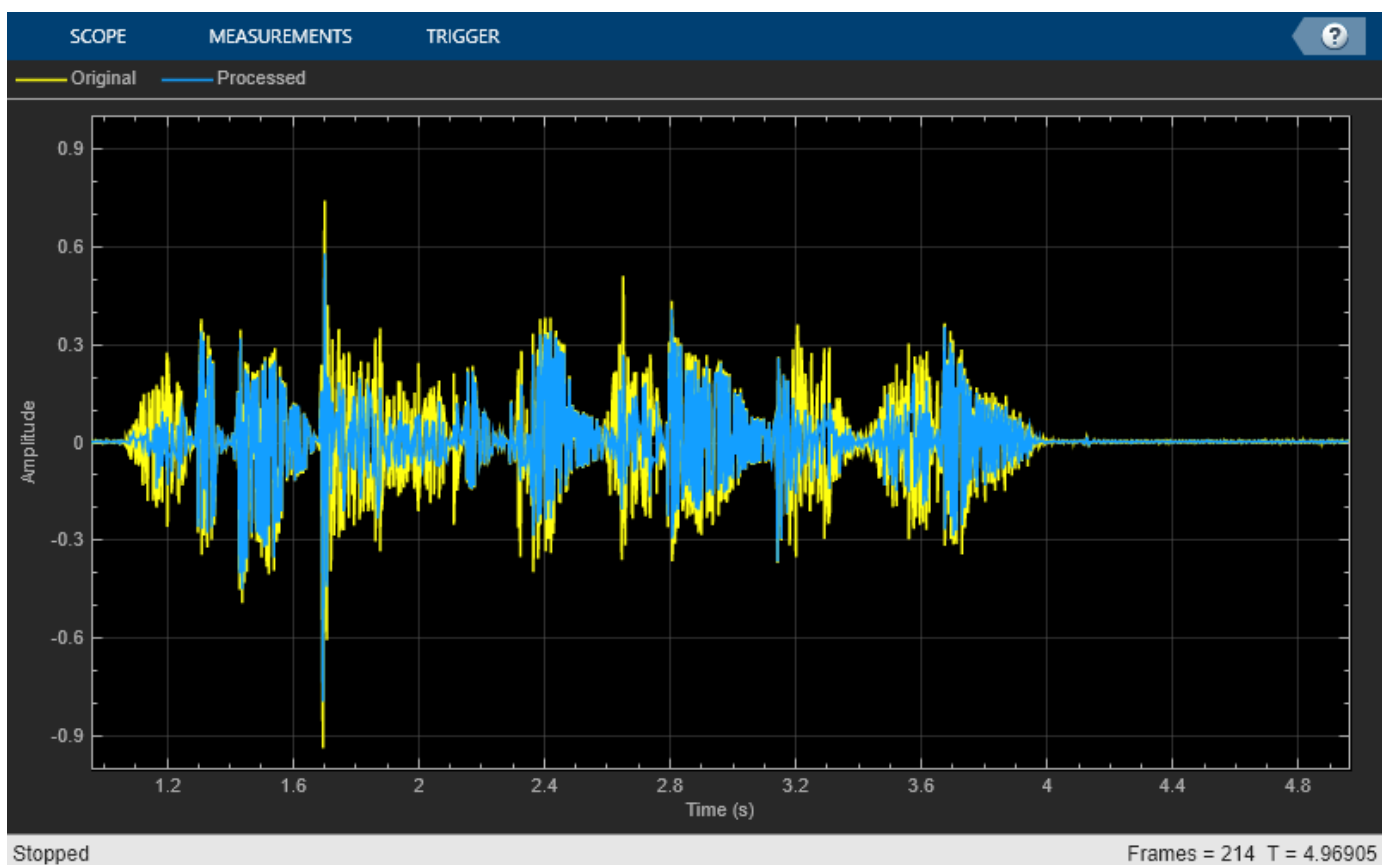
```

[band1,band2] = crossFilt(audioIn);
band2processed = dRExpander(band2);
procAudio = band1 + band2processed;
deviceWriter(procAudio);

scope([audioIn procAudio]);
end

release(deviceWriter)
release(fileReader)
release(scope)

```



```

release(crossFilt)
release(dRExpander)

```

Diminish Plosives from Speech Signal

Plosives are consonant sounds resulting from a sudden release of airflow. They are most pronounced in words beginning with *p*, *d*, and *g* sounds. Plosives can be emphasized by the recording process and

are often displeasurable to hear. In this example, you minimize the plosives of a speech signal by applying highpass filtering and low-band compression.

Create a `dsp.AudioFileReader` object and a `audioDeviceWriter` object to read an audio signal from a file and write an audio signal to a device. Play the unprocessed signal. Then release the file reader and device writer.

```
fileReader = dsp.AudioFileReader('audioPlosives.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

while ~isDone(fileReader)
    audioIn = fileReader();
    deviceWriter(audioIn);
end
release(deviceWriter)
release(fileReader)
```

Design a highpass filter with a steep rolloff of all frequencies below 120 Hz. Use a `dsp.BiquadFilter` object to implement the highpass filter design. Create a crossover filter with one crossover at 250 Hz. The crossover filter enables you to separate the band of interest for processing. Create a dynamic range compressor to compress the dynamic range of plosive sounds. To apply no make-up gain, set the `MakeUpGainMode` to "Property" and use the default 0 dB `MakeUpGain` property value. Create a time scope to visualize the processed and unprocessed audio signal.

```
[B,A] = designVarSlopeFilter(48,120/(fileReader.SampleRate/2),"hi");
biquadFilter = dsp.BiquadFilter( ...
    "SOSMatrixSource","Input port", ...
    "ScaleValuesInputPort",false);

crossFilt = crossoverFilter( ...
    "SampleRate",fileReader.SampleRate, ...
    "NumCrossovers",1, ...
    "CrossoverFrequencies",250, ...
    "CrossoverSlopes",48);

dRCompressor = compressor( ...
    "Threshold",-35, ...
    "Ratio",10, ...
    "KneeWidth",20, ...
    "AttackTime",1e-4, ...
    "ReleaseTime",3e-1, ...
    "MakeUpGainMode","Property", ...
    "SampleRate",fileReader.SampleRate);

scope = timescope( ...
    "SampleRate",fileReader.SampleRate, ...
    "TimeSpanSource","property","TimeSpan",3, ...
    "BufferLength",fileReader.SampleRate*3*2, ...
    "YLimits",[-1 1], ...
    "ShowGrid",true, ...
    "ShowLegend",true, ...
    "ChannelNames",{ 'Original', 'Processed' });
```

In an audio stream loop:

- 1 Read in a frame of the audio file.

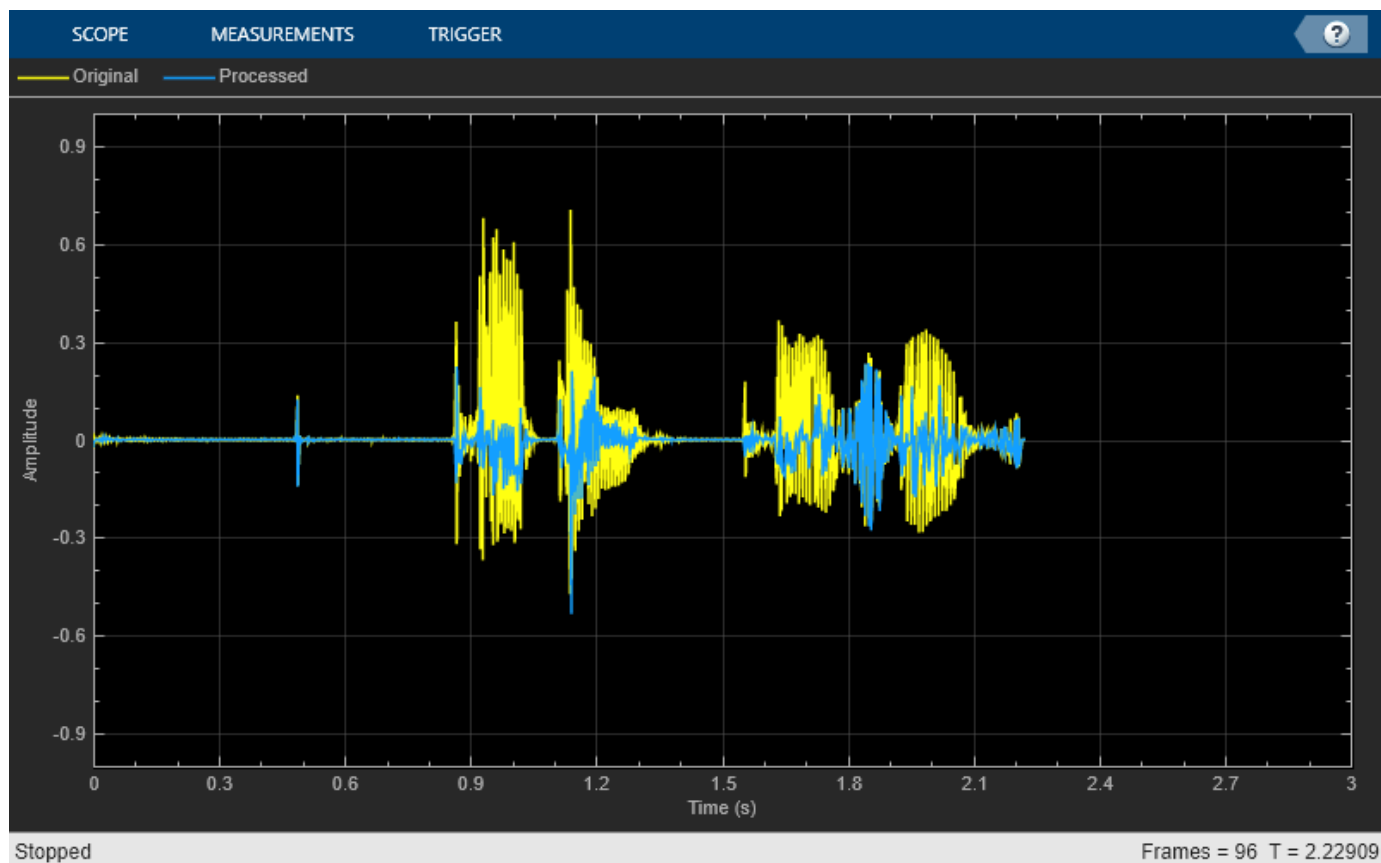
- 2 Apply highpass filtering using your biquad filter.
- 3 Split the audio signal into two bands.
- 4 Apply dynamic range compression to the lower band.
- 5 Remix the channels.
- 6 Write the processed audio signal to your audio device for listening.
- 7 Visualize the processed and unprocessed signals on a time scope.

As a best practice, release your objects once done.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioIn = biquadFilter(audioIn,B,A);
    [band1,band2] = crossFilt(audioIn);
    band1compressed = dRCompressor(band1);
    audioOut = band1compressed + band2;
    deviceWriter(audioOut);
    scope([audioIn audioOut])
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(crossFilt)
release(dRCompressor)
release(scope)
```

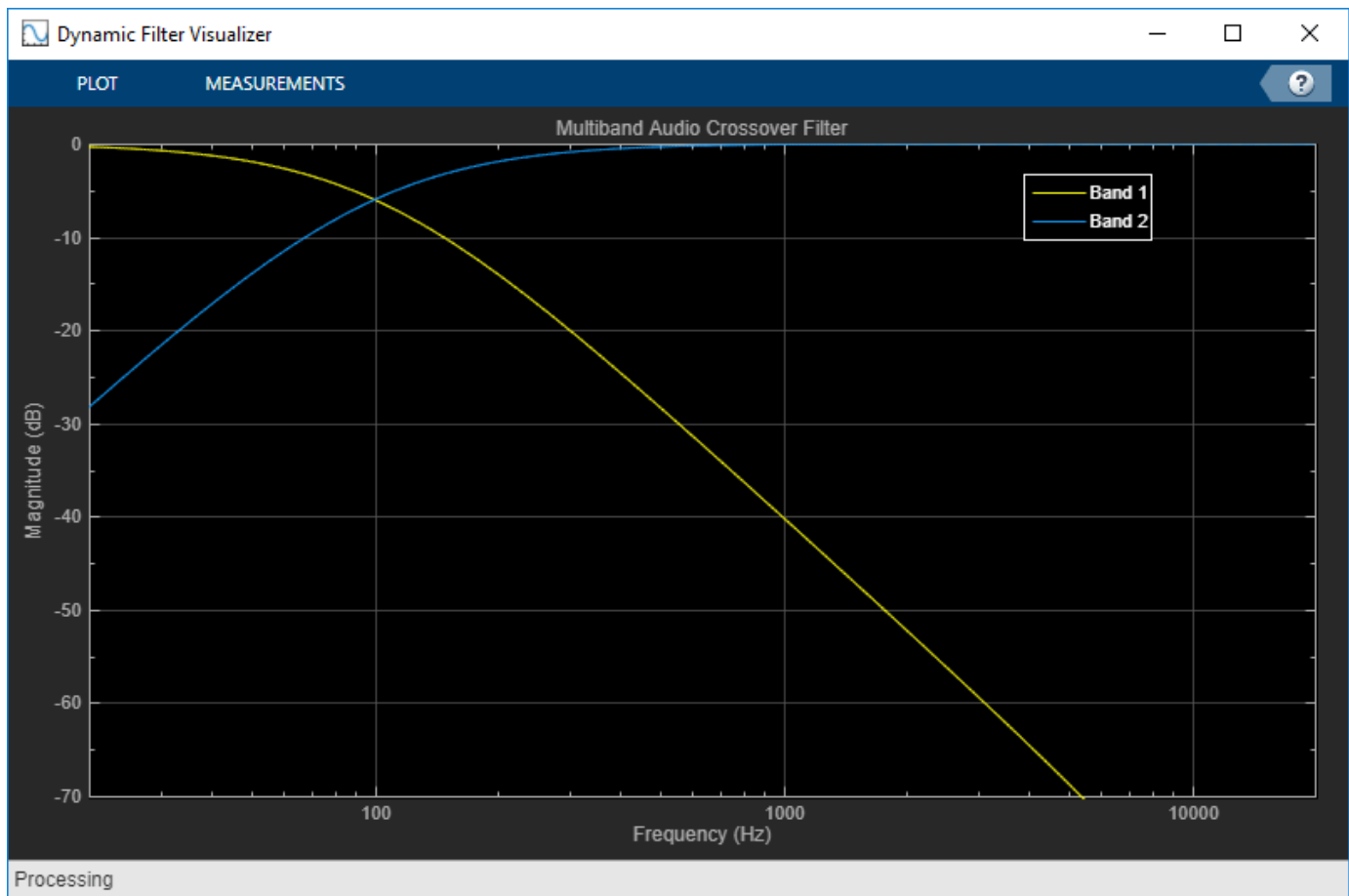


Tune Crossover Filter Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create a `audioDeviceWriter` to write audio to your sound card. Create a `crossoverFilter` to process the audio data. Call `visualize` to plot the frequency responses of the filters.

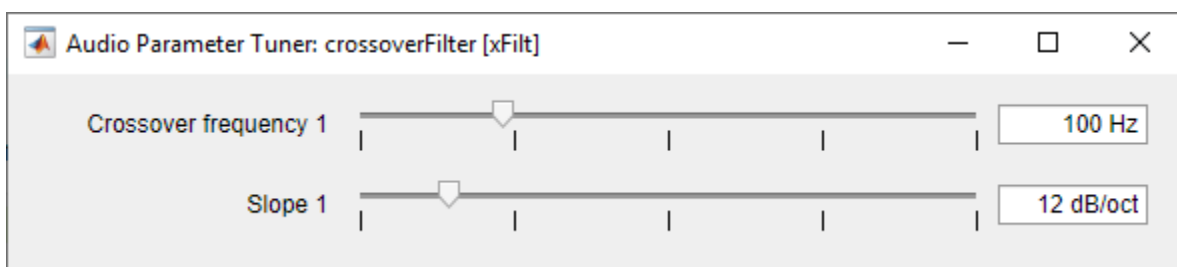
```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

xFilt = crossoverFilter('SampleRate',fileReader.SampleRate);
visualize(xFilt)
```



Call `parameterTuner` to open a UI to tune parameters of the crossover filter while streaming.

```
parameterTuner(xFilt)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply crossover filtering.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the crossover filter and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
```

```

[low,high] = xFilt(audioIn);
deviceWriter([low(:,1),high(:,1)]);
drawnow limitrate % required to update parameter
end

```

As a best practice, release your objects once done.

```

release(deviceWriter)
release(fileReader)
release(xFilt)

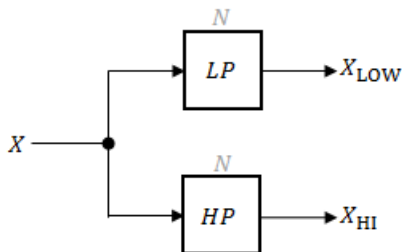
```

Algorithms

The crossover System object is implemented as a binary tree of crossover pairs with additional phase-compensating sections [1]. Odd-order crossovers are implemented with Butterworth filters, while even-order crossovers are implemented with cascaded Butterworth filters (Linkwitz-Riley filters).

Odd-Order Crossover Pair

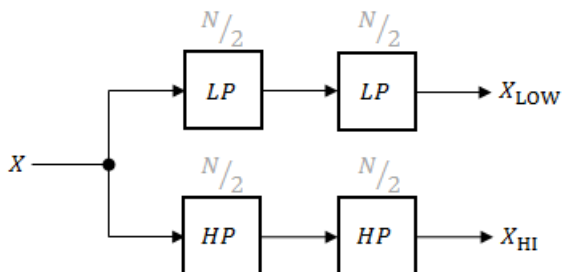
Odd-order two-band (one crossover) filters are implemented as parallel complementary highpass and lowpass filters.



LP and *HP* are Butterworth filters of order N , implemented as direct-form II transposed second-order sections. The shared cutoff frequency used in their design corresponds to the crossover of the resulting bands.

Even-Order Crossover Pair

Even-order two-band (one crossover) filters are implemented as parallel complementary highpass and lowpass filters.

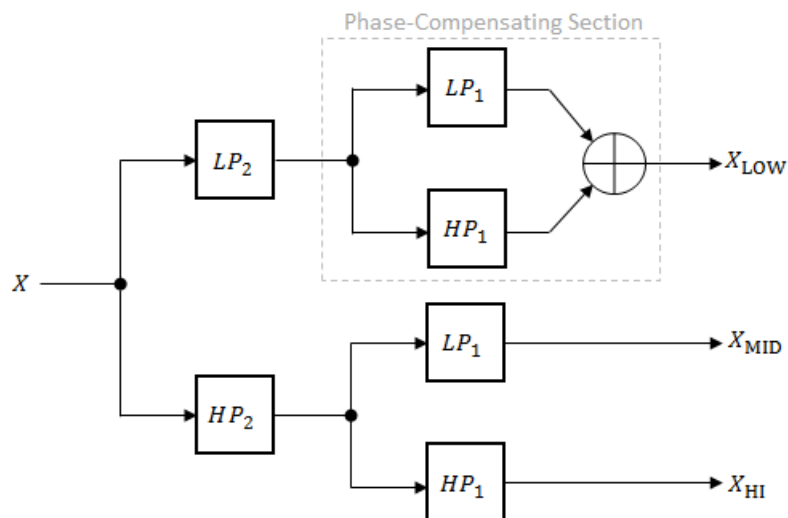


LP and *HP* are Butterworth filters of order $N/2$, where N is the order of the overall filter. The filters are implemented as direct-form II transposed second-order sections.

For overall filters of orders 2 and 6, X_{HI} is multiplied by -1 internally so that the branches of your crossover pair are in-phase.

Even-Order Three-Band Filter

Even-order three-band (two crossovers) filters are implemented as parallel complementary highpass and lowpass filters organized in a tree structure.



The phase-compensating section is equivalent to an allpass filter.

The design of four-band and five-band filters (three and four crossovers) are extensions of the pattern developed for even-order and odd-order crossovers and the tree structure specified for three-band (two crossover) filters.

References

- [1] D'Appolito, Joseph A. "Active Realization of Multiway All-Pass Crossover Systems." *Journal of Audio Engineering Society*. Vol. 35, Issue 4, 1987, pp. 239-245.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

Objects

multibandParametricEQ

Blocks

Crossover Filter

Introduced in R2016a

visualize

Visualize magnitude response of crossover filter

Syntax

```
visualize(crossFilt)
visualize(crossFilt,NFFT)
hvsz = visualize( ___ )
```

Description

`visualize(crossFilt)` plots the magnitude response of the `crossoverFilter`. The plot is updated automatically when properties of the object change.

`visualize(crossFilt,NFFT)` specifies an N-point FFT used to calculate the magnitude response.

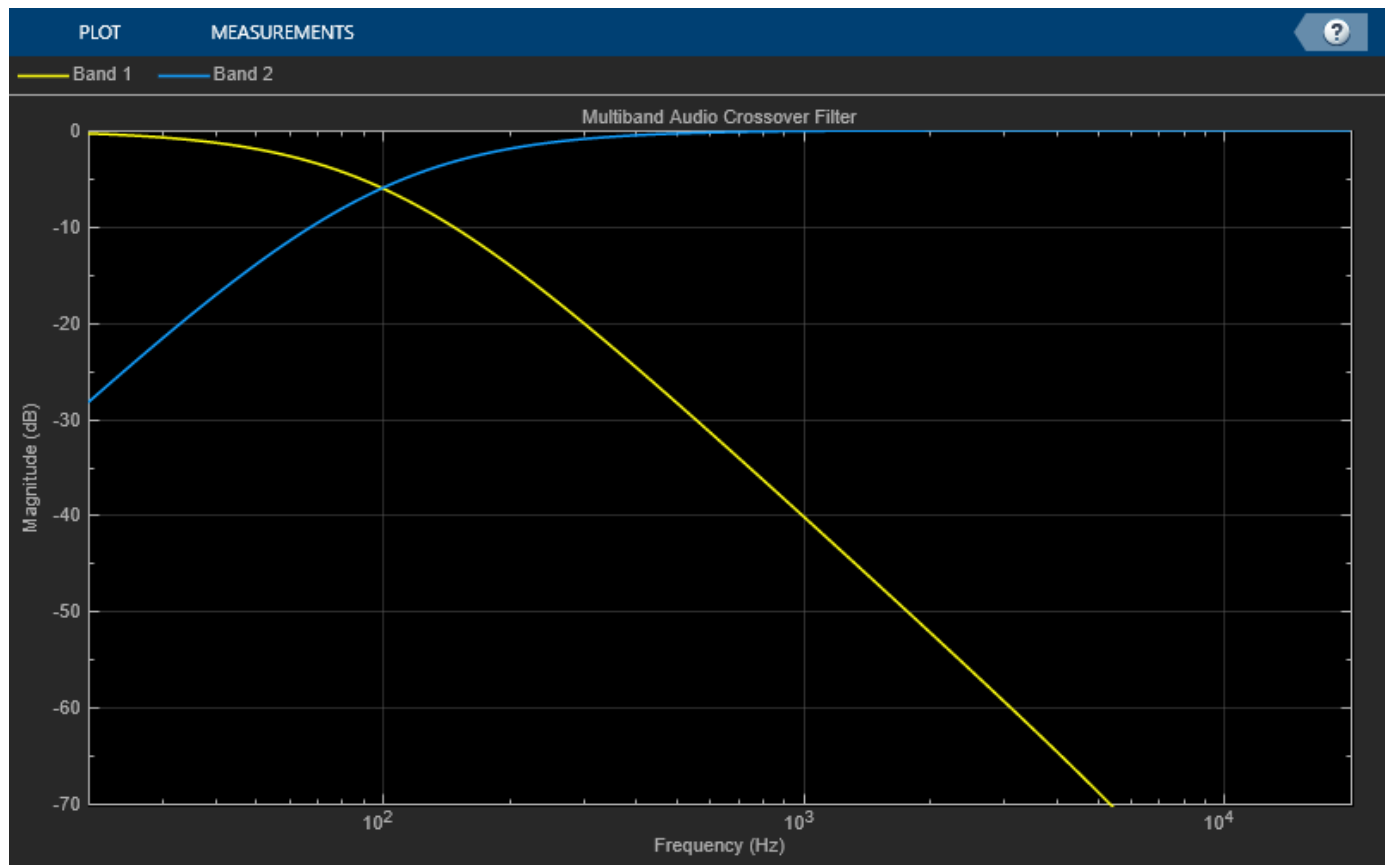
`hvsz = visualize(___)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when called with any of the previous syntaxes.

Examples

Visualize Magnitude Response of Crossover Filter

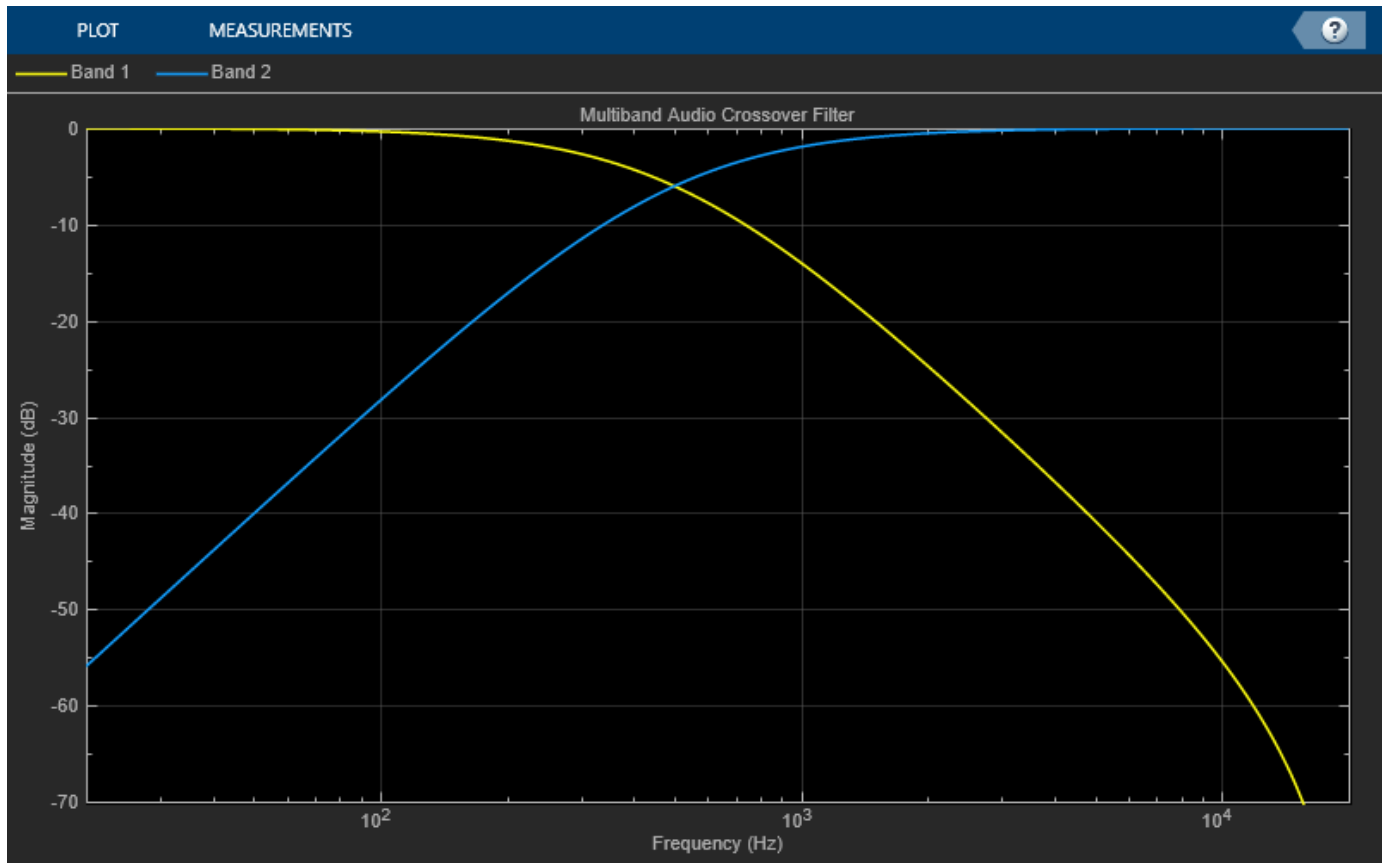
Create a `crossoverFilter` object, and then call `visualize` to plot the magnitude response of the filter.

```
crossFilt = crossoverFilter;
visualize(crossFilt)
```



Modify the crossover frequency and observe that the plot is updated automatically.

```
crossFilt.CrossoverFrequencies = 500;
```



Input Arguments

crossFilt – Crossover filter to visualize

object of `crossoverFilter` System object

Crossover filter whose magnitude response you want to plot.

NFFT – N-point FFT

2048 (default) | positive scalar

Number of bins used to calculate the DFT, specified as a positive scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also

`crossoverFilter`

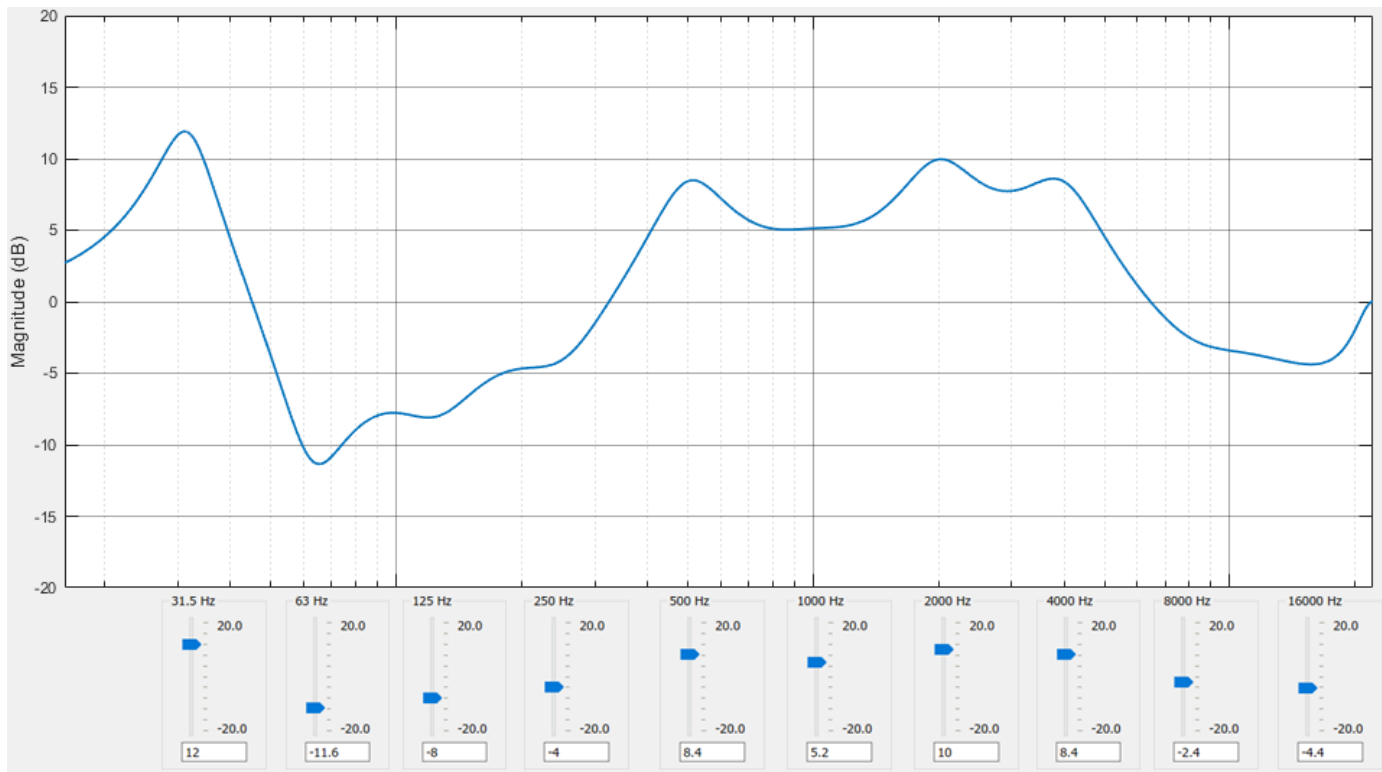
Introduced in R2016a

graphicEQ

Standards-based graphic equalizer

Description

The `graphicEQ` System object implements a graphic equalizer that can tune the gain on individual octave or fractional octave bands. The object filters the data independently across each input channel over time using the filter specifications. Center and edge frequencies of the bands are based on the ANSI S1.11-2004 standard.



To equalize an audio signal:

- 1 Create the `graphicEQ` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
equalizer = graphicEQ
```

```
equalizer = graphicEQ(Name,Value)
```

Description

`equalizer = graphicEQ` creates a graphic equalizer with default values.

`equalizer = graphicEQ(Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `equalizer = graphicEQ('Structure','Parallel','EQOrder','1/3 octave')` creates a System object, `equalizer`, which implements filtering using a parallel structure and one-third octave filter bandwidth.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Gains — Gain of each octave or fractional octave band (dB)

[0 0 0 0 0 0 0 0 0 0] (default) | 10-, 15-, or 30-element row vector

Gain of each octave of fractional octave band in dB, specified as a row vector with a length determined by the Bandwidth property:

- '1 octave' -- Specify gains as a 10-element row vector.
- '2/3 octave' -- Specify gains as a 15-element row vector.
- '1/3 octave' -- Specify gains as a 30-element row vector.

Example: `equalizer = graphicEQ('Bandwidth','2/3 octave','Gains',[5,5,5,5,5,0,0,0,0,0,-5,-5,-5,-5,-5])` creates a two-third octave graphic equalizer with specified gains.

You can tune the gains of your graphic equalizer when the object is locked. However, you cannot tune the length of the gains when the object is locked.

Tunable: Yes

Data Types: `single` | `double`

EQOrder — Order of individual equalizer bands

2 (default) | positive even integer

Order of individual equalizer bands, specified as a positive even integer. All equalizer bands have the same order.

Tunable: No

Data Types: `single` | `double`

Bandwidth — Filter bandwidth (octaves)

'1 octave' (default) | '2/3 octave' | '1/3 octave'

Filter bandwidth in octaves, specified as '1 octave', '2/3 octave', or '1/3 octave'.

The ANSI S1.11-2004 standard defines the center and edge frequencies of your equalizer. The ISO 266:1997(E) standard specifies corresponding preferred frequencies for labeling purposes.

1-Octave Bandwidth

Center frequencies	32 63 126 251 501 1000 1995 3981 7943 15849
Edge frequencies	22 45 89 178 355 708 1413 2818 5623 1122 22387
Preferred frequencies	31.5 63 125 250 500 1000 2000 4000 8000 16000

2/3-Octave Bandwidth

Center frequencies	25 40 63 100 158 251 398 631 1000 1585 2512 3981 6310 10000 15849
Edge frequencies	20 32 50 79 126 200 316 501 794 1259 1995 3162 5012 7943 12589 19953
Preferred frequencies	25 40 63 100 160 250 400 630 1000 1600 2500 4000 6300 10000 16000

1/3-Octave Bandwidth

Center frequencies	25 32 40 50 63 79 100 126 158 200 251 316 398 501 631 794 1000 1259 1585 1995 2512 3162 3981 5012 6310 7943 10000 12589 15849 19953
Edge frequencies	22 28 35 45 56 71 89 112 141 178 224 282 355 447 562 708 891 1122 1413 1778 2239 2818 3548 4467 5623 7079 8913 11220 14125 17783 22387
Preferred frequencies	25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000 6300 8000 10000 12500 16000 20000

Tunable: No

Data Types: char | string

Structure — Type of implementation

'Cascade' (default) | 'Parallel'

Type of implementation, specified as 'Cascade' or 'Parallel'. See “Algorithms” on page 3-202 and “Graphic Equalization” for information about these implementation structures.

Tunable: No

Data Types: char | string

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: single | double

Usage**Syntax**

audioOut = equalizer(audioIn)

Description

audioOut = equalizer(audioIn) performs graphic equalization on the input signal, audioIn, and returns the equalized signal, audioOut. The type of equalization is specified by the algorithm and properties of the graphicEQ System object, equalizer.

Input Arguments**audioIn — Audio input to graphic equalizer**

matrix

Audio input to the graphic equalizer, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: single | double

Output Arguments**audioOut — Audio output from graphic equalizer**

matrix

Audio output from the graphic equalizer, returned as a matrix the same size as audioIn.

Data Types: single | double

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

release(obj)

Specific to graphicEQ

createAudioPluginClass	Create audio plugin class that implements functionality of System object
coeffs	Get filter coefficients
info	Get filter information
visualize	Visualize magnitude response of graphic equalizer
parameterTuner	Tune object parameters while streaming

MIDI

configureMIDI	Configure MIDI connections between audio object and MIDI controller
disconnectMIDI	Disconnect MIDI controls from audio object
getMIDIConnections	Get MIDI connections of audio object

Common to All System Objects

clone	Create duplicate System object
isLocked	Determine if System object is in use
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
step	Run System object algorithm

The createAudioPluginClass and configureMIDI functions map tunable properties of the graphicEQ System object to user-facing parameters:

Property	Range	Mapping	Unit
Gains	[-20, 20]	linear	dB

Examples**Perform Graphic Equalization**

Create objects to read from an audio file and write to your audio device. Use the sample rate of the reader as the sample rate of the writer.

```
frameLength = 512;
reader = dsp.AudioFileReader('RockDrums-48-stereo-11secs.mp3', 'SamplesPerFrame', frameLength);
player = audioDeviceWriter('SampleRate', reader.SampleRate);
```

In an audio stream loop, read audio from a file and play the audio through your audio device.

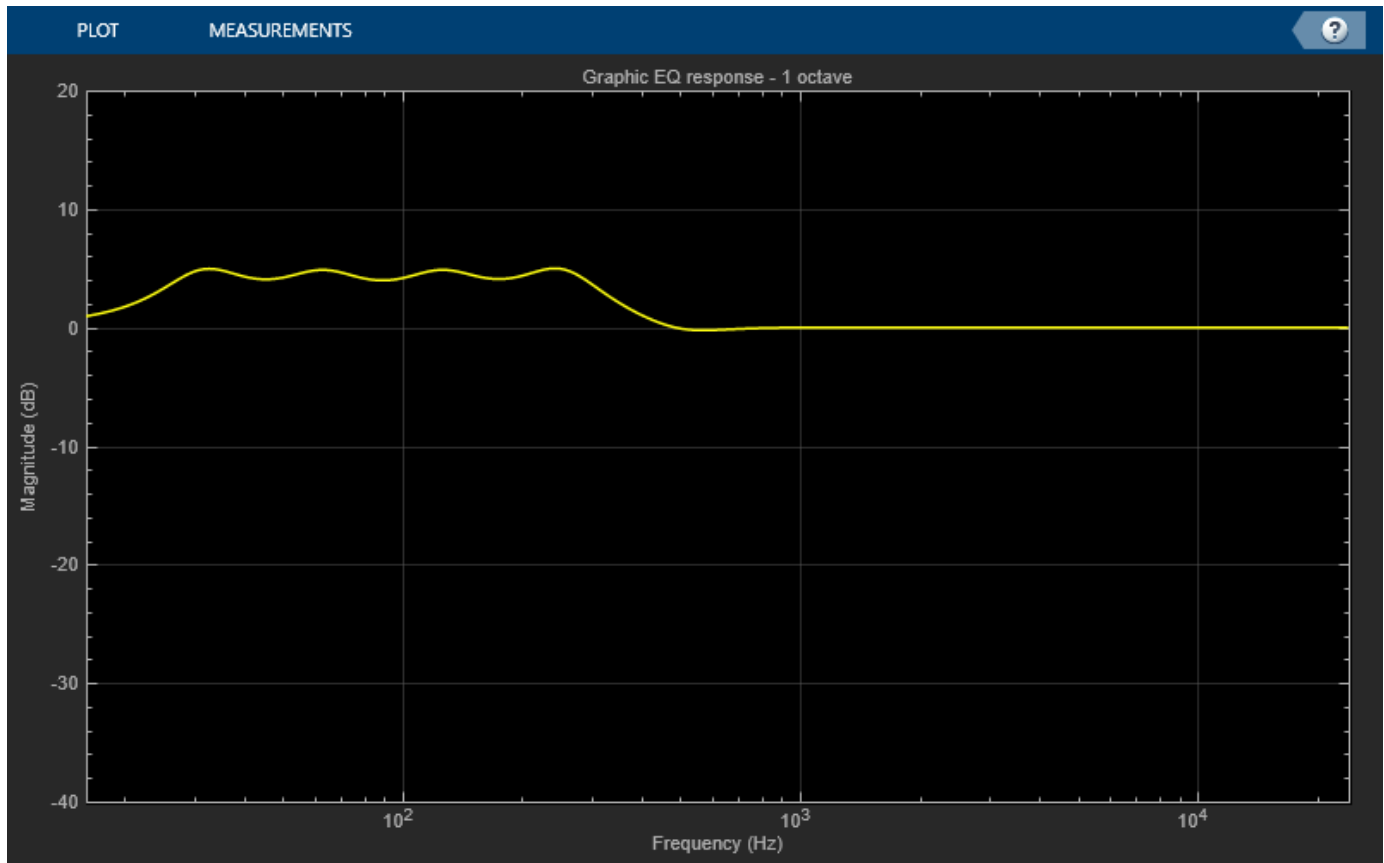
```
while ~isDone(reader)
    x = reader();
    player(x);
end
release(reader)
release(player)
```

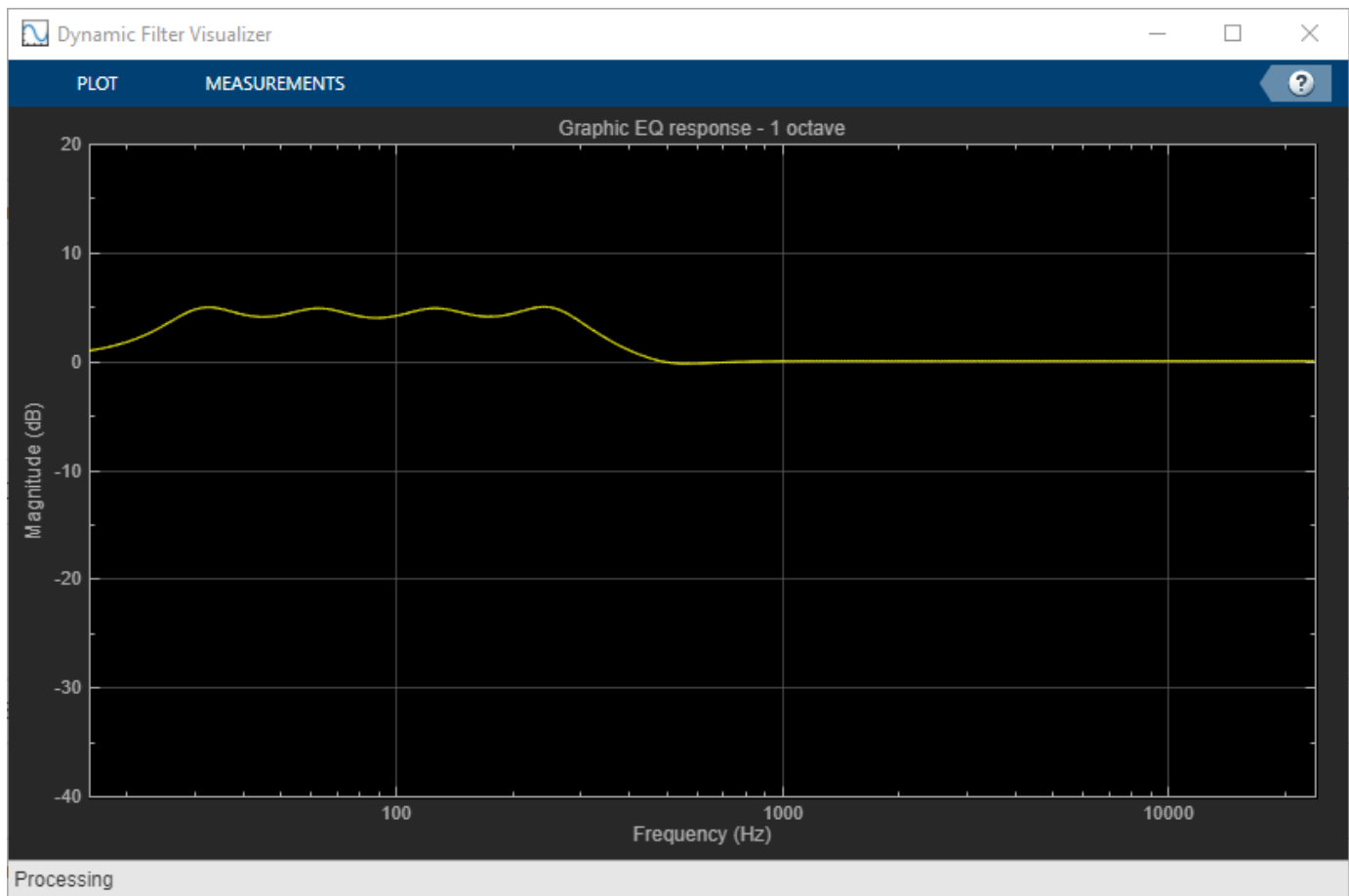
Create a one-octave graphic equalizer implemented with a cascade structure. Use the sample rate of the reader as the sample rate of the equalizer.

```
equalizer = graphicEQ( ...
    'Bandwidth', '1 octave', ...
    'Structure', 'Cascade', ...
    'SampleRate', reader.SampleRate);
```

Specify to increase the gain on low frequencies and then visualize the equalizer.

```
equalizer.Gains = [5,5,5,5,0,0,0,0,0,0];
visualize(equalizer)
```



In an audio stream loop, read audio from a file, apply equalization, and then play the equalized audio through your audio device.

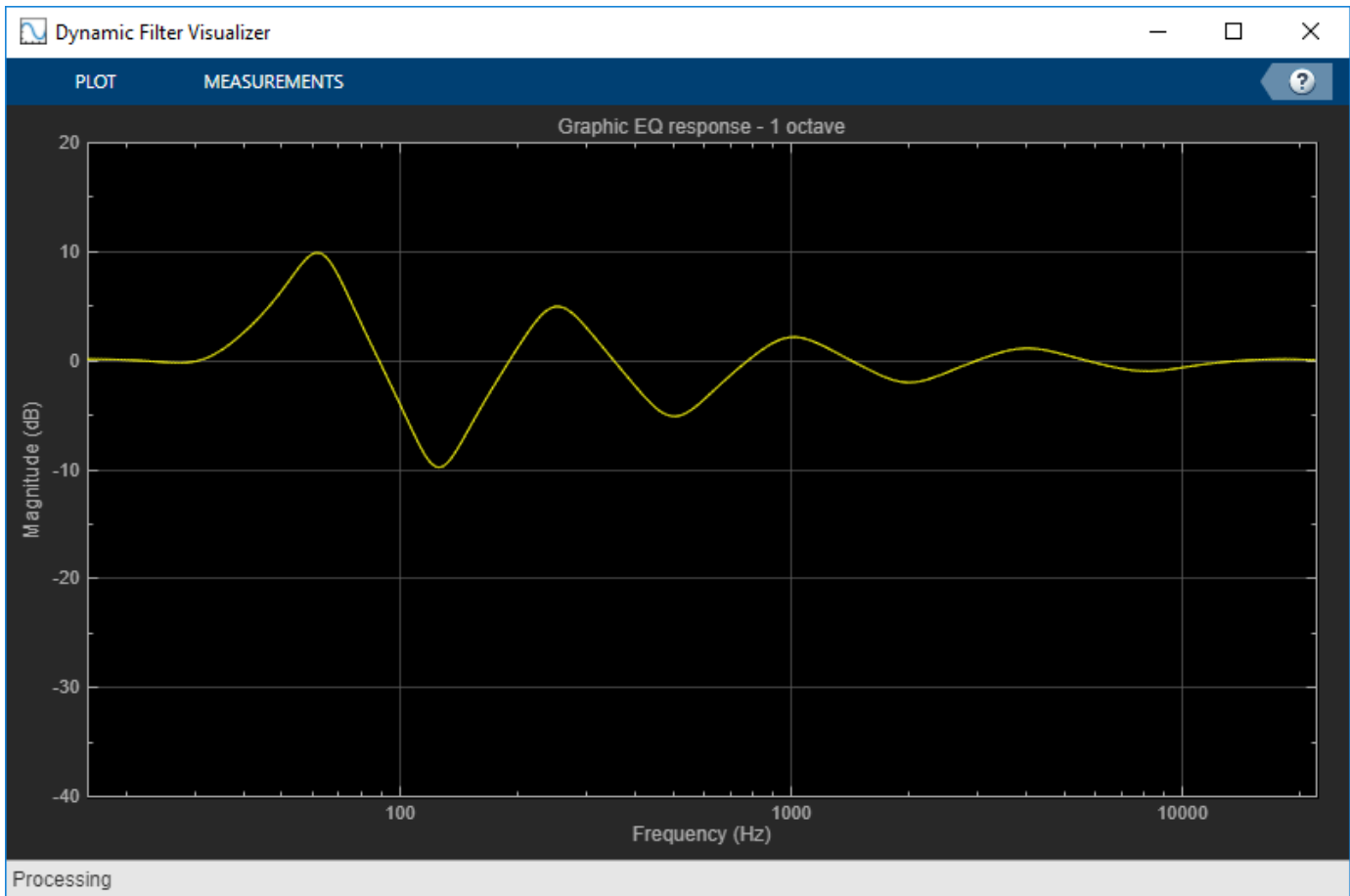
```
while ~isDone(reader)
    x = reader();
    y = equalizer(x);
    player(y);
end
release(reader)
release(player)
```

Tune Graphic EQ Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create a `graphicEQ` to process the audio data. Call `visualize` to plot the frequency response of the graphic equalizer.

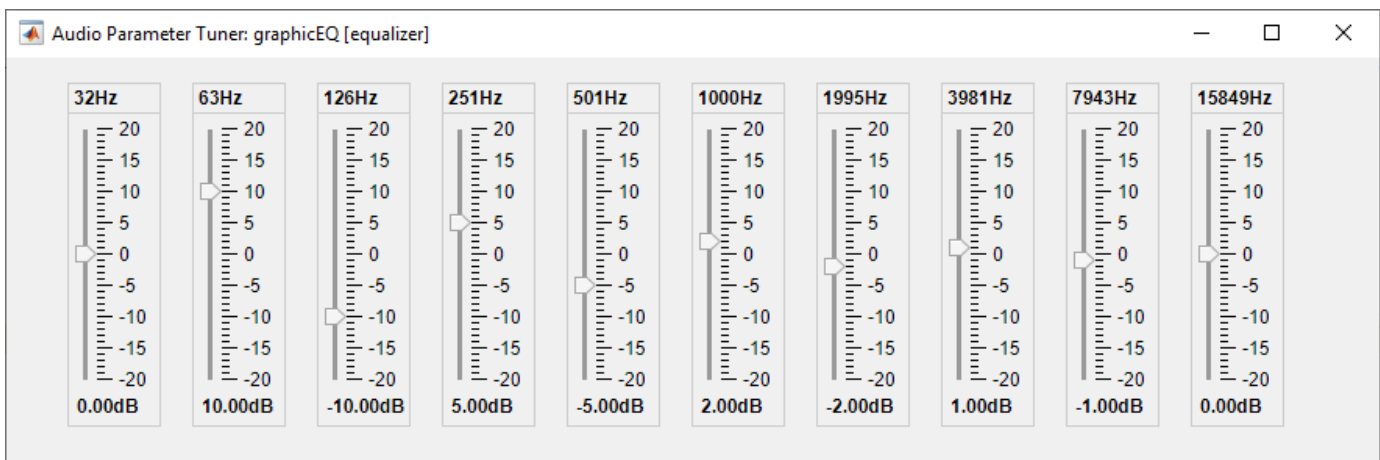
```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3','SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

equalizer = graphicEQ('SampleRate',fileReader.SampleRate,'Gains',[0,10,-10,5,-5,2,-2,1,-1,0]);
visualize(equalizer)
```



Call `parameterTuner` to open a UI to tune parameters of the equalizer while streaming.

```
parameterTuner(equalizer)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.

- 2 Apply equalization.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the equalizer and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = equalizer(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

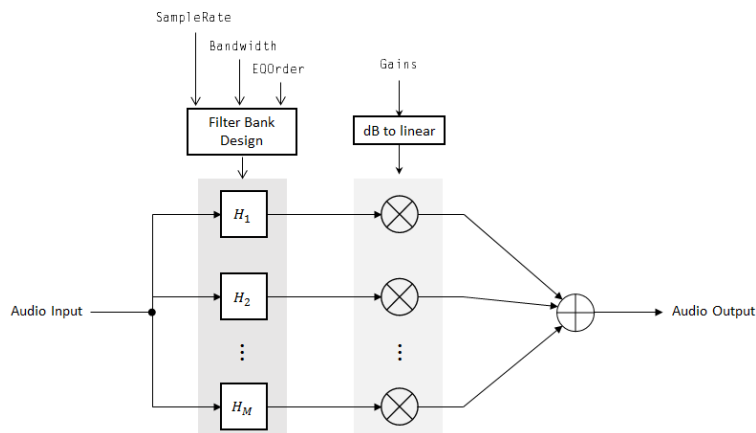
As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(equalizer)
```

Algorithms

The implementation of your graphic equalizer depends on the `Structure` property. See “Graphic Equalization” for a discussion of the pros and cons of the parallel and cascade implementations. Refer to the following sections to understand how these algorithms are implemented in Audio Toolbox.

Parallel Structure



Filter Bank Design

The parallel implementation designs the individual equalizers using the `octaveFilter design` method and spaces them on the spectrum according to the ANSI S1.11-2004 standard.

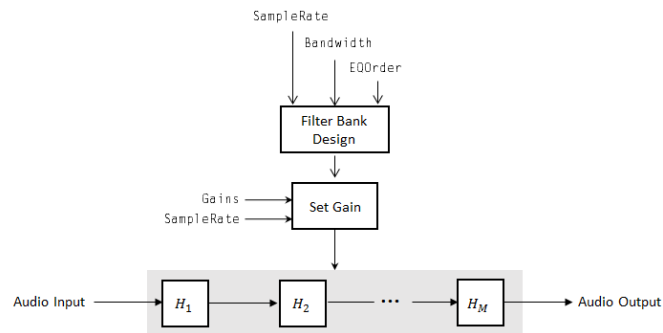
If you set the `SampleRate` property so that the Nyquist frequency ($\text{SampleRate}/2$) is less than the final bandpass edge defined by the ANSI S1.11-2004 standard, then:

- The final bandpass filter is the one whose upper bandpass edge is less than the Nyquist frequency.
- The final filter is implemented as a highpass filter designed by the `designParamEQ` function.

Real-Time Computation

- 1 The input signal is fed into a filterbank of M filters, where M depends on the specified `Bandwidth` and `SampleRate` properties.
- 2 Each branch of the filterbank is multiplied by the linear form of the corresponding element of the `Gains` property.
- 3 The branches are summed and the output signal is returned.

Cascade Structure



Filter Bank Design

The cascade implementation designs the graphic equalizer filter bank using the `multibandParametricEQ` System object.

Gain Setting

If the `EQOrder` property is set to 2, then a gain correction is calculated according to [1]. The gain correction is independent of the requested gains. The gain correction is recomputed during the real-time processing only if the `SampleRate` property is modified.

If the `EQOrder` property is not set to 2, no gain correction is applied, and the requested gains are passed on to the `multibandParametricEQ` object.

Real-Time Computation

The input signal is fed into a cascade of M biquad filters, where M depends on the specified `Bandwidth` and `SampleRate` properties.

References

- [1] Oliver, Richard J., and Jean-Marc Jot. "Efficient Multi-Band Digital Audio Graphic Equalizer with Accurate Frequency Response Control." Presented at the 139th Convention of the AES, New York, October 2015.
- [2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters*. ANSI S1.11-2004. Melville, NY: Acoustical Society of America, 2009.
- [3] International Organization for Standardization. *Acoustics -- Preferred frequencies*. ISO 266:1997(E). Second Edition. 1997.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

Blocks

Graphic EQ | Single-Band Parametric EQ | Multiband Parametric EQ

Functions

multibandParametricEQ | designParamEQ | designShelvingEQ | designVarSlopeFilter

Topics

“Graphic Equalization”

“Equalization”

Introduced in R2017b

info

Get filter information

Syntax

```
infoStruct = info(obj)
```

Description

`infoStruct = info(obj)` returns a structure, `infoStruct`, containing information about `obj`.

Examples

Get Graphic Equalizer Standards-Based Frequencies

Create a `graphicEQ` System object™. Call `info` to return a structure containing standards-based center, edge, and preferred frequencies.

```
equalizer = graphicEQ;
info(equalizer)
```

```
ans = struct with fields:
    CenterFrequencies: [31.6228 63.0957 125.8925 251.1886 501.1872 ... ]
    EdgeFrequencies: [22.3872 44.6684 89.1251 177.8279 354.8134 ... ]
    PreferredFrequencies: [31.5000 63 125 250 500 1000 2000 4000 8000 16000]
```

octaveFilterBank Info

Create a default `octaveFilterBank`. Call `info` to return a struct containing information about the octave filter bank.

```
octFiltBank = octaveFilterBank;
```

```
infoStruct = info(octFiltBank)
```

```
infoStruct = struct with fields:
    CenterFrequencies: [31.6228 63.0957 125.8925 251.1886 501.1872 ... ]
    BandedgeFrequencies: [22.3872 44.6684 89.1251 177.8279 354.8134 ... ]
    GroupDelays: [627.7755 314.6320 157.6887 79.0300 39.6056 ... ]
```

gammatoneFilterBank Info

Create a default `gammatoneFilterBank`. Call `info` to return a struct containing information about the octave filter bank.

```
gammaFiltBank = gammatoneFilterBank;  
  
infoStruct = info(gammaFiltBank)  
  
infoStruct = struct with fields:  
    CenterFrequencies: [50.0000 82.1776 118.0670 158.0966 202.7439 ... ]  
    Bandwidths: [30.6688 34.2080 38.1555 42.5583 47.4691 52.9463 ... ]  
    GroupDelays: [330.1033 295.5650 264.8688 237.2999 212.5619 ... ]
```

Input Arguments

obj — Object to get information from

graphicEQ | gammatoneFilterBank | octaveFilterBank

Object to get information from, specified as an object of gammatoneFilterBank, octaveFilterBank, or graphicEQ.

Output Arguments

infoStruct — Struct containing object information

struct

Struct containing information about the input obj.

See Also

graphicEQ | octaveFilterBank | gammatoneFilterBank

Introduced in R2017b

visualize

Visualize magnitude response of graphic equalizer

Syntax

```
visualize(equalizer)
visualize(equalizer,NFFT)
hvsz = visualize( ___ )
```

Description

`visualize(equalizer)` plots the magnitude response of the `graphicEQ` object, `equalizer`. The plot is updated automatically when properties of the object change.

`visualize(equalizer,NFFT)` specifies an N-point FFT used to calculate the magnitude response.

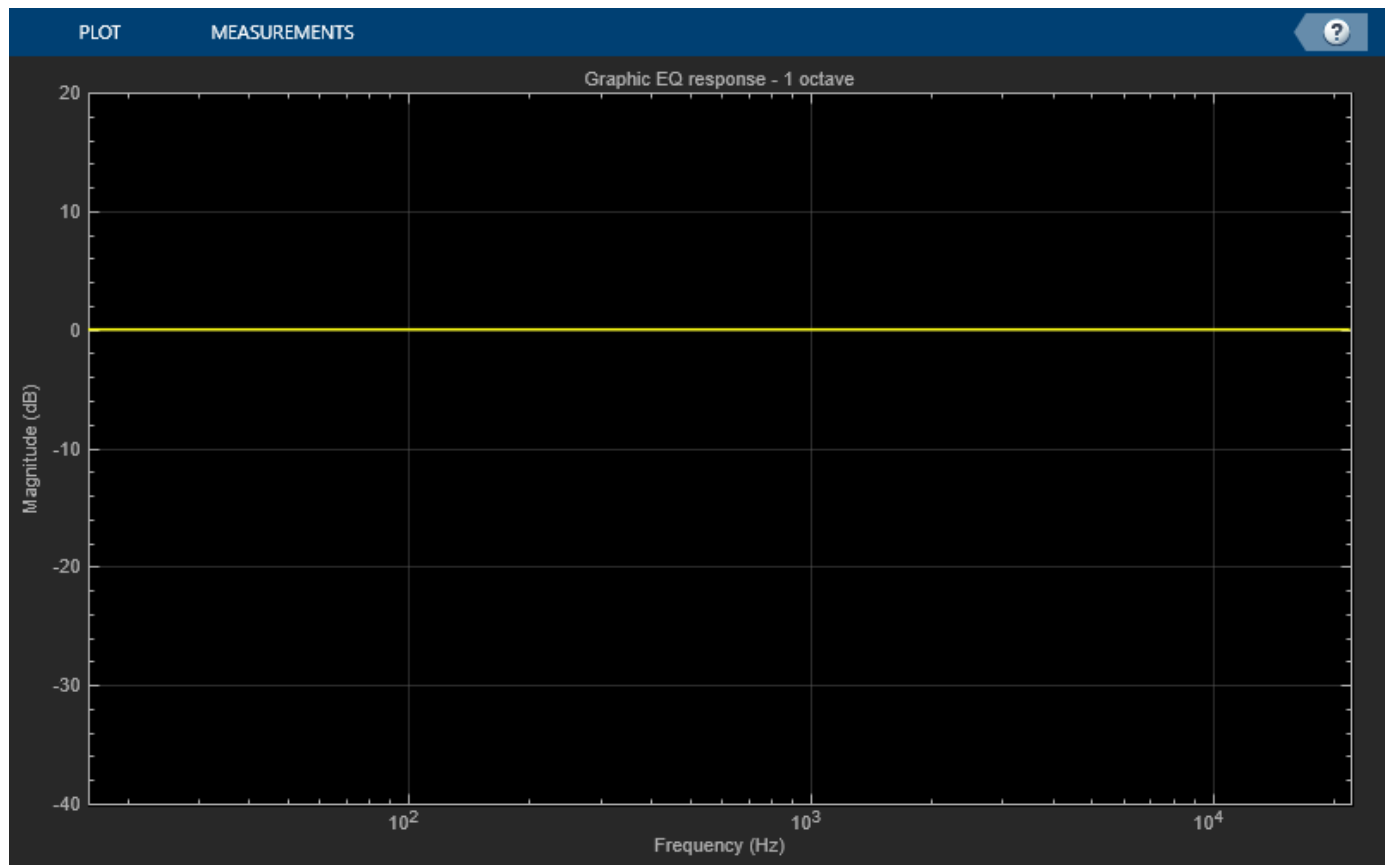
`hvsz = visualize(___)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when called with any of the previous syntaxes.

Examples

Visualize Magnitude Response of Graphic Equalizer

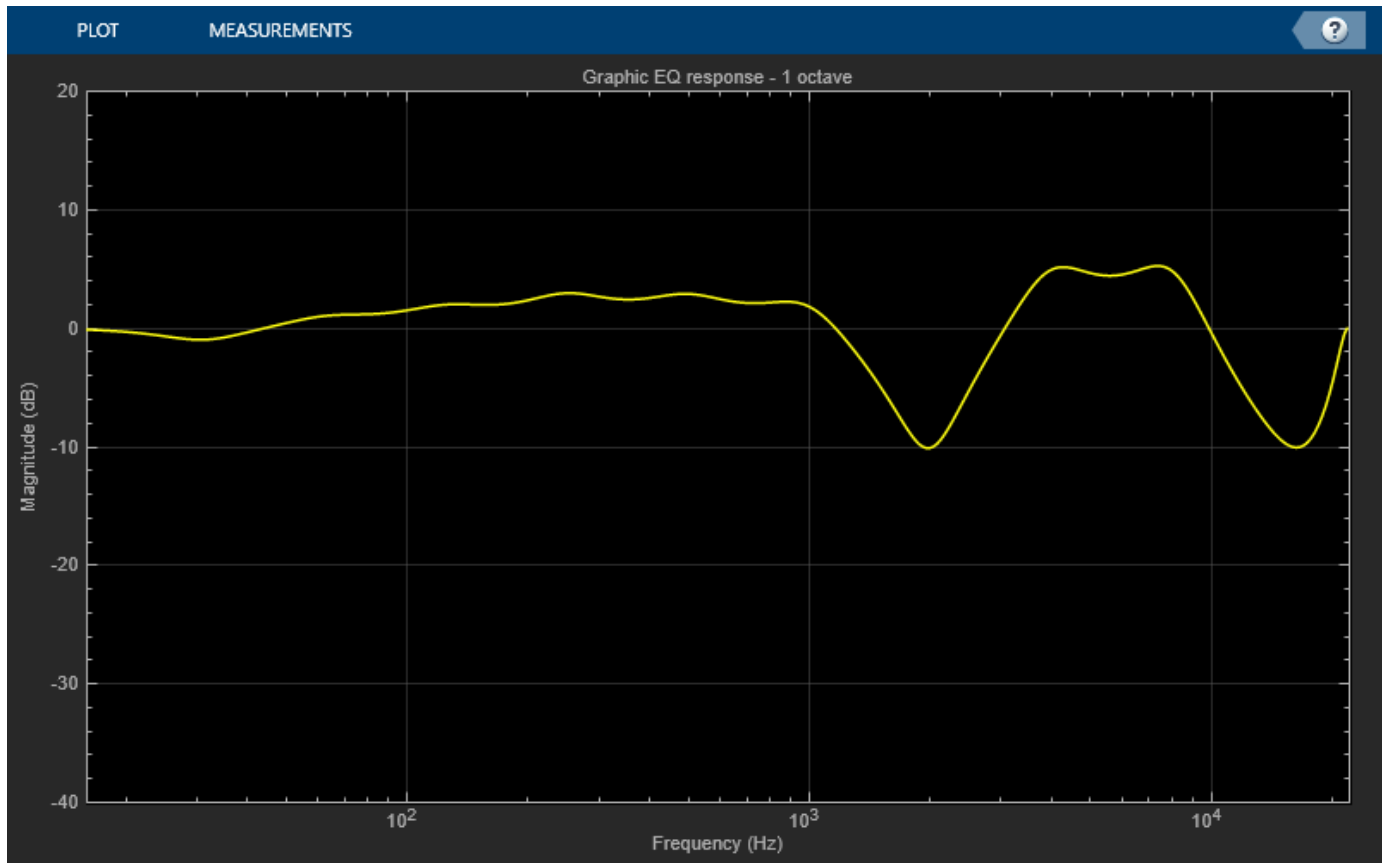
Create a default `graphicEQ` System object™ and then call `visualize`.

```
equalizer = graphicEQ;
visualize(equalizer)
```



Set the gains of the graphic equalizer to new values. The visualization of the magnitude response updates automatically.

```
equalizer.Gains = [-1,1,2,3,3,2,-10,5,5,-10];
```



Input Arguments

equalizer — Graphic equalizer to visualize

object of `graphicEQ` System object

Graphic equalizer whose magnitude response you want to plot.

NFFT — N-point FFT

2048 (default) | positive scalar

Number of bins used to calculate the DFT, specified as a positive scalar.

Data Types: `single` | `double`

See Also

`graphicEQ`

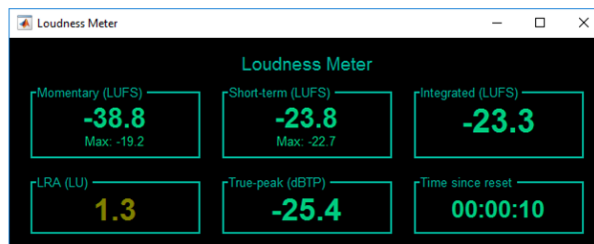
Introduced in R2017b

loudnessMeter

Standard-compliant loudness measurements

Description

The loudnessMeter System object computes the loudness, loudness range, and true-peak of an audio signal in accordance with EBU R 128 and ITU-R BS.1770-4 standards.



To implement loudness metering:

- 1 Create the loudnessMeter object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
loudMtr = loudnessMeter
loudMtr = loudnessMeter(Name, Value)
```

Description

`loudMtr = loudnessMeter` creates a System object, `loudMtr`, that performs loudness metering independently across each input channel.

`loudMtr = loudnessMeter(Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `loudMtr = loudnessMeter('ChannelWeights', [1.2, 0.8], 'SampleRate', 12000)` creates a System object, `loudMtr`, with channel weights of 1.2 and 0.8, and a sample rate of 12 kHz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

ChannelWeights — Linear weighting applied to each input channel

[1, 1, 1, 1.41, 1.41] (default) | nonnegative row vector

Linear weighting applied to each input channel, specified as a row vector of nonnegative values. The number of elements in the row vector must be equal to or greater than the number of input channels. Excess values in the vector are ignored.

The default channel weights follow the ITU-R BS.1170-4 standard. To use the default channel weights, specify the input signal channels as a matrix in this order: [Left, Right, Center, Left surround, Right surround].

As a best practice, specify the ChannelWeights property in order: [Left, Right, Center, Left surround, Right surround].

Tunable: Yes

Data Types: `single` | `double`

UseRelativeScale — Use relative scale for loudness measurements

`false` (default) | `true`

Use relative scale for loudness measurements, specified as a logical scalar.

- `false` -- The loudness measurements are absolute and returned in loudness units full scale (LUFS).
- `true` -- The loudness measurements are relative to the TargetLoudness value and returned in loudness units (LU).

Tunable: No

Data Types: `logical`

TargetLoudness — Target loudness level for relative scale (LUFS)

-23 (default) | real scalar

Target loudness level for relative scale in LUFS, specified as a real scalar.

For example, if the TargetLoudness is -23 LUFS, then a loudness value of -23 LUFS is reported as 0 LU.

Tunable: Yes

Dependencies

To enable this property, set UseRelativeScale to `true`.

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
[momentary,shortTerm,integrated,range,peak] = loudMtr(audioIn)
```

Description

`[momentary,shortTerm,integrated,range,peak] = loudMtr(audioIn)` returns measurement values for momentary and short-term loudness of the input to your loudness meter, and the true-peak value of the current input frame, `audioIn`. It also returns the integrated loudness and loudness range of the input to your loudness meter since the last time `reset` was called.

Input Arguments

audioIn — Audio input to loudness meter

matrix

Audio input to the loudness meter, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Note If you use the default `ChannelWeights` of the `LoudnessMeter`, as a best practice, specify the input channels in this order: [Left, Right, Center, Left surround, Right surround].

Data Types: `single` | `double`

Output Arguments

momentary — Momentary loudness (LUFS)

column vector

Momentary loudness in loudness units relative to full scale (LUFS), returned as a column vector with the same number of rows as `audioIn`.

By default, loudness measurements are returned in LUFS. If you set the `UseRelativeScale` property to `true`, loudness measurements are returned in loudness units (LU).

Data Types: `single` | `double`

shortTerm — Short-term loudness (LUFS)

column vector

Short-term loudness in loudness units relative to full scale (LUFS), returned as a column vector with the same number of rows as `audioIn`.

By default, loudness measurements are returned in LUFS. If you set the `UseRelativeScale` property to `true`, loudness measurements are returned in loudness units (LU).

Data Types: `single` | `double`

integrated — Integrated loudness (LUFS)

column vector

Integrated loudness in loudness units relative to full scale (LUFS), returned as a column vector with the same number of rows as `audioIn`.

By default, loudness measurements are returned in LUFS. If you set the `UseRelativeScale` property to `true`, loudness measurements are returned in loudness units (LU).

Data Types: `single` | `double`**range — Loudness range (LU)**

column vector

Loudness range in loudness units (LU), returned as a column vector with the same number of rows as `audioIn`.

Data Types: `single` | `double`**peak — True-peak loudness (dB-TP)**

scalar

True-peak loudness in dB-TP, returned as a column vector with the same number of rows as `audioIn`.

Data Types: `single` | `double`**Object Functions**

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to LoudnessMeter

`visualize` Open 'EBU Mode' meter display

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm

Examples**Loudness of Audio Signal**

Create a `dsp.AudioFileReader` System object™ to read in an audio file. Create a `loudnessMeter` System object. Use the sample rate of the audio file as the sample rate of the `loudnessMeter`.

```
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3');
loudMtr = loudnessMeter('SampleRate',fileReader.SampleRate);
```

Read in the audio file in an audio stream loop. Use the loudness meter to determine the momentary, short-term, and integrated loudness of the audio signal. Cache the loudness measurements for analysis.

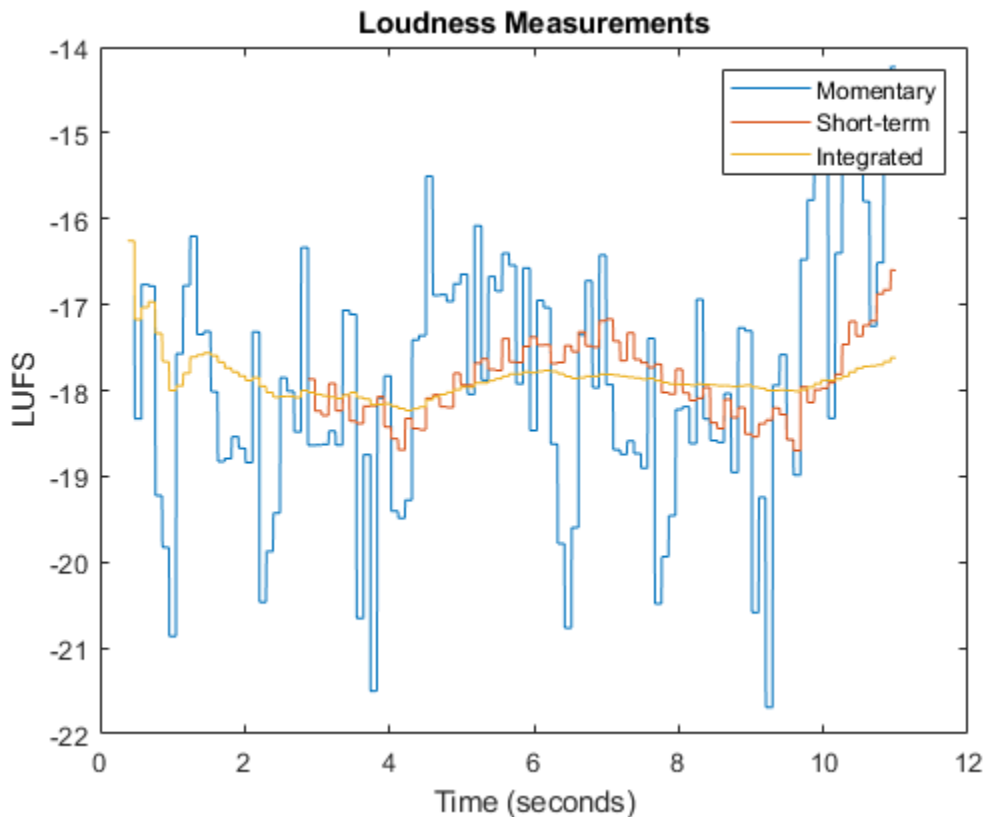
```
momentary = [];
shortTerm = [];
integrated = [];

while ~isDone(fileReader)
    x = fileReader();
    [m,s,i] = loudMtr(x);
    momentary = [momentary;m];
    shortTerm = [shortTerm;s];
    integrated = [integrated;i];
end

release(fileReader)
```

Plot the momentary, short-term, and integrated loudness of the audio signal.

```
t = linspace(0,11,length(momentary));
plot(t,[momentary,shortTerm,integrated])
title('Loudness Measurements')
legend('Momentary','Short-term','Integrated')
xlabel('Time (seconds)')
ylabel('LUFS')
```



Plot Momentary Loudness and Loudness Range of Audio Stream

Create an audio file reader and an audio device writer.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3', ...
    'SamplesPerFrame',1024);
fs = fileReader.SampleRate;
deviceWriter = audioDeviceWriter('SampleRate',fs);
```

Create a time scope to visualize your audio stream loop.

```
timeScope = timescope('NumInputPorts',2, ...
    'SampleRate',fs, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'LayoutDimensions',[2,1], ...
    'TimeSpanSource','Property','TimeSpan',5, ...
    'BufferLength',5*fs);
```

% Top subplot of scope

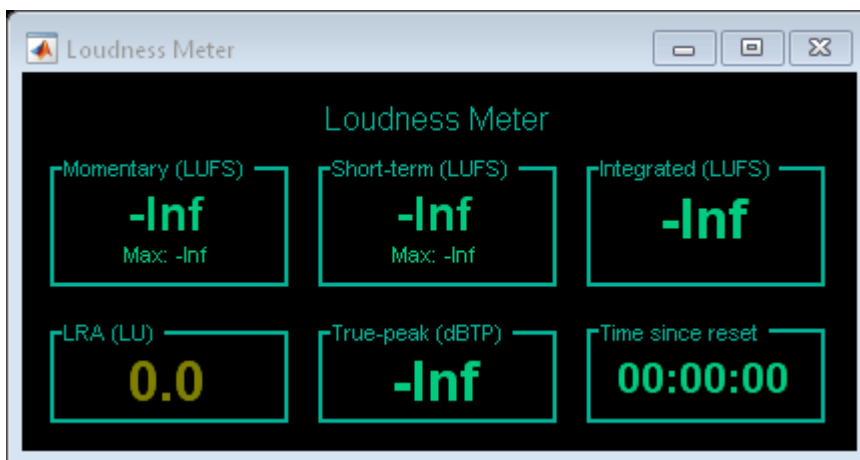
```
timeScope.Title = 'Momentary Loudness';
timeScope.YLabel = 'LUFS';
timeScope.YLimits = [-40, 0];
```

% Bottom subplot of scope

```
timeScope.ActiveDisplay = 2;
timeScope.Title = 'Loudness Range';
timeScope.YLabel = 'LU';
timeScope.YLimits = [-1, 2];
```

Create a loudness meter. Use the sample rate of your input file as the sample rate of your loudness meter. Call visualize to open an 'EBU-mode' visualization for your loudness meter.

```
loudMtr = loudnessMeter('SampleRate',fs);
visualize(loudMtr)
```



In an audio stream loop:

- Read in your audio file.

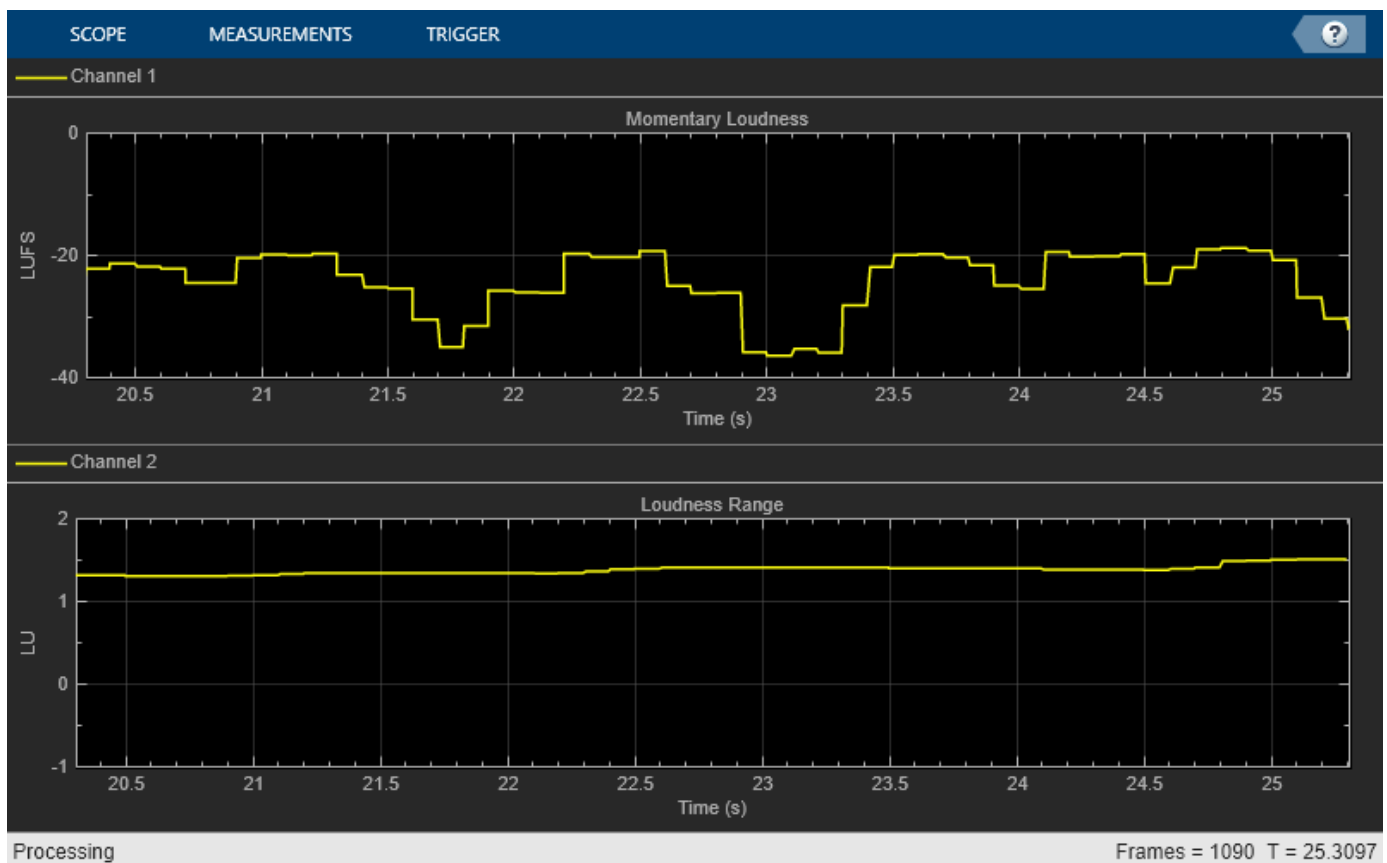
- Compute the momentary loudness and loudness range.
- Visualize the momentary loudness and loudness range on your time scope.
- Play the audio signal.

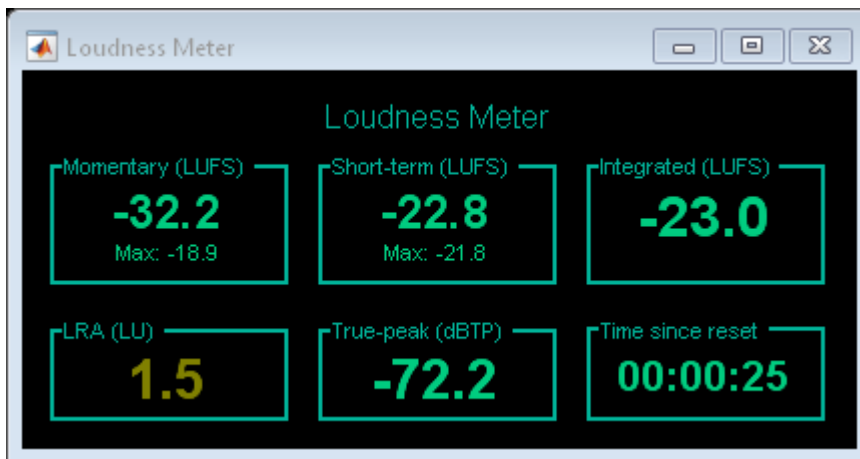
The 'EBU-mode' loudness meter visualization updates automatically while it is open. As a best practice, release your file reader and device writer once the loop is completed.

```

while ~isDone(fileReader)
    audioIn = fileReader();
    [momentaryLoudness,~,~,LRA] = loudMtr(audioIn);
    timeScope(momentaryLoudness,LRA);
    deviceWriter(audioIn);
end

release(fileReader)
release(deviceWriter)
    
```





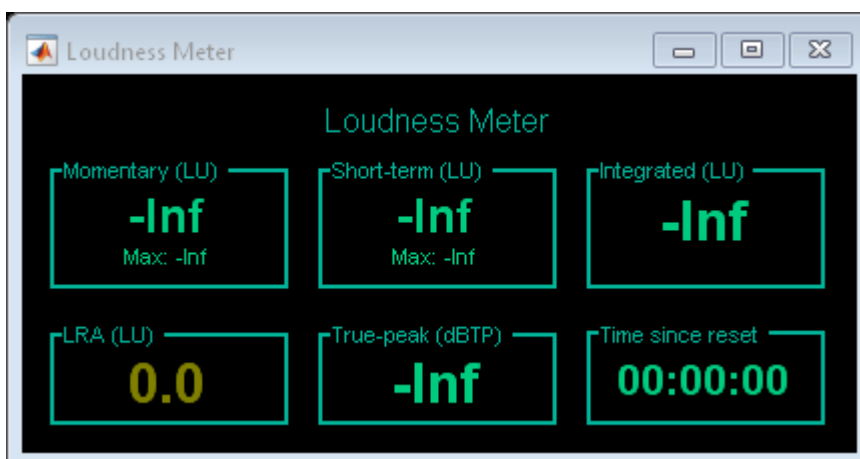
Relative Scale for Loudness Measurements

Create an audio file reader to read in an audio file. Create an audio device writer to write the audio file to your audio device. Use the sample rate of your file reader as the sample rate of your device writer.

```
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav', ...
    'SamplesPerFrame', 1024);
fs = fileReader.SampleRate;
deviceWriter = audioDeviceWriter('SampleRate', fs);
```

Create a loudness meter with the target loudness set to the default -23 LUFS. Open the 'EBU-mode' loudness meter visualization.

```
loudMtr = loudnessMeter('UseRelativeScale', true);
visualize(loudMtr)
```



Create a time scope to visualize your audio signal and its measured relative momentary and short-term loudness.

```
scope = timescope( ...
    'NumInputPorts', 3, ...
```

```

'SampleRate',fs, ...
'TimeSpanOvverrunAction','Scroll', ...
'TimeSpanSource','Property','TimeSpan',5, ...
'BufferLength',5*fs, ...
'Title','Audio Signal, Momentary Loudness, and Short-Term Loudness', ...
'ChannelNames',{'Audio signal','Momentary loudness','Short-term loudness'}, ...
'YLimits',[-16,16], ...
'YLabel','Amplitude / LU', ...
>ShowLegend',true);

```

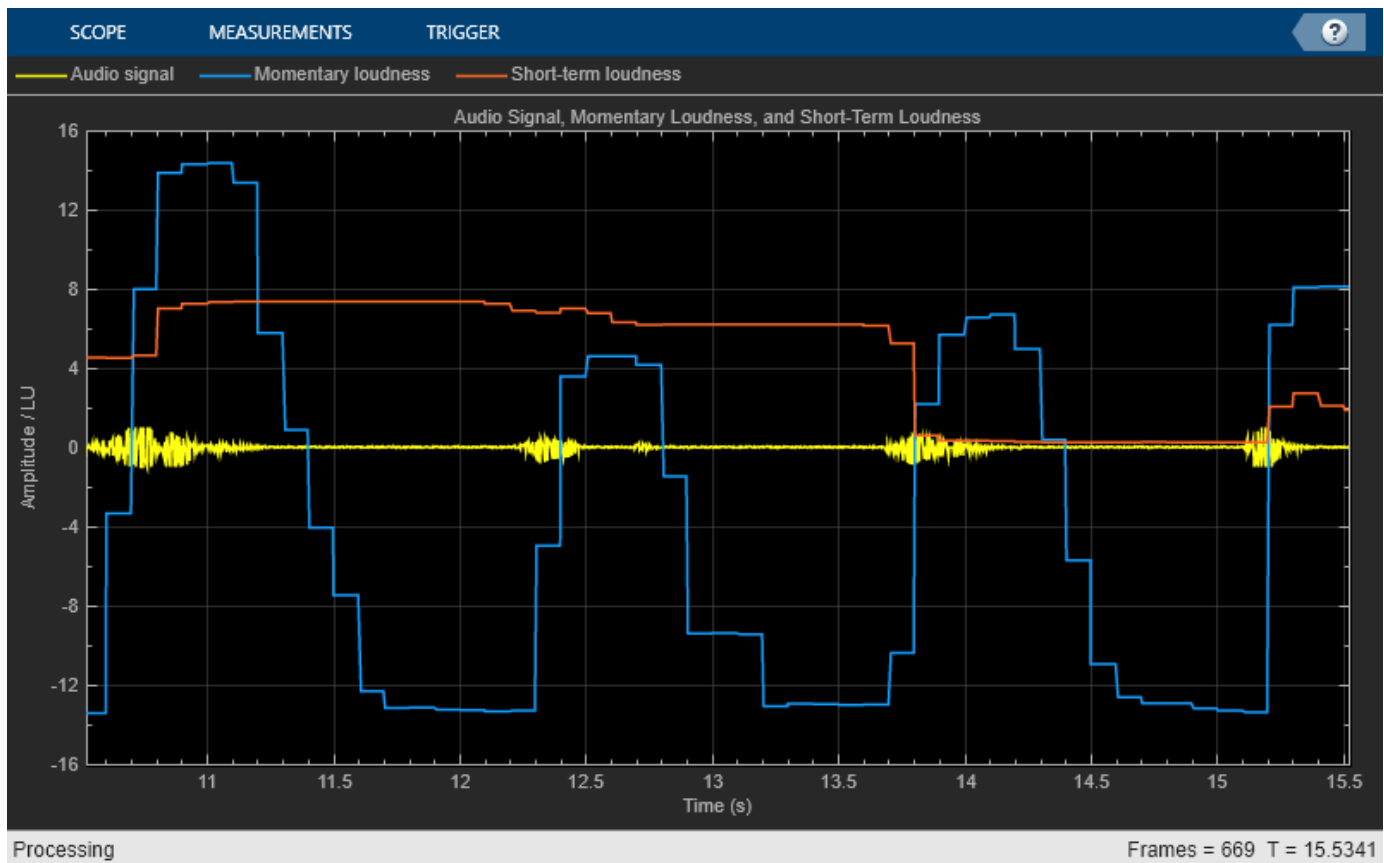
In an audio stream loop, listen to and visualize the audio signal.

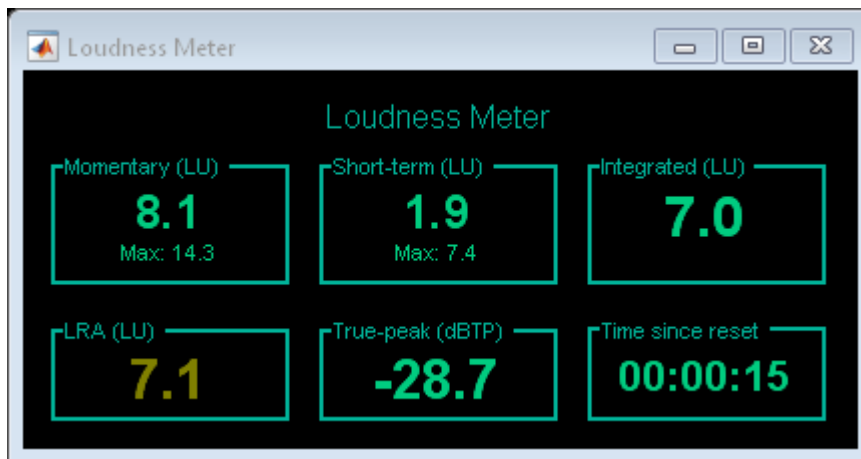
```

while ~isDone(fileReader)
    x = fileReader();
    [momentary,shortTerm] = loudMtr(x);
    scope(x,momentary,shortTerm)
    deviceWriter(x);
end

release(deviceWriter)
release(fileReader)

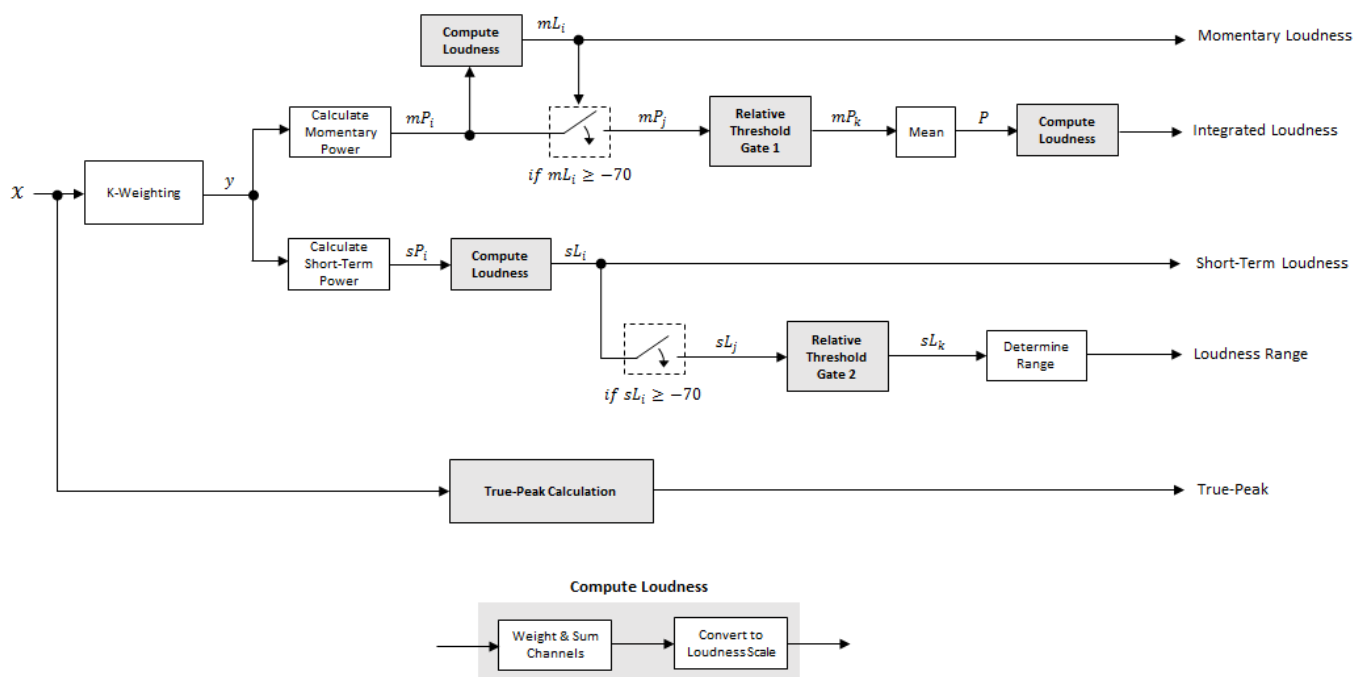
```





Algorithms

The loudnessMeter System object calculates the momentary loudness, short-term loudness, integrated loudness, loudness range (LRA), and true-peak value of an audio signal. You can specify any number of channels and nondefault channel weights used for loudness measurements. The loudnessMeter algorithm is described for the general case of n channels with default channel weights.



Loudness Measurements

The input channels, x , pass through a K-weighted weightingFilter. The K-weighted filter shapes the frequency spectrum to reflect perceived loudness.

Momentary Loudness and Integrated Loudness

- 1 The K-weighted channels, y , are divided into 0.4-second segments with 0.3-second overlap. If the required number of samples have not been collected yet, the `LoudnessMeter` System object returns the last computed values for momentary and integrated loudness. If enough samples have been collected, then the power (mean square) of each segment of the K-weighted channels is calculated:

$$mP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- mP_i is the momentary power of the i th segment.
- w is the segment length in samples.

- 2 The momentary loudness, mL , is computed in LUFS for each segment:

$$mL_i = -0.691 + 10\log_{10}\left(\sum_{c=1}^n G_c \times mP_{(i,c)}\right)$$

- G_c is the weighting for channel c .

mL is the momentary loudness returned by your `LoudnessMeter` System object. It is also used internally to calculate the integrated loudness (steps 3-6).

- 3 The *integrated loudness* measurement considers the audio signal since the last reset of your loudness meter. To calculate integrated loudness, the momentary power is passed through a gating system. The gate system pauses the measurement during periods of low sound, such as stretches of silence in a movie.

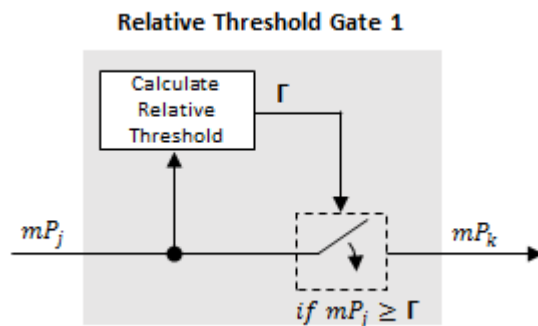
The momentary power segment is gated using the corresponding momentary loudness segment calculation:

$$mP_i \rightarrow mP_j$$

$$j = \{ i \mid mL_i \geq -70 \}$$

mP_j is cached until your `LoudnessMeter` is reset.

- 4 The momentary power subset, mP_j , passes through a relative threshold gate.



- a The relative threshold, Γ , is computed:

$$\Gamma = -0.691 + 10\log_{10}\left(\sum_{c=1}^n G_c \times l_c\right) - 10$$

l_c is the mean momentary power of channel c :

$$l_c = \frac{1}{|j|} \sum_j mP_{(j,c)}$$

b The momentary power subset, mP_j , is gated using relative threshold Γ :

$$mP_j \rightarrow mP_k$$

$$k = \{ j \mid mP_j \geq \Gamma \}$$

The relative threshold is recomputed during each call to your `loudnessMeter` object. The cached values of mP_j are gated again depending on the updated value of Γ .

5 The momentary power segments are averaged:

$$P = \frac{1}{|k|} \sum_k mP_k$$

6 The integrated loudness is computed in LUFS by passing the mean momentary power, P , through the Compute Loudness system:

$$\text{Integrated Loudness} = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times P_c \right)$$

Short-Term Loudness and Loudness Range

1 The K-weighted channels, y , are divided into 3-second segments with 2.9-second overlap. If the required number of samples have not been collected yet, the `loudnessMeter System` object returns the last computed values for short-term loudness and loudness range. If enough samples have been collected, then the power (mean square) of each K-weighted channel is calculated:

$$sP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- sP_i is the short-term power of the i th segment of a channel.
- w is the segment length in samples.

2 The short-term loudness, sL , is computed in LUFS for each segment:

$$sL_i = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times sP_{(i,c)} \right)$$

- G_c is the weighting for channel c .

sL is the short-term loudness returned by your `loudnessMeter System` object. It is also used internally to calculate the loudness range (steps 3-5).

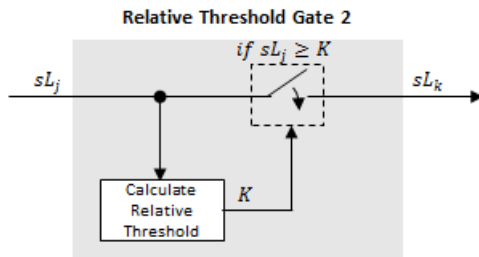
3 The short-term loudness is gated using an absolute threshold:

$$sL_i \rightarrow sL_j$$

$$j = \{ i \mid sL_i \geq -70 \}$$

sL_j is cached until your `loudnessMeter` is reset.

- 4 The short-term loudness subset, sL_j passes through a relative threshold gate.



- a The gated short-term loudness is converted back to linear and then the mean is taken:

$$sP_j = \frac{1}{|j|} \sum_j 10^{(sL_j/10)}$$

The relative threshold, K , is computed:

$$K = -20 + 10\log_{10}(sP_j)$$

- b The short-term loudness subset, sL_j , is gated using the relative threshold:

$$sL_j \rightarrow sL_k$$

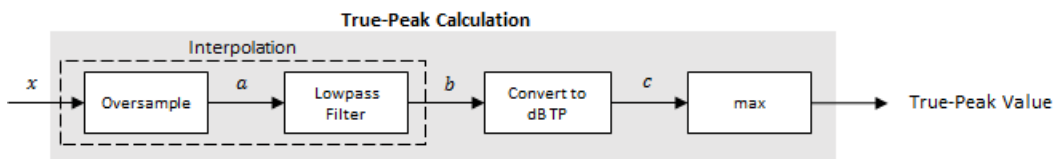
$$k = \{ j \mid sL_j \geq K \}$$

The relative threshold, K , is recomputed during each call to your `LoudnessMeter` object. The cached values of sL_j are gated again depending on the updated value of K .

- 5 The short-term loudness subset, sL_k , is sorted. The loudness range is calculated as between the 10th and 95th percentiles of the distribution and is returned in loudness units (LU).

True-Peak

The *true-peak* measurement considers only the current input frame of a call to your loudness meter.



- 1 The signal is oversampled to at least 192 kHz. To optimize processing, the input sample rate determines the exact oversampling. An input sample rate below 750 Hz is not considered.

Input Sample Rate (kHz)	Upsample Factor
[0.75, 1.5)	256
[1.5, 3)	128
[3, 6)	64
[6, 12)	32
[12, 24)	16

Input Sample Rate (kHz)	Upsample Factor
[24, 48)	8
[48, 96)	4
[96,192)	2
[192, ∞)	Not required

- 2 The oversampled signal, a , passes through a lowpass filter with a half-polyphase length of 12 and stopband attenuation of 80 dB. The filter design uses `designMultirateFIR`.
- 3 The filtered signal, b , is rectified and converted to the dB TP scale:

$$c = 20 \times \log_{10}(|b|)$$
- 4 The true-peak is determined as the maximum of the converted signal, c .

References

- [1] International Telecommunication Union; Radiocommunication Sector. *Algorithms to Measure Audio Programme Loudness and True-Peak Audio Level*. ITU-R BS.1770-4. 2015.
- [2] European Broadcasting Union. *Loudness Normalisation and Permitted Maximum Level of Audio Signals*. EBU R 128. 2014.
- [3] European Broadcasting Union. *Loudness Metering: 'EBU Mode' Metering to Supplement EBU R 128 Loudness Normalization*. EBU R 128 Tech 3341. 2014.
- [4] European Broadcasting Union. *Loudness Range: A Measure to Supplement EBU R 128 Loudness Normalization*. EBU R 128 Tech 3342. 2016.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

Supports MATLAB Function block: No

Dynamic Memory Allocation must not be turned off.

See Also

Blocks

Loudness Meter

Functions

`octaveFilter` | `weightingFilter` | `integratedLoudness`

Introduced in R2016b

visualize

Open 'EBU Mode' meter display

Syntax

```
visualize(loudMtr)
hvsz = visualize(loudMtr)
```

Description

`visualize(loudMtr)` opens an 'EBU Mode' loudness meter display. The values of momentary loudness, short-term loudness, integrated loudness, loudness range, and true-peak are updated as the simulation progresses. The display also shows the maximum value of momentary and short-term loudness, and the time since the last call to reset.

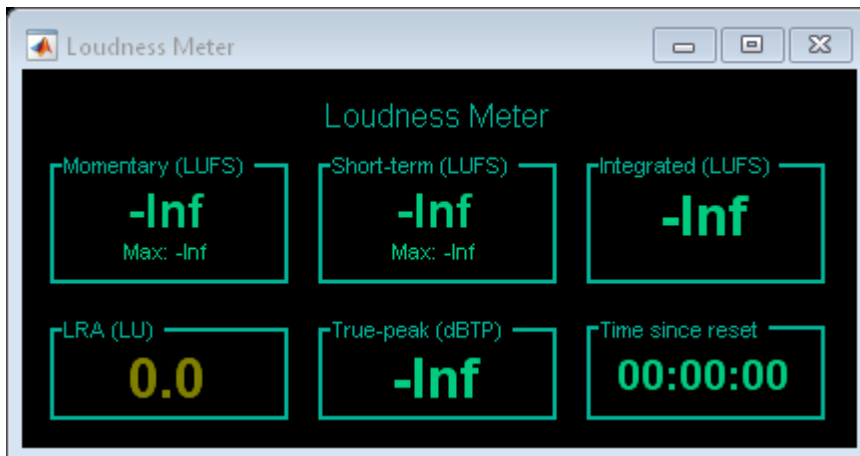
`hvsz = visualize(loudMtr)` returns a handle to the display.

Examples

Open an 'EBU Mode' Loudness Meter Display

Create a `loudnessMeter` System object™, and then call `visualize` to open an 'EBU Mode' loudness meter display.

```
loudMtr = loudnessMeter;
visualize(loudMtr)
```

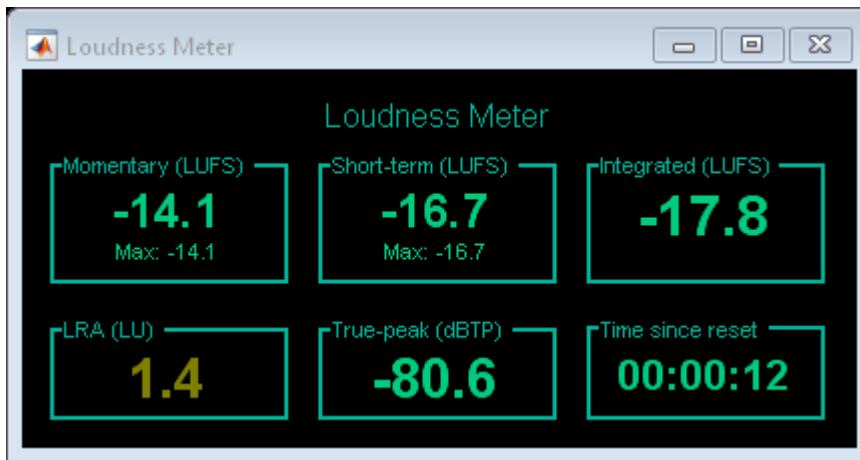


Create an audio file reader System object and specify the audio file to analyze. Create an audio device writer System object to play the audio to your output device.

```
fileReader = dsp.AudioFileReader('RockDrums-48-stereo-11secs.mp3');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

In an audio stream loop, read the audio from the file and play it to your device. The loudness meter visualization updates at each call.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    loudMtr(audioIn);
    deviceWriter(audioIn);
end
```



Input Arguments

LoudMtr — Object of LoudnessMeter

object

Object of the LoudnessMeter System object.

See Also

Blocks

Loudness Meter

Functions

integratedLoudness

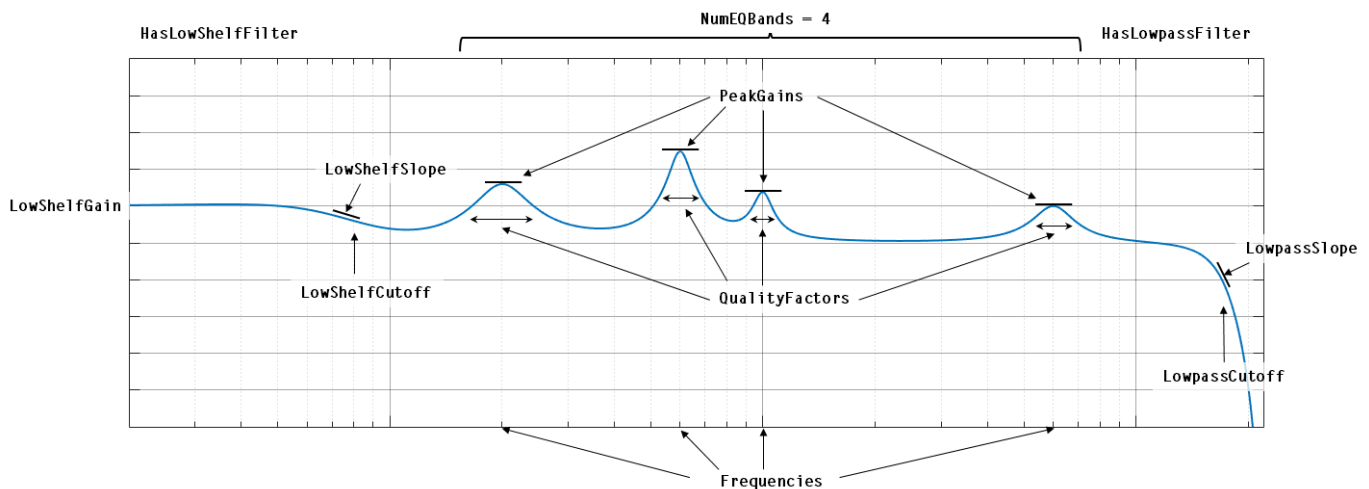
Introduced in R2016b

multibandParametricEQ

Multiband parametric equalizer

Description

The `multibandParametricEQ` System object performs multiband parametric equalization independently across each channel of input using specified center frequencies, gains, and quality factors. You can configure the System object with up to 10 bands. You can add low-shelf and high-shelf filters, as well as highpass (low-cut) and lowpass (high-cut) filters.



To implement a multiband parametric equalizer:

- 1 Create the `multibandParametricEQ` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
mPEQ = multibandParametricEQ
mPEQ = multibandParametricEQ(Name,Value)
```

Description

`mPEQ = multibandParametricEQ` creates a System object, `mPEQ`, that performs multiband parametric equalization.

`mPEQ = multibandParametricEQ(Name,Value)` sets each construction argument or property `Name` to the specified `Value`. Unspecified properties and creation arguments have default values.

Example: `mPEQ = multibandParametricEQ('NumEQBands',3,'Frequencies',[300,1200,5000])` creates a multiband parametric equalizer System object, `mPEQ`, with `NumEQBands` set to 3 and the `Frequencies` property set to `[300,1200,5000]`.

Note The value specified by `NumEQBands` must be the length of the row vectors specified by `Frequencies`, `QualityFactors`, and `PeakGains`. During creation of the System object, the first property you specify locks the value.

Creation Arguments

Creation arguments are properties which are set during creation of the System object and cannot be modified later. If you do not explicitly set a creation argument value, the property takes a default value.

NumEQBands — Number of equalizer bands

3 (default) | integer in the range [1, 10]

Number of equalizer bands, specified as an integer in the range [1, 10]. The number of equalizer bands does not include shelving filters, highpass filters, or lowpass filters.

`NumEQBands` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('NumEQBands',5)` creates a multiband parametric equalizer with 5 bands.

Data Types: `single` | `double`

EQOrder — Order of individual equalizer bands

2 (default) | even integer

Order of individual equalizer bands, specified as an even integer. All equalizer bands have the same order.

`EQOrder` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('EQOrder',6)` creates a multiband parametric equalizer with the default 3 bands, all of order 6.

Data Types: `single` | `double`

HasLowShelfFilter — Low-shelf filter toggle

false (default) | true

Low-shelf filter toggle, specified as `false` or `true`.

- `false` -- Do not enable low-shelf filtering in multiband parametric equalizer implementation.
- `true` -- Enable low-shelf filtering in multiband parametric equalizer implementation.

`HasLowShelfFilter` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('HasLowShelfFilter',true)` creates a default multiband parametric equalizer with low-shelf filtering enabled.

Data Types: `logical`

HasHighShelfFilter — High-shelf filter toggle

`false` (default) | `true`

High-shelf filter toggle, specified as `false` or `true`.

- `false` -- Do not enable high-shelf filtering in multiband parametric equalizer implementation.
- `true` -- Enable high-shelf filtering in multiband parametric equalizer implementation.

`HasHighShelfFilter` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('HasHighShelfFilter',true)` creates a default multiband parametric equalizer with high-shelf filtering enabled.

Data Types: `logical`

HasLowpassFilter — Lowpass filter toggle

`false` (default) | `true`

Lowpass filter toggle, specified as `false` or `true`.

- `false` -- Do not enable lowpass filtering in multiband parametric equalizer implementation.
- `true` -- Enable lowpass filtering in multiband parametric equalizer implementation.

`HasLowpassFilter` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('HasLowpassFilter',true)` creates a default multiband parametric equalizer with lowpass filtering enabled.

Data Types: `logical`

HasHighpassFilter — Highpass filter toggle

`false` (default) | `true`

Highpass filter toggle, specified as `false` or `true`.

- `false` -- Do not enable highpass filtering in multiband parametric equalizer implementation.
- `true` -- Enable highpass filtering in multiband parametric equalizer implementation.

`HasHighpassFilter` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('HasHighpassFilter',true)` creates a default multiband parametric equalizer with highpass filtering enabled.

Data Types: `logical`

Oversample — Oversample toggle

`false` (default) | `true`

Oversample toggle, specified as `false` or `true`.

- `false` -- Runs the multiband parametric equalizer at the input sample rate.

- `true` -- Runs the multiband parametric equalizer at two times the input sample rate. Oversampling minimizes the frequency-warping effects introduced by the bilinear transformation.

A halfband interpolator implements oversampling before equalization. A halfband decimator reduces the sample rate back to the input sampling rate after equalization.

`Oversample` is set during creation of the System object and cannot be modified later. If you do not explicitly set its value, the property takes the default value.

Example: `mPEQ = multibandParametricEQ('Oversample',true)` creates a default multiband parametric equalizer with oversampling enabled.

Data Types: `logical`

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Multiband Equalizer

Frequencies — Center frequencies of equalizer bands (Hz)

[100, 181, 325] (default) | row vector of length NumEQBands

Center frequencies of equalizer bands in Hz, specified as a row vector of length NumEQBands. The vector consists of real scalars in the range 0 to SampleRate/2.

Tunable: Yes

Data Types: `single` | `double`

QualityFactors — Quality factors of equalizer bands

[1.6, 1.6, 1.6] (default) | row vector of length NumEQBands

Quality factors of equalizer bands, specified as a row vector of length NumEQBands.

Tunable: Yes

Data Types: `single` | `double`

PeakGains — Peak or dip filter gains (dB)

[0, 0, 0] (default) | row vector of length NumEQBands

Peak or dip filter gains in dB, specified as a row vector of length NumEQBands. The vector consists of real scalars in the range [-inf, 20].

Tunable: Yes

Data Types: `single` | `double`

Low-Shelf Filter**LowShelfCutoff — Low-shelf filter cutoff (Hz)**

200 (default) | scalar

Low-shelf filter cutoff in Hz, specified as a scalar greater than or equal to 0.

Tunable: Yes**Dependencies**

To enable this property, set `HasLowShelfFilter` to `true` during creation.

Data Types: `single` | `double`**LowShelfSlope — Low-shelf filter slope coefficient**

1.5 (default) | positive scalar

Low-shelf filter slope coefficient, specified as a positive scalar.

Tunable: Yes**Dependencies**

To enable this property, set `HasLowShelfFilter` to `true` during creation.

Data Types: `single` | `double`**LowShelfGain — Low-shelf filter gain (dB)**

0 (default) | real scalar

Low-shelf filter gain in dB, specified as a real scalar.

Tunable: Yes**Dependencies**

To enable this property, set `HasLowShelfFilter` to `true` during creation.

Data Types: `single` | `double`**High-Shelf Filter****HighShelfCutoff — High-shelf filter cutoff (Hz)**

15000 (default) | nonnegative real scalar

High-shelf filter cutoff in Hz, specified as a real scalar greater than or equal to 0.

Tunable: Yes**Dependencies**

To enable this property, set `HasHighShelfFilter` to `true` during creation.

Data Types: `single` | `double`**HighShelfSlope — High-shelf slope coefficient**

1.5 (default) | positive scalar

High-shelf filter slope coefficient, specified as a positive scalar.

Tunable: Yes

Dependencies

To enable this property, set `HasHighShelfFilter` to `true` during creation.

Data Types: `single` | `double`

HighShelfGain — High-shelf filter gain (dB)

0 (default) | real scalar

High-shelf filter gain in dB, specified as a real scalar.

Tunable: Yes

Dependencies

To enable this property, set `HasHighShelfFilter` to `true` during creation.

Data Types: `single` | `double`

Lowpass Filter

LowpassCutoff — Lowpass filter cutoff frequency (Hz)

18000 (default) | nonnegative real scalar

Lowpass filter cutoff frequency in Hz, specified as a real scalar greater than or equal to 0.

Tunable: Yes

Dependencies

To enable this property, set `HasLowpassFilter` to `true` during creation.

Data Types: `single` | `double`

LowpassSlope — Lowpass filter slope (dB/octave)

12 (default) | real scalar in the range [0:6:48]

Lowpass filter slope in dB/octave, specified as a real scalar in the range [0:6:48]. Values that are not multiples of 6 are rounded to the nearest multiple of 6.

Tunable: Yes

Dependencies

To enable this property, set `HasLowpassFilter` to `true` during creation.

Data Types: `single` | `double`

Highpass Filter

HighpassCutoff — Highpass filter cutoff frequency (Hz)

20 (default) | nonnegative real scalar

Highpass filter cutoff in Hz, specified as a real scalar greater than or equal to 0.

Tunable: Yes

Dependencies

To enable this property, set `HasHighpassFilter` to `true` during creation.

Data Types: `single` | `double`

HighpassSlope — Highpass filter slope (dB/octave)

30 (default) | real scalar in the range [0:6:48]

Highpass filter slope in dB/octave, specified as a real scalar in the range [0:6:48]. Values that are not multiples of 6 are rounded to the nearest multiple of 6.

Tunable: Yes

Dependencies

To enable this property, set `HasHighpassFilter` to `true` during creation.

Data Types: `single` | `double`

Sampling

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
audioOut = mPEQ(audioIn)
```

Description

`audioOut = mPEQ(audioIn)` performs multiband parametric equalization on the input signal, `audioIn`, and returns the filtered signal, `audioOut`. The type of equalization is specified by the algorithm and properties of the `multibandParametricEQ` System object, `mPEQ`.

Input Arguments

audioIn — Audio input to equalizer

matrix

Audio input to the equalizer, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from equalizer

matrix

Audio output from the equalizer, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to `multibandParametricEQ`

`createAudioPluginClass` Create audio plugin class that implements functionality of System object
`visualize` Visualize magnitude response of multiband parametric equalizer
`parameterTuner` Tune object parameters while streaming

MIDI

`configureMIDI` Configure MIDI connections between audio object and MIDI controller
`disconnectMIDI` Disconnect MIDI controls from audio object
`getMIDIConnections` Get MIDI connections of audio object

Common to All System Objects

`clone` Create duplicate System object
`isLocked` Determine if System object is in use
`release` Release resources and allow changes to System object property values and input characteristics
`reset` Reset internal states of System object
`step` Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the `multibandParametricEQ` System object to user-facing parameters:

Property	Range	Mapping	Unit
Frequencies	[20, 20000]	log	Hz
QualityFactors	[0.2, 700]	linear	none
PeakGains	[-50, 20]	linear	dB
LowShelfCutoff	[20, 20000]	log	Hz
LowShelfSlope	[0.1, 5]	linear	none
LowShelfGain	[-12, 12]	linear	dB
HighShelfCutoff	[20, 20000]	log	Hz
HighShelfSlope	[0.1, 5]	linear	none
HighShelfGain	[-12, 12]	linear	dB
LowpassCutoff	[20, 20000]	log	Hz
LowpassSlope	[0, 48]	linear	dB/octave
HighpassCutoff	[20, 20000]	log	Hz
HighpassSlope	[0, 48]	linear	dB/octave

Examples

Multiband Parametric Equalization

Create `dsp.AudioFileReader` and `audioDeviceWriter` objects. Use the sample rate of the reader as the sample rate of the writer. Call `setup` to reduce the computational load of initialization in an audio stream loop.

```
frameLength = 512;

fileReader = dsp.AudioFileReader( ...
    'Filename','RockDrums-48-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);

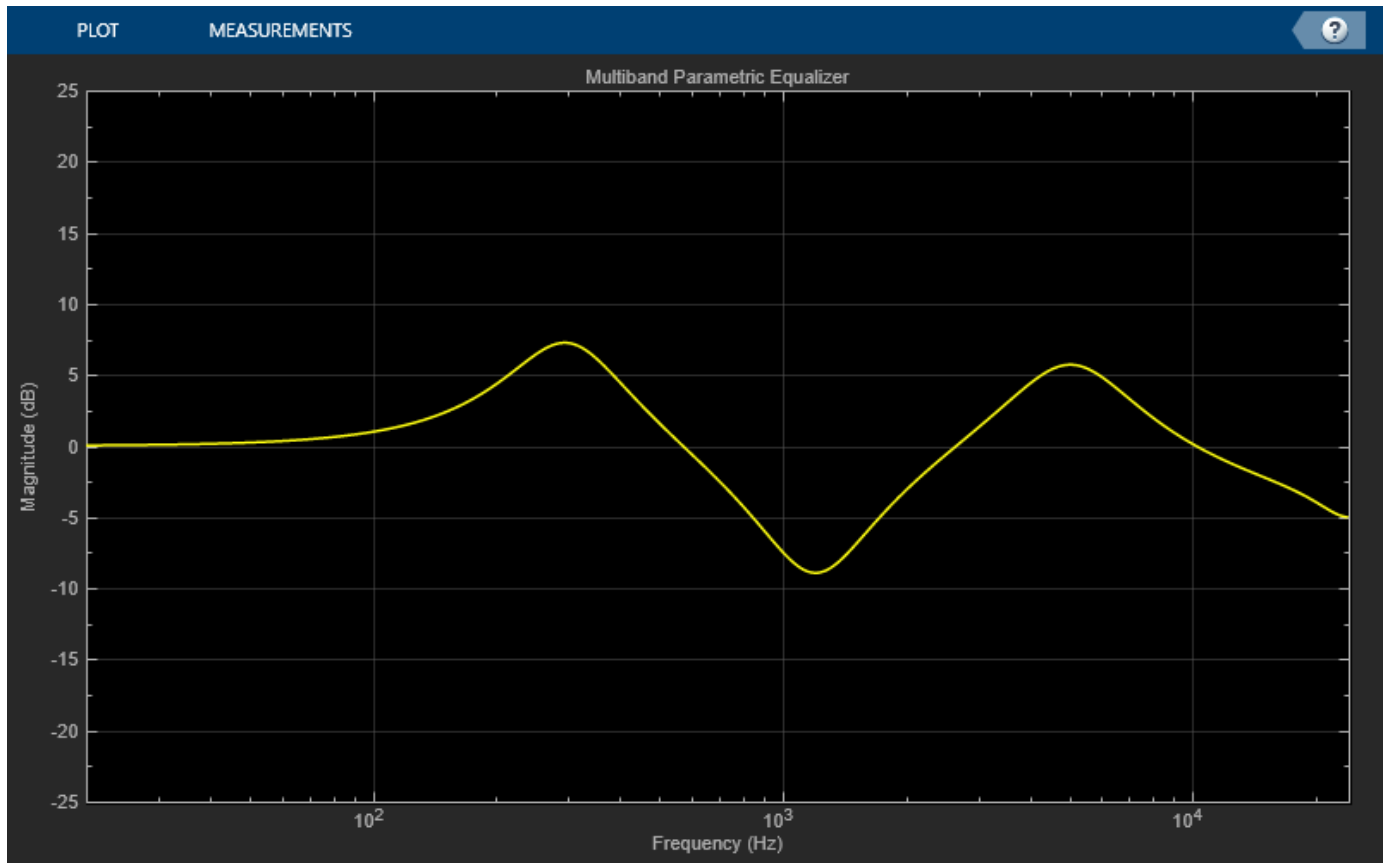
setup(deviceWriter,ones(frameLength,2))
```

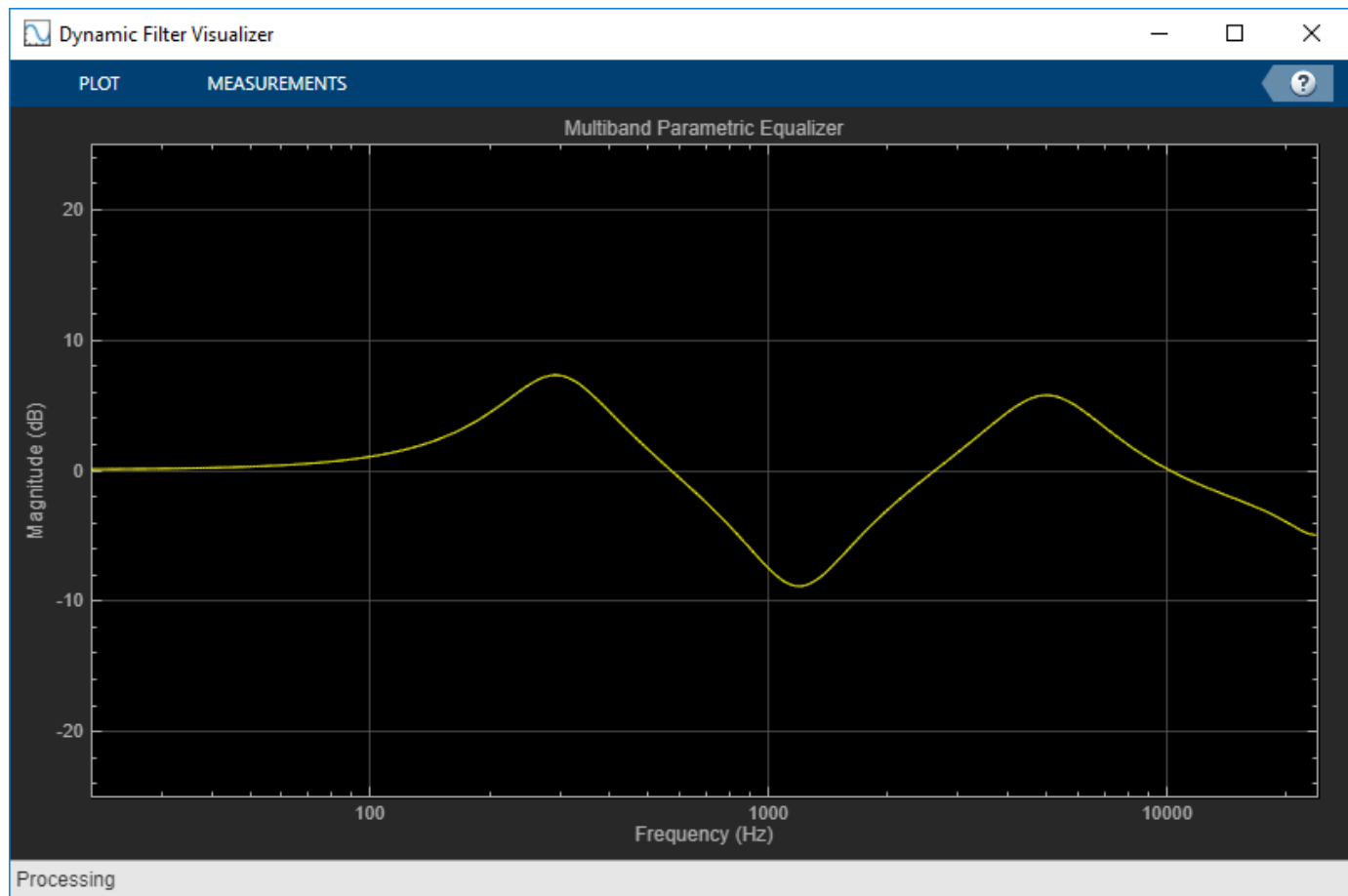
Construct a three-band parametric equalizer with a high-shelf filter.

```
mPEQ = multibandParametricEQ( ...
    'NumEQBands',3, ...
    'Frequencies',[300,1200,5000], ...
    'QualityFactors',[1,1,1], ...
    'PeakGains',[8,-10,7], ...
    'HasHighShelfFilter',true, ...
    'HighShelfCutoff',14000, ...
    'HighShelfSlope',0.3, ...
    'HighShelfGain',-5, ...
    'SampleRate',fileReader.SampleRate);
```

Visualize the magnitude frequency response of your multiband parametric equalizer.

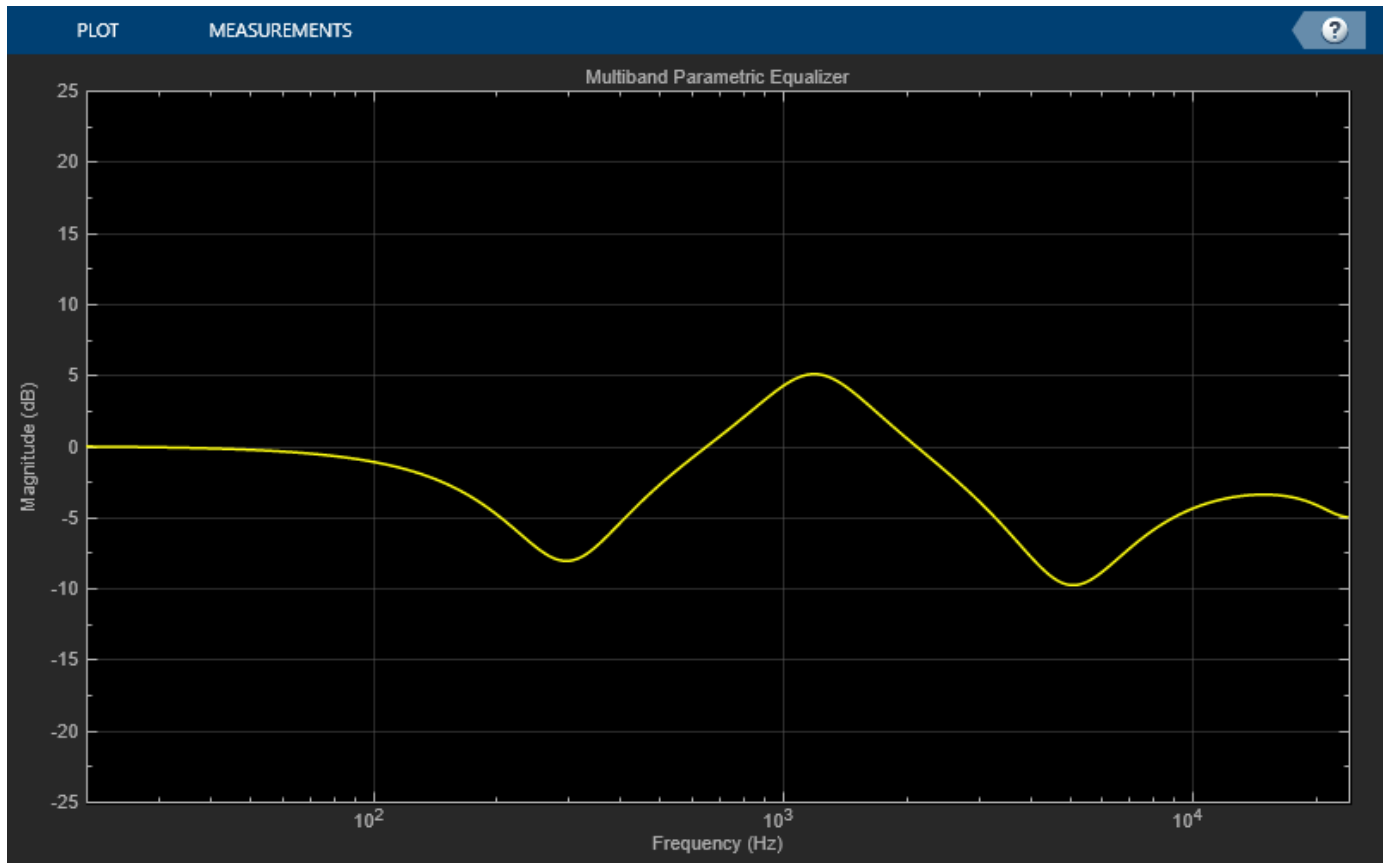
```
visualize(mPEQ)
```

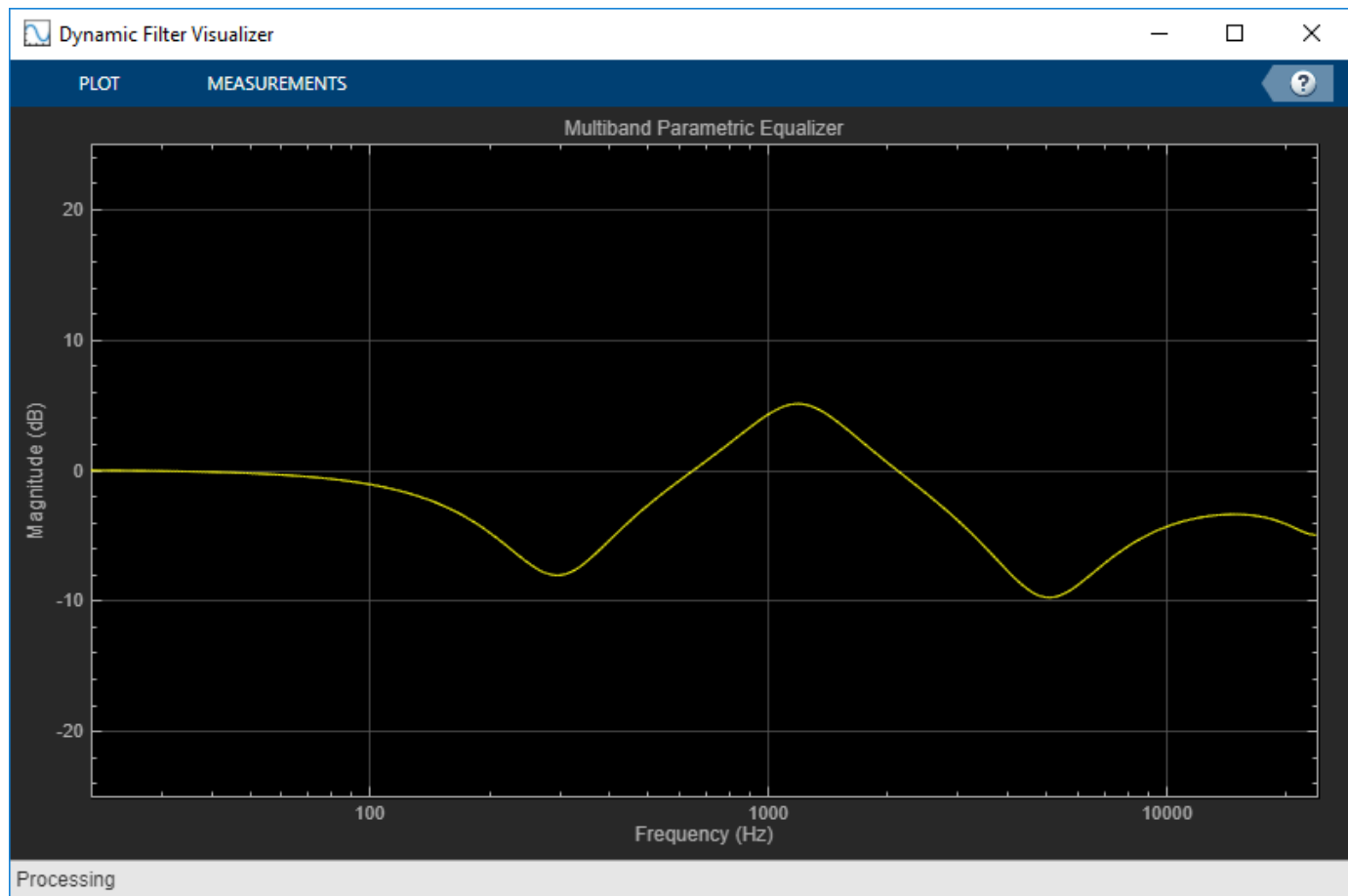




Play the equalized audio signal. Update the peak gains of your equalizer band to hear the effect of the equalizer and visualize the changing magnitude response.

```
count = 0;
while ~isDone(fileReader)
    originalSignal = fileReader();
    equalizedSignal = mPEQ(originalSignal);
    deviceWriter(equalizedSignal);
    if mod(count,100) == 0
        mPEQ.PeakGains(1) = mPEQ.PeakGains(1) - 1.5;
        mPEQ.PeakGains(2) = mPEQ.PeakGains(2) + 1.5;
        mPEQ.PeakGains(3) = mPEQ.PeakGains(3) - 1.5;
    end
    count = count + 1;
end
```





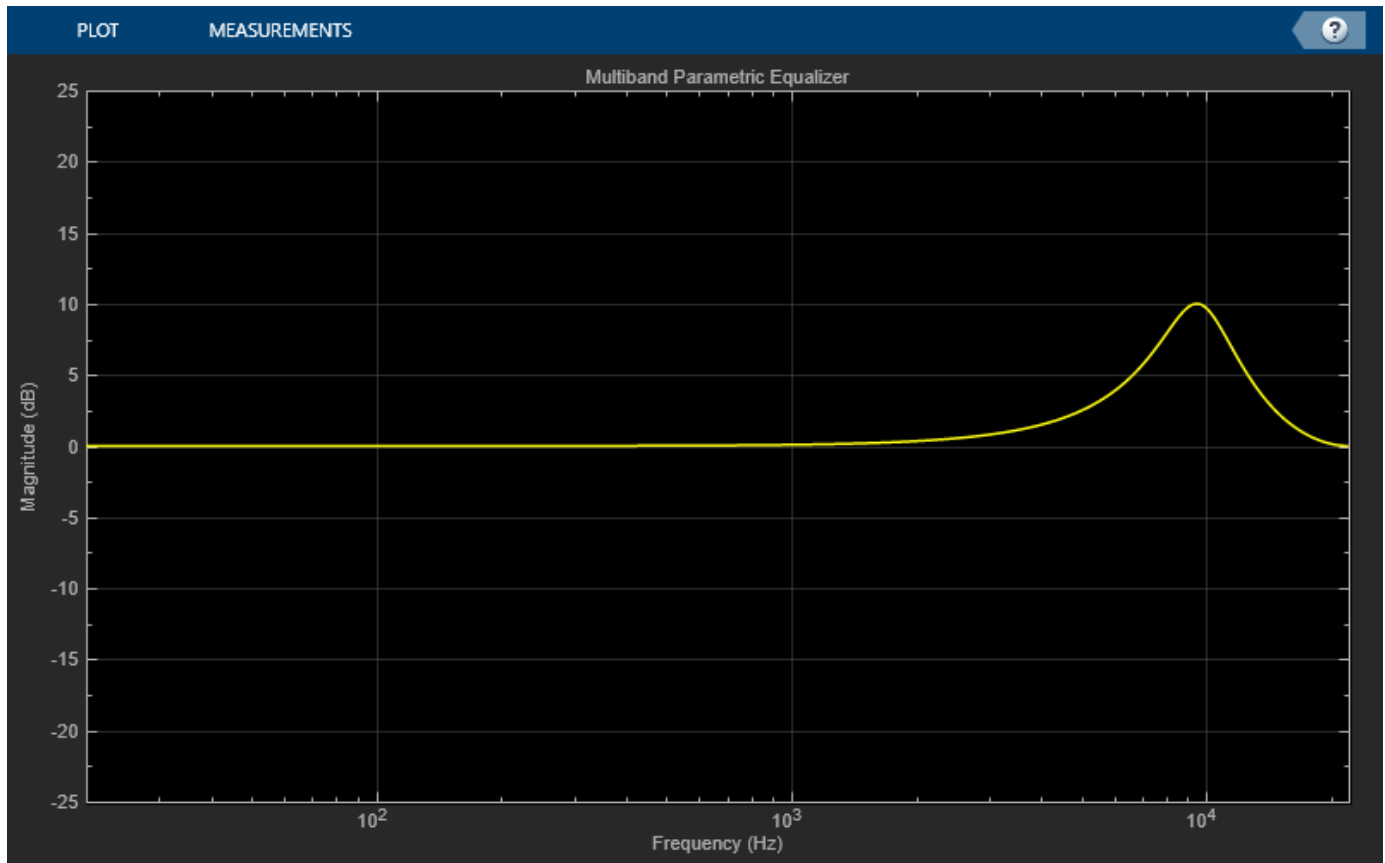
```
release(fileReader)
release(mPEQ)
release(deviceWriter)
```

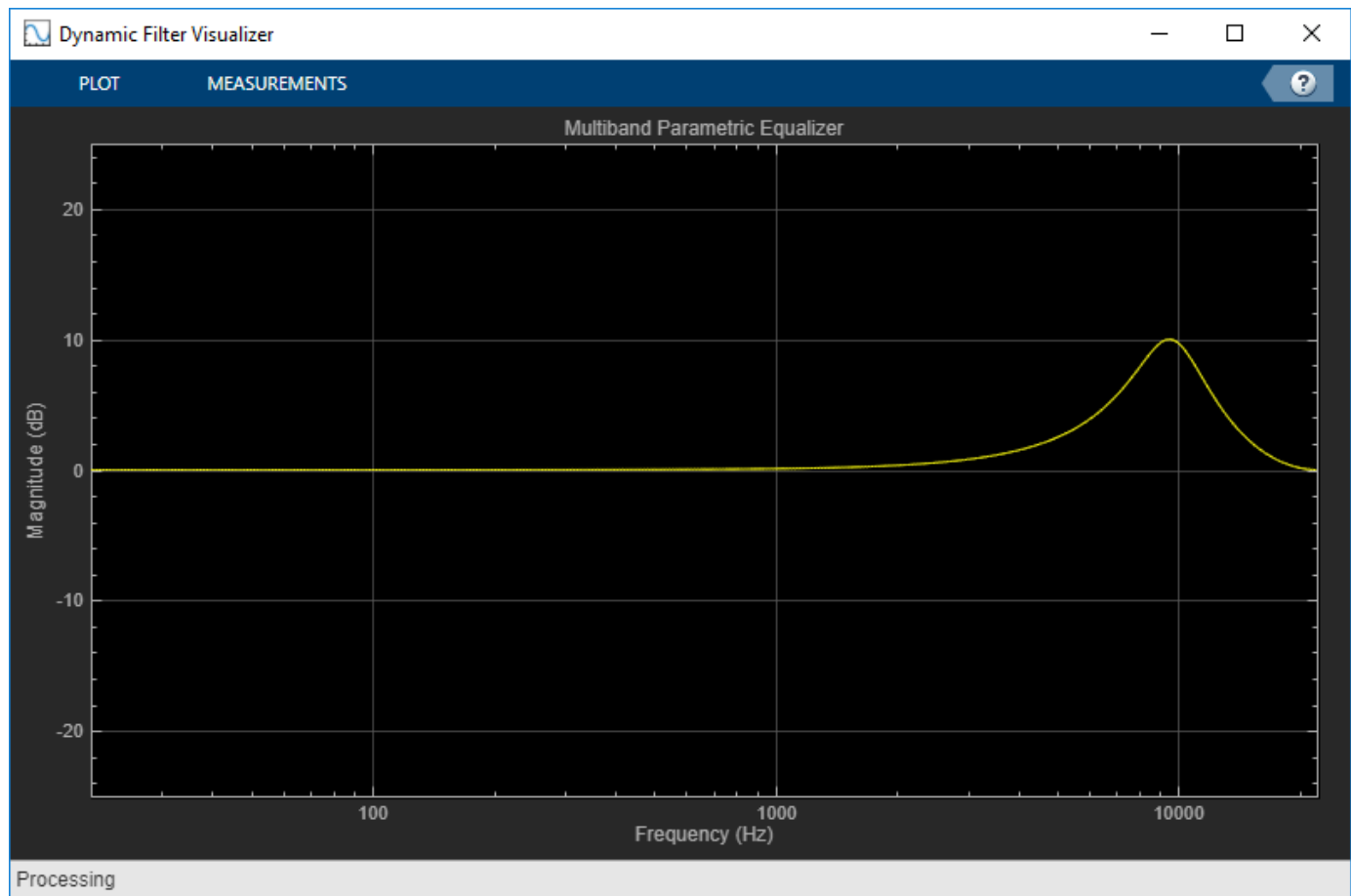
Oversample Audio Signal

Reduce warping by specifying your `multibandParametricEQ` object to perform oversampling before equalization.

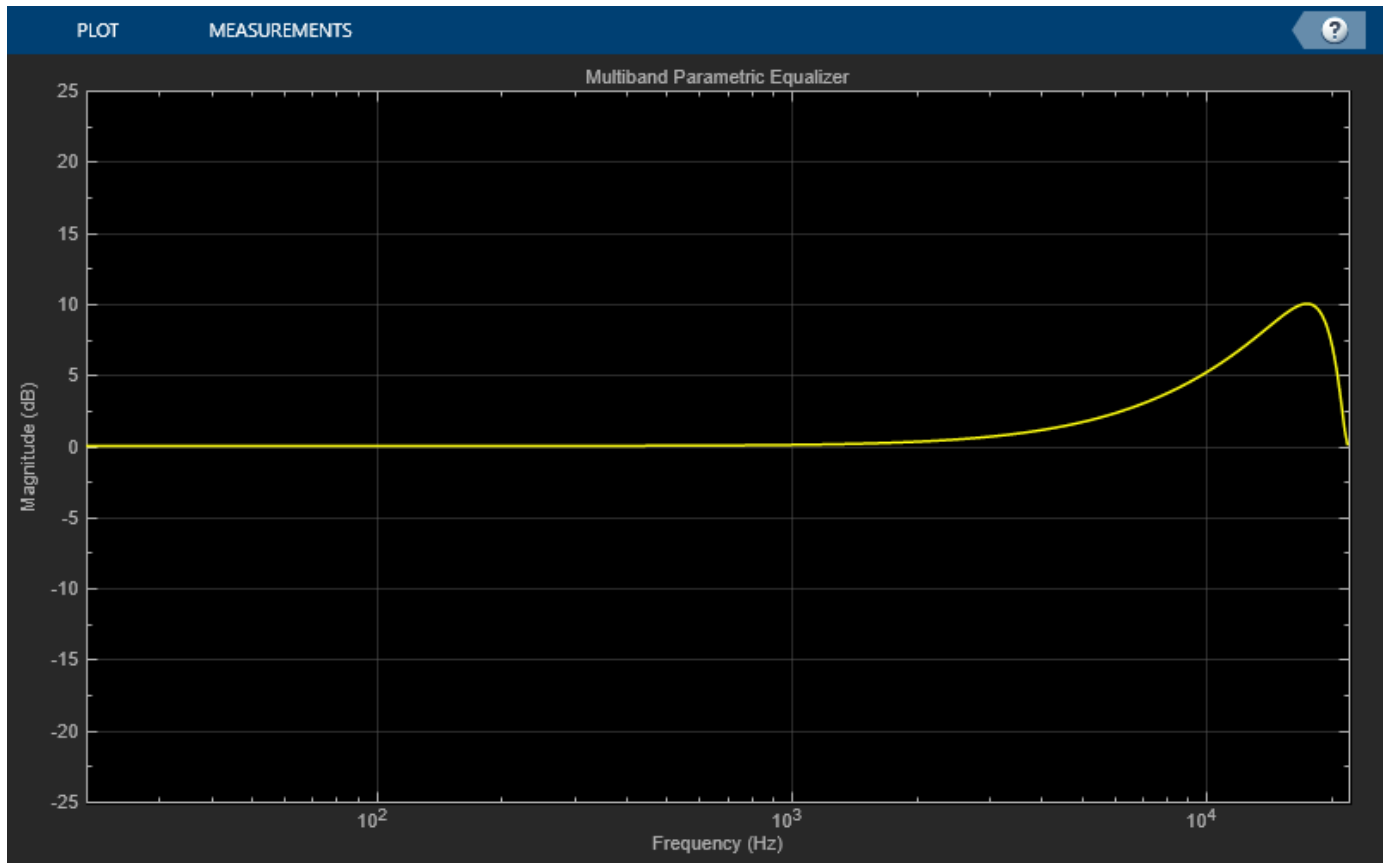
Create a one-band equalizer. Visualize the equalizer band as its center frequency approaches the Nyquist rate.

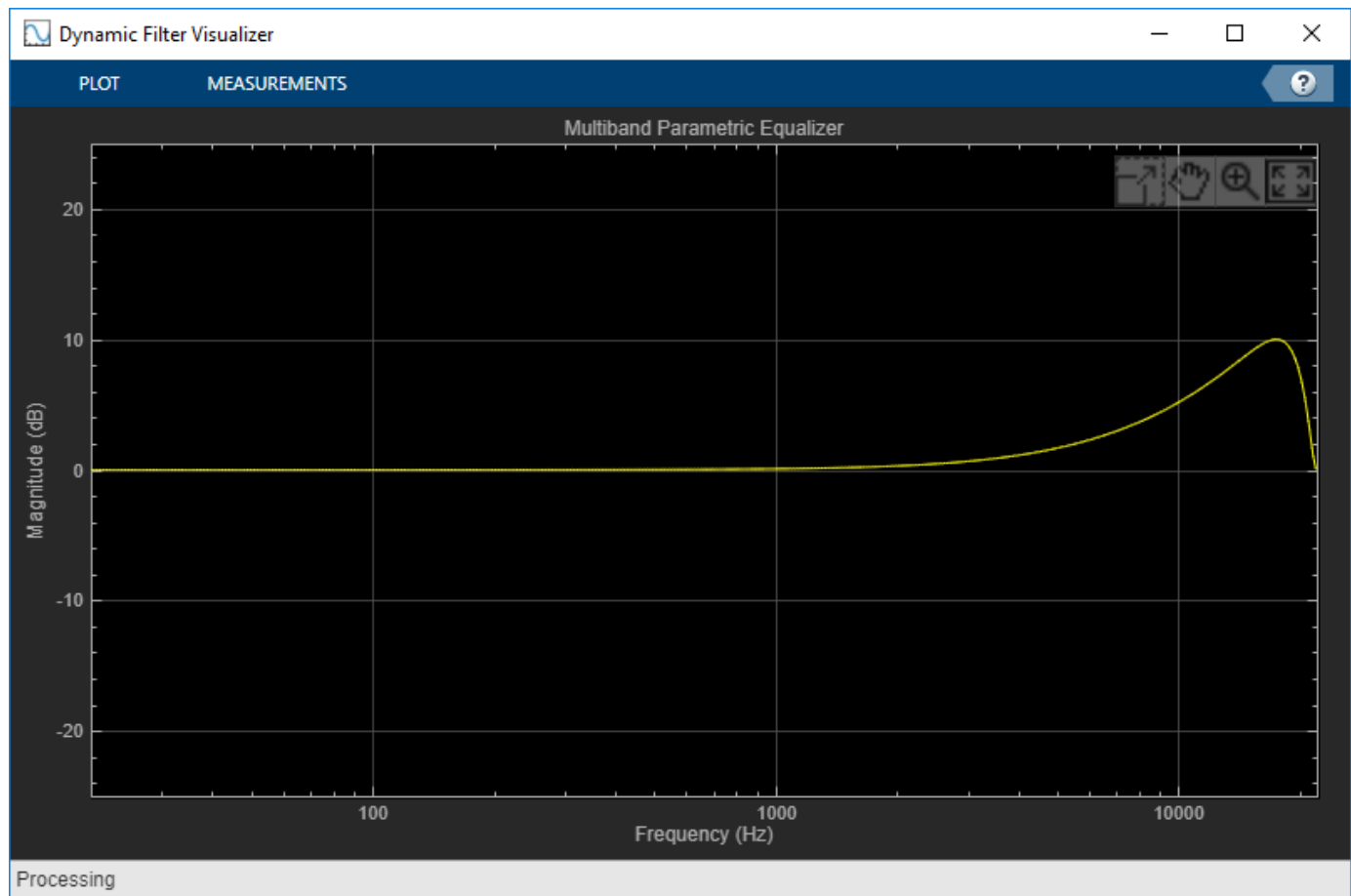
```
mPEQ = multibandParametricEQ( ...
    'NumEQBands',1, ...
    'Frequencies',9.5e3, ...
    'PeakGains',10);
visualize(mPEQ)
```



```
for i = 1:1000
    mPEQ.Frequencies = mPEQ.Frequencies + 8;
end
```

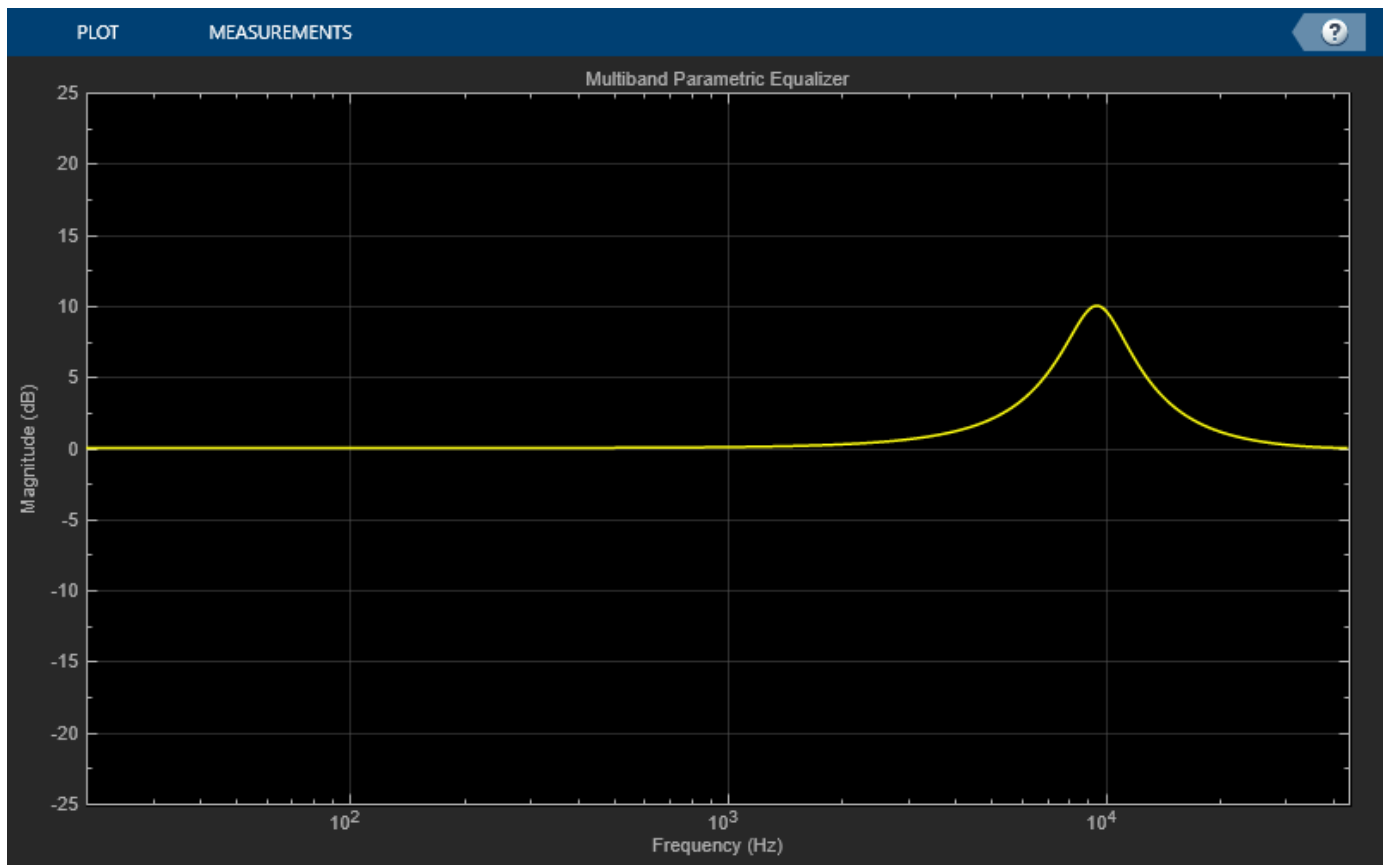


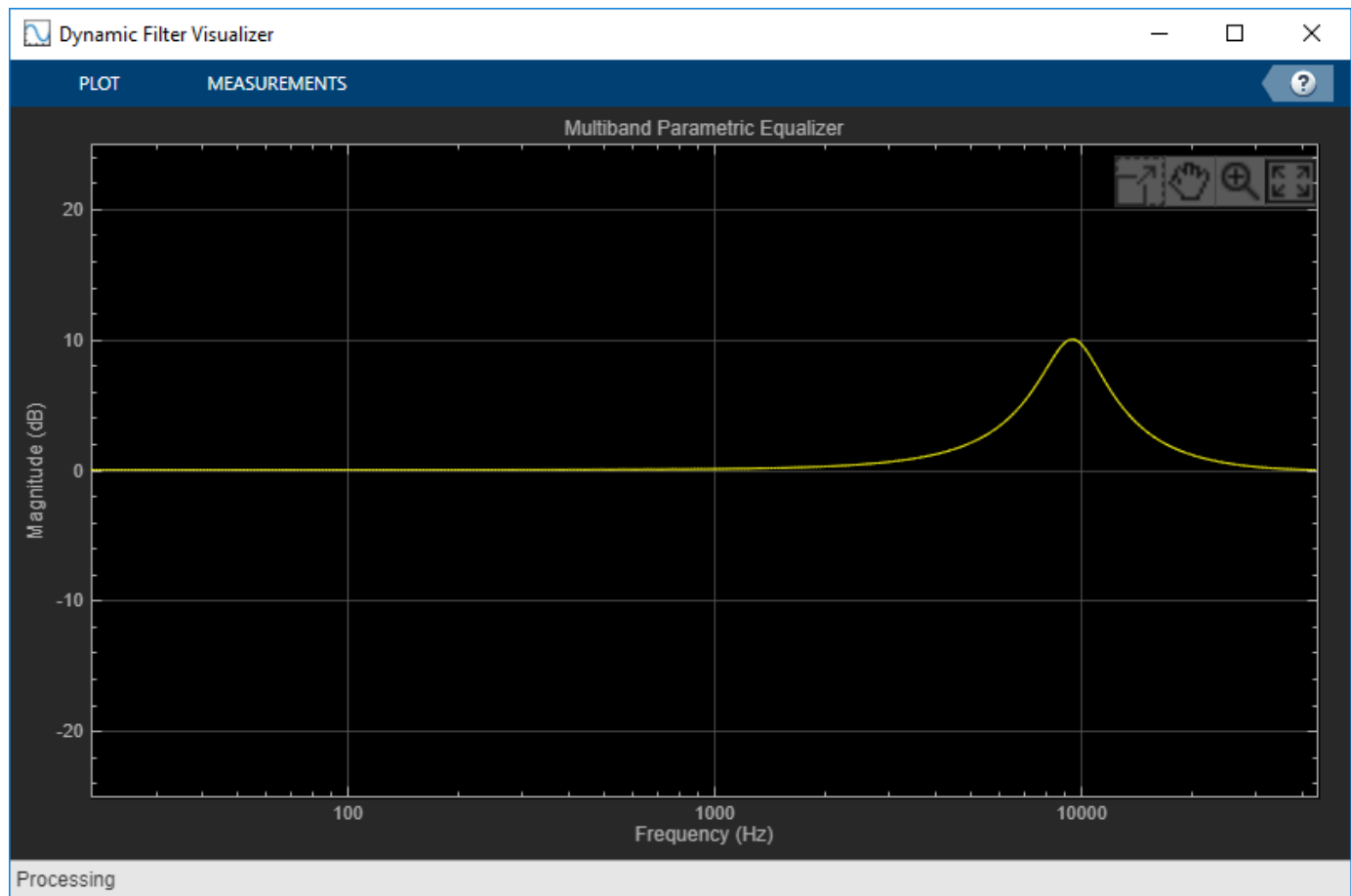


The equalizer band is warped.

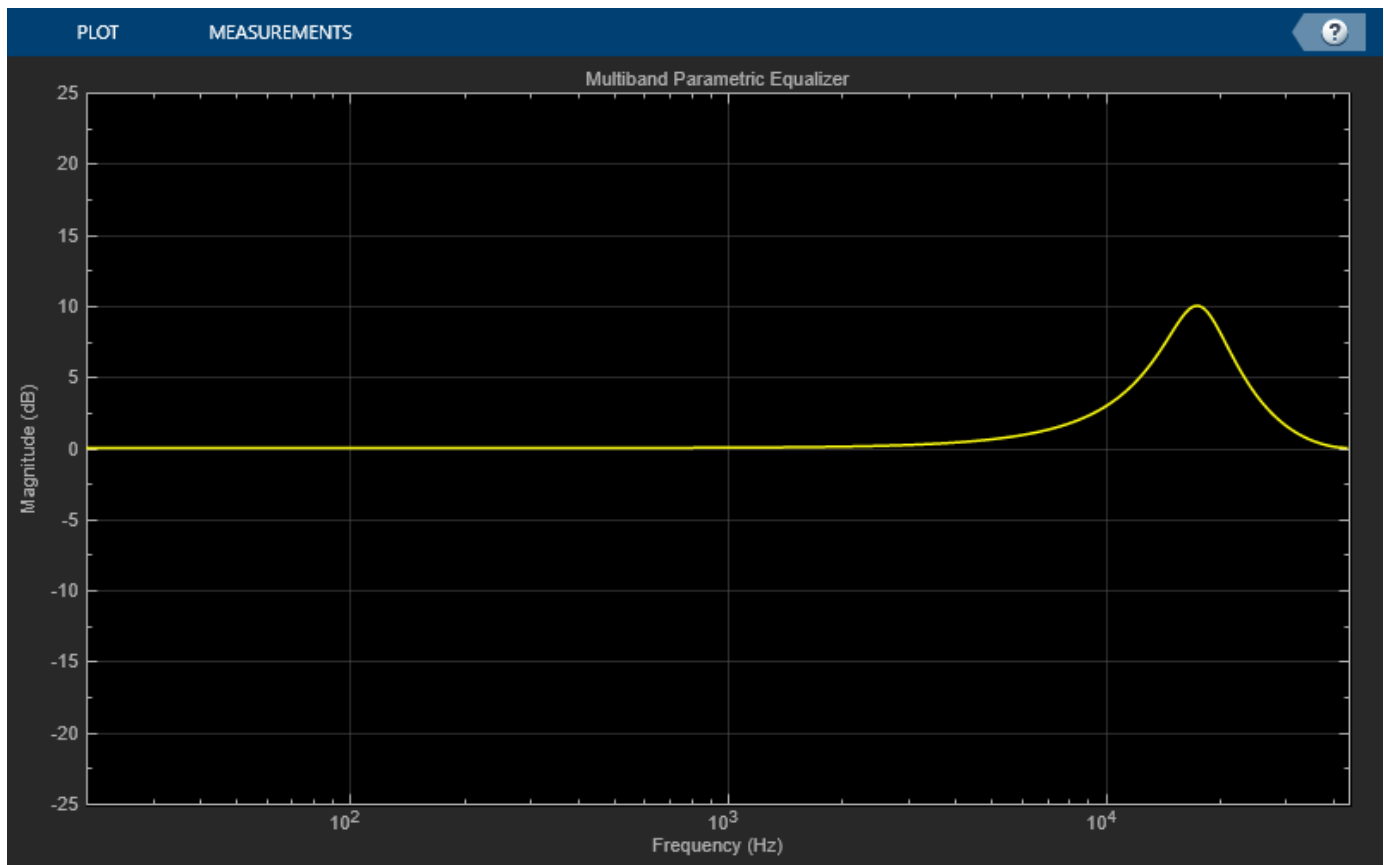
Create a one-band equalizer with `Oversample` set to `true`. Visualize the equalizer band as its center frequency approaches the Nyquist rate.

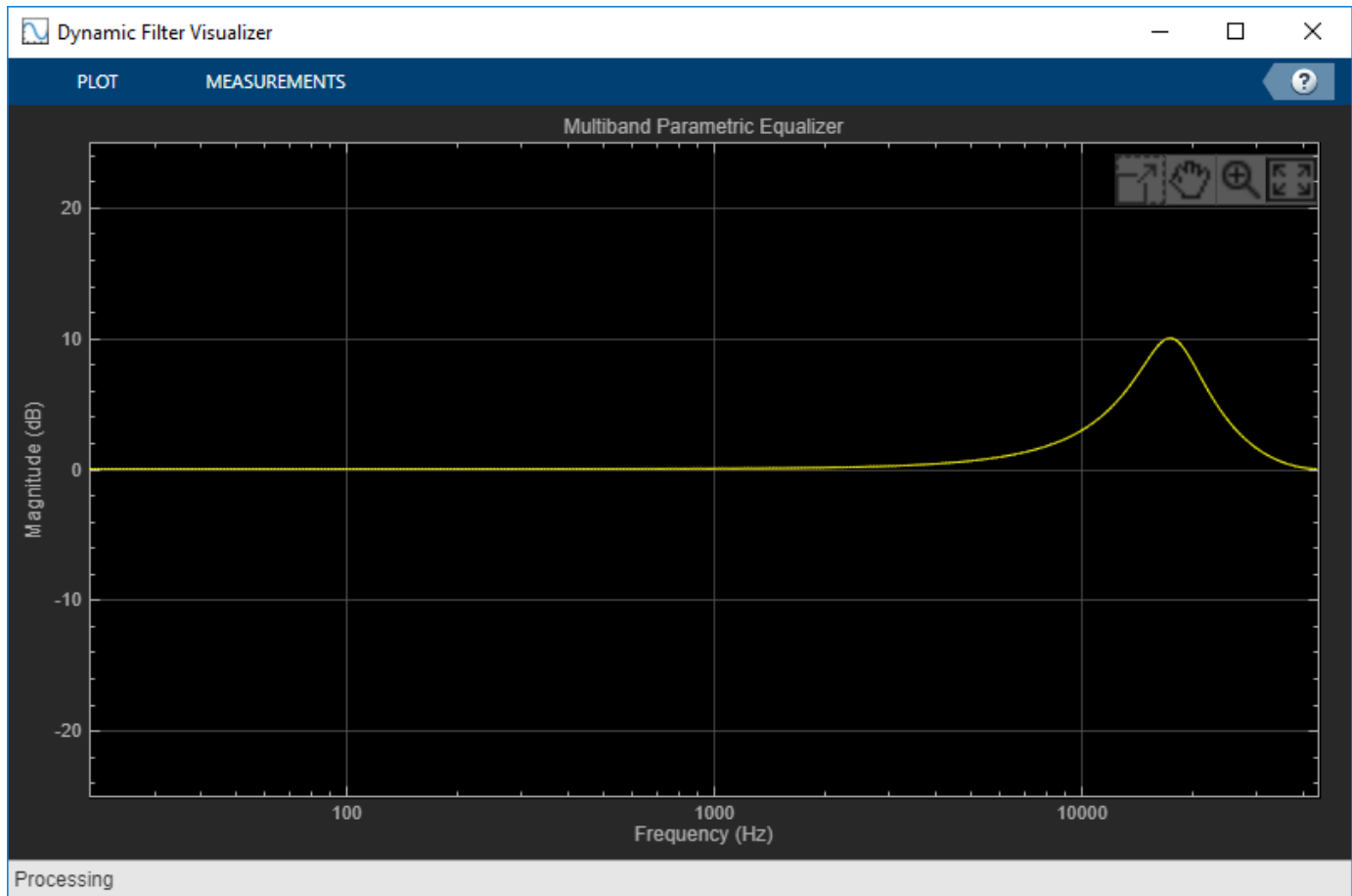
```
mPEQoversampled = multibandParametricEQ( ...
    'NumEQBands',1, ...
    'Frequencies',9.5e3, ...
    'PeakGains',10, ...
    'Oversample',true);
visualize(mPEQoversampled)
```





```
for i = 1:1000
    mPEQ0versampled.Frequencies = mPEQ0versampled.Frequencies + 8;
end
```





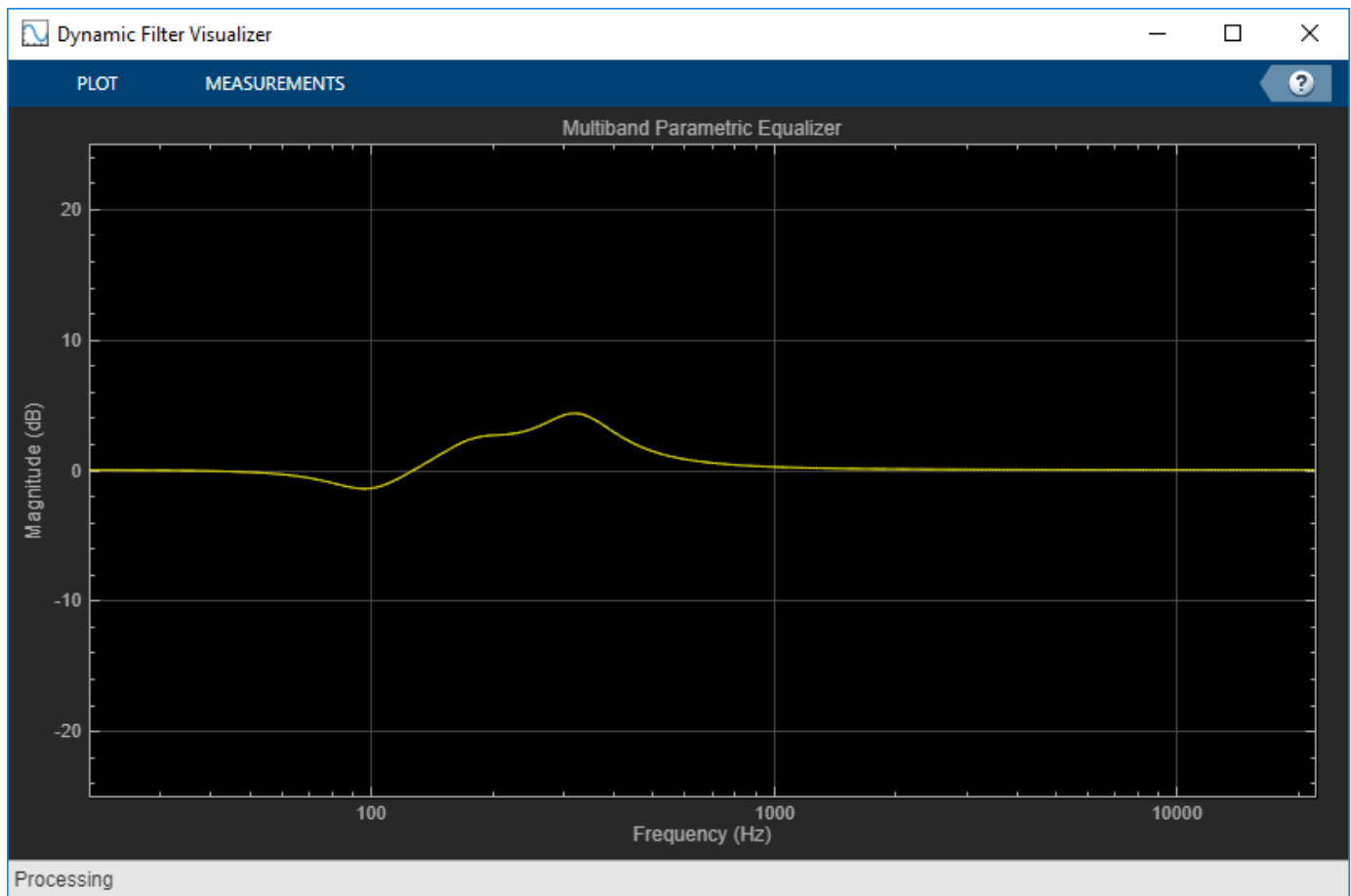
Warping is reduced.

Tune Multiband Parametric EQ Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create a `audioDeviceWriter` to write audio to your sound card. Create a `multibandParametricEQ` to process the audio data. Call `visualize` to plot the frequency response of the equalizer.

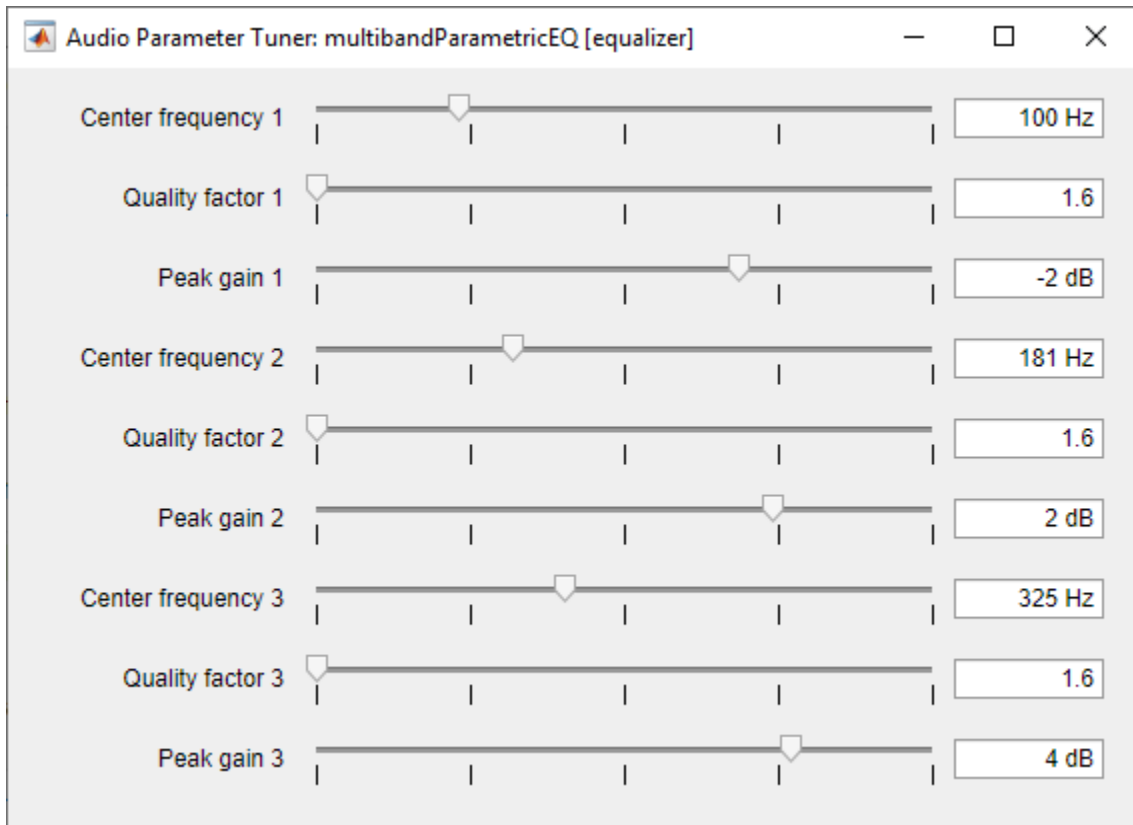
```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3','SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

equalizer = multibandParametricEQ('SampleRate',fileReader.SampleRate, 'PeakGains',[-2,2,4]);
visualize(equalizer)
```

Call `parameterTuner` to open a UI to tune parameters of the equalizer while streaming.

```
parameterTuner(equalizer)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply equalization.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the equalizer and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = equalizer(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(equalizer)
```

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

[designShelvingEQ](#) | [Single-Band Parametric EQ](#) | [Multiband Parametric EQ](#) | [designVarSlopeFilter](#) | [designParamEQ](#)

Topics

“Parametric Equalizer Design”

“Equalization”

Introduced in R2016a

visualize

Visualize magnitude response of multiband parametric equalizer

Syntax

```
visualize(mPEQ)
visualize(mPEQ,NFFT)
hvsz = visualize( ___ )
```

Description

`visualize(mPEQ)` plots the magnitude response of the `multibandParametricEQ` object `mPEQ`. The plot is updated automatically when properties of the object change.

`visualize(mPEQ,NFFT)` specifies an N-point FFT used to calculate the magnitude response.

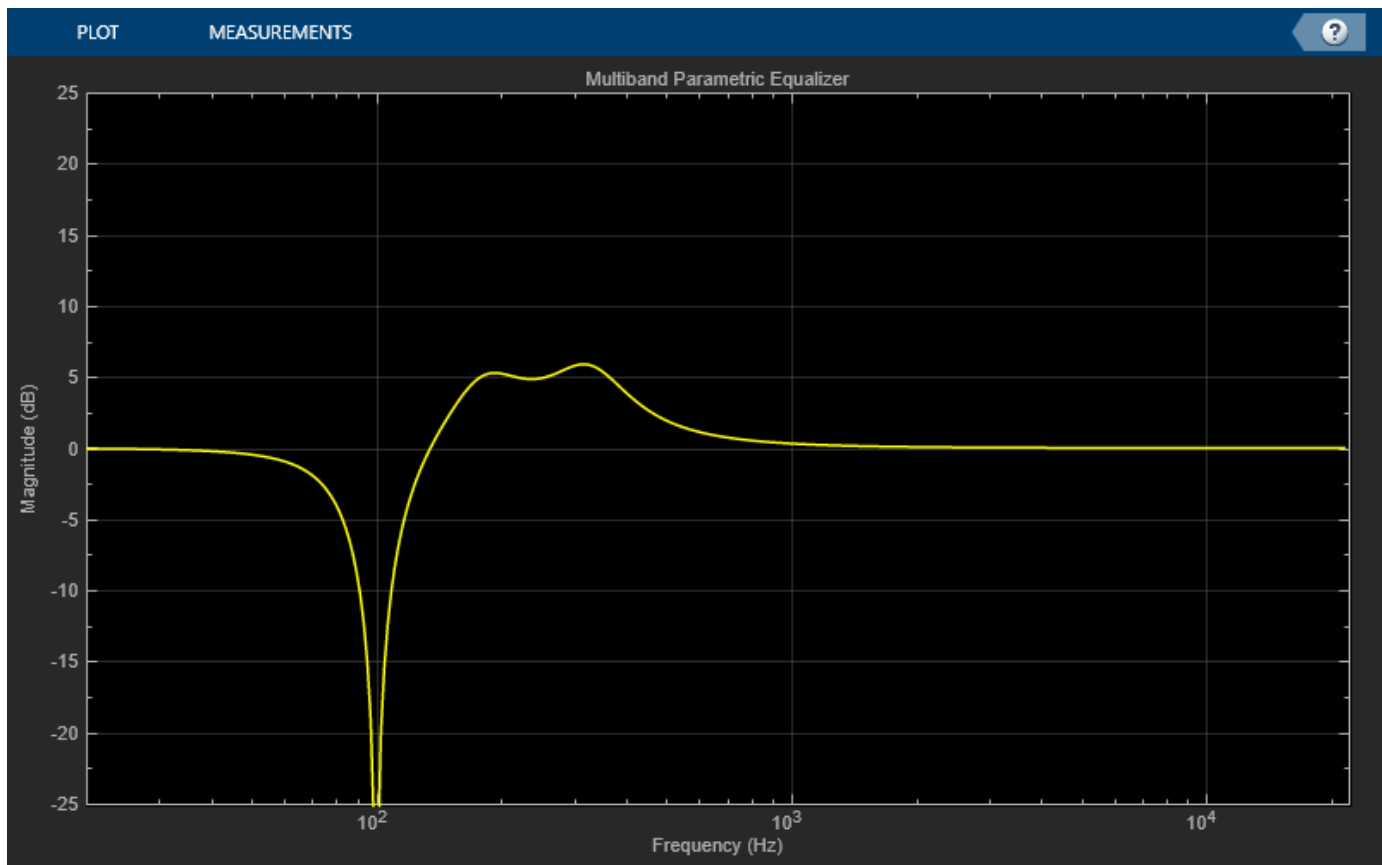
`hvsz = visualize(___)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when called with any of the previous syntaxes.

Examples

Specify a Nondefault Number of FFT Points

Create a `multibandParametricEQ` System object™, and then call `visualize` to plot the magnitude response using a 5096-point FFT.

```
mPEQ = multibandParametricEQ('PeakGains',[-inf,5,5]);
visualize(mPEQ,5096)
```



Input Arguments

mPEQ — Multiband parametric equalizer to visualize

object of `multibandParametricEQ` System object

Multiband parametric equalizer whose magnitude response you want to plot.

NFFT — N-point FFT

2048 (default) | positive scalar

Number of bins used to calculate the DFT, specified as a positive scalar.

Data Types: `single` | `double`

See Also

`multibandParametricEQ`

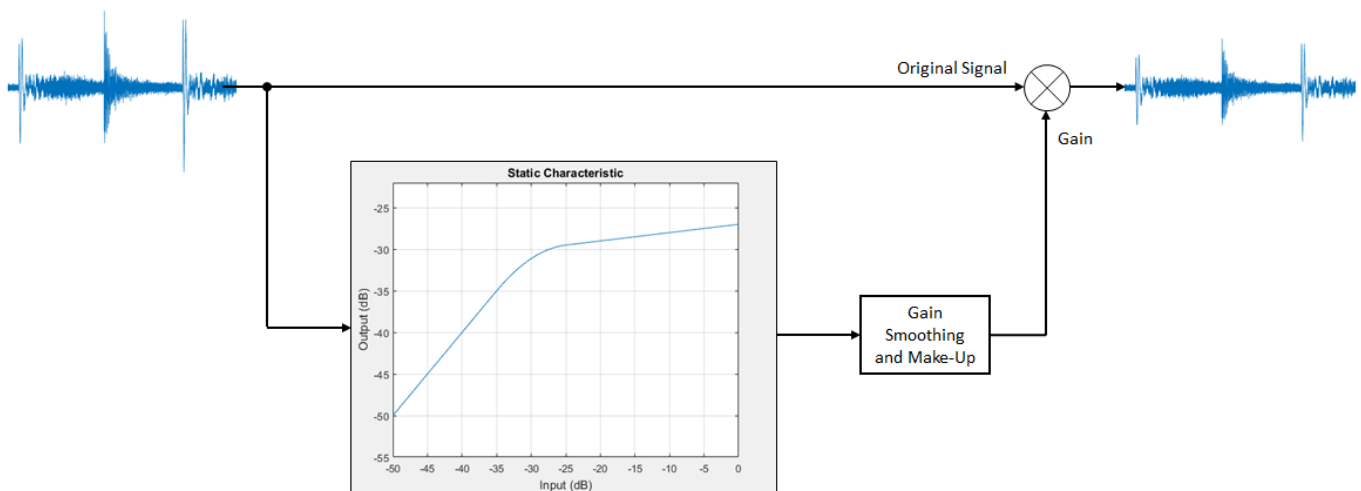
Introduced in R2016a

compressor

Dynamic range compressor

Description

The `compressor` System object performs dynamic range compression independently across each input channel. Dynamic range compression attenuates the volume of loud sounds that cross a given threshold. It uses specified attack and release times to achieve a smooth applied gain curve. Properties of the `compressor` System object specify the type of dynamic range compression.



To perform dynamic range compression:

- 1 Create the compressor object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
dRC = compressor
dRC = compressor(thresholdValue)
dRC = compressor(thresholdValue, ratioValue)
dRC = compressor( ___, Name, Value)
```

Description

`dRC = compressor` creates a System object, `dRC`, that performs dynamic range compression independently across each input channel over time.

`dRC = compressor(thresholdValue)` sets the `Threshold` property to `thresholdValue`.

`dRC = compressor(thresholdValue, ratioValue)` sets the `Ratio` property to `ratioValue`.

`dRC = compressor(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `dRC = compressor('AttackTime',0.01,'SampleRate',16000)` creates a System object, `dRC`, with a 10 ms attack time operating at a 16 kHz sample rate.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Threshold — Operation threshold (dB)

-10 (default) | real scalar

Operation threshold in dB, specified as a real scalar.

Operation threshold is the level above which gain is applied to the input signal.

Tunable: Yes

Data Types: `single` | `double`

Ratio — Compression ratio

5 (default) | real scalar

Compression ratio, specified as a real scalar greater than or equal to 1.

Compression ratio is the input/output ratio for signals that overshoot the operation threshold.

Assuming a hard knee characteristic and a steady-state input such that $x[n]$ dB > `Threshold`, the compression ratio is defined as $R = \frac{(x[n] - T)}{(y[n] - T)}$.

- R is the compression ratio.
- $x[n]$ is the input signal in dB.
- $y[n]$ is the output signal in dB.
- T is the threshold in dB.

Tunable: Yes

Data Types: `single` | `double`

KneeWidth — Knee width (dB)

0 (default) | real scalar

Knee width in dB, specified as a real scalar greater than or equal to 0.

Knee width is the transition area in the compression characteristic.

For soft knee characteristics, the transition area is defined by the relation

$$y = x + \frac{\left(\frac{1}{R} - 1\right) \times \left(x - T + \frac{W}{2}\right)^2}{2 \times W}$$

for the range $(2 \times |x - T|) \leq W$.

- y is the output level in dB.
- x is the input level in dB.
- R is the compression ratio.
- T is the threshold in dB.
- W is the knee width in dB.

Tunable: Yes

Data Types: `single` | `double`

AttackTime — Attack time (s)

`0.05` (default) | real scalar

Attack time in seconds, specified as a real scalar greater than or equal to 0.

Attack time is the time it takes the compressor gain to rise from 10% to 90% of its final value when the input goes above the threshold.

Tunable: Yes

Data Types: `single` | `double`

ReleaseTime — Release time (s)

`0.2` (default) | real scalar

Release time in seconds, specified as a real scalar greater than or equal to 0.

Release time is the time it takes the compressor gain to drop from 90% to 10% of its final value when the input goes below the threshold.

Tunable: Yes

Data Types: `single` | `double`

MakeUpGainMode — Make-up gain mode

`'Property'` (default) | `'Auto'`

Make-up gain mode, specified as `'Auto'` or `'Property'`.

- `'Auto'` -- Make-up gain is applied at the output of the dynamic range compressor such that a steady-state 0 dB input has a 0 dB output.
- `'Property'` -- Make-up gain is set to the value specified in the `MakeUpGain` property.

Tunable: No

Data Types: `char` | `string`

MakeUpGain — Make-up gain (dB)

0 (default) | real scalar

Make-up gain in dB, specified as a real scalar.

Make-up gain compensates for gain lost during compression. It is applied at the output of the dynamic range compressor.

Tunable: Yes

Dependencies

To enable this property, set `MakeUpGainMode` to 'Property'.

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

EnableSidechain — Enable sidechain input

false (default) | true

Enable sidechain input, specified as `true` or `false`. This property determines the number of available inputs on the compressor object.

- `false` -- Sidechain input is disabled and the `compressor` object accepts one input: the `audioIn` data to be compressed.
- `true` -- Sidechain input is enabled and the `compressor` object accepts two inputs: the `audioIn` data to be compressed and the sidechain input used to compute the compression gain.

The sidechain datatype and (frame) length must be the same as `audioIn`.

The number of channels of the sidechain input must be equal to the number of channels of `audioIn` or be equal to one. When the number of sidechain channels is one, the `gain` computed based on this channel is applied to all channels of `audioIn`. When the number of sidechain channels is equal to the number of channels in `audioIn`, the `gain` computed for each sidechain channel is applied to the corresponding channel of `audioIn`.

Tunable: No

Usage**Syntax**

```
audioOut = dRC(audioIn)
[audioOut,gain] = dRC(audioIn)
```

Description

`audioOut = dRC(audioIn)` performs dynamic range compression on the input signal, `audioIn`, and returns the compressed signal, `audioOut`. The type of dynamic range compression is specified by the algorithm and properties of the compressor System object, `dRC`.

`[audioOut,gain] = dRC(audioIn)` also returns the applied gain, in dB, at each input sample.

Input Arguments

audioIn — Audio input to compressor

matrix

Audio input to the compressor, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from compressor

matrix

Audio output from the compressor, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

gain — Gain applied by compressor (dB)

matrix

Gain applied by compressor, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to compressor

<code>visualize</code>	Visualize static characteristic of dynamic range controller
<code>staticCharacteristic</code>	Return static characteristic of dynamic range controller
<code>createAudioPluginClass</code>	Create audio plugin class that implements functionality of System object
<code>parameterTuner</code>	Tune object parameters while streaming

MIDI

<code>configureMIDI</code>	Configure MIDI connections between audio object and MIDI controller
<code>disconnectMIDI</code>	Disconnect MIDI controls from audio object
<code>getMIDIConnections</code>	Get MIDI connections of audio object

Common to All System Objects

clone	Create duplicate System object
isLocked	Determine if System object is in use
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
step	Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the compressor System object to user-facing parameters:

Property	Range	Mapping	Unit
Threshold	[-50, 0]	linear	dB
Ratio	[1, 50]	linear	none
KneeWidth	[0, 20]	linear	dB
AttackTime	[0, 4]	linear	seconds
ReleaseTime	[0, 4]	linear	seconds
MakeUpGain (available when you set MakeUpGainMode to 'Property')	[-10, 24]	linear	dB

Examples

Compress Audio Signal

Use dynamic range compression to attenuate the volume of loud sounds.

Set up the `dsp.AudioFileReader` and `audioDeviceWriter` System objects™.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader( ...
    'Filename','RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);
```

Set up the compressor to have a threshold of -15 dB, a ratio of 7, and a knee width of 5 dB. Use the sample rate of your audio file reader.

```
dRC = compressor(-15,7, ...
    'KneeWidth',5, ...
    'SampleRate',fileReader.SampleRate);
```

Set up the scope to visualize the original audio signal, the compressed audio signal, and the applied compressor gain.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanSource','Property','TimeSpan',1, ...
    'BufferLength',44100*4, ...
```

```

        'YLimits',[-1,1], ...
        'TimeSpanOverrunAction','Scroll', ...
        'ShowGrid',true, ...
        'LayoutDimensions',[2,1], ...
        'NumInputPorts',2, ...
        'Title', ...
        ['Original vs. Compressed Audio (top)' ...
        ' and Compressor Gain in dB (bottom)'];
scope.ActiveDisplay = 2;
scope.YLimits = [-4,0];
scope.YLabel = 'Gain (dB)';

```

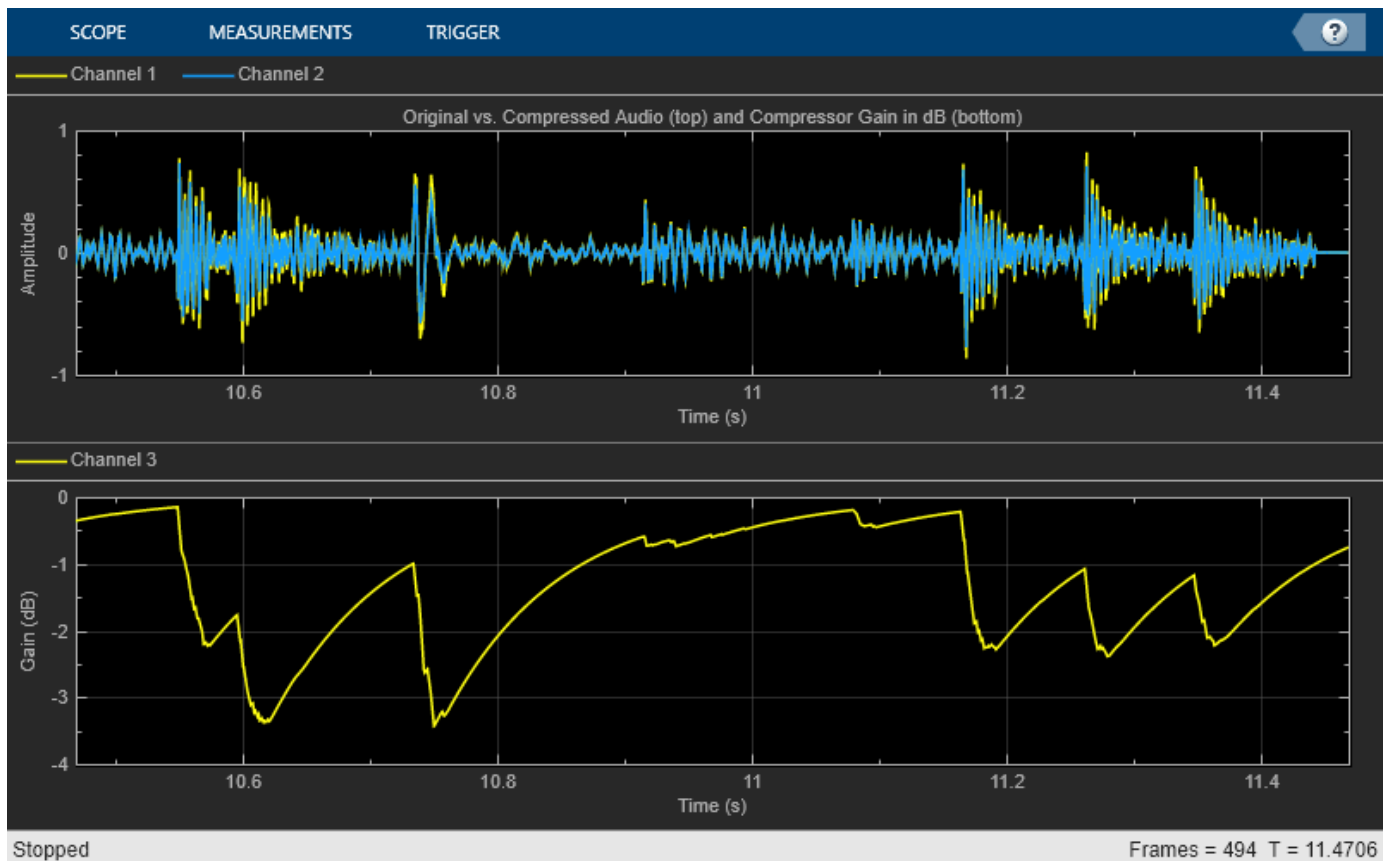
Play the processed audio and visualize it on the scope.

```

while ~isDone(fileReader)
    x = fileReader();
    [y,g] = dRC(x);
    deviceWriter(y);
    scope([x(:,1),y(:,1)],g(:,1))
end

release(dRC)
release(deviceWriter)
release(scope)

```



Compare Dynamic Range Limiter and Compressor

A dynamic range limiter is a special type of dynamic range compressor. In limiters, the level above an operational threshold is hard limited. In the simplest implementation of a limiter, the effect is equivalent to audio clipping. In compressors, the level above an operational threshold is lowered using a specified compression ratio. Using a compression ratio results in a smoother processed signal.

Compare Limiter and Compressor Applied to Sinusoid

Create a limiter System object™ and a compressor System object. Set the `AttackTime` and `ReleaseTime` properties of both objects to zero. Create an `audioOscillator` System object to generate a sinusoid with `Frequency` set to 5 and `Amplitude` set to 0.1.

```
dRL = limiter('AttackTime',0,'ReleaseTime',0);
dRC = compressor('AttackTime',0,'ReleaseTime',0);

osc = audioOscillator('Frequency',5,'Amplitude',0.1);
```

Create a time scope to visualize the generated sinusoid and the processed sinusoid.

```
scope = timescope( ...
    'SampleRate',osc.SampleRate, ...
    'TimeSpanSource','Property','TimeSpan',2, ...
    'BufferLength',osc.SampleRate*4, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2 1], ...
    'NumInputPorts',2);
scope.ActiveDisplay = 1;
scope.Title = 'Original Signal vs. Limited Signal';
scope.YLimits = [-1,1];
scope.ActiveDisplay = 2;
scope.Title = 'Original Signal vs. Compressed Signal';
scope.YLimits = [-1,1];
```

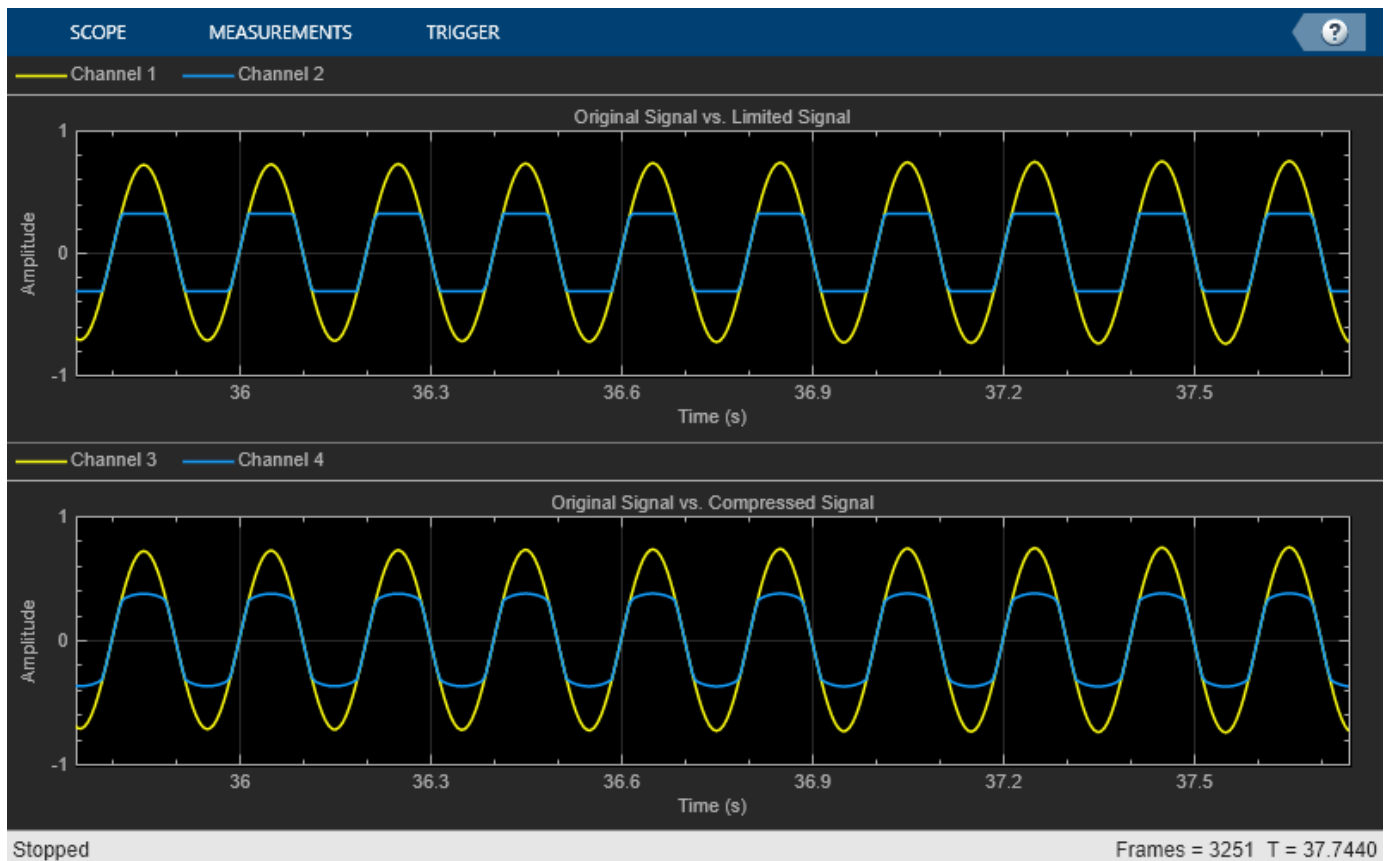
In an audio stream loop, visualize the original sinusoid and the sinusoid processed by a limiter and a compressor. Increment the amplitude of the original sinusoid to illustrate the effect.

```
while osc.Amplitude < 0.75
    x = osc();

    xLimited = dRL(x);
    xCompressed = dRC(x);

    scope([x xLimited],[x xCompressed]);

    osc.Amplitude = osc.Amplitude + 0.0002;
end
release(scope)
```



```
release(dRL)
release(dRC)
release(osc)
```

Compare Limiter and Compressor Applied to Audio Signal

Compare the effect of dynamic range limiters and compressors on a drum track. Create a `dsp.AudioFileReader` System object and a `audioDeviceWriter` System object to read audio from a file and write to your audio output device. To emphasize the effect of dynamic range control, set the operational threshold of the limiter and compressor to -20 dB.

```
dRL.Threshold = -20;
dRC.Threshold = -20;
```

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

Read successive frames from an audio file in a loop. Listen to and compare the effect of dynamic range limiting and dynamic range compression on an audio signal.

```
numFrames = 300;
```

```
fprintf('Now playing original signal...\n')
```

```
Now playing original signal...
```

```
for i = 1:numFrames
    x = fileReader();
```

```

        deviceWriter(x);
    end
    reset(fileReader);

    fprintf('Now playing limited signal...\n')
    Now playing limited signal...

    for i = 1:numFrames
        x = fileReader();
        xLimited = dRL(x);
        deviceWriter(xLimited);
    end
    reset(fileReader);

    fprintf('Now playing compressed signal...\n')
    Now playing compressed signal...

    for i = 1:numFrames
        x = fileReader();
        xCompressed = dRC(x);
        deviceWriter(xCompressed);
    end

    release(fileReader)
    release(deviceWriter)
    release(dRC)
    release(dRL)

```

Diminish Plosives from Speech Signal

Plosives are consonant sounds resulting from a sudden release of airflow. They are most pronounced in words beginning with *p*, *d*, and *g* sounds. Plosives can be emphasized by the recording process and are often displeasurable to hear. In this example, you minimize the plosives of a speech signal by applying highpass filtering and low-band compression.

Create a `dsp.AudioFileReader` object and a `audioDeviceWriter` object to read an audio signal from a file and write an audio signal to a device. Play the unprocessed signal. Then release the file reader and device writer.

```

fileReader = dsp.AudioFileReader('audioPlosives.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

while ~isDone(fileReader)
    audioIn = fileReader();
    deviceWriter(audioIn);
end
release(deviceWriter)
release(fileReader)

```

Design a highpass filter with a steep rolloff of all frequencies below 120 Hz. Use a `dsp.BiquadFilter` object to implement the highpass filter design. Create a crossover filter with one crossover at 250 Hz. The crossover filter enables you to separate the band of interest for processing. Create a dynamic range compressor to compress the dynamic range of plosive sounds. To apply no make-up gain, set the `MakeUpGainMode` to "Property" and use the default 0 dB

MakeUpGain property value. Create a time scope to visualize the processed and unprocessed audio signal.

```
[B,A] = designVarSlopeFilter(48,120/(fileReader.SampleRate/2),"hi");
biquadFilter = dsp.BiquadFilter( ...
    "SOSMatrixSource","Input port", ...
    "ScaleValuesInputPort",false);

crossFilt = crossoverFilter( ...
    "SampleRate",fileReader.SampleRate, ...
    "NumCrossovers",1, ...
    "CrossoverFrequencies",250, ...
    "CrossoverSlopes",48);

dRCompressor = compressor( ...
    "Threshold",-35, ...
    "Ratio",10, ...
    "KneeWidth",20, ...
    "AttackTime",1e-4, ...
    "ReleaseTime",3e-1, ...
    "MakeUpGainMode","Property", ...
    "SampleRate",fileReader.SampleRate);

scope = timescope( ...
    "SampleRate",fileReader.SampleRate, ...
    "TimeSpanSource","property","TimeSpan",3, ...
    "BufferLength",fileReader.SampleRate*3*2, ...
    "YLimits",[-1 1], ...
    "ShowGrid",true, ...
    "ShowLegend",true, ...
    "ChannelNames",{ 'Original', 'Processed' });
```

In an audio stream loop:

- 1 Read in a frame of the audio file.
- 2 Apply highpass filtering using your biquad filter.
- 3 Split the audio signal into two bands.
- 4 Apply dynamic range compression to the lower band.
- 5 Remix the channels.
- 6 Write the processed audio signal to your audio device for listening.
- 7 Visualize the processed and unprocessed signals on a time scope.

As a best practice, release your objects once done.

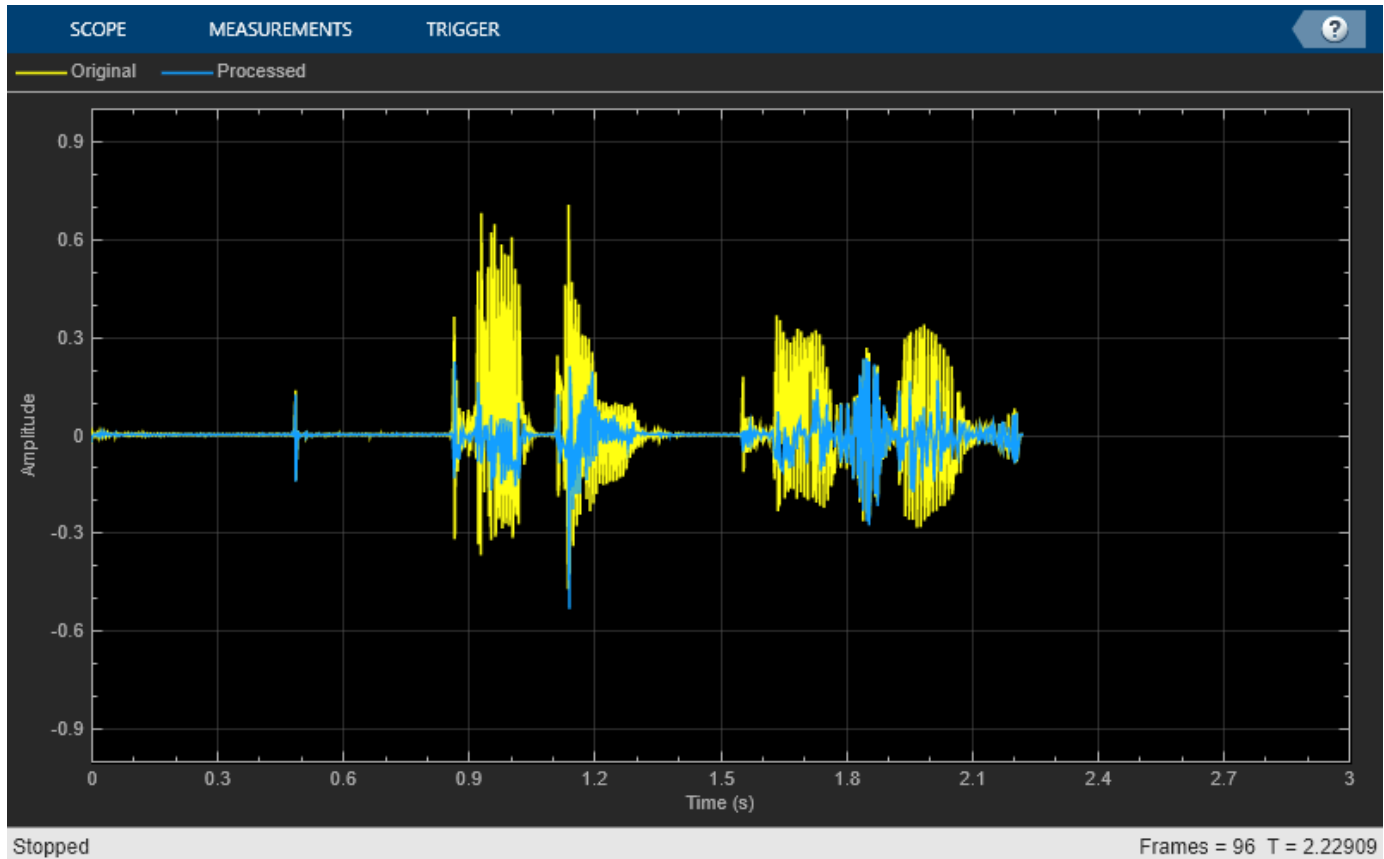
```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioIn = biquadFilter(audioIn,B,A);
    [band1,band2] = crossFilt(audioIn);
    band1compressed = dRCompressor(band1);
    audioOut = band1compressed + band2;
    deviceWriter(audioOut);
    scope([audioIn audioOut])
end
```

As a best practice, release your objects once done.


```

release(deviceWriter)
release(fileReader)
release(crossFilt)
release(dRCCompressor)
release(scope)

```



Tune Compressor Parameters

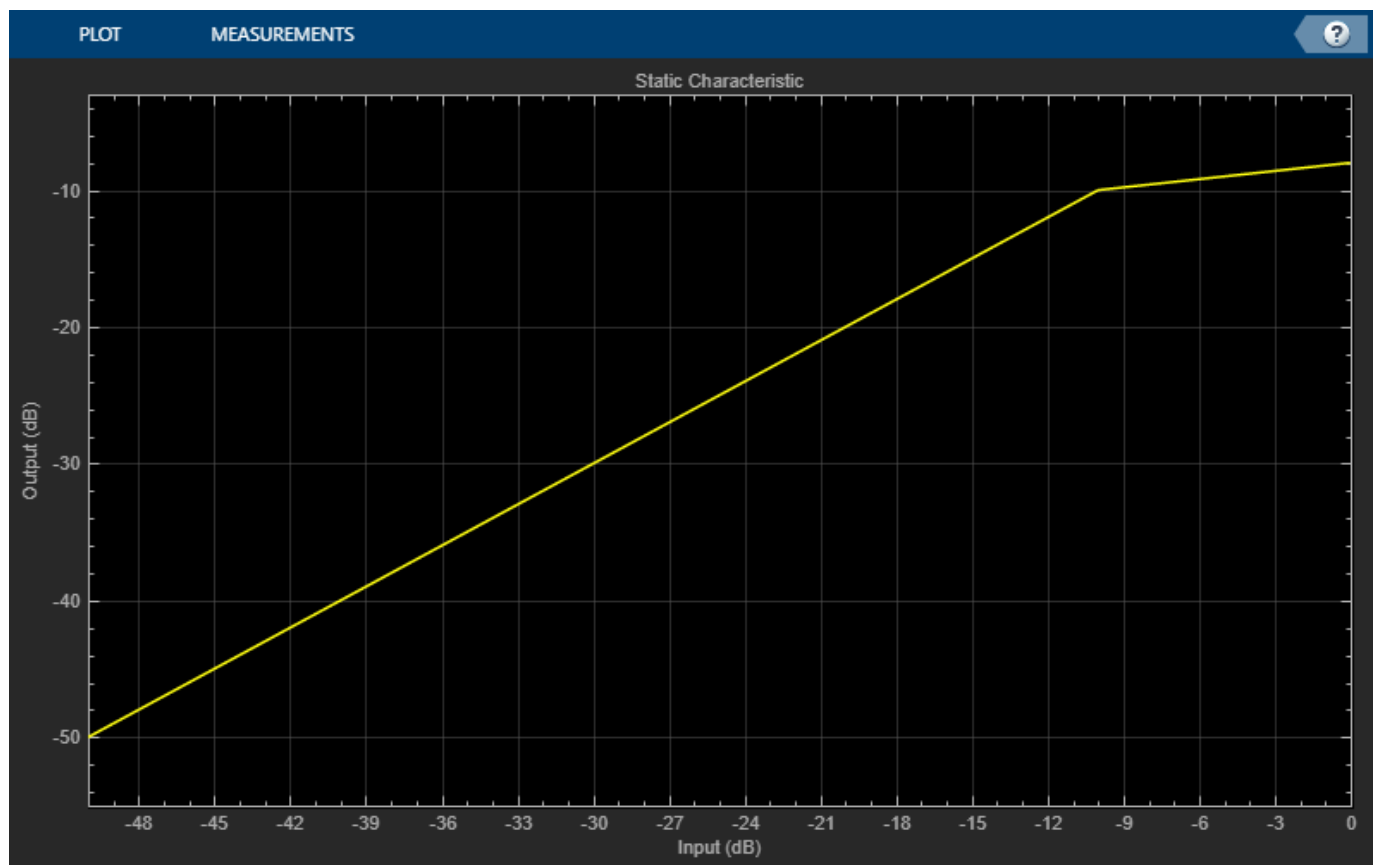
Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create a compressor to process the audio data. Call `visualize` to plot the static characteristic of the compressor.

```

frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

dRC = compressor('SampleRate',fileReader.SampleRate);
visualize(dRC)

```

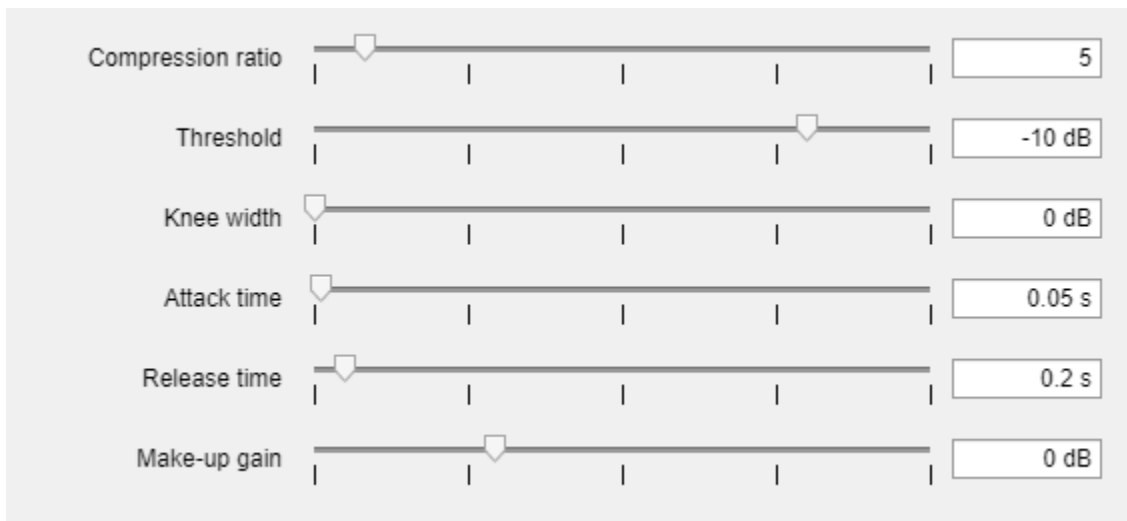


Create a timescope to visualize the original and processed audio.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanSource','property',...
    'TimeSpan',1, ...
    'BufferLength',fileReader.SampleRate*4, ...
    'YLimits',[-1,1], ...
    'TimeSpanOverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2,1], ...
    'NumInputPorts',2, ...
    'Title','Original vs. Compressed Audio (top) and Compressor Gain in dB (bottom)');
scope.ActiveDisplay = 2;
scope.YLimits = [-4,0];
scope.YLabel = 'Gain (dB)';
```

Call parameterTuner to open a UI to tune parameters of the compressor while streaming.

```
parameterTuner(dRC)
```



In an audio stream loop:

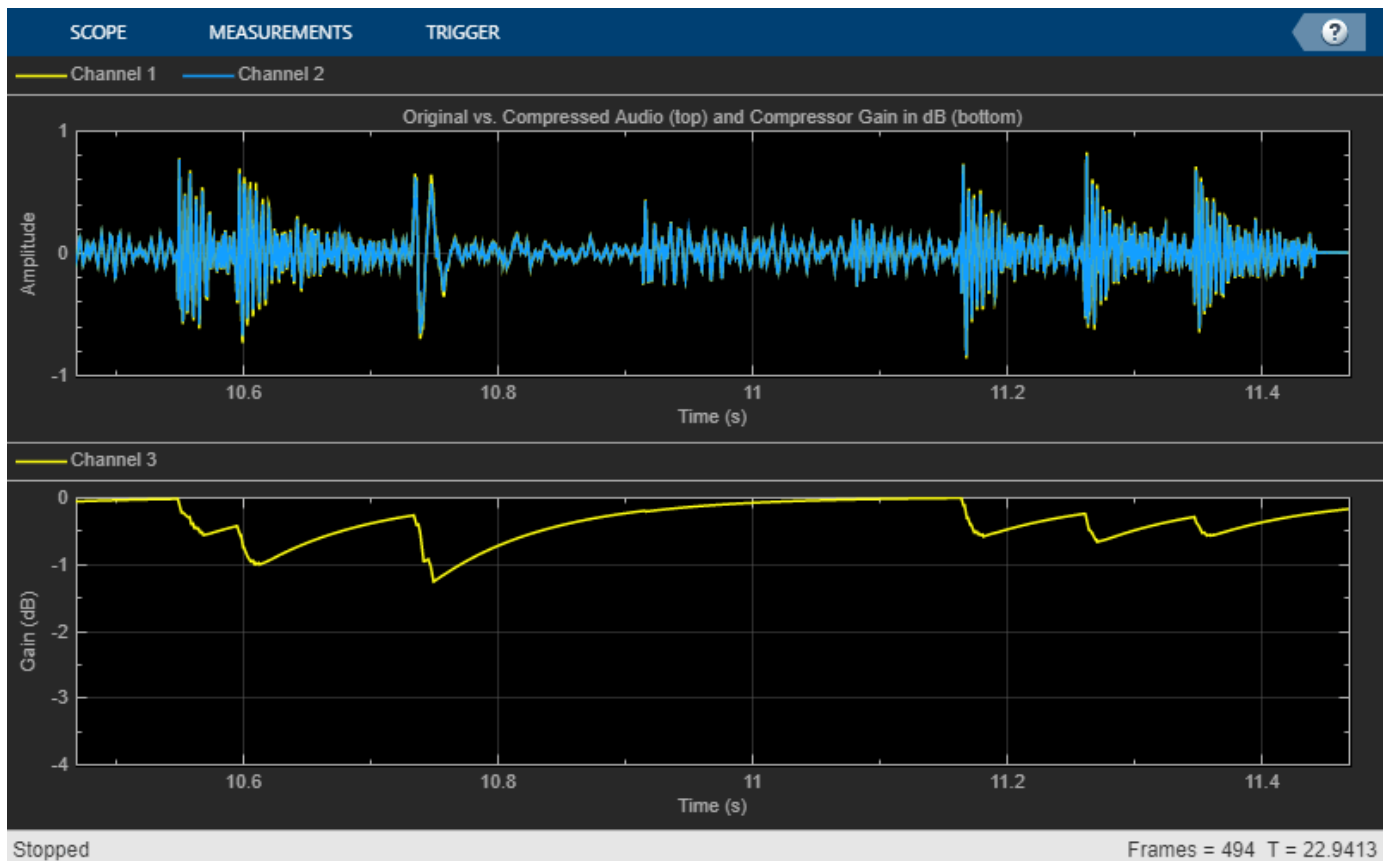
- 1 Read in a frame of audio from the file.
- 2 Apply dynamic range compression.
- 3 Write the frame of audio to your audio device for listening.
- 4 Visualize the original audio, the processed audio, and the gain applied.

While streaming, tune parameters of the dynamic range compressor and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    [audioOut,g] = dRC(audioIn);
    deviceWriter(audioOut);
    scope([audioIn(:,1),audioOut(:,1)],g(:,1));
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(dRC)
release(scope)
```



Sidechain Ducking with Compressor

Use the “EnableSidechain” on page 3-0 input of a `compressor` object to reduce the amplitude level of a separate audio signal. The sidechain signal controls the compression on the input audio signal. When the sidechain signal exceeds the compressor “Threshold” on page 3-0, the compressor activates and decreases the amplitude of the input signal. When the sidechain signal level falls below the threshold, the audio input returns to its uncompressed amplitude.

Prepare Audio Files

In this section, you resample and zero-pad a speech file to use as input to the `EnableSidechain` property of your `compressor` object.

Read in an audio signal. Resample it to match the sample rate of the input audio signal (44.1 kHz).

```
targetFs = 44100;
[originalSpeech,originalFs] = audioread('Rainbow-16-8-mono-114secs.wav');
resampledSpeech = resample(originalSpeech,targetFs,originalFs);
```

Pad the beginning of the resampled signal with 10 seconds worth of zeros. This allows the input audio signal to be clearly heard before any compression is applied.

```
resampledSpeech = [zeros(10*targetFs,1);resampledSpeech];
```

Normalize the amplitude to avoid potential clipping.

```
resampledSpeech = resampledSpeech ./ max(resampledSpeech);
```

Write the resampled, zero-padded, and normalized sidechain signal to a file.

```
audiowrite('resampledSpeech.wav', resampledSpeech, targetFs);
```

Construct Audio Objects

Construct a `dsp.AudioFileReader` object for the input and sidechain signals. Using the “ReadRange” property of the `AudioFileReader`, select the second verse of the input signal and the first 26.5 seconds of the sidechain signal for playback. To allow the script to run indefinitely, change the `playbackCount` variable from 1 to `Inf`.

```
inputAudio = 'SoftGuitar-44p1_mono-10mins.ogg';
sidechainAudio = 'resampledSpeech.wav';
playbackCount = 1;
inputAudioAFR = dsp.AudioFileReader(inputAudio, 'PlayCount', playbackCount, 'ReadRange', ...
    [115*targetFs round(145.4*targetFs)]);
sidechainAudioAFR = dsp.AudioFileReader(sidechainAudio, 'PlayCount', playbackCount, ...
    'ReadRange', [1 round(26.5*targetFs)]);
```

Construct a compressor object. Use a high “Ratio” on page 3-0 , a fast “AttackTime” on page 3-0 , and a moderately slow “ReleaseTime” on page 3-0 . These settings are ideal for voice-over work. The fast attack time ensures that the input audio is compressed almost immediately after the sidechain signal surpasses the compressor threshold. The slow release time ensures the compression on the input audio lasts through any potential short silent regions in the sidechain signal.

```
iAmYourCompressor = compressor('EnableSidechain', true, ...
    'SampleRate', targetFs, ...
    'Threshold', -40, ...
    'Ratio', 8, ...
    'AttackTime', 0.01, ...
    'ReleaseTime', 1.5);
```

Construct an `audioDeviceWriter` object to play the sidechain and input signals.

```
afw = audioDeviceWriter;
```

Construct a `timescope` object to view the uncompressed input signal, the sidechain signal, as well as the compressed input signal.

```
scope = timescope('NumInputPorts', 3, ...
    'SampleRate', targetFs, ...
    'TimeSpanSource', 'property', ...
    'TimeSpan', 5, ...
    'TimeDisplayOffset', 0, ...
    'LayoutDimensions', [3 1], ...
    'BufferLength', targetFs*15, ...
    'TimeSpanOverrunAction', 'Scroll', ...
    'YLimits', [-1 1], ...
    'ShowGrid', true, ...
    'Title', 'Uncompressed Input Audio - Guitar');
scope.ActiveDisplay = 2;
scope.YLimits = [-1 1];
scope.Title = 'Sidechain Audio - Speech';
scope.ShowGrid = true;
```

```
scope.ActiveDisplay = 3;  
scope.YLimits = [-1 1];  
scope.ShowGrid = true;  
scope.Title = 'Compressed Input Audio - Guitar';
```

Create Audio Streaming Loop

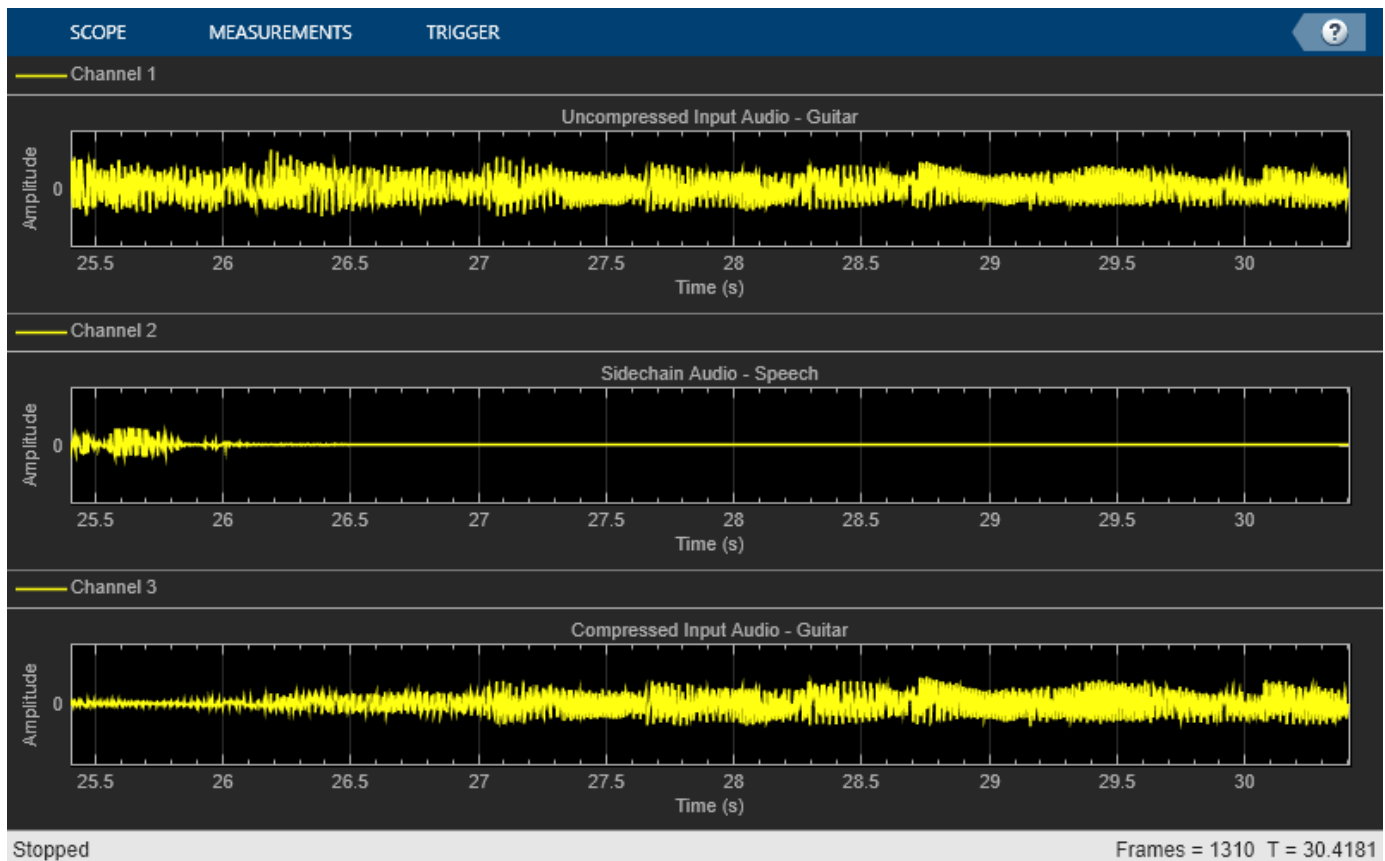
Read in a frame of audio from your input and sidechain signals. Process your input and sidechain signals with your compressor object. Playback your processed audio signals and display the audio data using a timescope object.

The top panel of your timescope displays the uncompressed input audio signal and the middle panel displays the sidechain audio signal. The bottom panel displays the compressed input audio signal. Notice the amplitudes of the signals in the top and bottom panels are identical until the sidechain signal begins. Once the sidechain signal activates, the amplitude of the signal in the bottom panel is compressed. Once the sidechain signal ends, the amplitude of the signal in the bottom panel begins to return to its uncompressed level.

```
while ~isDone(inputAudioAFR)  
    inputAudioFrame = inputAudioAFR();  
    sideChainAudioFrame = sidechainAudioAFR();  
    compressorOutput = iAmYourCompressor(inputAudioFrame,sideChainAudioFrame);  
    afw(sideChainAudioFrame+compressorOutput);  
    scope(inputAudioFrame,sideChainAudioFrame,compressorOutput);  
end
```

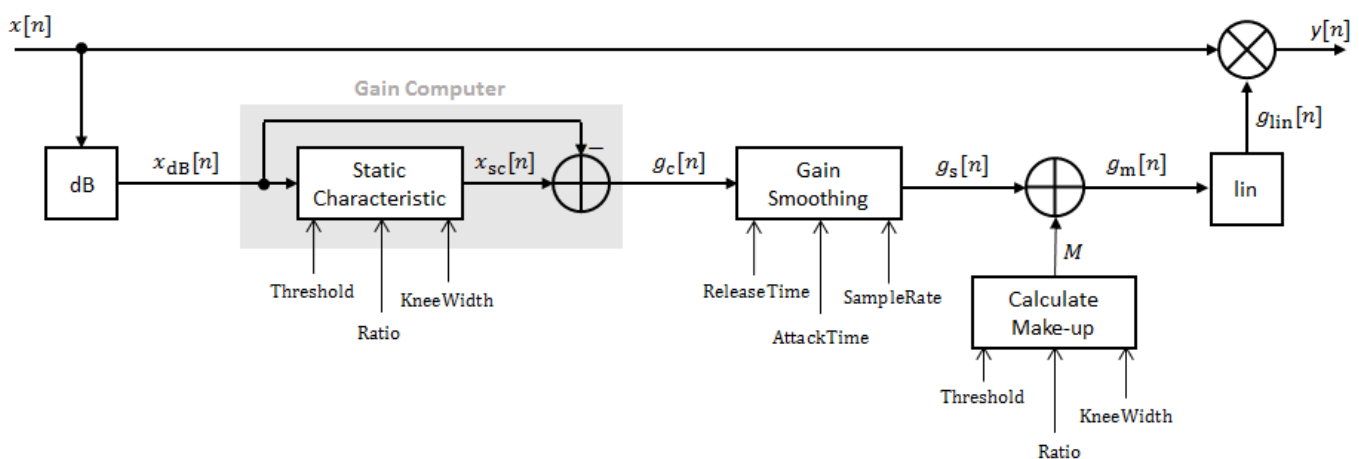
Release your objects.

```
release(inputAudioAFR)  
release(sidechainAudioAFR)  
release(iAmYourCompressor)  
release(afw)  
release(scope)
```



Algorithms

The compressor System object processes a signal frame by frame and element by element.



Convert Input Signal to dB

The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$

Gain Computer

$x_{dB}[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range compressor to attenuate gain that is above the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} + \frac{\left(\frac{1}{R} - 1\right)\left(x_{dB} - T + \frac{W}{2}\right)^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ T + \frac{(x_{dB} - T)}{R} & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases} ,$$

where T is the threshold, R is the ratio, and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < T \\ T + \frac{(x_{dB} - T)}{R} & x_{dB} \geq T \end{cases}$$

The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$

Gain Smoothing

$g_c[n]$ is smoothed using specified attack and release time properties:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n], & g_c[n] \leq g_s[n-1] \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n], & g_c[n] > g_s[n-1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{F_s \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_s \times T_R}\right).$$

T_A is the attack time period, specified by the `AttackTime` property. T_R is the release time period, specified by the `ReleaseTime` property. F_s is the input sampling rate, specified by the `SampleRate` property.

Calculate and Apply Make-up Gain

If `MakeUpGainMode` is set to the default 'Auto', the make-up gain is calculated as the negative of the computed gain for a 0 dB input,

$$M = -x_{sc}|_{x_{dB} = 0}.$$

Given a steady-state input of 0 dB, this configuration achieves a steady-state output of 0 dB. The make-up gain is determined by the Threshold, Ratio, and KneeWidth properties. It does not depend on the input signal.

The make-up gain, M , is added to the smoothed gain, $g_s[n]$:

$$g_m[n] = g_s[n] + M$$

Calculate and Apply Linear Gain

The calculated gain in dB, $g_m[n]$, is translated to a linear domain:

$$g_{lin}[n] = 10^{\left(\frac{g_m[n]}{20}\right)}$$

The output of the dynamic range compressor is given as

$$y[n] = x[n] \times g_{lin}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial and Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

noiseGate | expander | limiter | Compressor

Topics

"Dynamic Range Control"

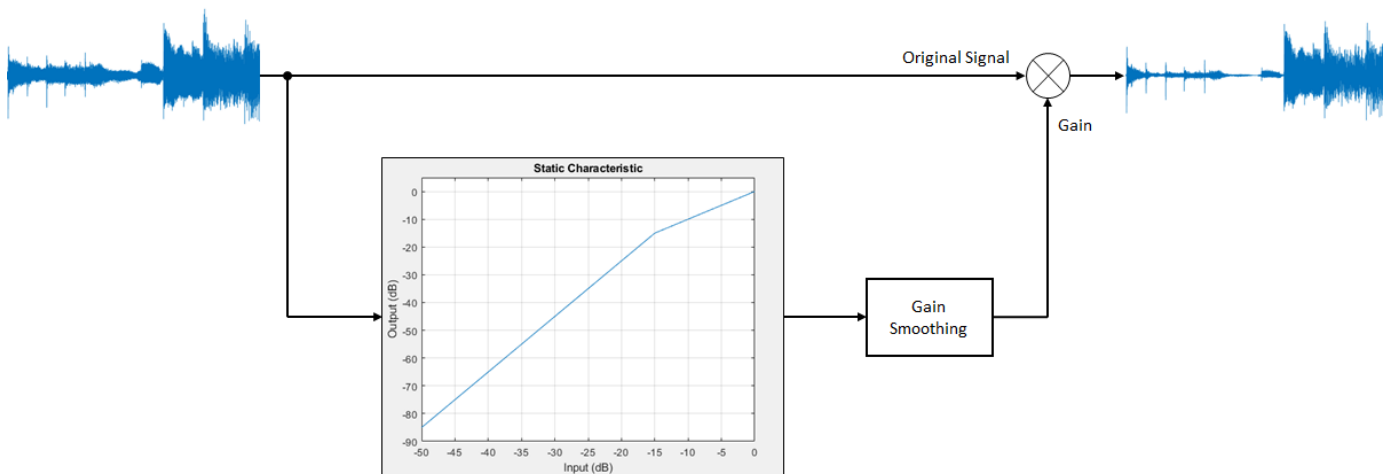
Introduced in R2016a

expander

Dynamic range expander

Description

The expander System object performs dynamic range expansion independently across each input channel. Dynamic range expansion attenuates the volume of quiet sounds below a given threshold. It uses specified attack, release, and hold times to achieve a smooth applied gain curve. Properties of the expander System object specify the type of dynamic range expansion.



To perform dynamic range expansion:

- 1 Create the expander object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
dRE = expander
dRE = expander(thresholdValue)
dRE = expander(thresholdValue, ratioValue)
dRE = expander( ___, Name, Value)
```

Description

`dRE = expander` creates a System object, `dRE`, that performs dynamic range expansion independently across each input channel.

`dRE = expander(thresholdValue)` sets the `Threshold` property to `thresholdValue`.

`dRE = expander(thresholdValue, ratioValue)` sets the `Ratio` property to `ratioValue`.

`dRE = expander(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `dRE = expander('AttackTime', 0.01, 'SampleRate', 16000)` creates a `System` object, `dRE`, with a 0.01 second attack time and a 16 kHz sample rate.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

Threshold — Operation threshold (dB)

-10 (default) | real scalar

Operation threshold in dB, specified as a real scalar.

Operation threshold is the level below which gain is applied to the input signal.

Tunable: Yes

Data Types: `single` | `double`

Ratio — Expansion ratio

5 (default) | real scalar

Expansion ratio, specified as a real scalar greater than or equal to 1.

Expansion ratio is the input/output ratio for signals that undershoot the operation threshold.

Assuming a hard knee characteristic and a steady-state input such that $x[n]$ dB < `thresholdValue`, the expansion ratio is defined as $R = \frac{(y[n] - T)}{(x[n] - T)}$.

- R is the expansion ratio.
- $y[n]$ is the output signal in dB.
- $x[n]$ is the input signal in dB.
- T is the threshold in dB.

Tunable: Yes

Data Types: `single` | `double`

KneeWidth — Knee width (dB)

0 (default) | real scalar

Knee width in dB, specified as a real scalar greater than or equal to 0.

Knee width is the transition area in the expansion characteristic.

For soft knee characteristics, the transition area is defined by the relation

$$y = x + \frac{(1 - R) \times \left(x - T - \frac{W}{2}\right)^2}{(2 \times W)}$$

for the range $(2 \times |x - T|) \leq W$.

- y is the output level in dB.
- x is the input level in dB.
- R is the expansion ratio.
- T is the threshold in dB.
- W is the knee width in dB.

Tunable: Yes

Data Types: `single` | `double`

AttackTime — Attack time (s)

0.05 (default) | real scalar

Attack time in seconds, specified as a real scalar greater than or equal to 0.

Attack time is the time it takes the expander gain to rise from 10% to 90% of its final value when the input goes below the threshold.

Tunable: Yes

Data Types: `single` | `double`

ReleaseTime — Release time (s)

0.2 (default) | real scalar

Release time in seconds, specified as a real scalar greater than or equal to 0.

Release time is the time it takes the expander gain to drop from 90% to 10% of its final value when the input goes above the threshold.

Tunable: Yes

Data Types: `single` | `double`

HoldTime — Hold time (s)

0.05 (default) | real scalar

Hold time in seconds, specified as a real scalar greater than or equal to 0.

Hold time is the period for which the (negative) gain is held before starting to decrease towards its steady state value when the input level drops below the threshold.

Tunable: Yes

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: YesData Types: `single` | `double`**EnableSidechain — Enable sidechain input**`false` (default) | `true`

Enable sidechain input, specified as `true` or `false`. This property determines the number of available inputs on the expander object.

- `false` -- Sidechain input is disabled and the expander object accepts one input: the `audioIn` data to be expanded.
- `true` -- Sidechain input is enabled and the expander object accepts two inputs: the `audioIn` data to be expanded and the sidechain input used to compute the expander gain.

The sidechain datatype and (frame) length must be the same as `audioIn`.

The number of channels of the sidechain must be equal to the number of channels of `audioIn` or be equal to one. When the number of sidechain channels is one, the gain computed based on this channel is applied to all channels of `audioIn`. When the number of sidechain channels is equal to the number of channels in `audioIn`, the gain computed for each sidechain channel is applied to the corresponding channel of `audioIn`.

Tunable: No**Usage****Syntax**

```
audioOut = dRE(audioIn)
[audioOut,gain] = dRE(audioIn)
```

Description

`audioOut = dRE(audioIn)` performs dynamic range expansion on the input signal, `audioIn`, and returns the expanded signal, `audioOut`. The type of dynamic range expansion is specified by the algorithm and properties of the expander System object, `dRE`.

`[audioOut,gain] = dRE(audioIn)` also returns the applied gain, in dB, at each input sample.

Input Arguments**audioIn — Audio input to expander**`matrix`

Audio input to the expander, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from expander

matrix

Audio output from the expander, returned as a matrix the same size as audioIn.

Data Types: single | double

gain — Gain applied by expander (dB)

matrix

Gain applied by expander, returned as a matrix the same size as audioIn.

Data Types: single | double

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named obj, use this syntax:

```
release(obj)
```

Specific to expander

visualize	Visualize static characteristic of dynamic range controller
staticCharacteristic	Return static characteristic of dynamic range controller
createAudioPluginClass	Create audio plugin class that implements functionality of System object
parameterTuner	Tune object parameters while streaming

MIDI

configureMIDI	Configure MIDI connections between audio object and MIDI controller
disconnectMIDI	Disconnect MIDI controls from audio object
getMIDIConnections	Get MIDI connections of audio object

Common to All System Objects

clone	Create duplicate System object
isLocked	Determine if System object is in use
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
step	Run System object algorithm

The createAudioPluginClass and configureMIDI functions map tunable properties of the expander System object to user-facing parameters:

Property	Range	Mapping	Unit
Threshold	[-140, 0]	linear	dB
Ratio	[1, 50]	linear	none
KneeWidth	[0, 20]	linear	dB
AttackTime	[0, 4]	linear	seconds

Property	Range	Mapping	Unit
ReleaseTime	[0, 4]	linear	seconds
HoldTime	[0, 4]	linear	seconds

Examples

Expand Audio Signal

Use dynamic range expansion to attenuate background noise from an audio signal.

Set up the `dsp.AudioFileReader` and `audioDeviceWriter` System objects.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader( ...
    'Filename','Counting-16-44p1-mono-15secs.wav', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);
```

Corrupt the audio signal with Gaussian noise. Play the audio.

```
while ~isDone(fileReader)
    x = fileReader();
    xCorrupted = x + (1e-2/4)*randn(frameLength,1);
    deviceWriter(xCorrupted);
end

release(fileReader)
```

Set up the expander with a threshold of -40 dB, a ratio of 10, an attack time of 0.01 seconds, a release time of 0.02 seconds, and a hold time of 0 seconds. Use the sample rate of your audio file reader.

```
dRE = expander(-40,10, ...
    'AttackTime',0.01, ...
    'ReleaseTime',0.02, ...
    'HoldTime',0, ...
    'SampleRate',fileReader.SampleRate);
```

Set up the scope to visualize the signal before and after dynamic range expansion.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanOverrunAction','Scroll', ...
    'TimeSpanSource','property','TimeSpan',16, ...
    'BufferLength',1.5e6, ...
    'YLimits',[-1 1], ...
    'ShowGrid',true, ...
    'ShowLegend',true, ...
    'Title','Corrupted vs. Expanded Audio');
```

Play the processed audio and visualize it on the scope.

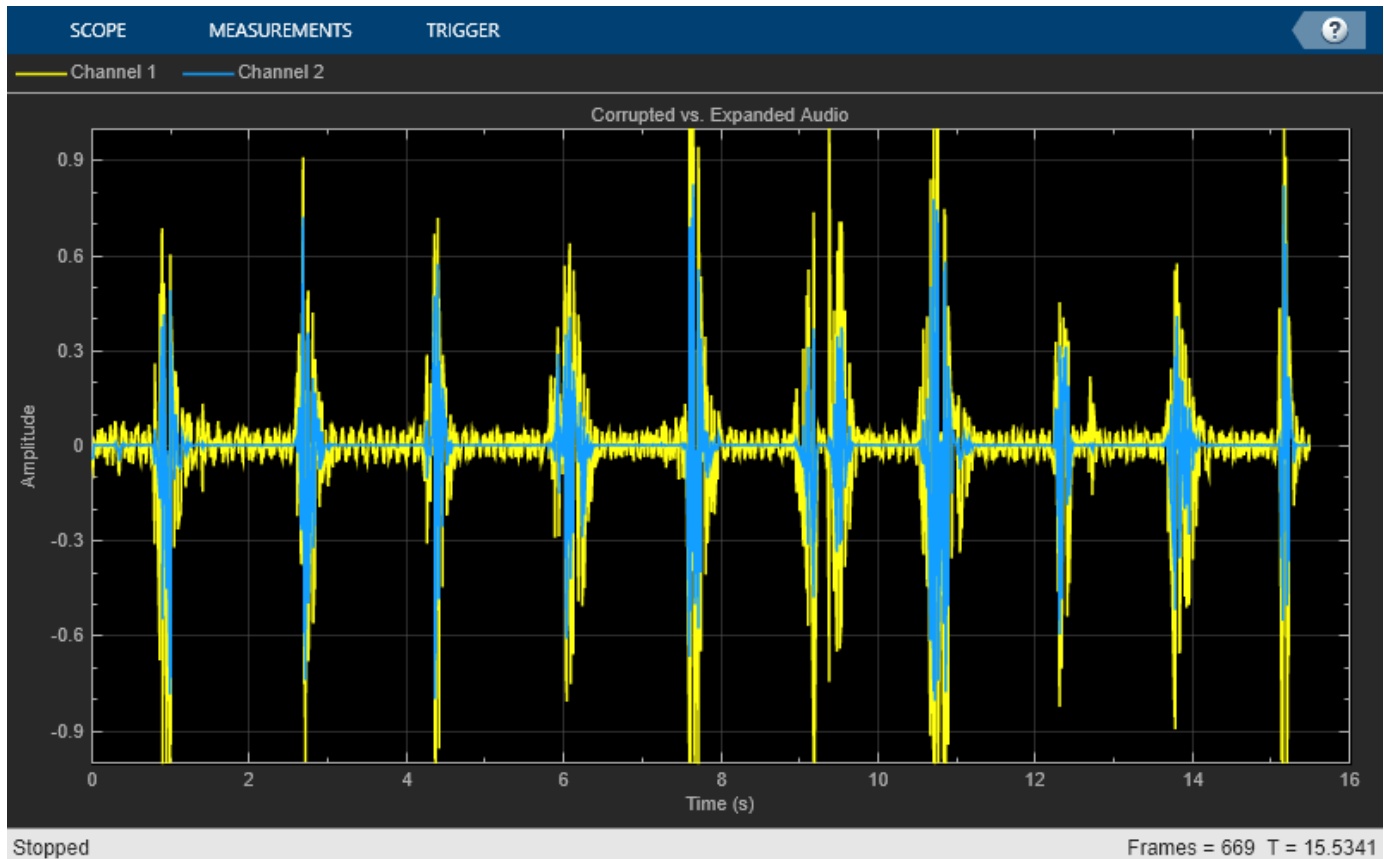
```
while ~isDone(fileReader)
    x = fileReader();
    xCorrupted = x + (1e-2/4)*randn(frameLength,1);
```

```

    y = dRE(xCorrupted);
    deviceWriter(y);
    scope([xCorrupted,y])
end

release(fileReader)
release(dRE)
release(deviceWriter)
release(scope)

```



Apply Split-Band De-Essing

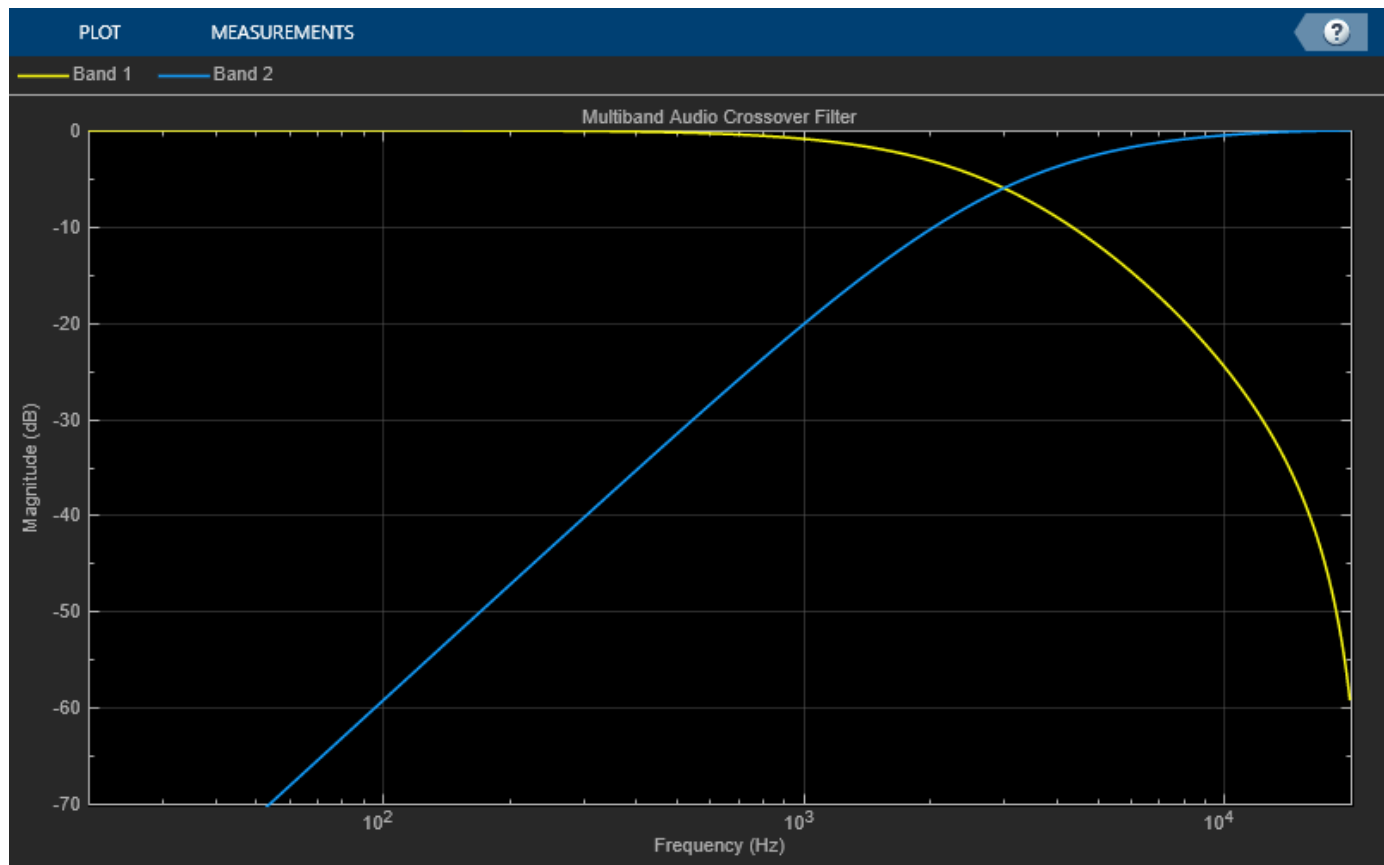
De-essing is the process of diminishing sibilant sounds in an audio signal. Sibilance refers to the *s*, *z*, and *sh* sounds in speech, which can be disproportionately emphasized during recording. *es* sounds fall under the category of unvoiced speech with all consonants and have a higher frequency than voiced speech. In this example, you apply split-band de-essing to a speech signal by separating the signal into high and low frequencies, applying an expander to diminish the sibilant frequencies, and then remixing the channels.

Create a `dsp.AudioFileReader` object and an `audioDeviceWriter` object to read from a sound file and write to an audio device. Listen to the unprocessed signal. Then release the file reader and device writer.


```
fileReader = dsp.AudioFileReader( ...  
    'Sibilance.wav');  
deviceWriter = audioDeviceWriter;  
  
while ~isDone(fileReader)  
    audioIn = fileReader();  
    deviceWriter(audioIn);  
end  
  
release(deviceWriter)  
release(fileReader)
```

Create an expander System object to de-ess the audio signal. Set the sample rate of the expander to the sample rate of the audio file. Create a two-band crossover filter with a crossover of 3000 Hz. Sibilance is usually found in this range. Set the crossover slope to 12. Plot the frequency response of the crossover filter to confirm your design visually.

```
dRExpander = expander( ...  
    'Threshold',-50, ...  
    'AttackTime',0.05, ...  
    'ReleaseTime',0.05, ...  
    'HoldTime',0.005, ...  
    'SampleRate',fileReader.SampleRate);  
  
crossFilt = crossoverFilter( ...  
    'NumCrossovers',1, ...  
    'CrossoverFrequencies',3000, ...  
    'CrossoverSlopes',12);  
visualize(crossFilt)
```



Create a timescope object to visualize the original and processed audio signals.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'TimeSpanSource','Property','TimeSpan',4, ...
    'BufferLength',fileReader.SampleRate*8, ...
    'YLimits',[-1 1], ...
    'ShowGrid',true, ...
    'ShowLegend',true, ...
    'ChannelNames',{'Original','Processed'});
```

In an audio stream loop:

- 1 Read in a frame of the audio file.
- 2 Split the audio signal into two bands.
- 3 Apply dynamic range expansion to the upper band.
- 4 Remix the channels.
- 5 Write the processed audio signal to your audio device for listening.
- 6 Visualize the processed and unprocessed signals on a time scope.

As a best practice, release your objects once done.

```
while ~isDone(fileReader)
    audioIn = fileReader();
```

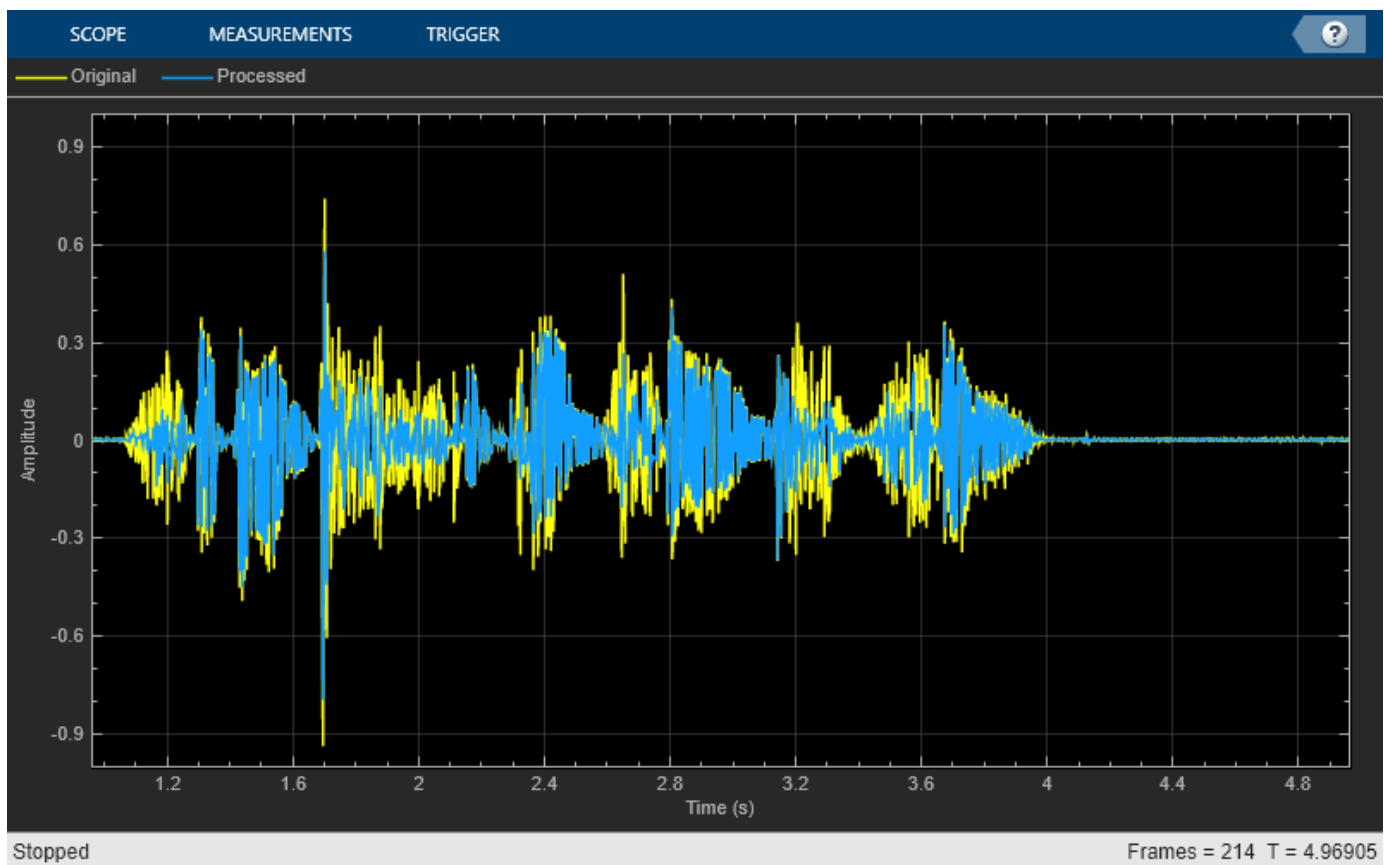
```

[band1,band2] = crossFilt(audioIn);
band2processed = dRExpander(band2);
procAudio = band1 + band2processed;
deviceWriter(procAudio);

scope([audioIn procAudio]);
end

release(deviceWriter)
release(fileReader)
release(scope)

```



```

release(crossFilt)
release(dRExpander)

```

Tune Expander Parameters

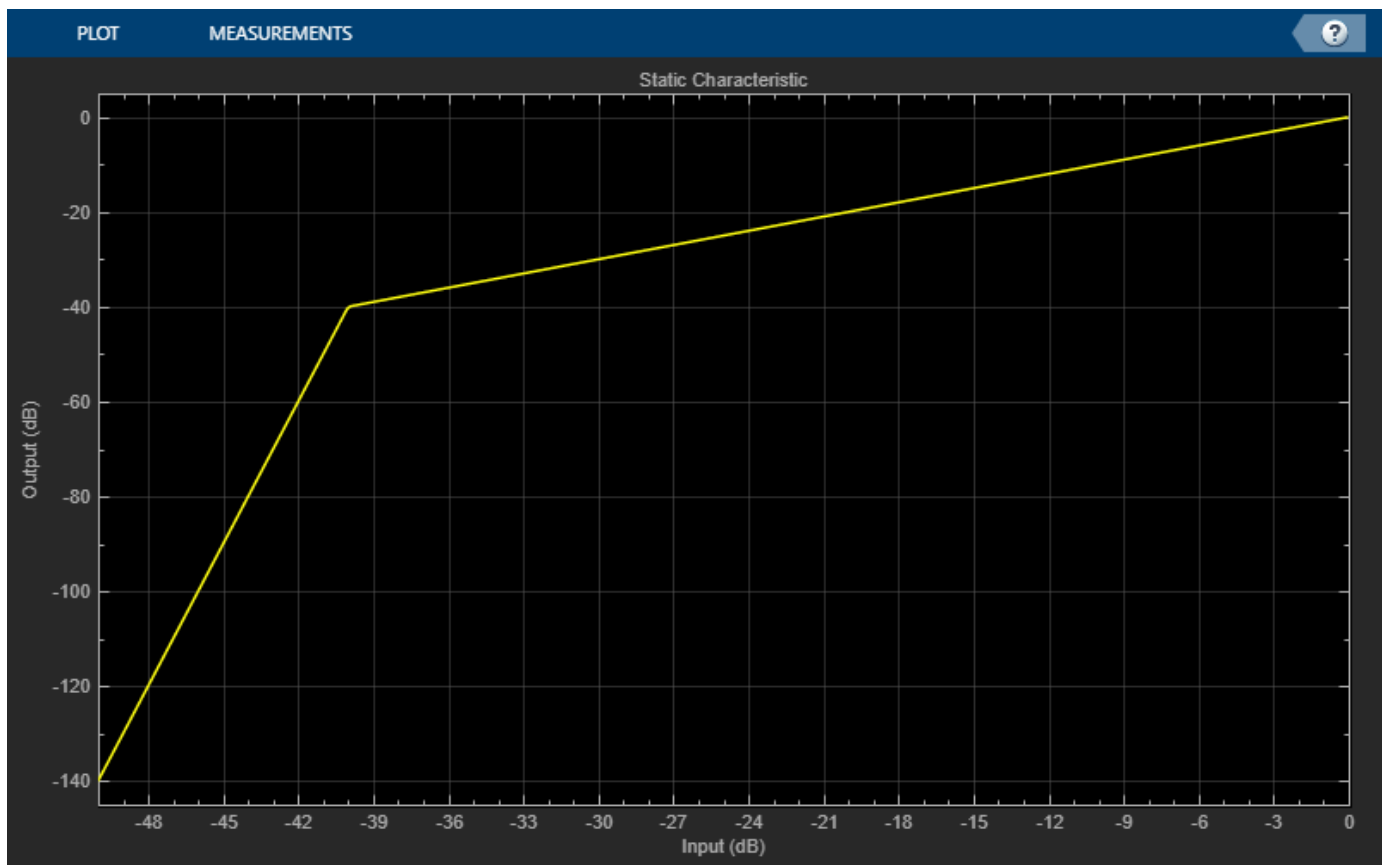
Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create a `audioDeviceWriter` to write audio to your sound card. Create a `expander` to process the audio data. Call `visualize` to plot the static characteristic of the expander.

```

frameLength = 1024;
fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

dRE = expander(-40,10, ...
    'AttackTime',0.01, ...
    'ReleaseTime',0.02, ...
    'HoldTime',0, ...
    'SampleRate',fileReader.SampleRate);
visualize(dRE)

```



Create a timescope to visualize the original and processed audio.

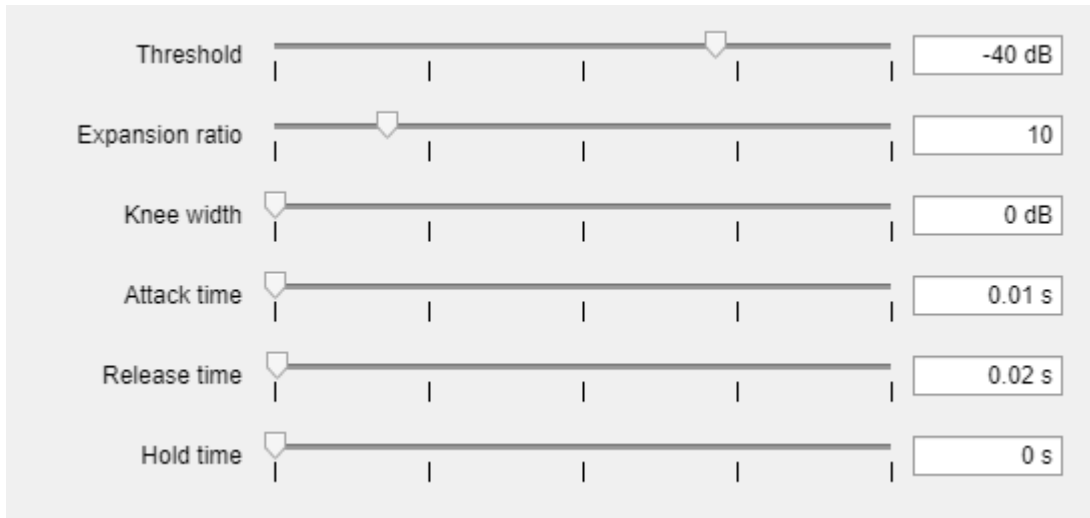
```

scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanSource','property','TimeSpan',1, ...
    'BufferLength',fileReader.SampleRate*4, ...
    'YLimits',[-1,1], ...
    'TimeSpanOverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2,1], ...
    'NumInputPorts',2, ...
    'Title','Original vs. Processed Audio (top) and Applied Gain in dB (bottom)');
scope.ActiveDisplay = 2;
scope.YLimits = [-300,0];
scope.YLabel = 'Gain (dB)';

```

Call `parameterTuner` to open a UI to tune parameters of the expander while streaming.

`parameterTuner(dRE)`



In an audio stream loop:

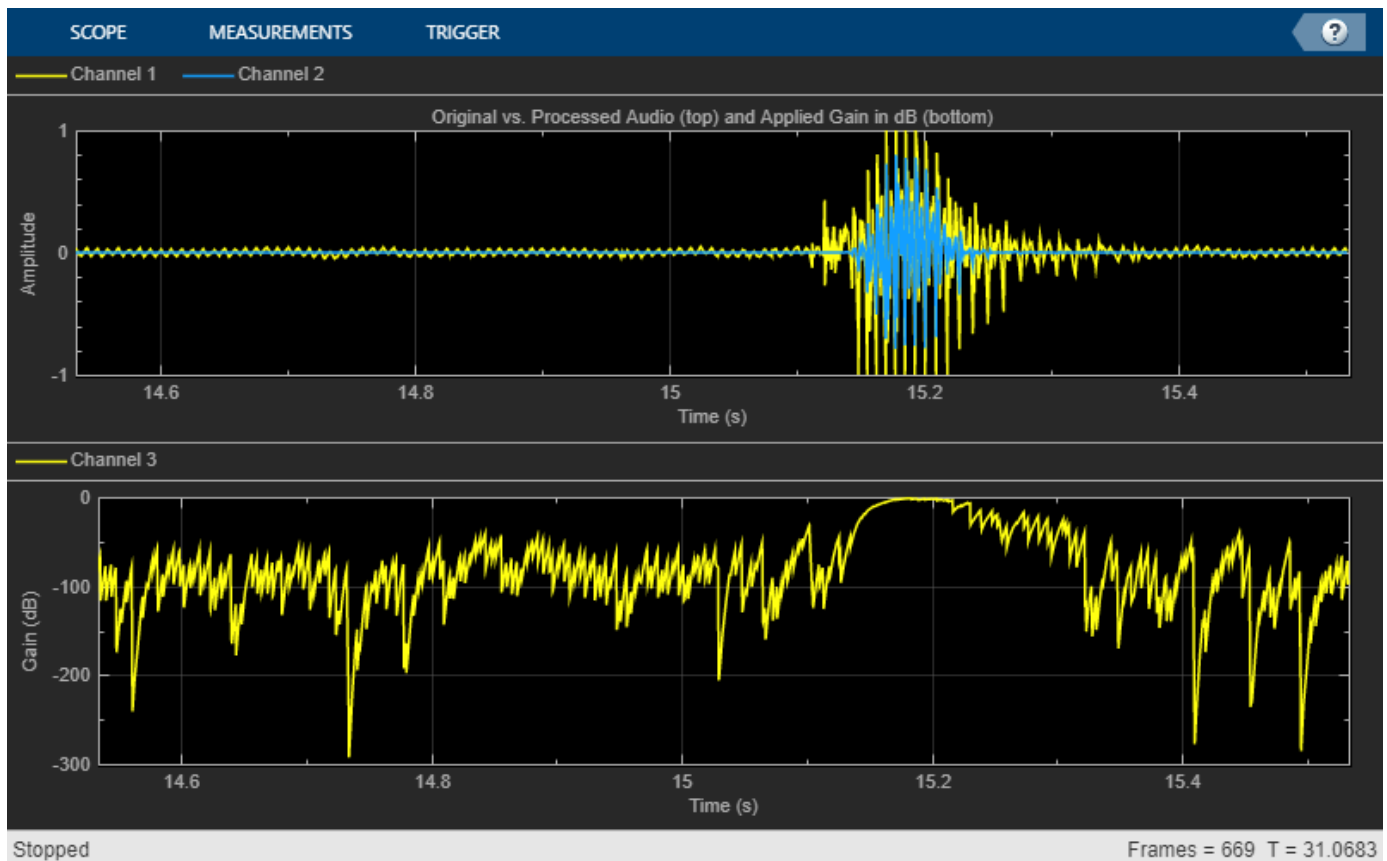
- 1 Read in a frame of audio from the file.
- 2 Apply dynamic range expansion.
- 3 Write the frame of audio to your audio device for listening.
- 4 Visualize the original and processed audio, and the gain applied.

While streaming, tune parameters of the dynamic range expander and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    [audioOut,g] = dRE(audioIn);
    deviceWriter(audioOut);
    scope([audioIn(:,1),audioOut(:,1)],g(:,1));
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects when done.

```
release(deviceWriter)
release(fileReader)
release(dRE)
release(scope)
```



Sidechain Dynamic Range Expansion

Use the “EnableSidechain” on page 3-0 input of an expander object to emulate an electronic drum controller, also known as a *multipad*. This technique is common in recording studio production and creates interesting changes to the timbre of an instrument. The sidechain signal controls the expansion on the input signal. Sidechain expansion decreases the amplitude of the input signal when the sidechain signal falls below the “Threshold” on page 3-0 of the expander.

Prepare Audio Files

Convert the sidechain signal from stereo to mono.

```
[expanderSideChainStereo,Fs] = audioread('FunkyDrums-44p1-stereo-25secs.mp3');
expanderSideChainMono = (expanderSideChainStereo(:,1) + expanderSideChainStereo(:,2)) / 2;
```

Write the converted sidechain signal to a file.

```
audiowrite('convertedSidechainSig.wav',expanderSideChainMono,Fs);
```

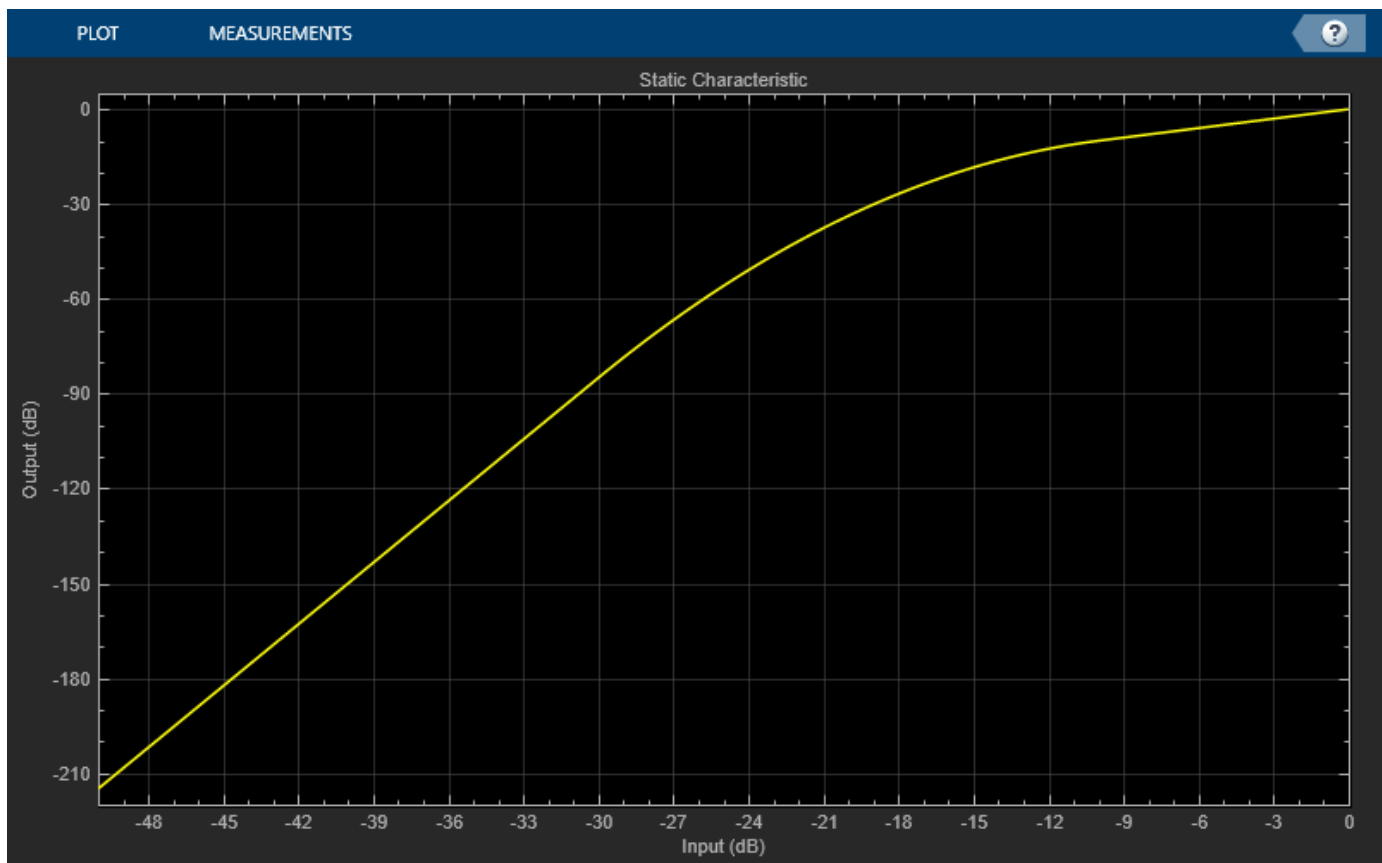
Construct Audio Objects

Construct a `dsp.AudioFileReader` object for the input and sidechain signals. To allow the script to run indefinitely, change the `playbackCount` variable from 1 to `Inf`.

```
inputAudio = 'SoftGuitar-44p1_mono-10mins.ogg';
sidechainAudio = 'convertedSidechainSig.wav';
playbackCount = 1;
inputAudioAFR = dsp.AudioFileReader(inputAudio,'PlayCount',playbackCount);
sidechainAudioAFR = dsp.AudioFileReader(sidechainAudio,'PlayCount',playbackCount);
```

Construct and visualize an expander object. Use a high “Ratio” on page 3-0 , a soft “KneeWidth” on page 3-0 , a fast “AttackTime” on page 3-0 and “ReleaseTime” on page 3-0 , and a short “HoldTime” on page 3-0 .

```
dRE = expander('EnableSidechain',true,'Threshold',-20,'Ratio',6.5,...
    'KneeWidth',20,'AttackTime',0.84,'ReleaseTime',0.001,'HoldTime',0.0001);
visualize(dRE)
```



Construct an `audioDeviceWriter` object to play the sidechain and input signals.

```
afw = audioDeviceWriter;
```

Construct a `timescope` object to view the input signal, the sidechain signal, as well as the expanded input signal.

```
scope = timescope('NumInputPorts',3,...
    'SampleRate',Fs,...
    'TimeSpanSource','property',...
    'TimeSpan',5,...
    'TimeDisplayOffset',0,...
    'LayoutDimensions',[3 1],...)
```

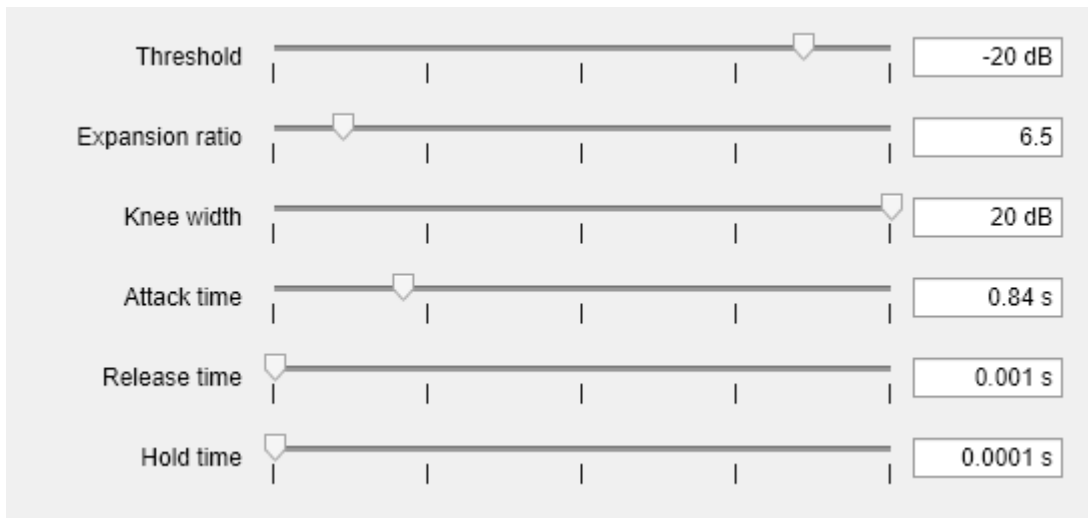
```

        'BufferLength',Fs*15,...
        'TimeSpanOverrunAction','Scroll',...
        'YLimits',[-1 1],...
        'ShowGrid',true,...
        'Title','Input Audio - Classical Guitar');
scope.ActiveDisplay = 2;
scope.YLimits = [-1 1];
scope.Title = 'Sidechain Audio - Drums';
scope.ShowGrid = true;
scope.ActiveDisplay = 3;
scope.YLimits = [-1 1];
scope.ShowGrid = true;
scope.Title = 'Expanded Input Audio - Classical Guitar';

```

Call `parameterTuner` to open a UI to tune parameters of the expander while streaming. Adjust the property values and listen to the effect in real time.

```
parameterTuner(dRE)
```



Create Audio Streaming Loop

Read in a frame of audio from your input and sidechain signals. Process your input and sidechain signals with your `expander` object. Playback your processed audio signals and display the audio data using a `timescope` object.

The top panel of your `timescope` displays the input audio signal and the middle panel displays the sidechain audio signal. The bottom panel displays the expanded input audio signal.

Substitute different audio files for your `inputAudio` variable to create different textures and timbres in your drum mix.

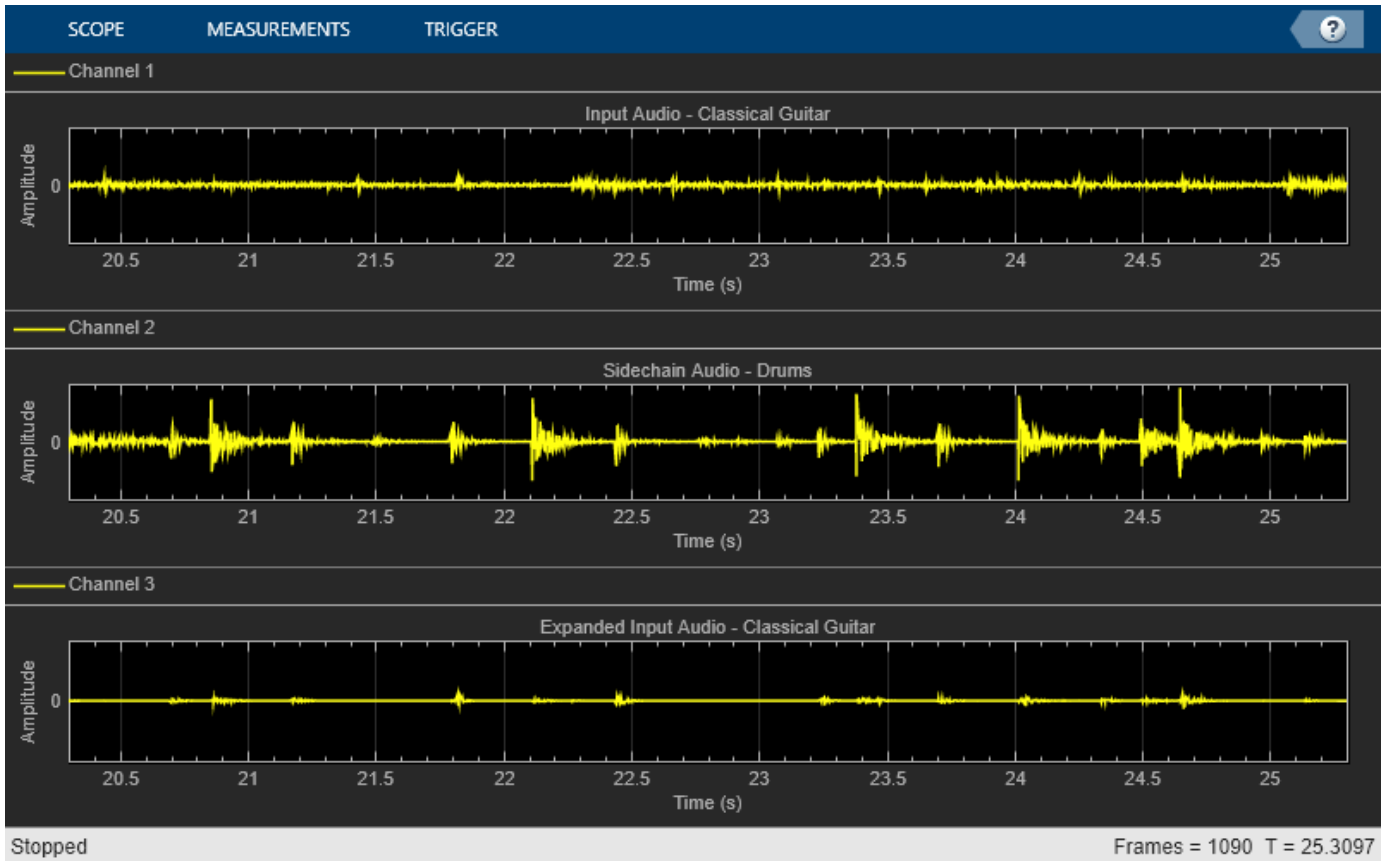
```

while ~isDone(sidechainAudioAFR)
    inputAudioFrame = inputAudioAFR();
    sideChainAudioFrame = sidechainAudioAFR();
    expanderOutput = dRE(inputAudioFrame,sideChainAudioFrame);
    afw(sideChainAudioFrame+expanderOutput);
    scope(inputAudioFrame,sideChainAudioFrame,expanderOutput);
    drawnow limitrate; % required to update parameter settings from UI
end

```

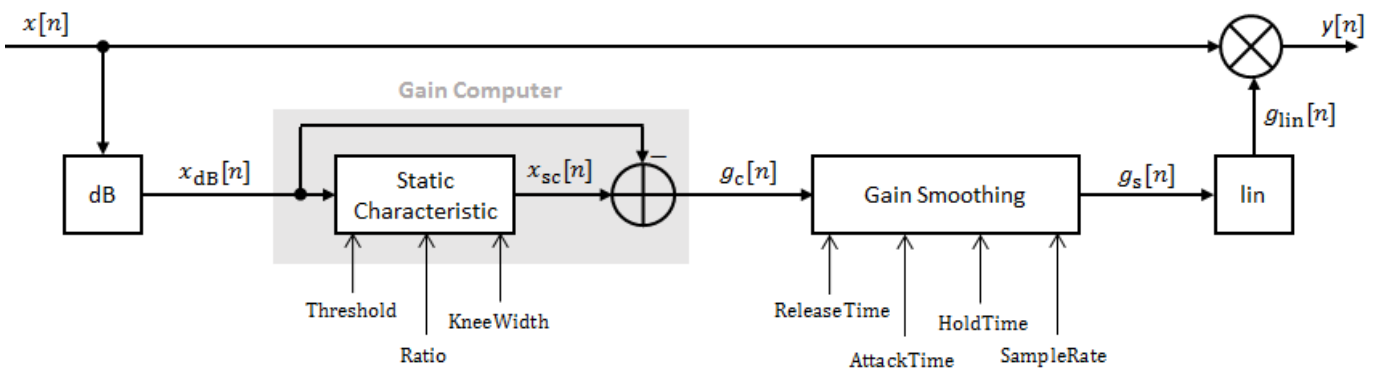

Release your objects.

```
release(inputAudioAFR)
release(sidechainAudioAFR)
release(dRE)
release(afw)
release(scope)
```



Algorithms

The expander System object processes a signal frame by frame and element by element.



Convert Input Signal to dB

The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$

Gain Computer

$x_{dB}[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range expander to attenuate gain that is below the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} T + (x_{dB} - T) \times R & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} + \frac{(1 - R)\left(x_{dB} - T - \frac{W}{2}\right)^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ x_{dB} & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases} ,$$

where T is the threshold, R is the ratio, and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} T + (x_{dB} - T) \times R & x_{dB} < T \\ x_{dB} & x_{dB} \geq T \end{cases}$$

The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$

Gain Smoothing

$g_c[n]$ is smoothed using specified attack, release, and hold time properties:

$$g_s[n] = \begin{cases} \alpha_A g_s[n - 1] + (1 - \alpha_A) g_c[n] & (C_A > T_H) \ \& \ (g_c[n] \leq g_s[n - 1]) \\ g_s[n - 1] & C_A \leq T_H \\ \alpha_R g_s[n - 1] + (1 - \alpha_R) g_c[n] & g_c[n] > g_s[n - 1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{F_S \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the `AttackTime` property. T_R is the release time period, specified by the `ReleaseTime` property. F_S is the input sampling rate, specified by the `SampleRate` property.

C_A is the hold counter for attack. The limit, T_H , is determined by the `HoldTime` property.

Calculate and Apply Linear Gain

The smoothed gain in dB, $g_s[n]$, is translated to a linear domain:

$$g_{\text{lin}}[n] = 10^{\left(\frac{g_s[n]}{20}\right)}$$

The output of the dynamic range expander is given as

$$y[n] = x[n] \times g_{\text{lin}}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial and Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

noiseGate | compressor | limiter | Expander

Topics

“Dynamic Range Control”

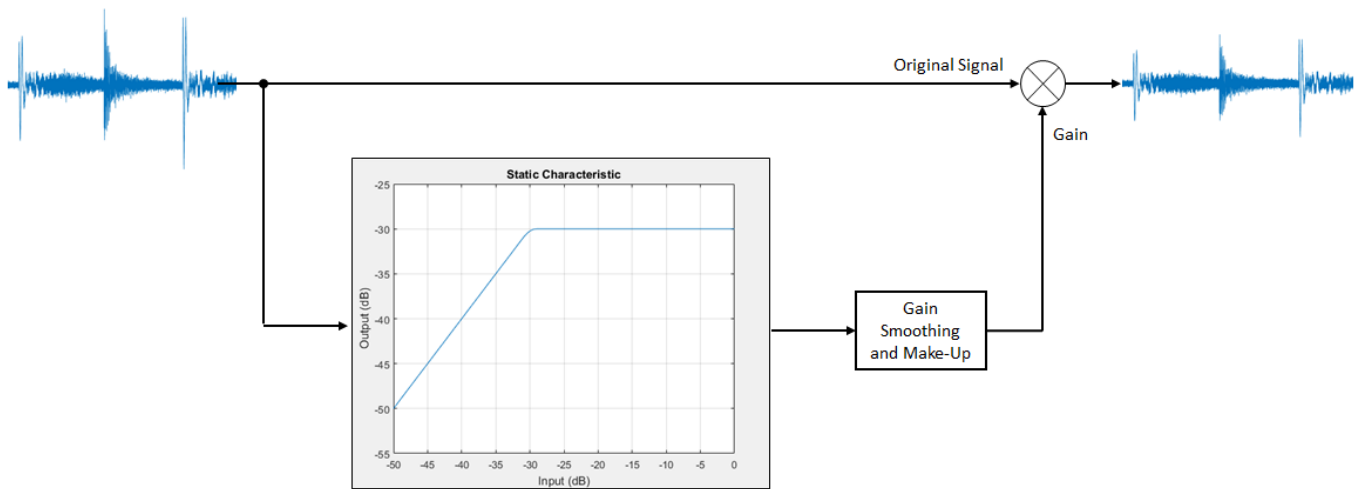
Introduced in R2016a

limiter

Dynamic range limiter

Description

The `limiter` System object performs brick-wall dynamic range limiting independently across each input channel. Dynamic range limiting suppresses the volume of loud sounds that cross a given threshold. It uses specified attack and release times to achieve a smooth applied gain curve. Properties of the `limiter` System object specify the type of dynamic range limiting.



To perform dynamic range limiting:

- 1 Create the `limiter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
dRL = limiter
dRL = limiter(thresholdValue)
dRL = limiter(__, Name, Value)
```

Description

`dRL = limiter` creates a System object, `dRL`, that performs brick-wall dynamic range limiting independently across each input channel.

`dRL = limiter(thresholdValue)` sets the `Threshold` property to `thresholdValue`.

`dRL = limiter(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `dRL = limiter('AttackTime', 0.01, 'SampleRate', 16000)` creates a System object, `dRL`, with a 10 ms attack time and a sample rate of 16 kHz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Threshold — Operation threshold (dB)

-10 (default) | real scalar

Operation threshold in dB, specified as a real scalar.

Operation threshold is the level above which gain is applied to the input signal.

Tunable: Yes

Data Types: `single` | `double`

KneeWidth — Knee width (dB)

0 (default) | real scalar

Knee width in dB, specified as a real scalar greater than or equal to 0.

Knee width is the transition area in the limiter characteristic.

For soft knee characteristics, the transition area is defined by the relation

$$y = x - \frac{\left(x - T + \frac{W}{2}\right)^2}{(2 \times W)}$$

for the range $(2 \times |x - T|) \leq W$.

- y is the output level in dB.
- x is the input level in dB.
- T is the threshold in dB.
- W is the knee width in dB.

Tunable: Yes

Data Types: `single` | `double`

AttackTime — Attack time (s)

0 (default) | real scalar

Attack time in seconds, specified as a real scalar greater than or equal to 0.

Attack time is the time it takes the limiter gain to rise from 10% to 90% of its final value when the input goes above the threshold.

Tunable: Yes

Data Types: `single` | `double`

ReleaseTime — Release time (s)

0.2 (default) | real scalar

Release time in seconds, specified as a real scalar greater than or equal to 0.

Release time is the time it takes the limiter gain to drop from 90% to 10% of its final value when the input goes below the threshold.

Tunable: Yes

Data Types: `single` | `double`

MakeUpGainMode — Make-up gain mode

'Property' (default) | 'Auto'

Make-up gain mode, specified as 'Auto' or 'Property'.

- 'Auto' -- Make-up gain is applied at the output of the dynamic range limiter such that a steady-state 0 dB input has a 0 dB output.
- 'Property' -- Make-up gain is set to the value specified in the MakeUpGain property.

Tunable: No

Data Types: `char` | `string`

MakeUpGain — Make-up gain (dB)

0 (default) | real scalar

Make-up gain in dB, specified as a real scalar.

Make-up gain compensates for gain lost during limiting. It is applied at the output of the dynamic range limiter.

Tunable: Yes

Dependencies

To enable this property, set MakeUpGainMode to 'Property'.

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

EnableSidechain — Enable sidechain input`false (default) | true`

Enable sidechain input, specified as `true` or `false`. This property determines the number of available inputs on the `limiter` object.

- `false` -- Sidechain input is disabled and the `limiter` object accepts one input: the `audioIn` data to be limited.
- `true` -- Sidechain input is enabled and the `limiter` object accepts two inputs: the `audioIn` data to be limited and the sidechain input used to compute the limiter gain.

The sidechain datatype and (frame) length must be the same as `audioIn`.

The number of channels of the sidechain input must be equal to the number of channels of `audioIn` or be equal to one. When the number of sidechain channels is one, the `gain` computed based on this channel is applied to all channels of `audioIn`. When the number of sidechain channels is equal to the number of channels in `audioIn`, the `gain` computed for each sidechain channel is applied to the corresponding channel of `audioIn`.

Tunable: No

Usage**Syntax**

```
audioOut = dRL(audioIn)
[audioOut,gain] = dRL(audioIn)
```

Description

`audioOut = dRL(audioIn)` performs dynamic range limiting on the input signal, `audioIn`, and returns the limited signal, `audioOut`. The type of dynamic range limiting is specified by the algorithm and properties of the `limiter` System object, `dRL`.

`[audioOut,gain] = dRL(audioIn)` also returns the applied gain, in dB, at each input sample.

Input Arguments**audioIn — Audio input to limiter**`matrix`

Audio input to the limiter, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments**audioOut — Audio output from limiter**`matrix`

Audio output from the limiter, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

gain — Gain applied by limiter (dB)

matrix

Gain applied by the limiter, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to limiter

- `visualize` Visualize static characteristic of dynamic range controller
- `staticCharacteristic` Return static characteristic of dynamic range controller
- `createAudioPluginClass` Create audio plugin class that implements functionality of System object
- `parameterTuner` Tune object parameters while streaming

MIDI

- `configureMIDI` Configure MIDI connections between audio object and MIDI controller
- `disconnectMIDI` Disconnect MIDI controls from audio object
- `getMIDIConnections` Get MIDI connections of audio object

Common to All System Objects

- `clone` Create duplicate System object
- `isLocked` Determine if System object is in use
- `release` Release resources and allow changes to System object property values and input characteristics
- `reset` Reset internal states of System object
- `step` Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the limiter System object to user-facing parameters:

Property	Range	Mapping	Unit
Threshold	[-50, 0]	linear	dB
KneeWidth	[0, 20]	linear	dB
AttackTime	[0, 4]	linear	seconds
ReleaseTime	[0, 4]	linear	seconds
MakeUpGain (available when you set MakeUpGainMode to 'Property')	[-10, 24]	linear	dB

Examples

Limit Audio Signal

Use dynamic range limiting to suppress the volume of loud sounds.

Set up the `dsp.AudioFileReader` and `audioDeviceWriter` System objects™.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader( ...
    'Filename','RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);
```

Set up the limiter to have a threshold of -15 dB, an attack time of 0.005 seconds, and a release time of 0.1 seconds. Set make-up gain to 0 dB (default). To specify this value, set the make-up gain mode to 'Property' but do not specify the `MakeUpGain` property. Use the sample rate of your audio file reader.

```
dRL = limiter(-15, ...
    'AttackTime',0.005, ...
    'ReleaseTime',0.1, ...
    'MakeUpGainMode','Property', ...
    'SampleRate',fileReader.SampleRate);
```

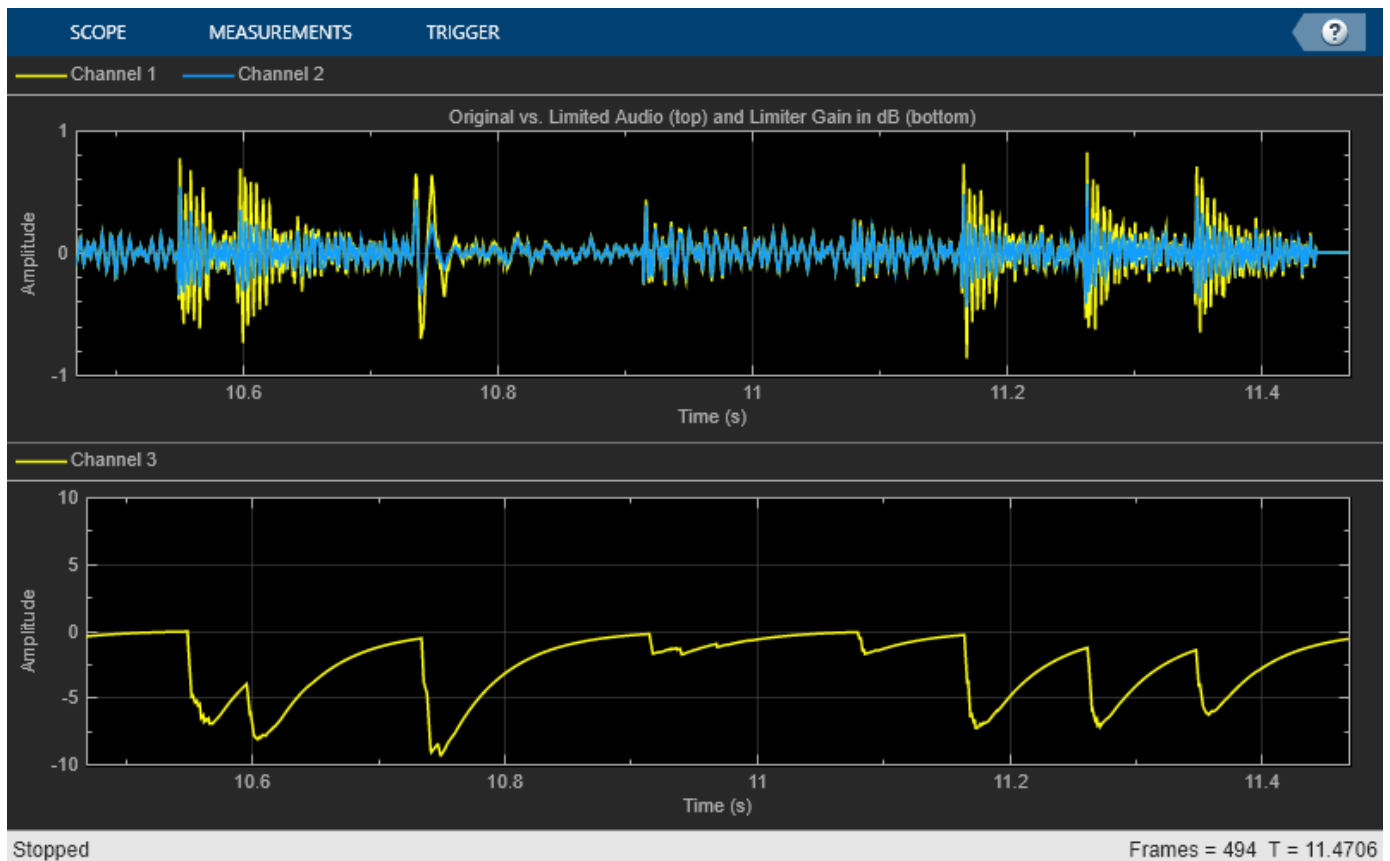
Set up a time scope to visualize the original signal and the limited signal.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'TimeSpanSource','property',...
    'TimeSpan',1, ...
    'BufferLength',44100*4, ...
    'YLimits',[-1 1], ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2,1], ...
    'NumInputPorts',2, ...
    'ShowLegend',true, ...
    'Title',['Original vs. Limited Audio (top)' ...
    ' and Limiter Gain in dB (bottom)']);
```

Play the processed audio and visualize it on the scope.

```
while ~isDone(fileReader)
    x = fileReader();
    [y,g] = dRL(x);
    deviceWriter(y);
    x1 = x(:,1);
    y1 = y(:,1);
    g1 = g(:,1);
    scope([x1,y1],g1);
end
```

```
release(fileReader)
release(dRL)
release(deviceWriter)
release(scope)
```



Compare Dynamic Range Limiter and Compressor

A dynamic range limiter is a special type of dynamic range compressor. In limiters, the level above an operational threshold is hard limited. In the simplest implementation of a limiter, the effect is equivalent to audio clipping. In compressors, the level above an operational threshold is lowered using a specified compression ratio. Using a compression ratio results in a smoother processed signal.

Compare Limiter and Compressor Applied to Sinusoid

Create a limiter System object™ and a compressor System object. Set the `AttackTime` and `ReleaseTime` properties of both objects to zero. Create an `audioOscillator` System object to generate a sinusoid with `Frequency` set to 5 and `Amplitude` set to 0.1.

```
dRL = limiter('AttackTime',0,'ReleaseTime',0);
dRC = compressor('AttackTime',0,'ReleaseTime',0);

osc = audioOscillator('Frequency',5,'Amplitude',0.1);
```

Create a time scope to visualize the generated sinusoid and the processed sinusoid.

```
scope = timescope( ...
    'SampleRate',osc.SampleRate, ...
    'TimeSpanSource','Property','TimeSpan',2, ...
```

```

    'BufferLength',osc.SampleRate*4, ...
    'TimeSpanOverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'LayoutDimensions',[2 1], ...
    'NumInputPorts',2);
scope.ActiveDisplay = 1;
scope.Title = 'Original Signal vs. Limited Signal';
scope.YLimits = [-1,1];
scope.ActiveDisplay = 2;
scope.Title = 'Original Signal vs. Compressed Signal';
scope.YLimits = [-1,1];

```

In an audio stream loop, visualize the original sinusoid and the sinusoid processed by a limiter and a compressor. Increment the amplitude of the original sinusoid to illustrate the effect.

```

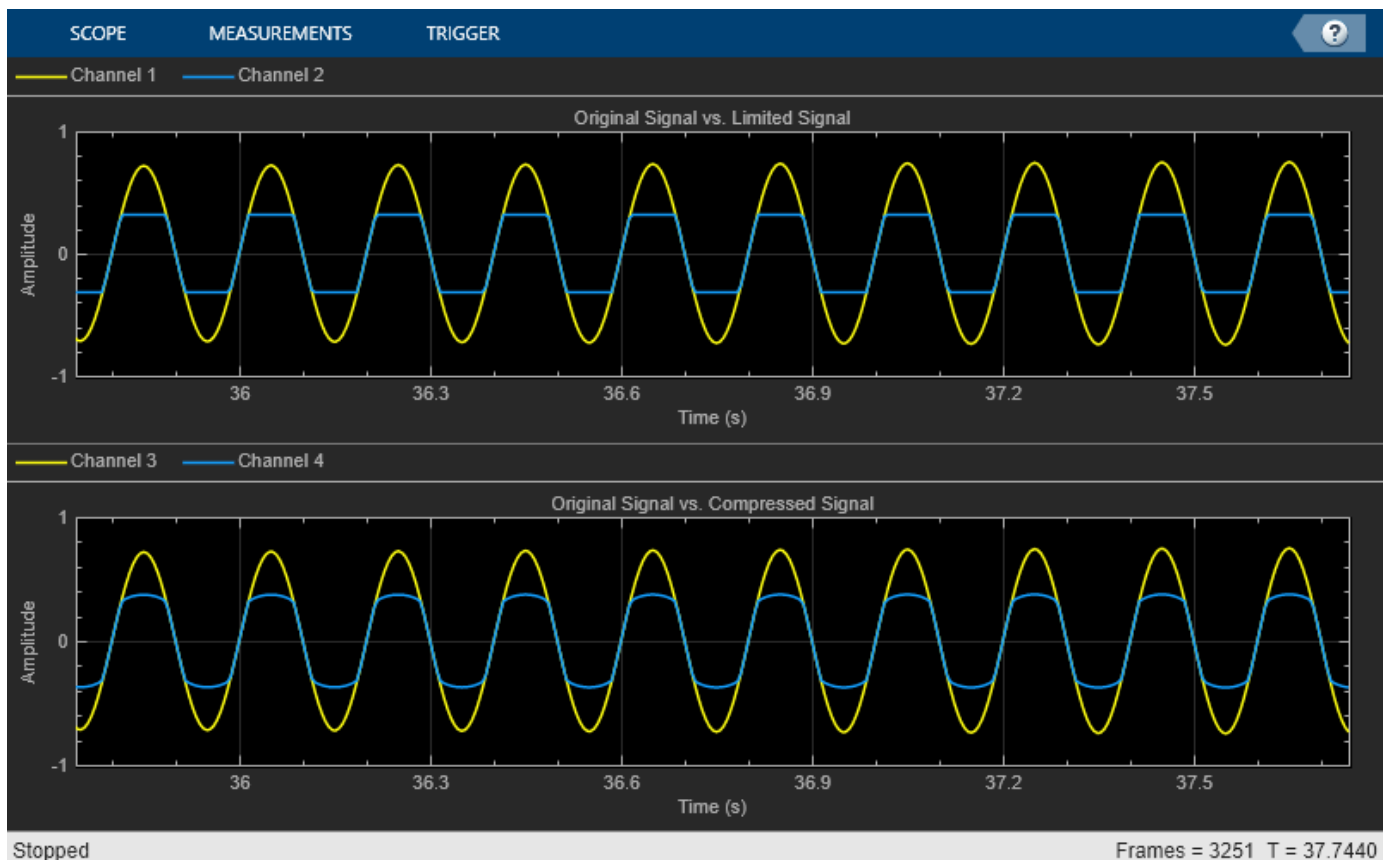
while osc.Amplitude < 0.75
    x = osc();

    xLimited    = dRL(x);
    xCompressed = dRC(x);

    scope([x xLimited],[x xCompressed]);

    osc.Amplitude = osc.Amplitude + 0.0002;
end
release(scope)

```



```
release(dRL)
release(dRC)
release(osc)
```

Compare Limiter and Compressor Applied to Audio Signal

Compare the effect of dynamic range limiters and compressors on a drum track. Create a `dsp.AudioFileReader` System object and a `audioDeviceWriter` System object to read audio from a file and write to your audio output device. To emphasize the effect of dynamic range control, set the operational threshold of the limiter and compressor to -20 dB.

```
dRL.Threshold = -20;
dRC.Threshold = -20;
```

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

Read successive frames from an audio file in a loop. Listen to and compare the effect of dynamic range limiting and dynamic range compression on an audio signal.

```
numFrames = 300;

fprintf('Now playing original signal...\n')
Now playing original signal...

for i = 1:numFrames
    x = fileReader();
    deviceWriter(x);
end
reset(fileReader);

fprintf('Now playing limited signal...\n')
Now playing limited signal...

for i = 1:numFrames
    x = fileReader();
    xLimited = dRL(x);
    deviceWriter(xLimited);
end
reset(fileReader);

fprintf('Now playing compressed signal...\n')
Now playing compressed signal...

for i = 1:numFrames
    x = fileReader();
    xCompressed = dRC(x);
    deviceWriter(xCompressed);
end

release(fileReader)
release(deviceWriter)
release(dRC)
release(dRL)
```

Tune Limiter Parameters

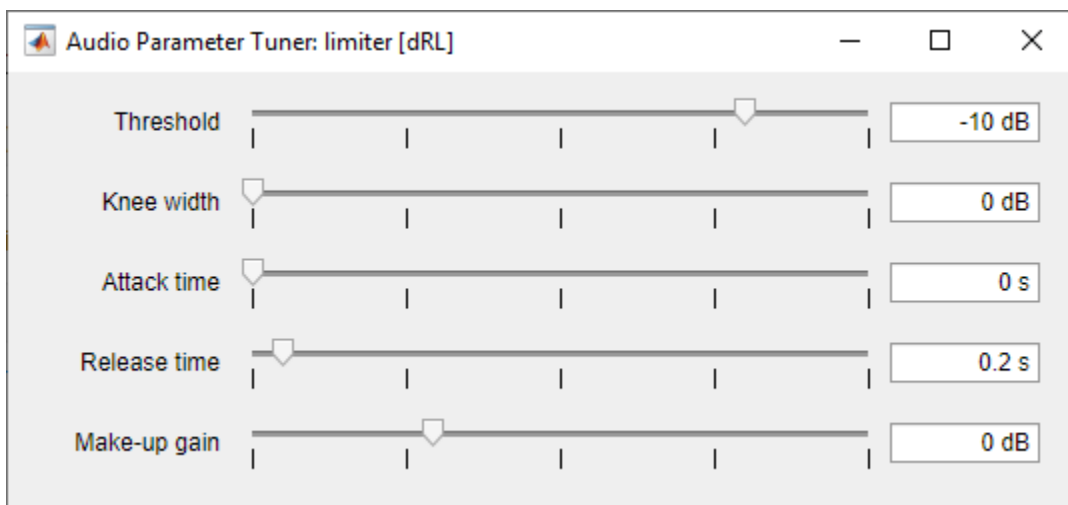
Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create a `audioDeviceWriter` to write audio to your sound card. Create a `limiter` to process the audio data.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

```
dRL = limiter('SampleRate',fileReader.SampleRate);
```

Call `parameterTuner` to open a UI to tune parameters of the limiter while streaming.

```
parameterTuner(dRL)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply dynamic range limiting.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the dynamic range limiter and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = dRL(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(dRL)
```

Sidechain Ducking with Limiter

Use the “EnableSidechain” on page 3-0 input of a `limiter` object to limit the amplitude level of a separate audio signal. The sidechain signal controls the dynamic range limiting of the input audio signal. When the sidechain signal exceeds the limiter “Threshold” on page 3-0, the limiter activates and limits the amplitude of the input signal. When the sidechain signal level falls below the threshold, the audio input returns to its original amplitude. For a detailed comparison of compression and dynamic range limiting, see “Compare Dynamic Range Limiter and Compressor” on page 3-258.

Prepare Audio Files

In this section, you resample and zero-pad a speech file to use as input to the `EnableSidechain` property of your `limiter` object.

Read in an audio signal. Resample it to match the sample rate of the input audio signal (44.1 kHz).

```
targetFs = 44100;
[originalSpeech,originalFs] = audioread('Rainbow-16-8-mono-114secs.wav');
resampledSpeech = resample(originalSpeech,targetFs,originalFs);
```

Pad the beginning of the resampled signal with 10 seconds worth of zeros. This allows the input audio signal to be clearly heard before any limiting is applied.

```
resampledSpeech = [zeros(10*targetFs,1);resampledSpeech];
```

Normalize the amplitude to avoid potential clipping.

```
resampledSpeech = resampledSpeech ./ max(resampledSpeech);
```

Write the resampled, zero-padded, and normalized sidechain signal to a file.

```
audiowrite('resampledSpeech.wav',resampledSpeech,targetFs);
```

Construct Audio Objects

Construct a `dsp.AudioFileReader` object for the input and sidechain signals. Using the “ReadRange” property of the `AudioFileReader`, select the second verse of the input signal and the first 26.5 seconds of the sidechain signal for playback. To allow the script to run indefinitely, change the `playbackCount` variable from 1 to `Inf`.

```
inputAudio = 'SoftGuitar-44p1_mono-10mins.ogg';
sidechainAudio = 'resampledSpeech.wav';
playbackCount = 1;
inputAudioAFR = dsp.AudioFileReader(inputAudio,'PlayCount',playbackCount,'ReadRange',...
    [115*targetFs round(145.4*targetFs)]);
sidechainAudioAFR = dsp.AudioFileReader(sidechainAudio,'PlayCount',playbackCount,...
    'ReadRange',[1 round(26.5*targetFs)]);
```

Construct a `limiter` object. Use a fast “AttackTime” on page 3-0, and a moderately slow “ReleaseTime” on page 3-0. These settings are ideal for voice-over work. The fast attack time ensures that the input audio is limited almost immediately after the sidechain signal surpasses the limiter threshold. The slow release time ensures the limiting on the input audio lasts through any potential short silent regions in the sidechain signal.

```
iAmYourLimiter = limiter('EnableSidechain',true,...
    'SampleRate',targetFs,...
    'Threshold',-48,...
```

```

    'AttackTime',0.01,...
    'ReleaseTime',1.75);

```

Construct an `audioDeviceWriter` object to play the sidechain and input signals.

```
afw = audioDeviceWriter;
```

Construct a `timescope` object to view the uncompressed input signal, the sidechain signal, as well as the compressed input signal.

```

scope = timescope('NumInputPorts',3,...
    'SampleRate',targetFs,...
    'TimeSpanSource','property',...
    'TimeSpan',5,...
    'TimeDisplayOffset',0,...
    'LayoutDimensions',[3 1],...
    'BufferLength',targetFs*15,...
    'TimeSpanOvrerrunAction','Scroll',...
    'YLimits',[-1 1],...
    'ShowGrid',true,...
    'Title','Original Input Audio - Guitar');
scope.ActiveDisplay = 2;
scope.YLimits = [-1 1];
scope.Title = 'Sidechain Audio - Speech';
scope.ShowGrid = true;
scope.ActiveDisplay = 3;
scope.YLimits = [-1 1];
scope.ShowGrid = true;
scope.Title = 'Dynamic Range Limited Input Audio - Guitar';

```

Create Audio Streaming Loop

Read in a frame of audio from your input and sidechain signals. Process your input and sidechain signals with your `limiter` object. Playback your processed audio signals and display the audio data using a `timescope` object.

The top panel of your `timescope` displays the unprocessed input audio signal and the middle panel displays the sidechain audio signal. The bottom panel displays the limited input audio signal. Notice the amplitudes of the signals in the top and bottom panels are identical until the sidechain signal begins. Once the sidechain signal activates, the amplitude in the bottom panel decreases. Once the sidechain signal ends, the amplitude of the bottom panel returns to its original level.

```

while ~isDone(inputAudioAFR)
    inputAudioFrame = inputAudioAFR();
    sideChainAudioFrame = sidechainAudioAFR();
    limiterOutput = iAmYourLimiter(inputAudioFrame,sideChainAudioFrame);
    afw(sideChainAudioFrame+limiterOutput);
    scope(inputAudioFrame,sideChainAudioFrame,limiterOutput);
end

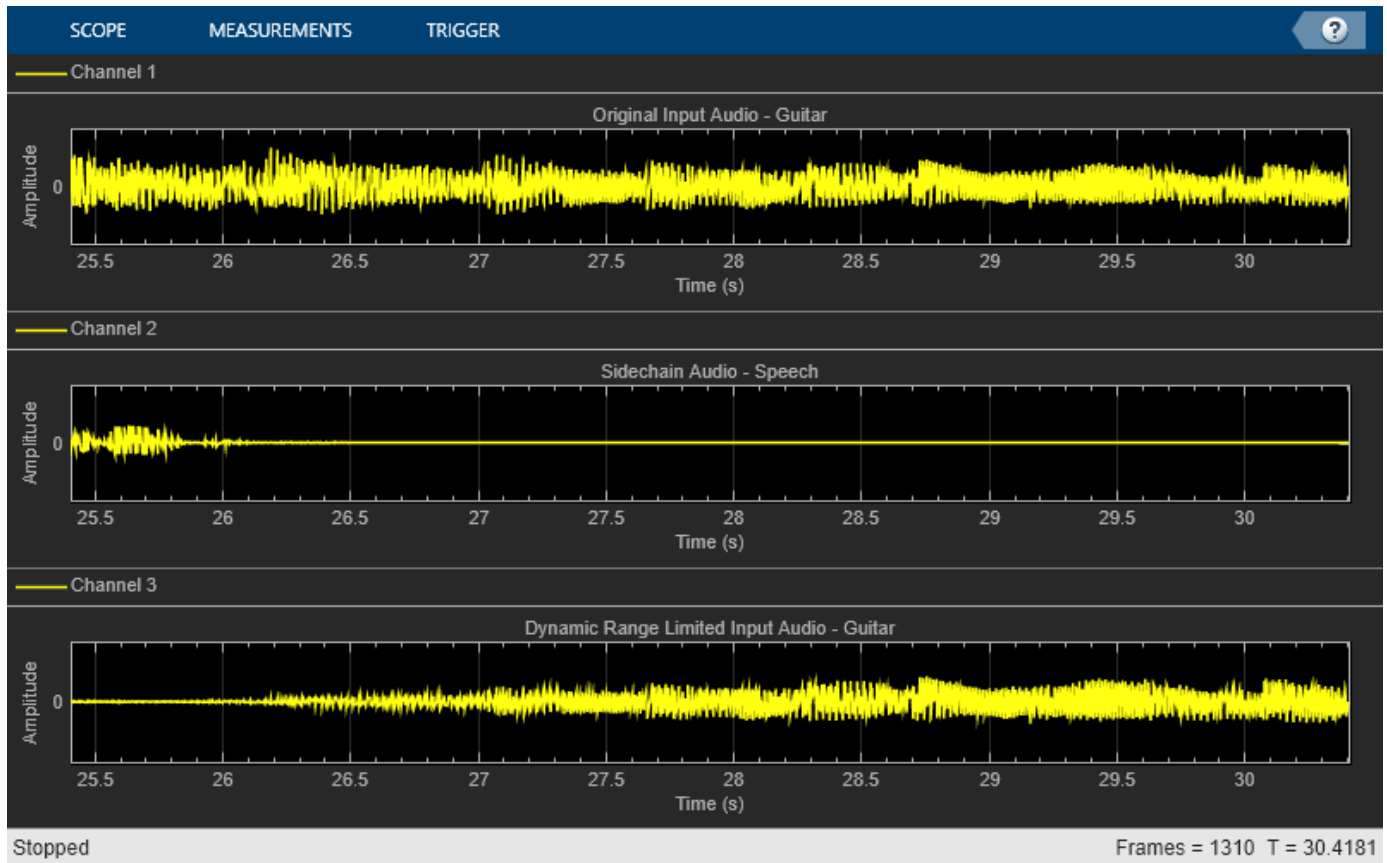
```

Release your objects.

```

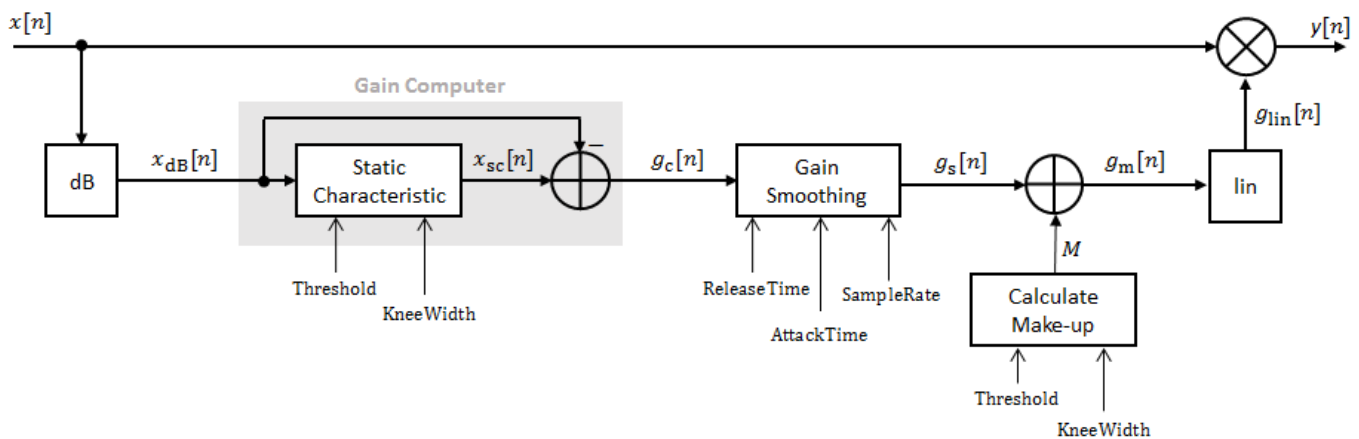
release(inputAudioAFR)
release(sidechainAudioAFR)
release(iAmYourLimiter)
release(afw)
release(scope)

```



Algorithms

The limiter System object processes a signal frame by frame and element by element.



Convert Input Signal to dB

The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$

Gain Computer

$x_{dB}[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range limiter to brick-wall gain that is above the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} - \frac{\left(x_{dB} - T + \frac{W}{2}\right)^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ T & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases} ,$$

where T is the threshold and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < T \\ T & x_{dB} \geq T \end{cases}$$

The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$

Gain Smoothing

$g_c[n]$ is smoothed using specified attack and release time:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n], & g_c[n] \leq g_s[n-1] \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n], & g_c[n] > g_s[n-1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{F_S \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the `AttackTime` property. T_R is the release time period, specified by the `ReleaseTime` property. F_S is the input sampling rate, specified by the `SampleRate` property.

Calculate and Apply Make-up Gain

If `MakeUpGainMode` is set to the default 'Auto', the make-up gain is calculated as the negative of the computed gain for a 0 dB input:

$$M = -x_{sc}|_{x_{dB} = 0}$$

Given a steady-state input of 0 dB, this configuration achieves a steady-state output of 0 dB. The make-up gain is determined by the `Threshold` and `KneeWidth` properties. It does not depend on the input signal.

The make-up gain, M , is added to the smoothed gain, $g_s[n]$:

$$g_m[n] = g_s[n] + M$$

Calculate and Apply Linear Gain

The calculated gain in dB, $g_m[n]$, is translated to a linear domain:

$$g_{lin}[n] = 10\left(\frac{g_m[n]}{20}\right).$$

The output of the dynamic range limiter is given as

$$y[n] = x[n] \times g_{lin}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial and Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

`Limiter` | `noiseGate` | `compressor` | `expander`

Topics

"Dynamic Range Control"

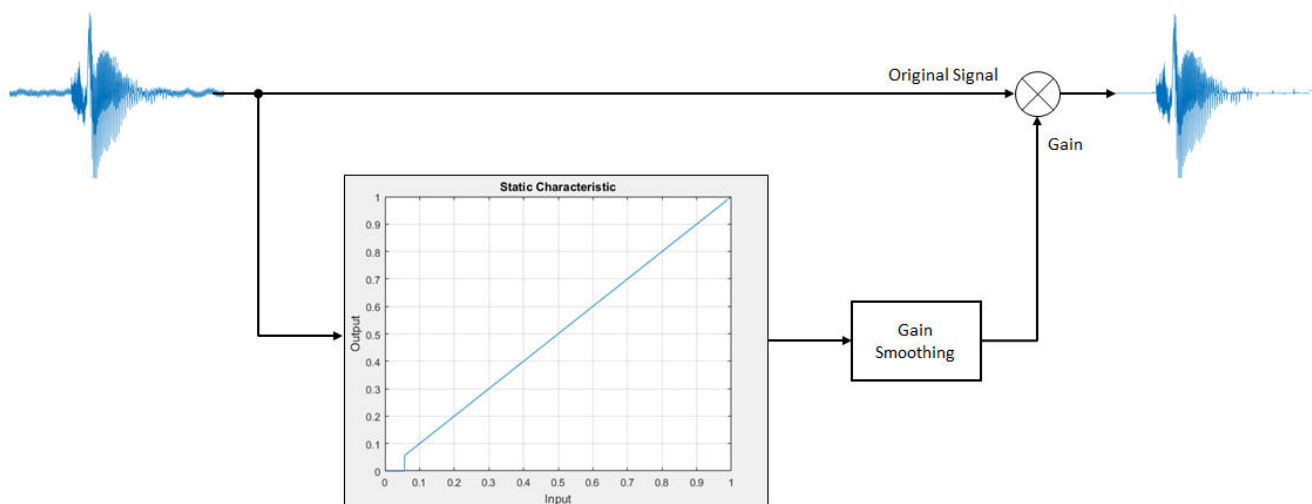
Introduced in R2016a

noiseGate

Dynamic range gate

Description

The `noiseGate` System object performs dynamic range gating independently across each input channel. Dynamic range gating suppresses signals below a given threshold. It uses specified attack, release, and hold times to achieve a smooth applied gain curve. Properties of the `noiseGate` System object specify the type of dynamic range gating.



To perform dynamic range gating:

- 1 Create the `noiseGate` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
dRG = noiseGate
dRG = noiseGate(thresholdValue)
dRG = noiseGate( __ ,Name,Value)
```

Description

`dRG = noiseGate` creates a System object, `dRG`, that performs dynamic range gating independently across each input channel.

`dRG = noiseGate(thresholdValue)` sets the `Threshold` property to `thresholdValue`.

`dRG = noiseGate(____, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `dRG = noiseGate('AttackTime', 0.01, 'SampleRate', 16000)` creates a System object, `dRG`, with a 10 ms attack time and a 16 kHz sample rate.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

Threshold — Operation threshold (dB)

-10 (default) | real scalar

Operation threshold in dB, specified as a real scalar.

Operation threshold is the level below which gain is applied to the input signal.

Tunable: Yes

Data Types: `single` | `double`

AttackTime — Attack time (s)

0.05 (default) | real scalar

Attack time in seconds, specified as a real scalar greater than or equal to 0.

Attack time is the time it takes the applied gain to rise from 10% to 90% of its final value when the input goes below the threshold.

Tunable: Yes

Data Types: `single` | `double`

ReleaseTime — Release time (s)

0.02 (default) | real scalar

Release time in seconds, specified as a real scalar greater than or equal to 0.

Release time is the time it takes the applied gain to drop from 90% to 10% of its final value when the input goes above the threshold.

Tunable: Yes

Data Types: `single` | `double`

HoldTime — Hold time (s)

0.05 (default) | real finite scalar

Hold time in seconds, specified as a real scalar greater than or equal to 0.

Hold time is the period for which the (negative) gain is held before starting to decrease towards its steady state value when the input level drops below the threshold.

Tunable: Yes

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

EnableSidechain — Enable sidechain input

`false` (default) | `true`

Enable sidechain input, specified as `true` or `false`. This property determines the number of available inputs on the `noiseGate` object.

- `false` -- Sidechain input is disabled and the `noiseGate` object accepts one input: the `audioIn` data to be gated.
- `true` -- Sidechain input is enabled and the `noiseGate` object accepts two inputs: the `audioIn` data to be gated and the sidechain input used to compute the `gain` applied by `noiseGate`.

The sidechain datatype and (frame) length must be the same as `audioIn`.

The number of channels of the sidechain must be equal to the number of channels of `audioIn` or be equal to one. When the number of sidechain channels is one, the `gain` computed based on this channel is applied to all channels of `audioIn`. When the number of sidechain channels is equal to the number of channels in `audioIn`, the `gain` computed for each sidechain channel is applied to the corresponding channel of `audioIn`.

Tunable: No

Usage

Syntax

```
audioOut = dRG(audioIn)
[audioOut,gain] = dRG(audioIn)
```

Description

`audioOut = dRG(audioIn)` performs dynamic range gating on the input signal, `audioIn`, and returns the gated signal, `audioOut`. The type of dynamic range gating is specified by the algorithm and properties of the `noiseGate` System object, `dRG`.

`[audioOut,gain] = dRG(audioIn)` also returns the applied gain, in dB, at each input sample.

Input Arguments

audioIn — Audio input to noise gate

matrix

Audio input to the noise gate, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from noise gate

matrix

Audio output from the noise gate, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

gain — Gain applied by noise gate (dB)

matrix

Gain applied by noise gate, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to noiseGate

<code>visualize</code>	Visualize static characteristic of dynamic range controller
<code>createAudioPluginClass</code>	Create audio plugin class that implements functionality of System object
<code>parameterTuner</code>	Tune object parameters while streaming

MIDI

<code>configureMIDI</code>	Configure MIDI connections between audio object and MIDI controller
<code>disconnectMIDI</code>	Disconnect MIDI controls from audio object
<code>getMIDIConnections</code>	Get MIDI connections of audio object

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the `noiseGate` System object to user-facing parameters:

Property	Range	Mapping	Unit
Threshold	[-140, 0]	linear	dB
AttackTime	[0, 4]	linear	seconds
ReleaseTime	[0, 4]	linear	seconds
HoldTime	[0, 4]	linear	seconds

Examples

Gate Audio Signal

Use dynamic range gating to attenuate background noise from an audio signal.

Set up the `dsp.AudioFileReader` and `audioDeviceWriter` System objects™.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader( ...
    'Filename','Counting-16-44p1-mono-15secs.wav', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter( ...
    'SampleRate',fileReader.SampleRate);
```

Corrupt the audio signal with Gaussian noise. Play the audio.

```
while ~isDone(fileReader)
    x = fileReader();
    xCorrupted = x + (1e-2/4)*randn(frameLength,1);
    deviceWriter(xCorrupted);
end
```

```
release(fileReader)
```

Set up a dynamic range gate with a threshold of -25 dB, an attack time of 0.01 seconds, a release time of 0.02 seconds, and a hold time of 0 seconds. Use the sample rate of your audio file reader.

```
gate = noiseGate(-25, ...
    'AttackTime',0.01, ...
    'ReleaseTime',0.02, ...
    'HoldTime',0, ...
    'SampleRate',fileReader.SampleRate);
```

Set up a time scope to visualize the signal before and after dynamic range gating.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate, ...
    'TimeSpanOvverrunAction','Scroll', ...
    'TimeSpanSource','property',...
    'TimeSpan',16, ...
    'BufferLength',1.5e6, ...
    'YLimits',[-1 1], ...
    'ShowGrid',true, ...
    'ShowLegend',true, ...
    'Title','Corrupted vs. Gated Audio');
```

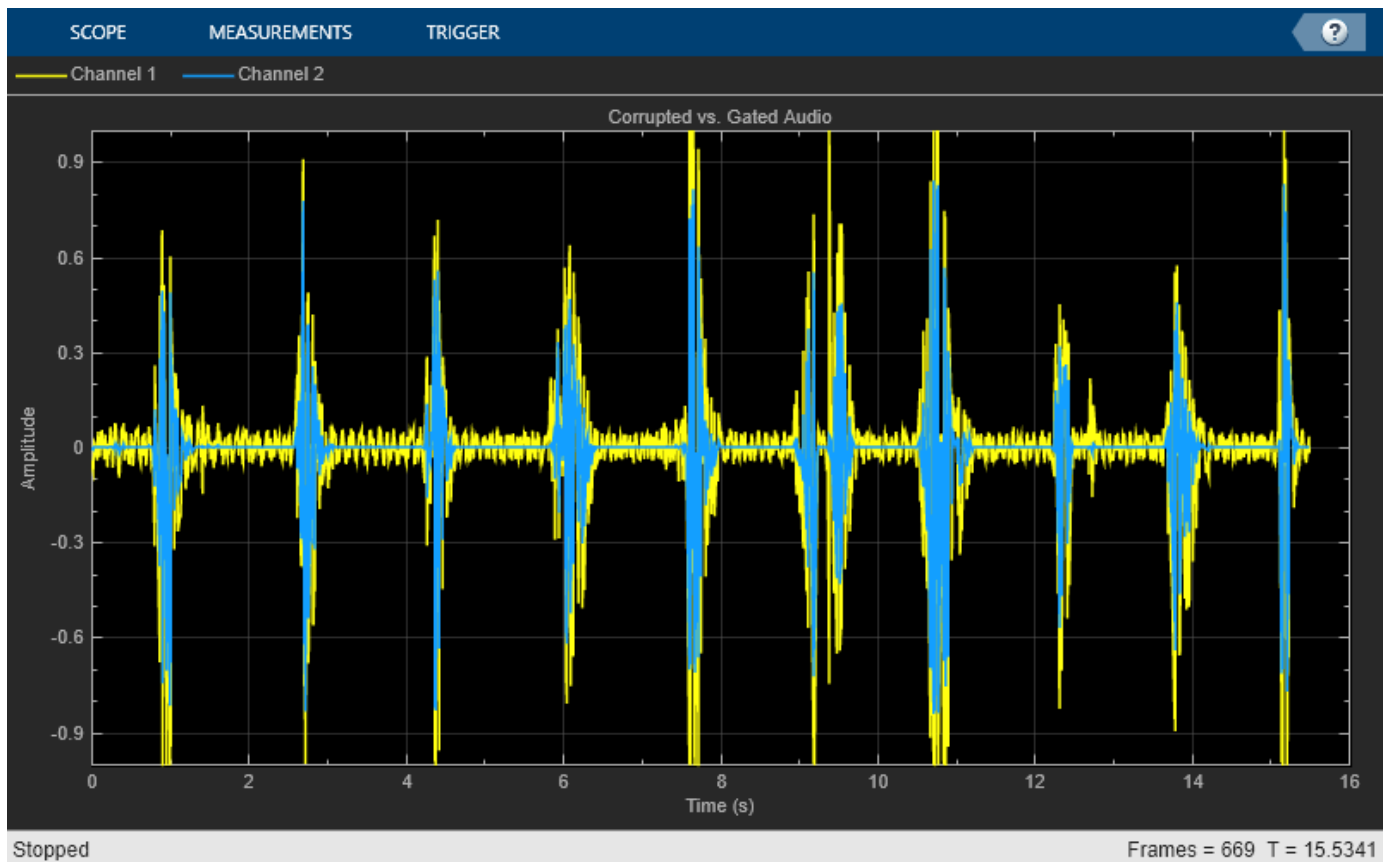
Play the processed audio and visualize it on scope.

```

while ~isDone(fileReader)
    x = fileReader();
    xCorrupted = x + (1e-2/4)*randn(frameLength,1);
    y = gate(xCorrupted);
    deviceWriter(y);
    scope([xCorrupted,y]);
end

release(fileReader)
release(gate)
release(deviceWriter)
release(scope)

```



Tune Noise Gate Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create a `noiseGate` to process the audio data.

```

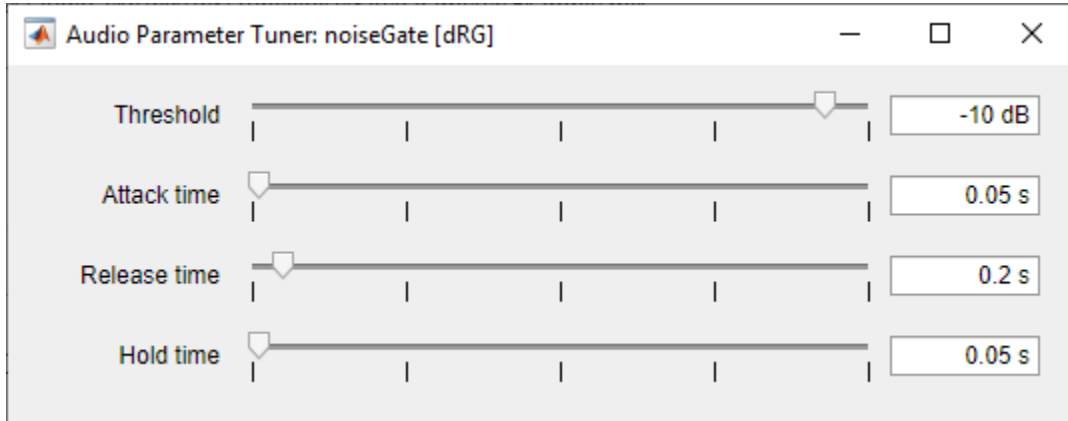
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

dRG = noiseGate('SampleRate',fileReader.SampleRate);

```


Call `parameterTuner` to open a UI to tune parameters of the `noiseGate` while streaming.

```
parameterTuner(dRG)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply dynamic range gating.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the dynamic range gate and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
    audioOut = dRG(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(dRG)
```

Sidechain Dynamic Range Gating

Use the “EnableSidechain” on page 3-0 input of a `noiseGate` object to emulate an electronic drum controller, also known as a *multipad*. This technique is common in recording studio production and creates interesting changes to the timbre of an instrument. The sidechain signal controls the gating on the input signal. Sidechain gating decreases the amplitude of the input signal when the sidechain signal falls below the “Threshold” on page 3-0 of the `noiseGate`. A noise gate is essentially an expander with an infinite “Ratio” on page 3-0 .

Prepare Audio Files

Convert the sidechain signal from stereo to mono.

```
[expanderSideChainStereo,Fs] = audioread('FunkyDrums-44p1-stereo-25secs.mp3');
expanderSideChainMono = (expanderSideChainStereo(:,1) + expanderSideChainStereo(:,2)) / 2;
```

Write the converted sidechain signal to a file.

```
audiowrite('convertedSidechainSig.wav',expanderSideChainMono,Fs);
```

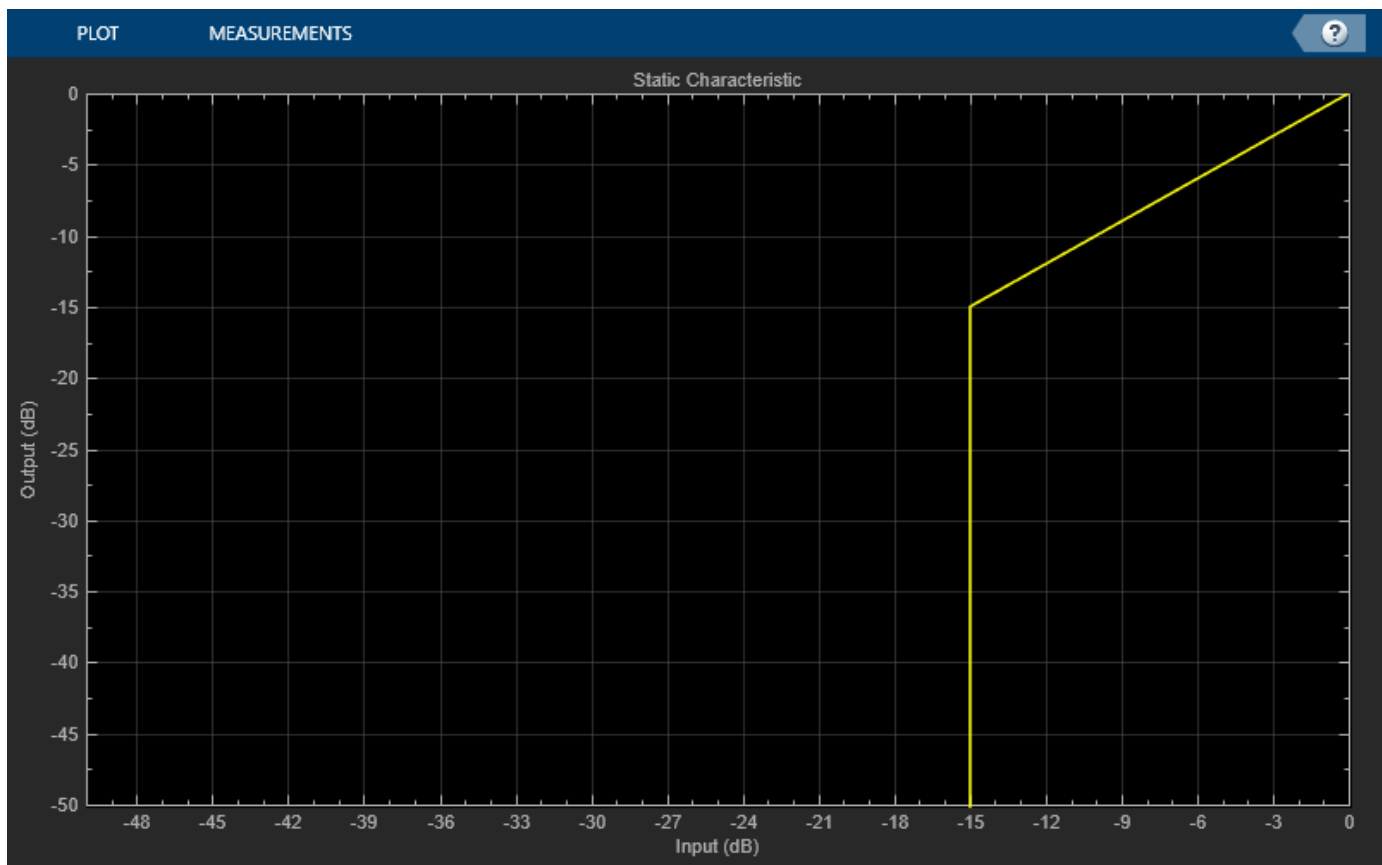
Construct Audio Objects

Construct a `dsp.AudioFileReader` object for the input and sidechain signals. To allow the script to run indefinitely, change the `playbackCount` variable from 1 to `Inf`.

```
inputAudio = 'SoftGuitar-44p1_mono-10mins.ogg';
sidechainAudio = 'convertedSidechainSig.wav';
playbackCount = 1;
inputAudioAFR = dsp.AudioFileReader(inputAudio,'PlayCount',playbackCount);
sidechainAudioAFR = dsp.AudioFileReader(sidechainAudio,'PlayCount',playbackCount);
```

Construct and visualize a `noiseGate` object. Use fast “AttackTime” on page 3-0 and “ReleaseTime” on page 3-0, and a short “HoldTime” on page 3-0.

```
dRG = noiseGate('EnableSidechain',true,'Threshold',-15,'AttackTime',...
    0.08,'ReleaseTime',0.0001,'HoldTime',0.0001);
visualize(dRG)
```



Construct an `audioDeviceWriter` object to play the sidechain and input signals.

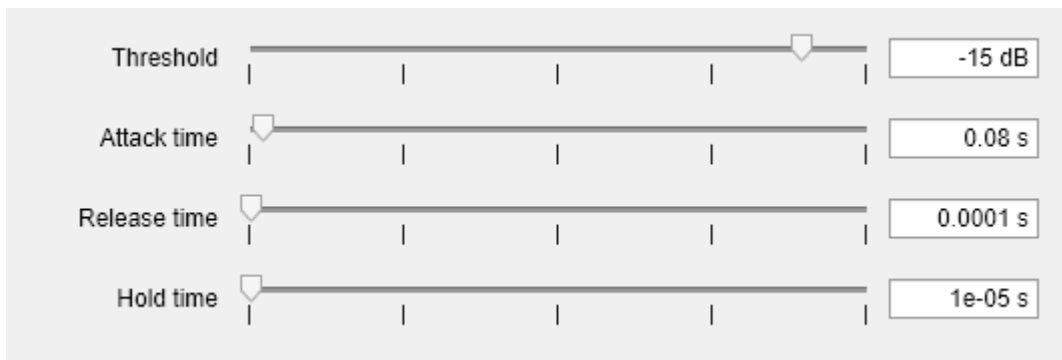
```
afw = audioDeviceWriter;
```

Construct a `timescope` object to view the input signal, the sidechain signal, as well as the gated input signal.

```
scope = timescope('NumInputPorts',3,...
    'SampleRate',Fs,...
    'TimeSpanSource','property',...
    'TimeSpan',5,...
    'TimeDisplayOffset',0,...
    'LayoutDimensions',[3 1],...
    'BufferLength',Fs*15,...
    'TimeSpanOvverrunAction','Scroll',...
    'YLimits',[-1 1],...
    'ShowGrid',true,...
    'Title','Input Audio - Classical Guitar');
scope.ActiveDisplay = 2;
scope.YLimits = [-1 1];
scope.Title = 'Sidechain Audio - Drums';
scope.ShowGrid = true;
scope.ActiveDisplay = 3;
scope.YLimits = [-1 1];
scope.ShowGrid = true;
scope.Title = 'Gated Input Audio - Classical Guitar';
```

Call `parameterTuner` to open a UI to tune parameters of the gate while streaming. Adjust the property values and listen to the effect in real time.

```
parameterTuner(dRG)
```



Create Audio Streaming Loop

Read in a frame of audio from your input and sidechain signals. Process your input and sidechain signals with your `noiseGate` object. Playback your processed audio signals and display the audio data using a `timescope` object.

The top panel of your `timescope` displays the input audio signal and the middle panel displays the sidechain audio signal. The bottom panel displays the gated input audio signal.

Substitute different audio files for your `inputAudio` variable to create different textures and timbres in your drum mix.

```
while ~isDone(sidechainAudioAFR)
    inputAudioFrame = inputAudioAFR();
    sideChainAudioFrame = sidechainAudioAFR();
    noiseGateOutput = dRG(inputAudioFrame,sideChainAudioFrame);
```

```

afw(sideChainAudioFrame+noiseGateOutput);
scope(inputAudioFrame,sideChainAudioFrame,noiseGateOutput);
drawnow limitrate; % required to update parameter settings from UI
end

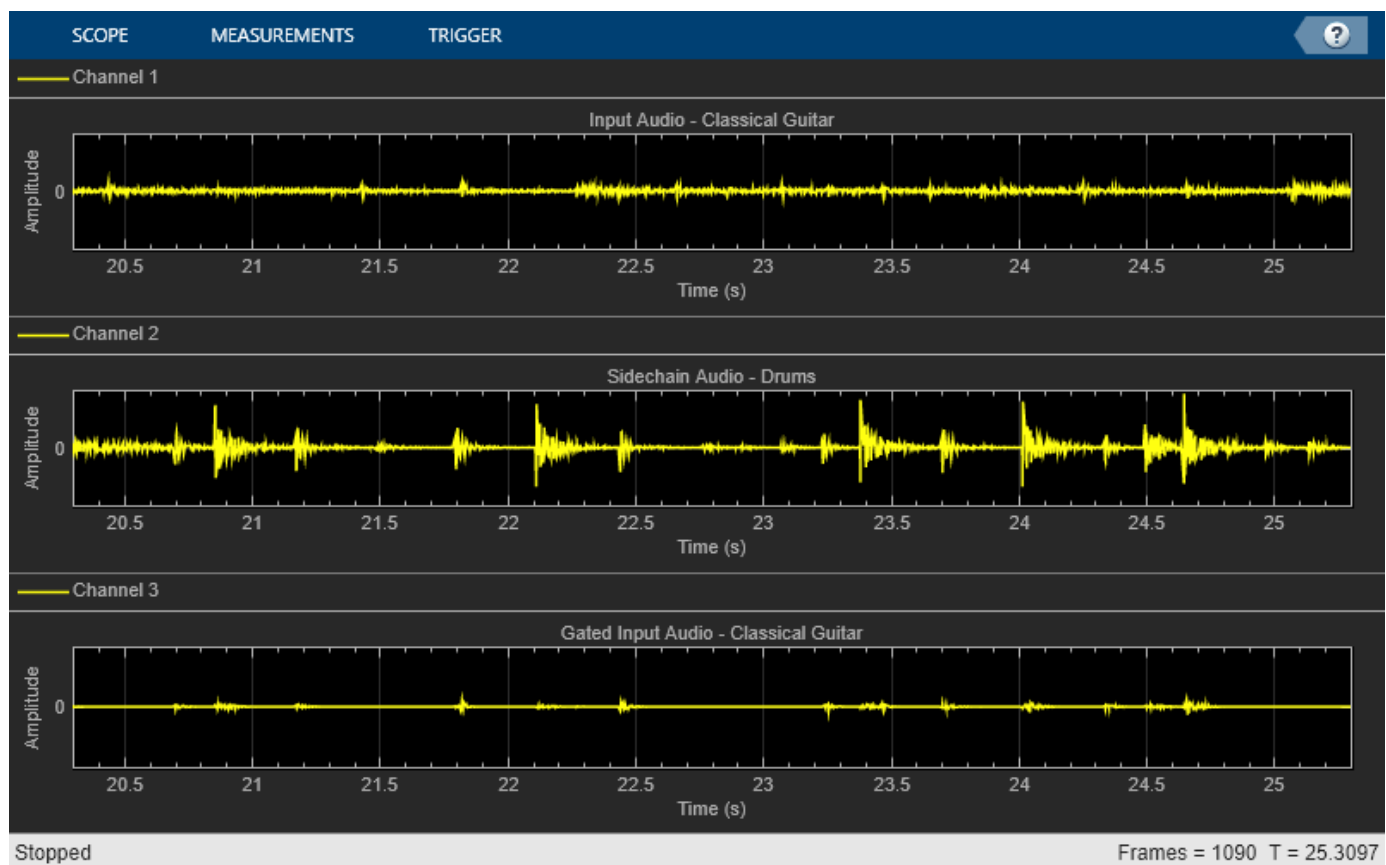
```

Release your objects.

```

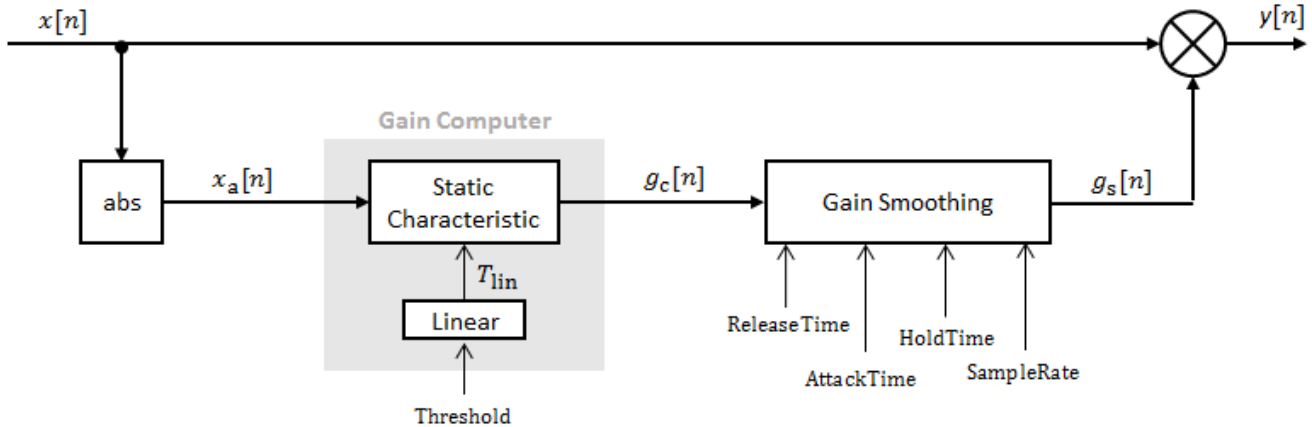
release(inputAudioAFR)
release(sidechainAudioAFR)
release(dRG)
release(afw)
release(scope)

```



Algorithms

The noiseGate System object processes a signal frame by frame and element by element.



Convert Input Signal to Magnitude

The N -point signal, $x[n]$, is converted to magnitude:

$$x_a[n] = |x[n]|.$$

Gain Computer

$x_a[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range gate to determine a brick-wall gain for signal below the threshold:

$$g_c(x_a) = \begin{cases} 0 & x_a < T_{\text{lin}} \\ 1 & x_a \geq T_{\text{lin}} \end{cases}.$$

T_{lin} is the threshold property converted to a linear domain:

$$T_{\text{lin}} = 10^{(T_{\text{dB}}/20)}.$$

Gain Smoothing

The computed gain, $g_c[n]$, is smoothed using specified attack, release, and hold time properties:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n] & (C_A > T_H) \ \& \ (g_c[n] \leq g_s[n-1]) \\ g_s[n-1] & C_A \leq T_H \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n] & g_c[n] > g_s[n-1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{FS \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{FS \times T_R}\right).$$

T_A is the attack time period, specified by the `AttackTime` property. T_R is the release time period, specified by the `ReleaseTime` property. F_s is the input sampling rate, specified by the `SampleRate` property.

C_A is the hold counter for attack. The limit, T_H , is determined by the `HoldTime` property.

Apply Gain

The output of the dynamic range gate is given as

$$y[n] = x[n] \times g_s[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial and Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

"System Objects in MATLAB Code Generation" (MATLAB Coder)

See Also

Noise Gate | expander | compressor | limiter

Topics

"Dynamic Range Control"

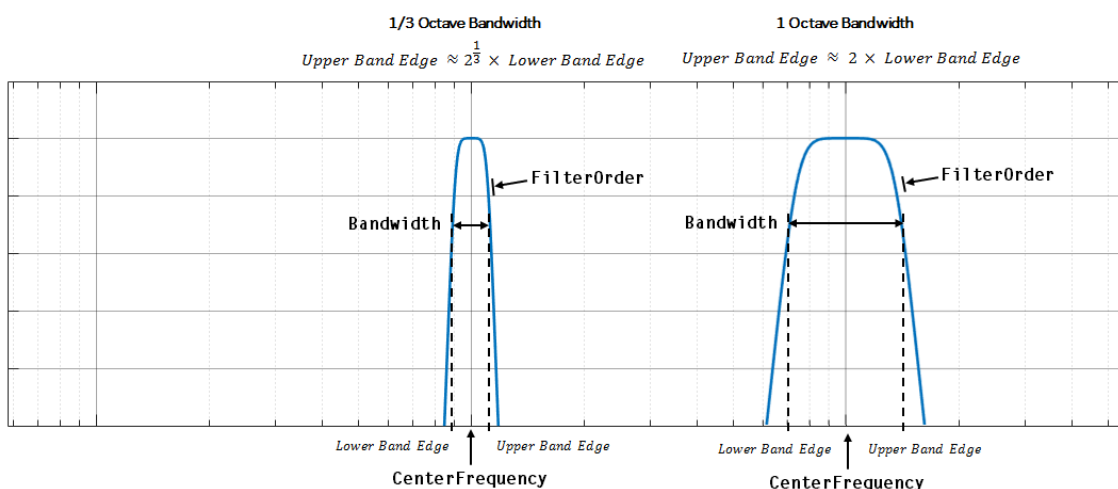
Introduced in R2016a

octaveFilter

Octave-band and fractional octave-band filter

Description

The `octaveFilter` System object performs octave-band or fractional octave-band filtering independently across each input channel. An octave-band is a frequency band where the highest frequency is twice the lowest frequency. Octave-band and fractional octave-band filters are commonly used to mimic how humans perceive loudness. Octave filters are best understood when viewed on a logarithmic scale, which models how the human ear weights the spectrum.



To perform octave-band or fractional octave-band filtering on your input:

- 1 Create the `octaveFilter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
octFilt = octaveFilter
octFilt = octaveFilter(centerFreq)
octFilt = octaveFilter(centerFreq,bw)
octFilt = octaveFilter( ___,Name,Value)
```

Description

`octFilt = octaveFilter` creates a System object, `octFilt`, that performs octave-band filtering independently across each input channel.

`octFilt = octaveFilter(centerFreq)` sets the `CenterFrequency` property to `centerFreq`.

`octFilt = octaveFilter(centerFreq,bw)` sets the `Bandwidth` property to `bw`.

`octFilt = octaveFilter(____,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `octFilt = octaveFilter(1000,'1/3 octave','SampleRate',96000)` creates a System object, `octFilt`, with a center frequency of 1000 Hz, a 1/3 octave filter bandwidth, and a sample rate of 96,000 Hz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

FilterOrder — Order of octave filter

6 (default) | even integer

Order of the octave filter, specified as an even integer.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

CenterFrequency — Center frequency of octave filter (Hz)

1000 (default) | positive scalar

Center frequency of the octave filter in Hz, specified as a positive scalar.

When using the `parameterTuner`, the center frequency must be in the range `[0.2, SampleRate/2]` Hz.

Tunable: Yes

Data Types: `single` | `double`

Bandwidth — Filter bandwidth (octaves)

'1 octave' (default) | '2/3 octave' | '1/2 octave' | '1/3 octave' | '1/6 octave' | '1/12 octave' | '1/24 octave' | '1/48 octave'

Filter bandwidth in octaves, specified as '1 octave', '2/3 octave', '1/2 octave', '1/3 octave', '1/6 octave', '1/12 octave', '1/24 octave', or '1/48 octave'.

Tunable: Yes

Data Types: `char` | `string`

Oversample — Oversample toggle

false (default) | true

Oversample toggle, specified as false or true.

- `false` -- The octave filter runs at the input sample rate.
- `true` -- The octave filter runs at two times the input sample rate. Oversampling minimizes the frequency warping effects introduced by the bilinear transformation. An FIR halfband interpolator implements oversampling before octave filtering. A halfband decimator reduces the sample rate back to the input sampling rate after octave filtering.

Tunable: No

Data Types: `logical`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
audioOut = octFilt(audioIn)
```

Description

`audioOut = octFilt(audioIn)` applies octave-band filtering to the input signal, `audioIn`, and returns the filtered signal, `audioOut`. The type of filtering is specified by the algorithm and properties of the `octaveFilter` System object, `octFilt`.

Input Arguments

audioIn — Audio input to octave filter

matrix

Audio input to the octave filter, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from octave filter

matrix

Audio output from the octave filter, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

release(obj)

Specific to octaveFilter

createAudioPluginClass	Create audio plugin class that implements functionality of System object
visualize	Visualize and validate filter response
isStandardCompliant	Verify octave filter design is ANSI S1.11-2004 compliant
getFilter	Return biquad filter object with design parameters set
getANSICenterFrequencies	Get the list of valid ANSI S1.11-2004 center frequencies
parameterTuner	Tune object parameters while streaming

MIDI

configureMIDI	Configure MIDI connections between audio object and MIDI controller
disconnectMIDI	Disconnect MIDI controls from audio object
getMIDIConnections	Get MIDI connections of audio object

Common to All System Objects

clone	Create duplicate System object
isLocked	Determine if System object is in use
release	Release resources and allow changes to System object property values and input characteristics
reset	Reset internal states of System object
step	Run System object algorithm

Note octaveFilter supports additional filter analysis functions. See Analyze Octave Filter Design on page 3-322 for details.

Examples

Perform Fractional Octave-Band Filtering

Use octaveFilter to design a 1/3 octave-band filter centered at 1000 Hz. Process an audio signal using your octave filter design.

Create a dsp.AudioFileReader object.

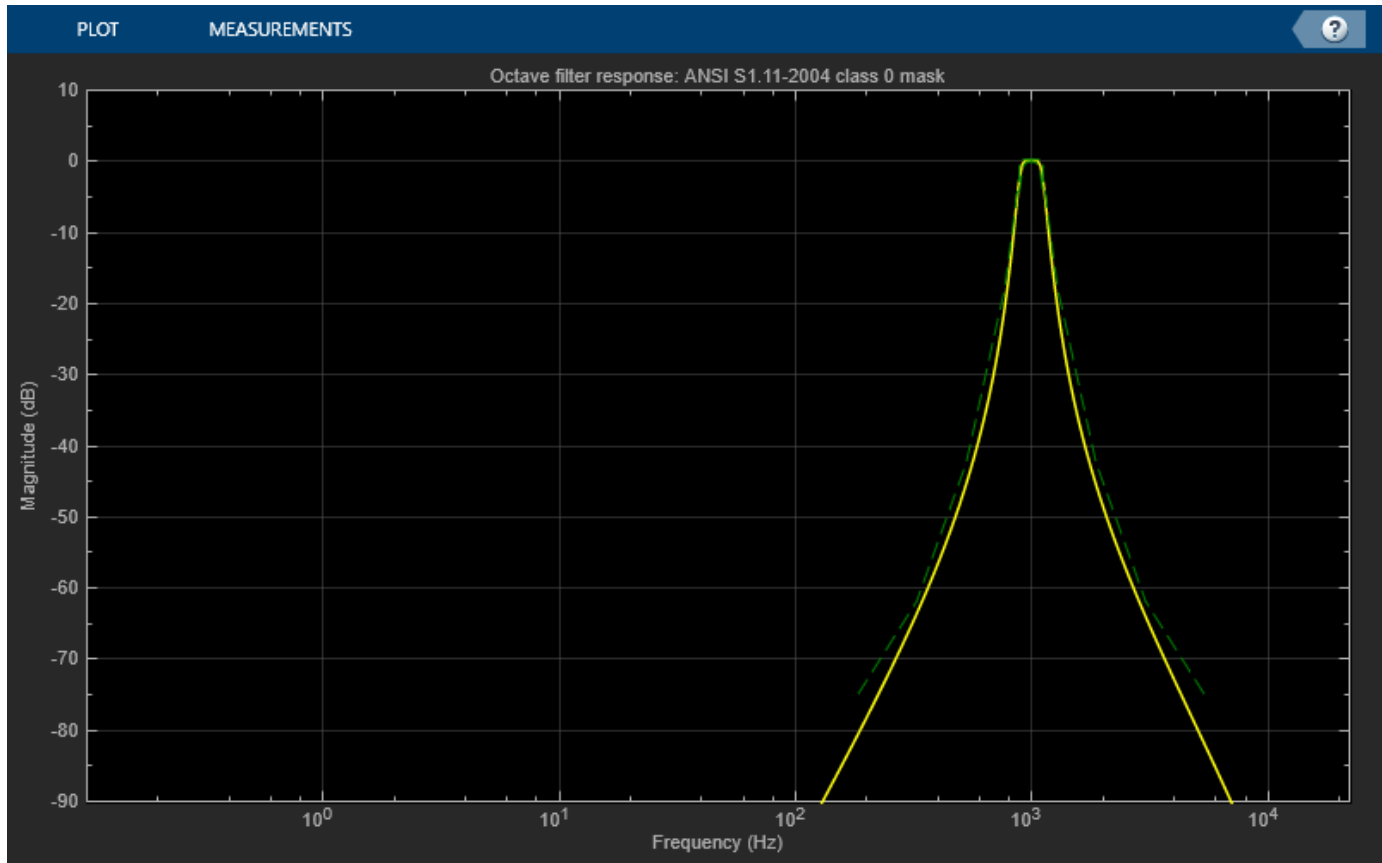
```
samplesPerFrame = 1024;  
reader = dsp.AudioFileReader('RockGuitar-16-44p1-stereo-72secs.wav', 'SamplesPerFrame', samplesPerFrame);
```

Create an octaveFilter object. Use the sample rate of the reader as the sample rate of the octave filter.

```
centerFreq = 1000;  
bw = '1/3 octave';  
Fs = reader.SampleRate;  
  
octFilt = octaveFilter(centerFreq, bw, 'SampleRate', Fs);
```

Visualize the filter response and verify that it fits within the class 0 mask of the ANSI S1.11-2004 standard.

```
visualize(octFilt,'class 0')
```



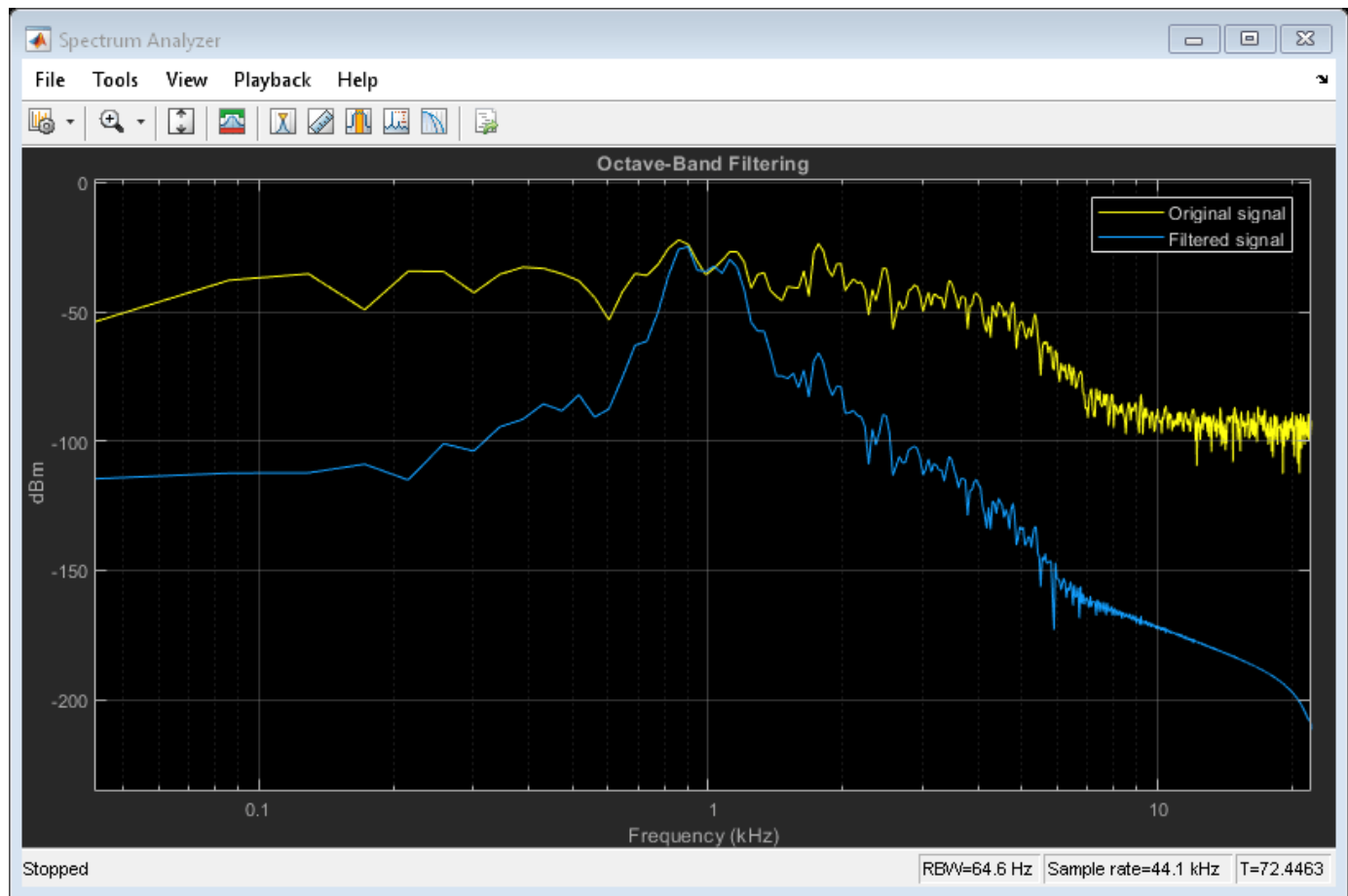
Create a spectrum analyzer to visualize the original audio signal and the audio signal after octave-band filtering.

```
scope = dsp.SpectrumAnalyzer( ...
    'SampleRate',Fs, ...
    'PlotAsTwoSidedSpectrum',false, ...
    'FrequencyScale','Log', ...
    'FrequencyResolutionMethod','WindowLength', ...
    'WindowLength',samplesPerFrame, ...
    'Title','Octave-Band Filtering', ...
    'ShowLegend',true, ...
    'ChannelNames',{'Original signal','Filtered signal'});
```

Process the audio signal in an audio stream loop. Visualize the filtered audio and the original audio. As a best practice, release the System objects when complete.

```
while ~isDone(reader)
    x = reader();
    y = octFilt(x);
    scope([x(:,1),y(:,1)])
end

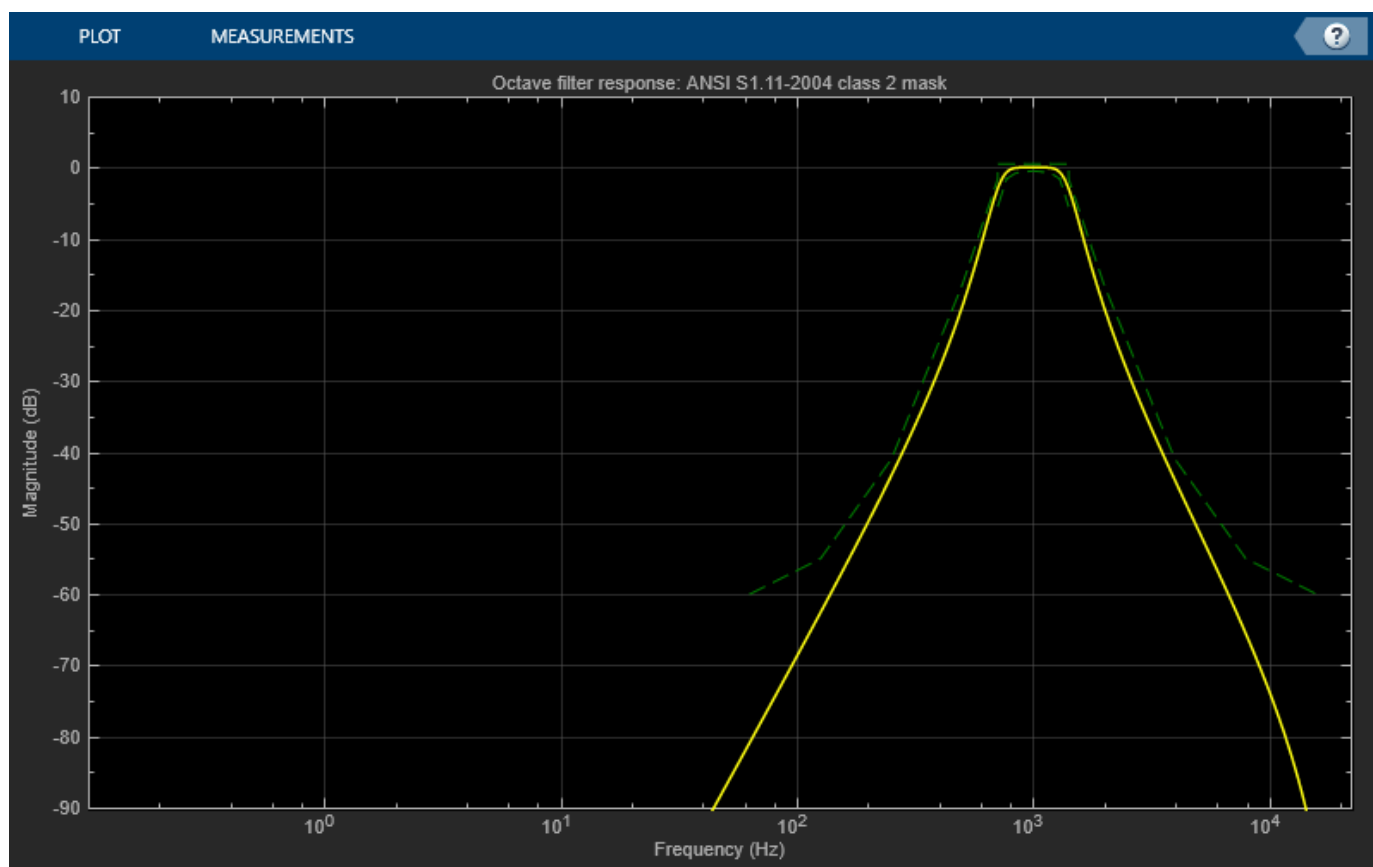
release(octFilt)
release(reader)
release(scope)
```

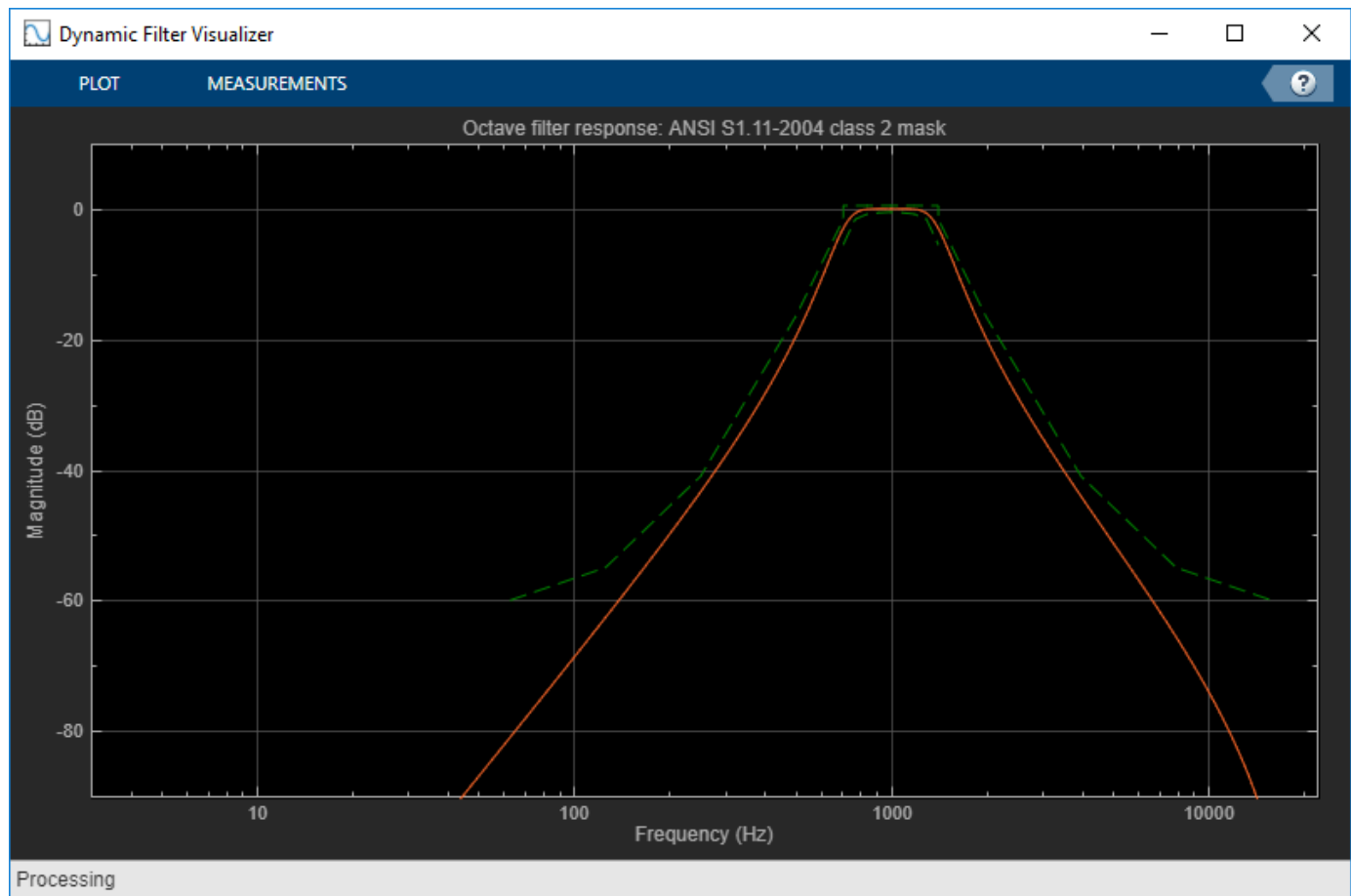


Analyze Octave Filter Design

Create an octave filter. Visualize the filter response and validate that it is class 2 compliant.

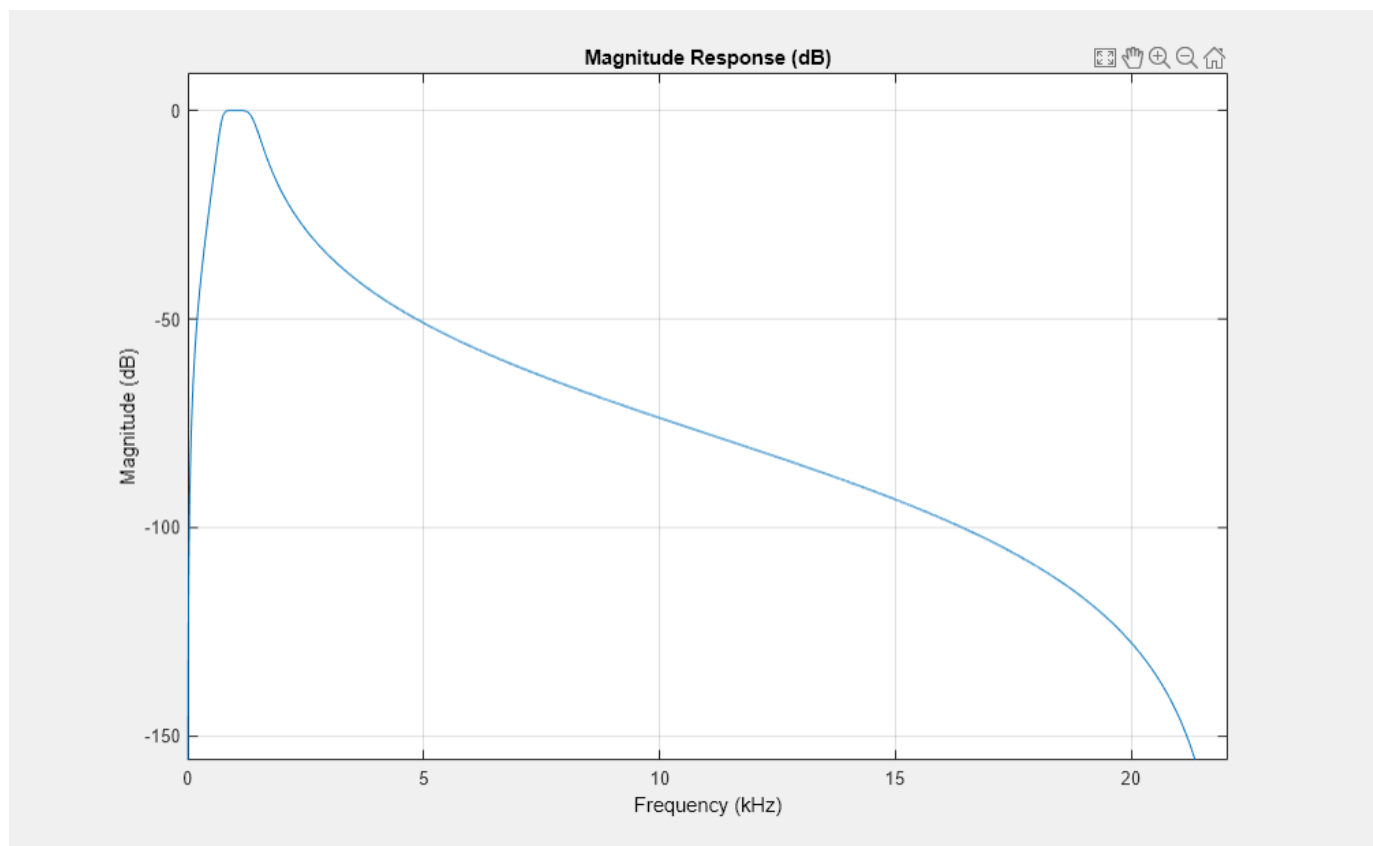
```
octFilt = octaveFilter('CenterFrequency',1000);  
visualize(octFilt,'class 2')
```





Analyze the filter using `fvtool`.

```
fvtool(octFilt, 'Fs', octFilt.SampleRate)
```



The `octaveFilter` object supports several filter analysis methods. For more information, use `help` at the command line:

`help octaveFilter.helpFilterAnalysis`

The following analysis methods are available for discrete-time filter System objects:

<code>fvtool</code>	- Filter visualization tool
<code>info</code>	- Filter information
<code>freqz</code>	- Frequency response
<code>phasez</code>	- Phase response
<code>zerophase</code>	- Zero-phase response
<code>grpdelay</code>	- Group delay response
<code>phasedelay</code>	- Phase delay response
<code>impz</code>	- Impulse response
<code>impzlength</code>	- Length of impulse response
<code>stepz</code>	- Step response
<code>zplane</code>	- Pole/zero plot
<code>cost</code>	- Cost estimate for implementation of the filter System object
<code>measure</code>	- Measure characteristics of the frequency response
<code>outputDelay</code>	- Output delay value
<code>order</code>	- Filter order
<code>coeffs</code>	- Filter coefficients in a structure
<code>firtype</code>	- Determine the type (1-4) of a linear phase FIR filter System object
<code>tf</code>	- Convert to transfer function
<code>zpk</code>	- Convert to zero-pole-gain
<code>ss</code>	- Convert to state space representation

`isallpass` - Verify if filter System object is allpass
`isfir` - Verify if filter System object is FIR
`islinphase` - Verify if filter System object is linear phase
`ismaxphase` - Verify if filter System object is maximum phase
`isminphase` - Verify if filter System object is minimum phase
`isreal` - Verify if filter System object is minimum real
`issos` - Verify if filter System object is in second-order sections form
`isstable` - Verify if filter System object is stable

`realizemdl` - Filter realization (Simulink diagram)

`specifyall` - Fully specify fixed-point filter System object settings

`cascade` - Create a `FilterCascade` System object

Second-order sections:

`scale` - Scale second-order sections of `BiquadFilter` System object
`scalecheck` - Check scaling of `BiquadFilter` System object
`reorder` - Reorder second-order sections of `BiquadFilter` System object
`cumsec` - Cumulative second-order section of `BiquadFilter` System object
`scaleopts` - Create an options object for second-order section scaling
`sos` - Convert to second-order-sections (for `IIRFilter` System objects only)

Fixed-Point (Fixed-Point Designer Required):

`freqrespest` - Frequency response estimate via filtering
`freqrespopts` - Create an options object for frequency response estimate
`noisepsd` - Power spectral density of filter output due to roundoff noise
`noisepsdopts` - Create an options object for output noise PSD computation

Multirate Analysis:

`polyphase` - Polyphase decomposition of multirate filter System object
`gain (CIC decimator)` - Gain of CIC decimator filter System object
`gain (CIC interpolator)` - Gain of CIC interpolator filter System object

For decimator, interpolator, or rate change filter System objects the analysis tools perform computations relative to the rate at which the filter is running. If a sampling frequency is specified, it is assumed that the filter is running at that rate.

Help for `octaveFilter.helpFilterAnalysis` is inherited from superclass `dsp.internal.FilterAnalysis`.

Effect of Center Frequency on Octave-Band Filtering

Process a speech signal using different octave bands from an octave-band filter bank.

Design a 1/2 octave filter with an estimated center frequency of 800 Hz. Use `isStandardCompliant` to find the nearest compliant center frequency.

```
octFilt = octaveFilter(800,'1/2 octave');  
[complianceStatus,suggestedCenterFrequency] = isStandardCompliant(octFilt,'class 0')
```



```

complianceStatus =
    logical
    0

suggestedCenterFrequency =
    841.3951

```

Change the center frequency of the `octFilt` object to the suggested center frequency returned by `isStandardCompliant`. Get a list of valid ANSI S1.11-2004 center frequencies, given your specified `octFilt` center frequency.

```

octFilt.CenterFrequency = suggestedCenterFrequency;
Fo = getANSICenterFrequencies(octFilt);

```

Create an audio file reader and audio device writer.

```

fileReader = dsp.AudioFileReader('Counting-16-44p1-mono-15secs.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

```

Create a scope to visualize the filtered and unfiltered signals.

```

scope = dsp.SpectrumAnalyzer(...
    'PlotAsTwoSidedSpectrum',false,...
    'FrequencyScale','Log',...
    'Title','Octave-Band Filtering',...
    'ShowLegend',true,...
    'ChannelNames',{'Original signal','Filtered signal'});

```

In an audio stream loop, process the audio signal using your octave-band filter. Vary the center frequency to hear the effect. As a best practice, release your objects after processing.

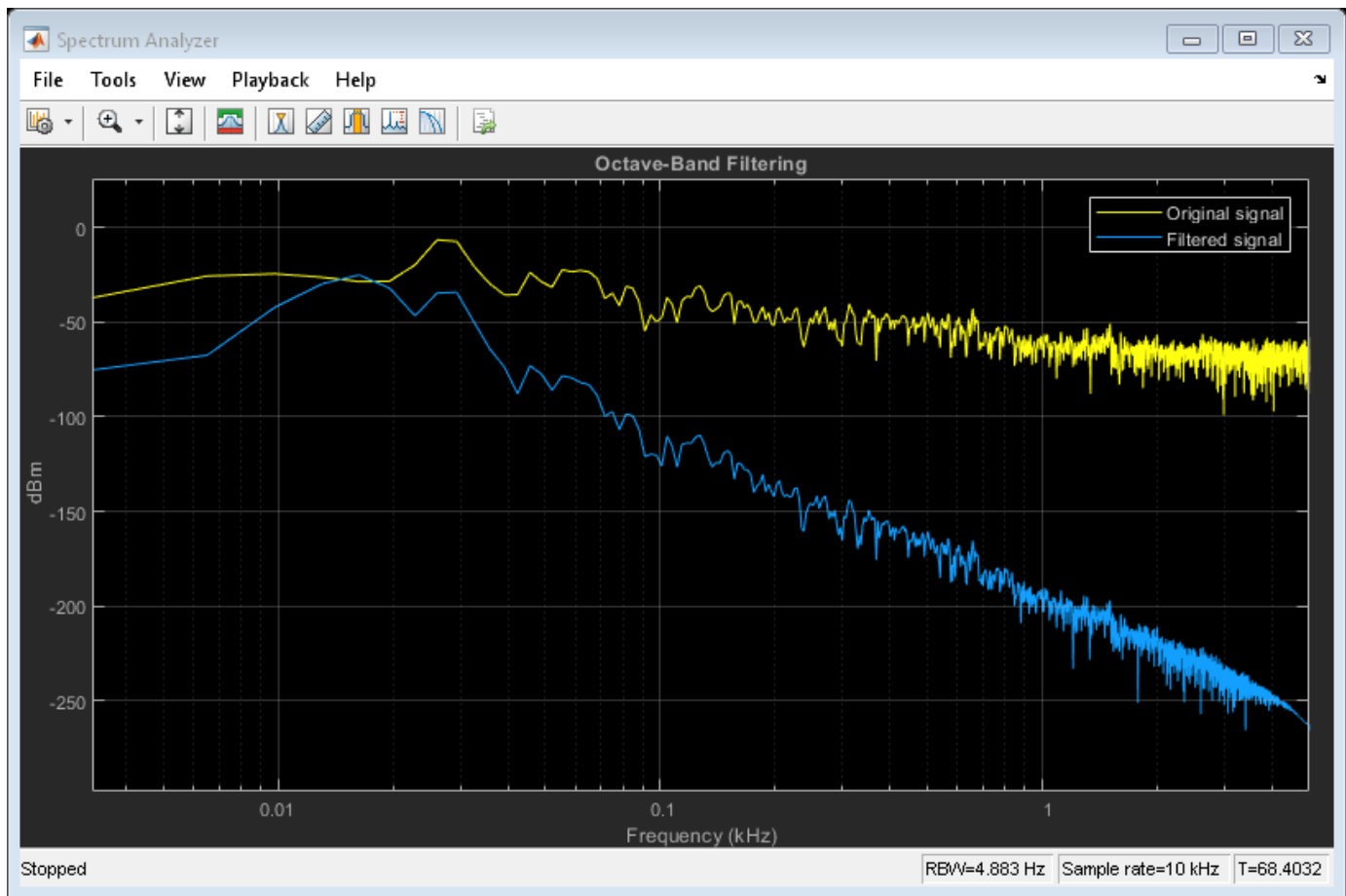
```

index = 12;
octFilt.CenterFrequency = Fo(index);
count = 1;
while ~isDone(fileReader)
    x = fileReader();
    y = octFilt(x);
    scope([x,y])
    deviceWriter(y);

    if mod(count,100)==0
        octFilt.CenterFrequency = Fo(index);
        index = index+1;
    end
    count = count+1;
end

release(scope)
release(deviceWriter)
release(fileReader)

```



Remove Noise from Tone Scale

Remove additive noise from an audio tone scale using an `octaveFilter`.

Create `audioOscillator` and `audioDeviceWriter` objects with default properties. Create an `octaveFilter` object with the center frequency set to 100 Hz.

```
osc = audioOscillator;
deviceWriter = audioDeviceWriter;
octFilt = octaveFilter(100);
```

In an audio stream loop, listen to a tone created by your audio oscillator. The tone contains additive Gaussian noise.

```
for i = 1:400
    x = osc();
    x1 = x + 0.1*randn(512,1);
    deviceWriter(x1);
    if rem(i,100)==0
        osc.Frequency = osc.Frequency*2;
    end
end
```

Create a spectrum analyzer to view your filtered and unfiltered signals.

```
scope = dsp.SpectrumAnalyzer( ...
    'PlotAsTwoSidedSpectrum',false, ...
    'FrequencyScale','Log', ...
    'FrequencyResolutionMethod','WindowLength', ...
    'Title','Octave-Band Filtering', ...
    'ShowLegend',true, ...
    'SpectralAverages',10, ...
    'ChannelNames',{'Original signal','Filtered signal'});
```

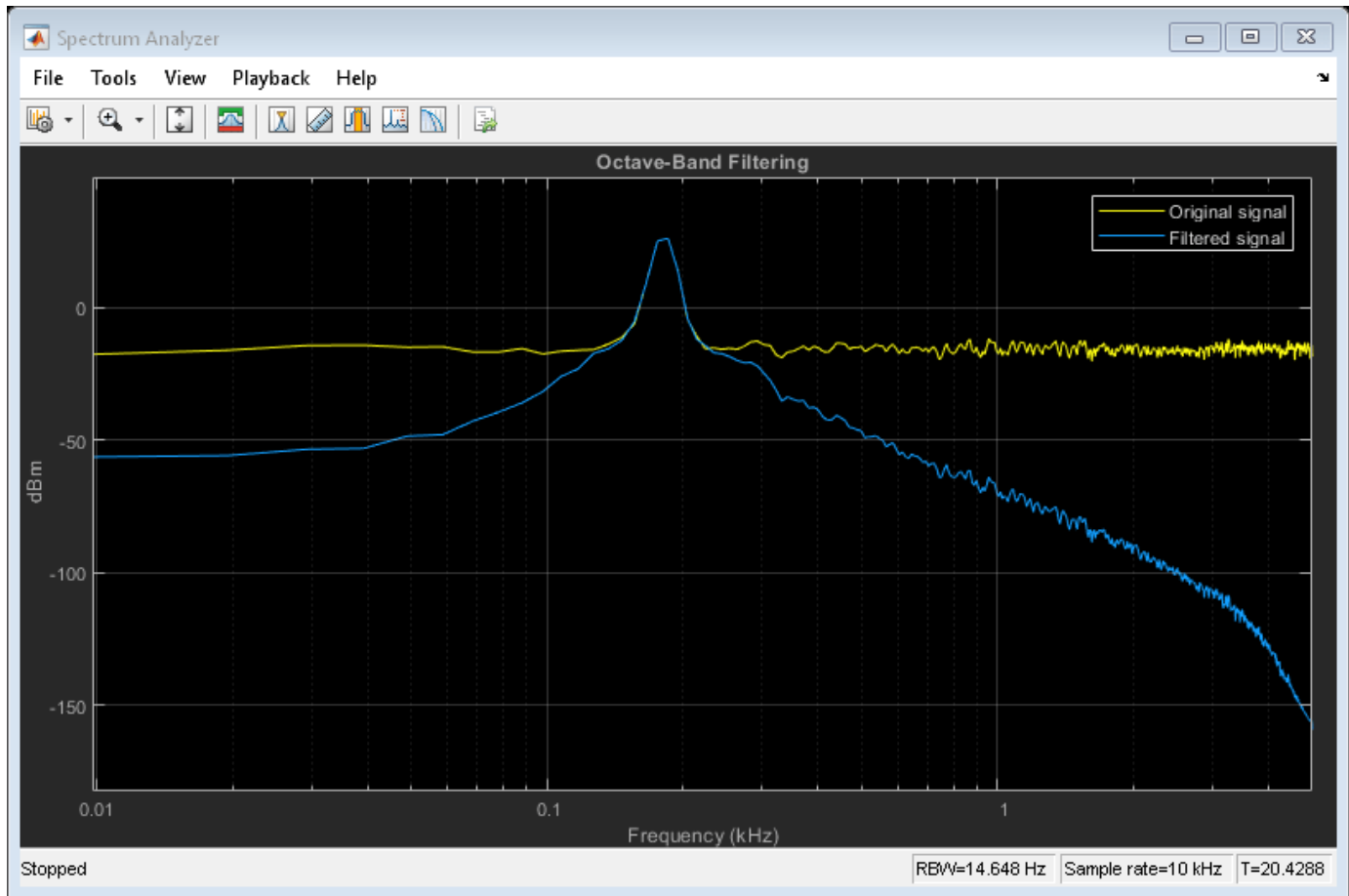
Reset the frequency of your audio oscillator to its default, 100 Hz.

```
osc.Frequency = 100;
```

In an audio stream loop, filter the corrupted tone using your octave-band filter. When the tone changes frequency in the loop, change the center frequency of your octave filter to match. As a best practice, release your audio device once done.

```
for i = 1:400
    x = osc();
    x1 = x + 0.1*randn(512,1);
    x2 = octFilt(x1);
    deviceWriter(x2);
    if rem(i,100)==0
        osc.Frequency = osc.Frequency*2;
        octFilt.CenterFrequency = octFilt.CenterFrequency*2;
    end
    scope([x1,x2])
end

release(deviceWriter)
release(scope)
```



Design Compliant High-Frequency Filters

Design a sixth-order 1/3 octave filter with a sample rate of 96 kHz.

```
octFilt = octaveFilter('FilterOrder',6, ...
    'Bandwidth','1/3 octave', ...
    'SampleRate',96e3);
```

Get the center frequencies defined by the ANSI S1.11-2004 standard. The center frequencies defined by the standard depend on the Bandwidth and SampleRate properties.

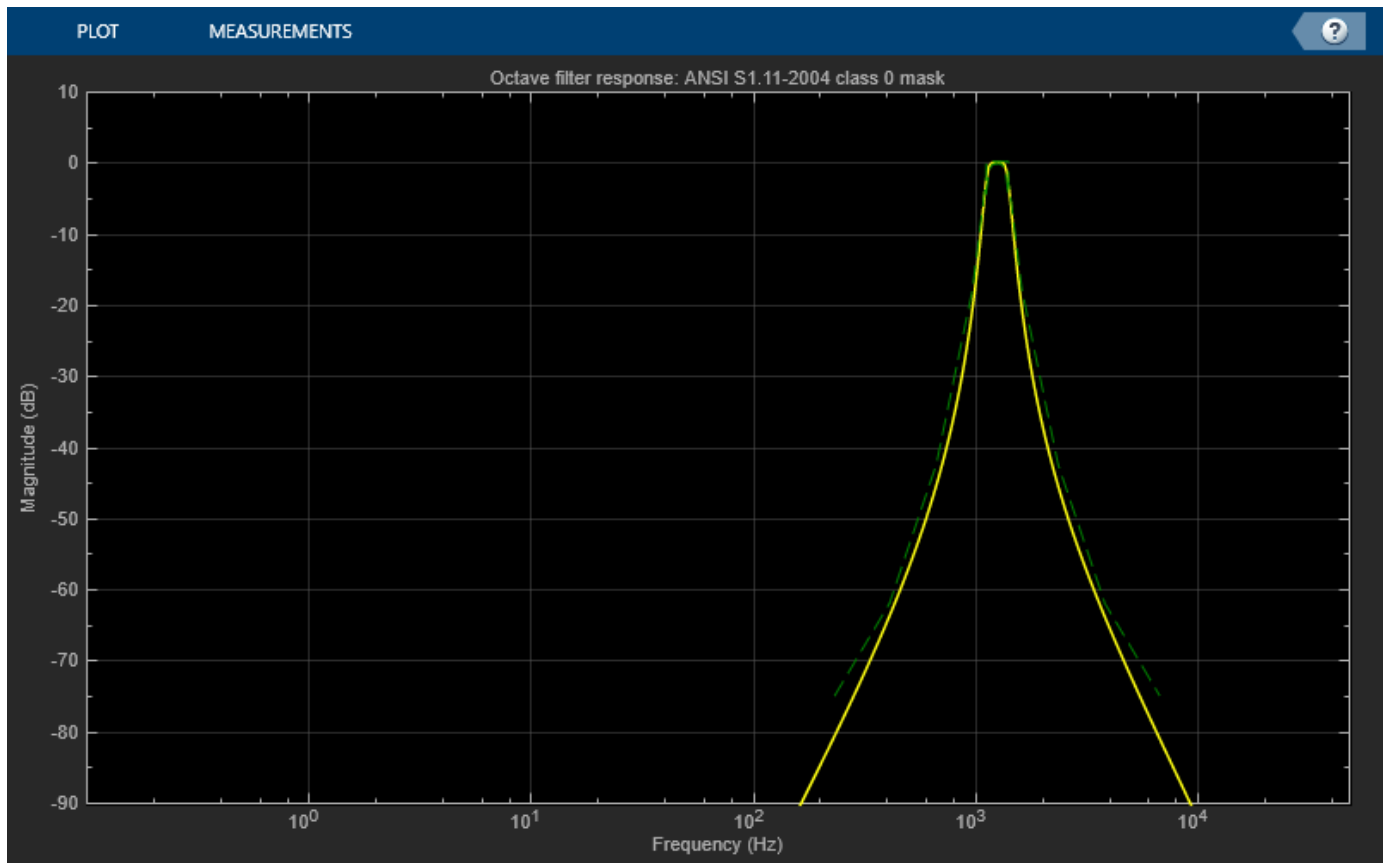
```
centerFrequencies = getANSICenterFrequencies(octFilt)
```

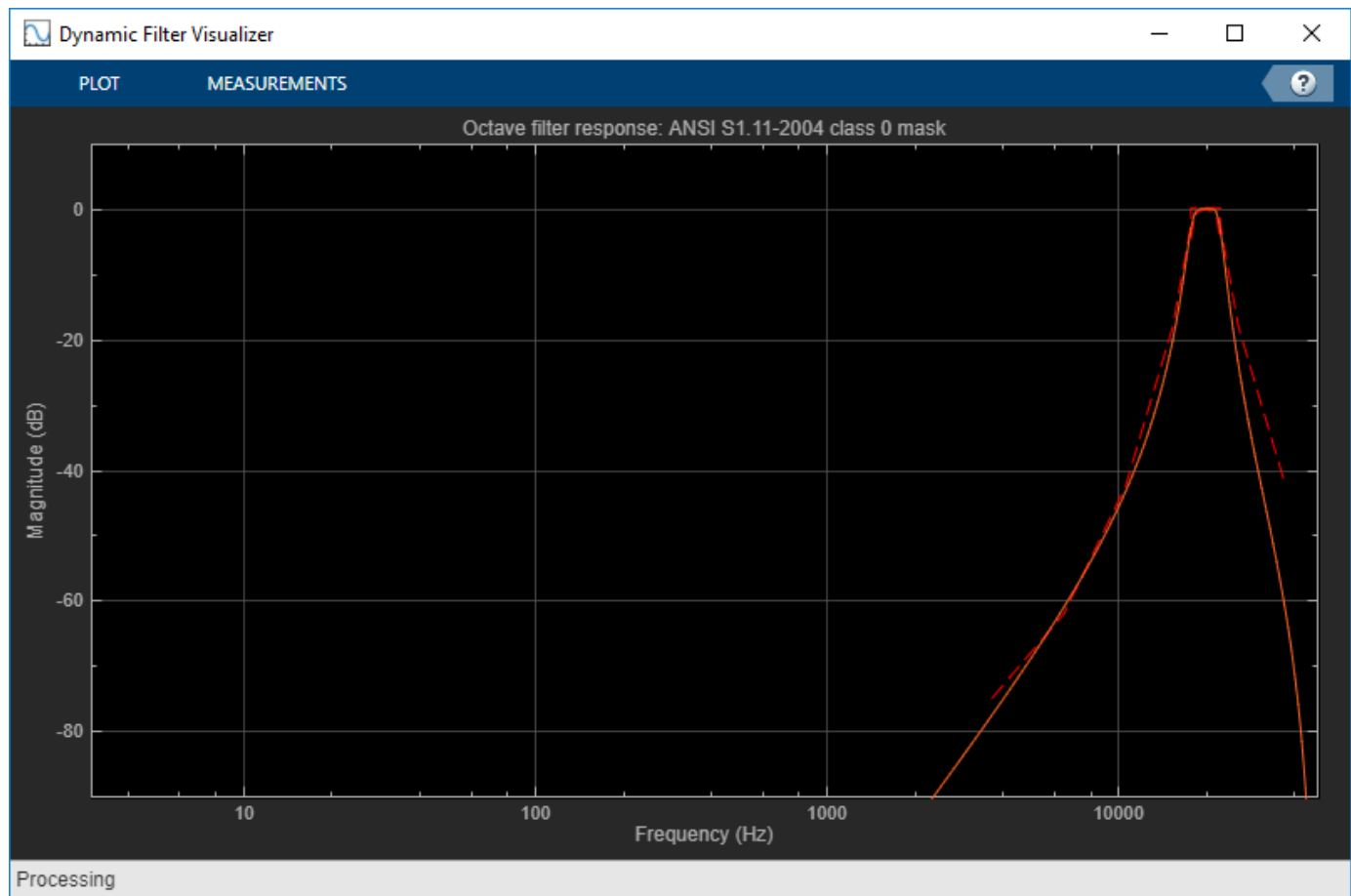
```
centerFrequencies = 1x53
104 ×
```

```
0.0000 0.0000 0.0000 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0002 0.0002
```

Set the center frequency of the octave filter to 19.953 kHz and visualize the response with a 'class 0' compliance mask.

```
octFilt.CenterFrequency = centerFrequencies(38);  
visualize(octFilt, 'class 0')
```

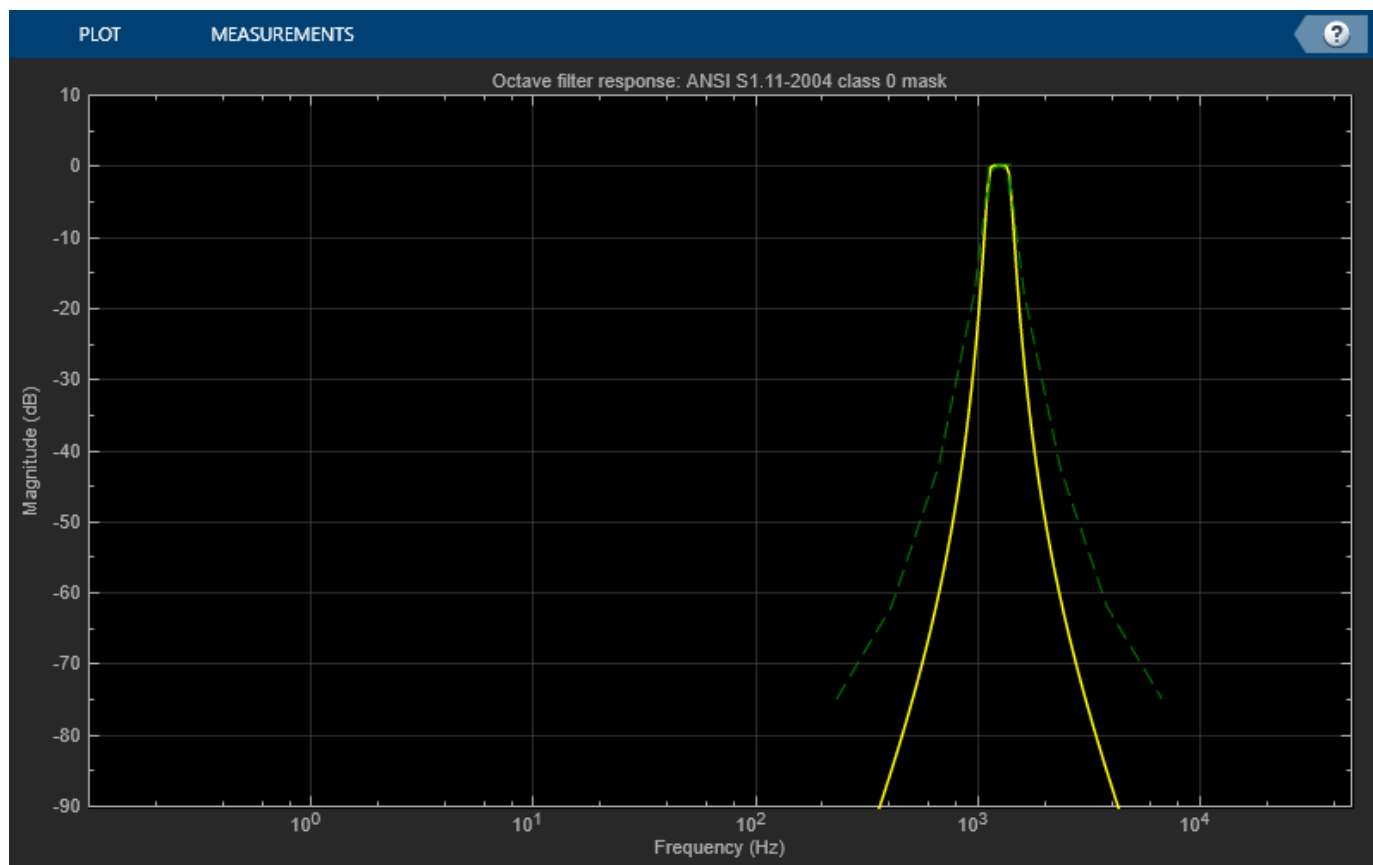


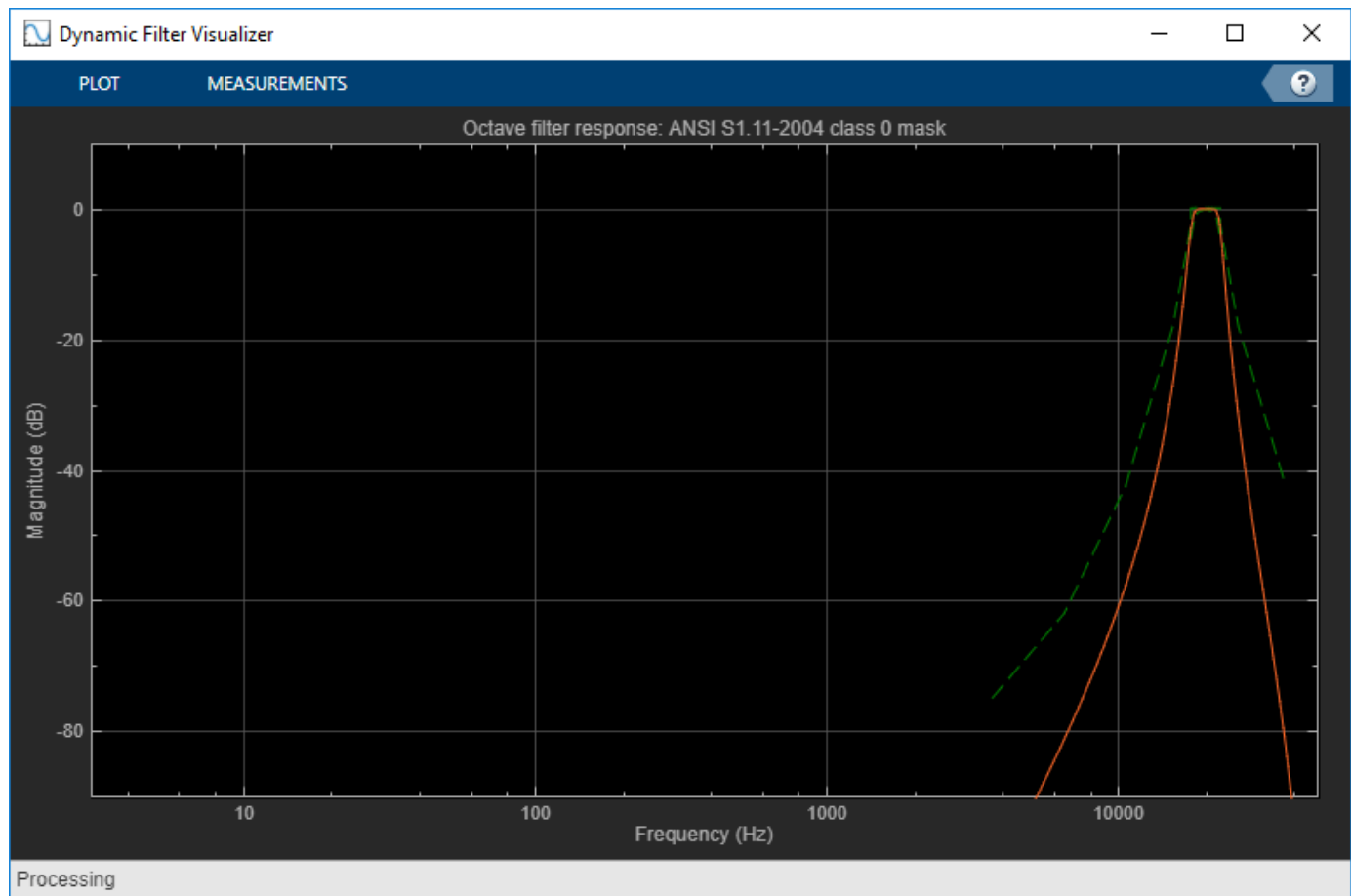


The red mask on the plot defines the bounds for the magnitude response of the filter. The magnitude response of this filter goes above the upper bound of the compliance mask around 6.6 kHz. One way to counter this is to increase the filter order so that the filter's rolloff is steeper.

To bring the octave filter design into compliance, set the octave filter order to 8.

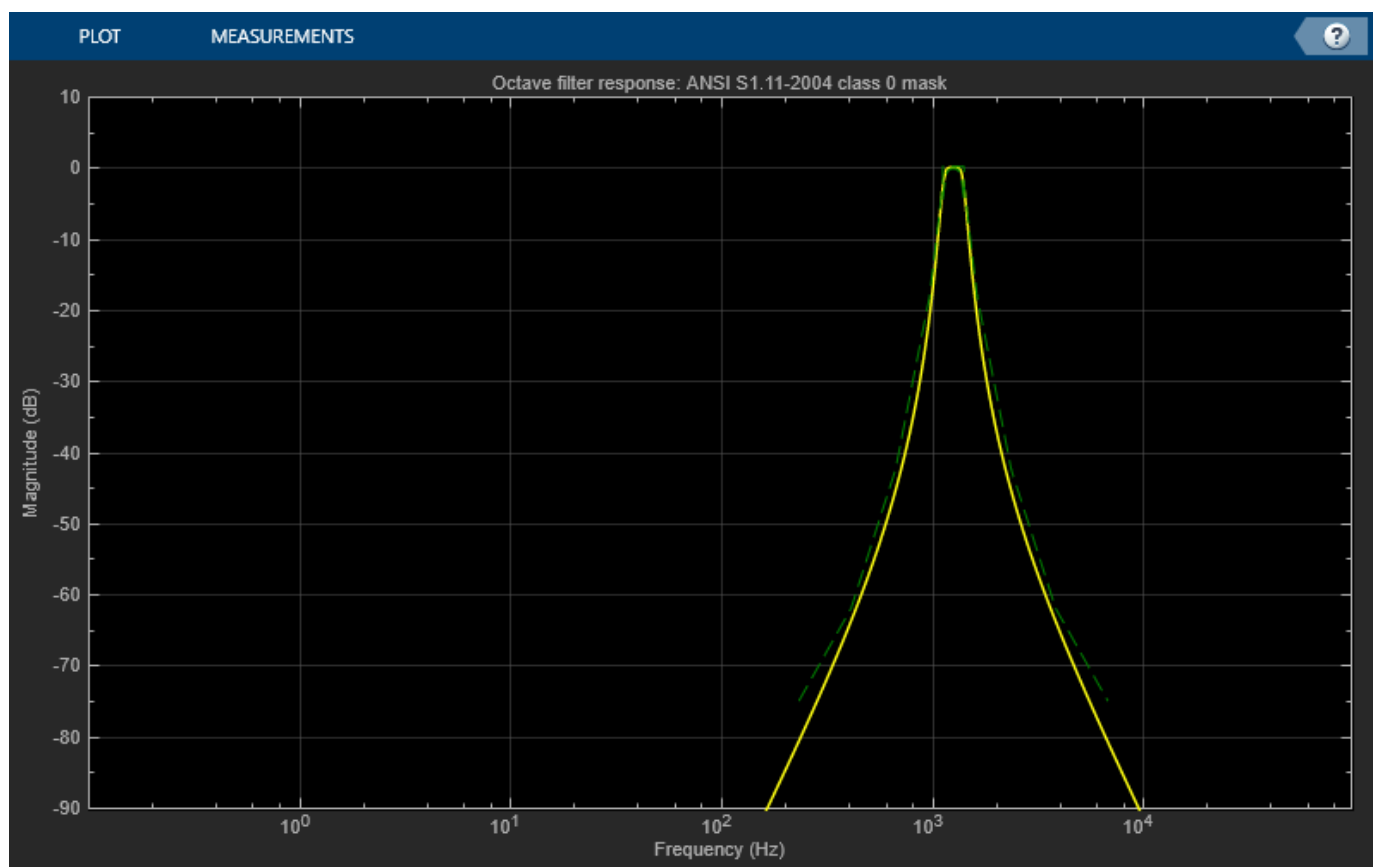
```
octFilt.FilterOrder = 8;
```

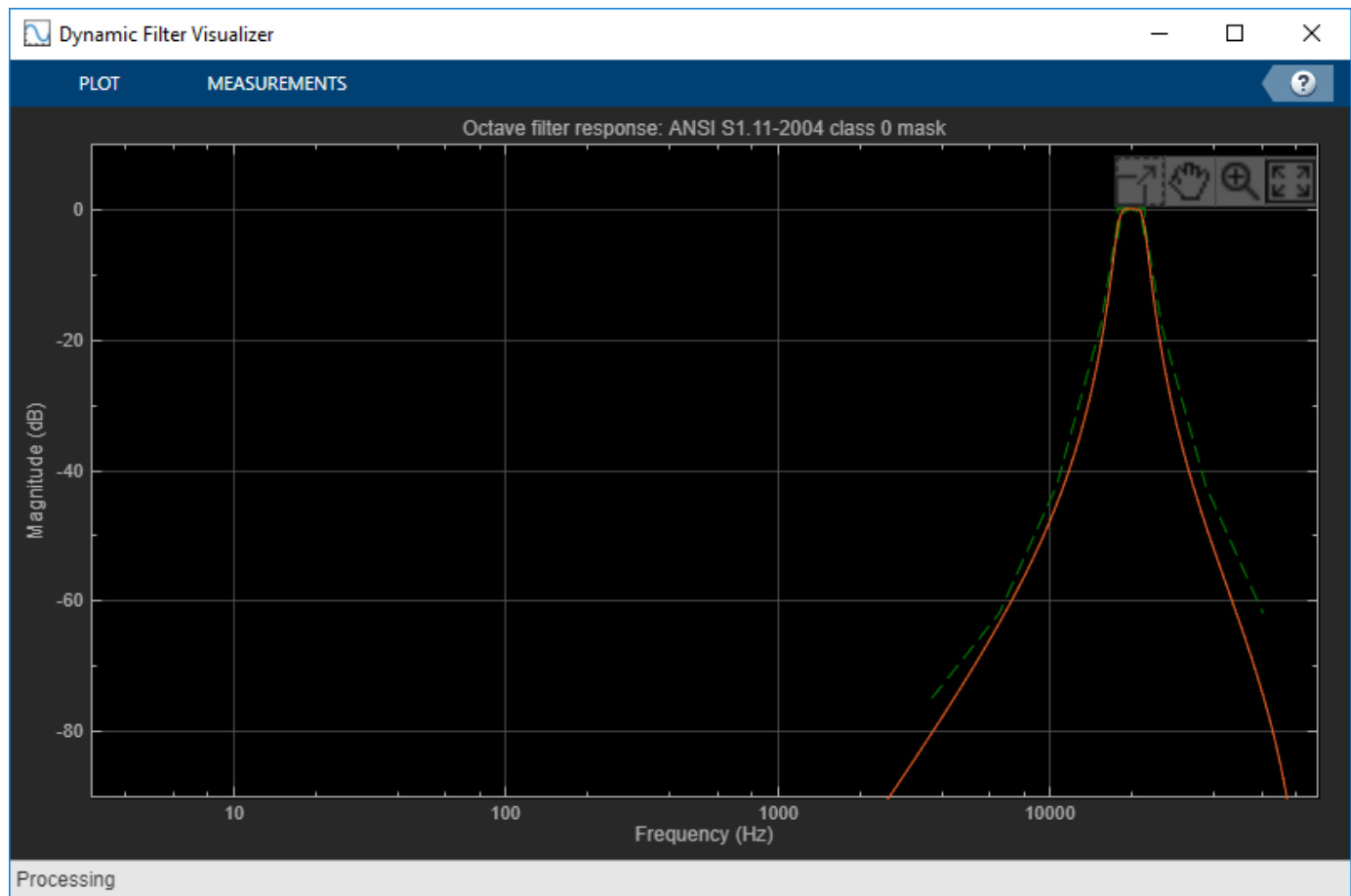




Another option to bring the octave filter design into compliance is to set the `Oversample` property to `true`. This designs and runs the filter at twice the specified `SampleRate` to reduce the effects of the bilinear transformation during the design stage.

```
octFilt.FilterOrder = 6;  
octFilt.Oversample = true;
```



Design Compliant Low-Frequency Filters

Design a sixth-order 2/3 octave filter with a 96 kHz sample rate.

```
octFilt = octaveFilter('FilterOrder',6, ...
    'Bandwidth','2/3 octave', ...
    'SampleRate',96e3);
```

Get the center frequencies defined by the ANSI S1.11-2004 standard. The center frequencies defined by the standard depend on the Bandwidth and SampleRate properties.

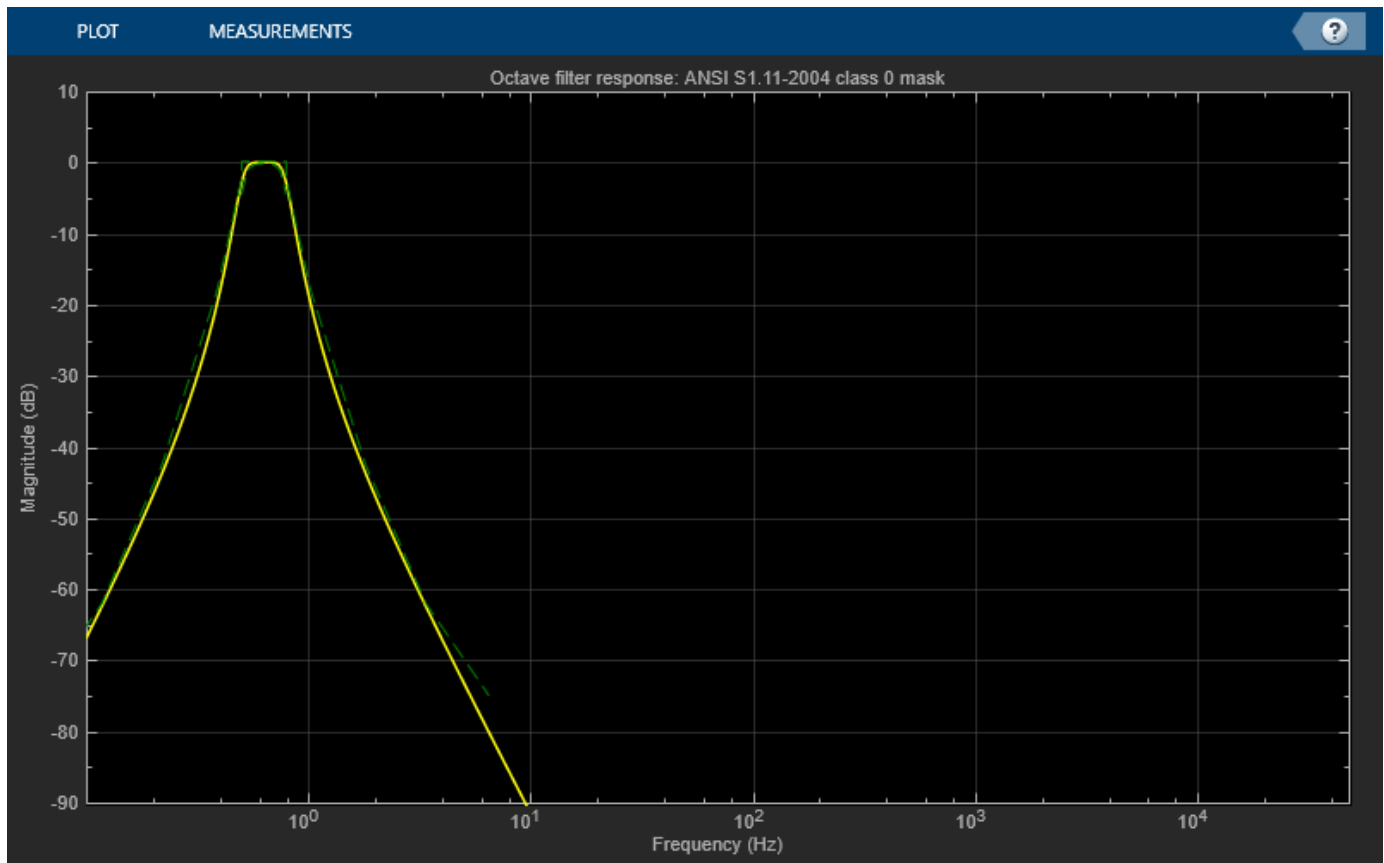
```
centerFrequencies = getANSICenterFrequencies(octFilt)
```

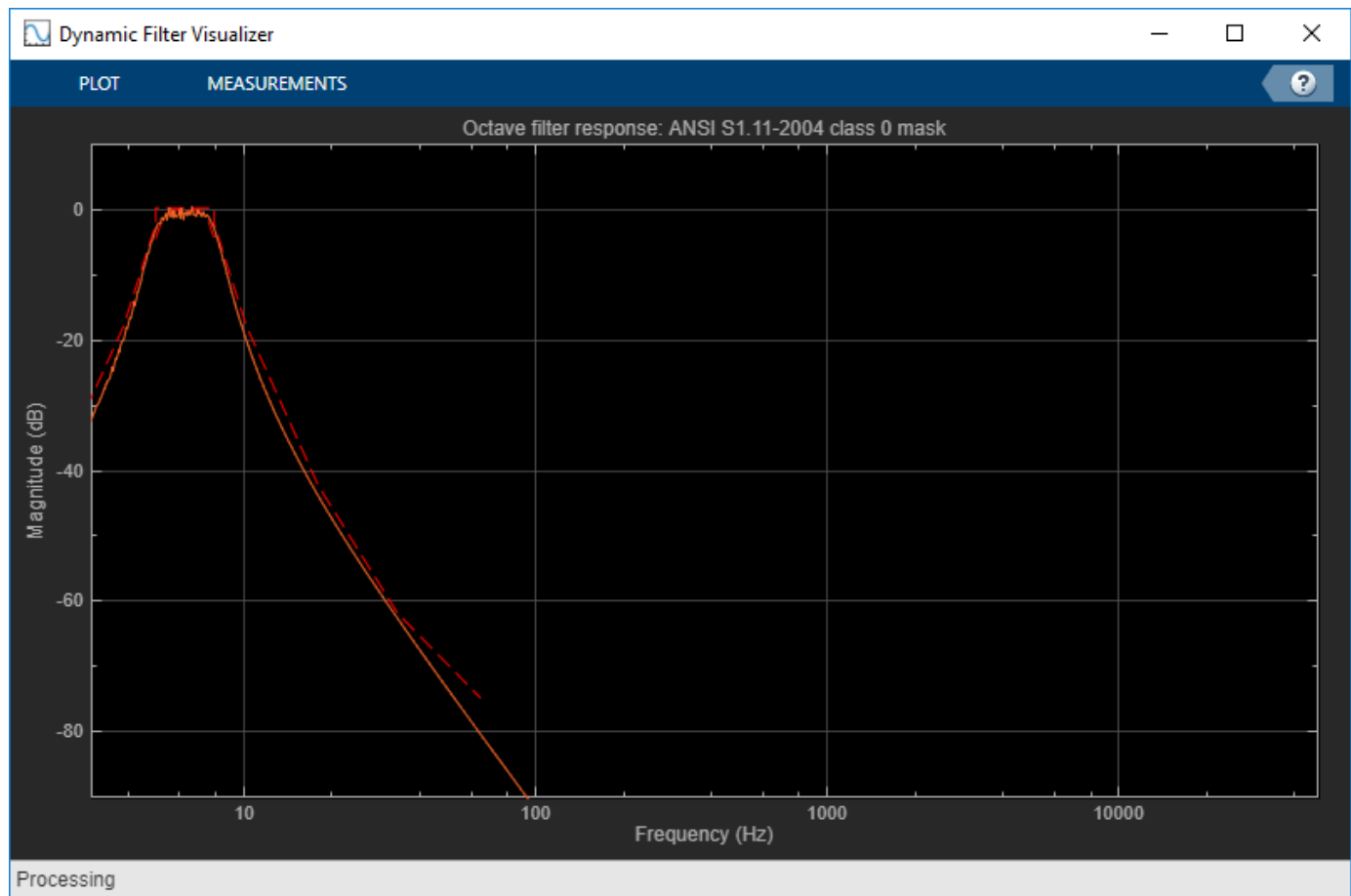
```
centerFrequencies = 1×25
104 ×
```

```
0.0000 0.0001 0.0001 0.0002 0.0003 0.0004 0.0006 0.0010 0.0016 0.0025
```

Set the center frequency of the octave filter to ~6 Hz and visualize the response with a 'class 0' compliance mask.

```
octFilt.CenterFrequency = centerFrequencies(2);  
visualize(octFilt, 'class 0')
```



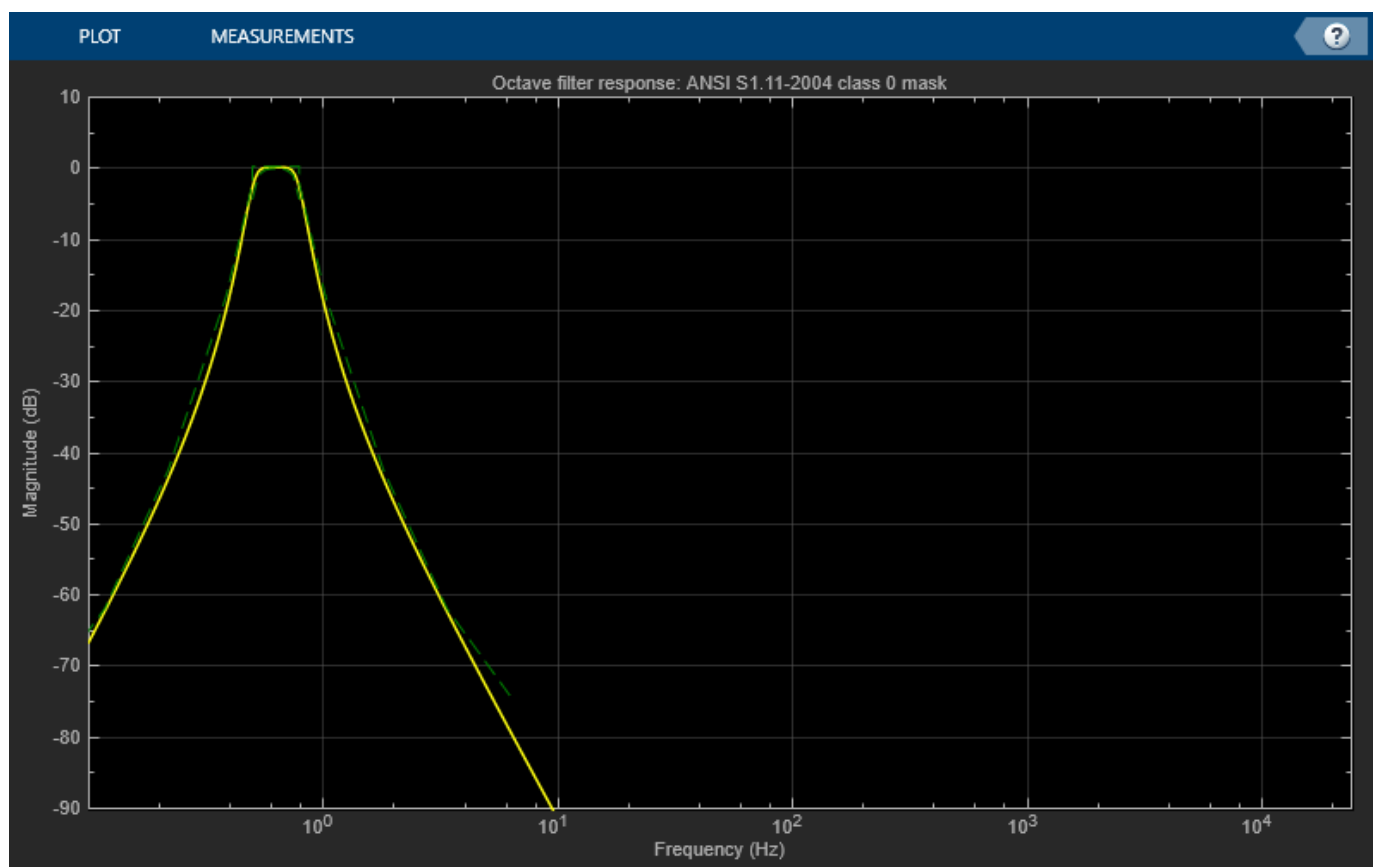


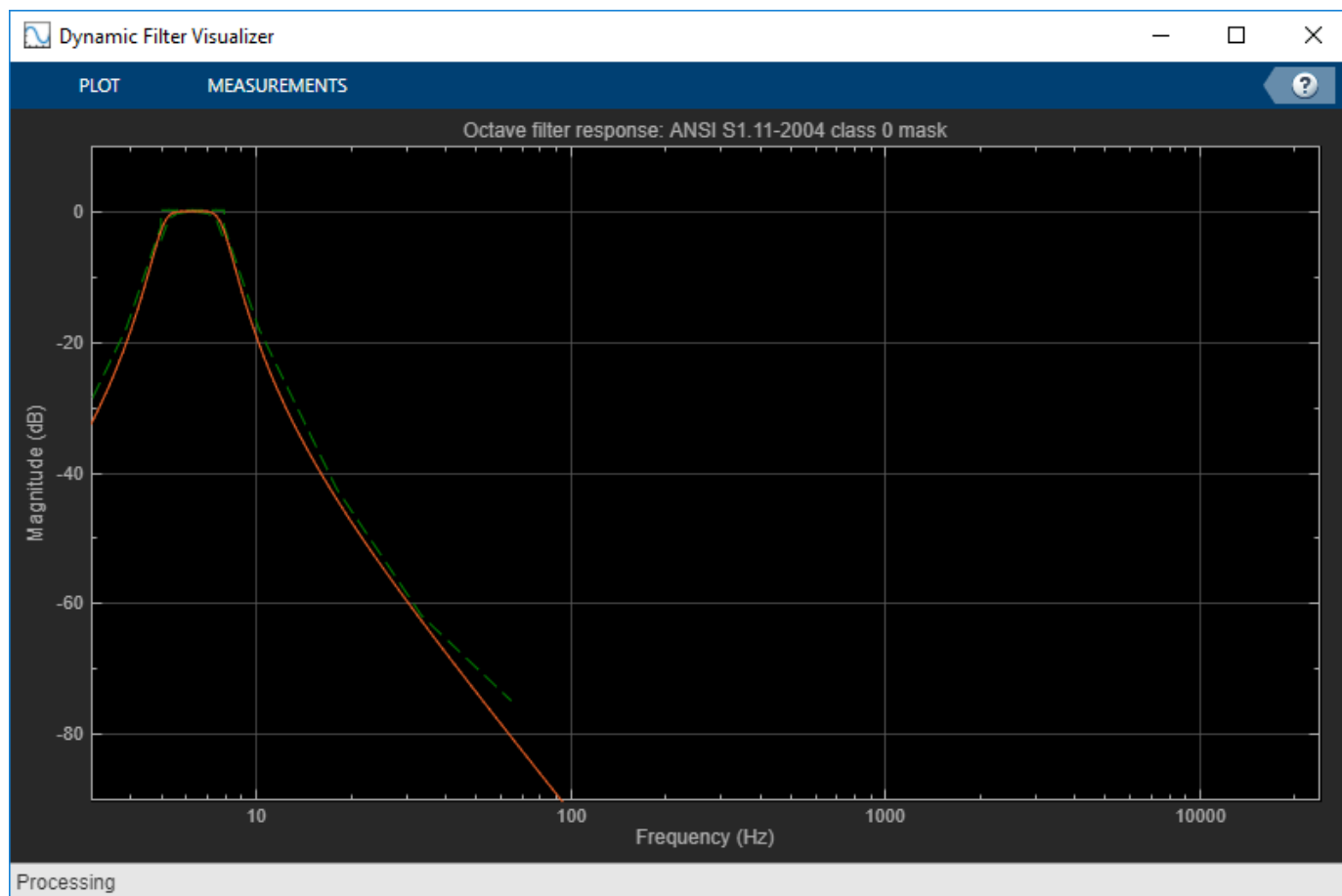
The red mask on the plot defines the bounds for the magnitude response of the filter. The magnitude response of this filter goes below the lower bound of the compliance mask between 5.5 and 7.5 Hz.

Low-frequency filters in an octave filter bank have very low normalized center frequencies, and the filters designed for them have poles that are almost on the unit circle. To make this filter ANSI compliant, it has to be designed and operated at a lower sample rate.

To bring the octave filter design into compliance, set the sample rate to 48 kHz.

```
octFilt.SampleRate = 48e3;
```



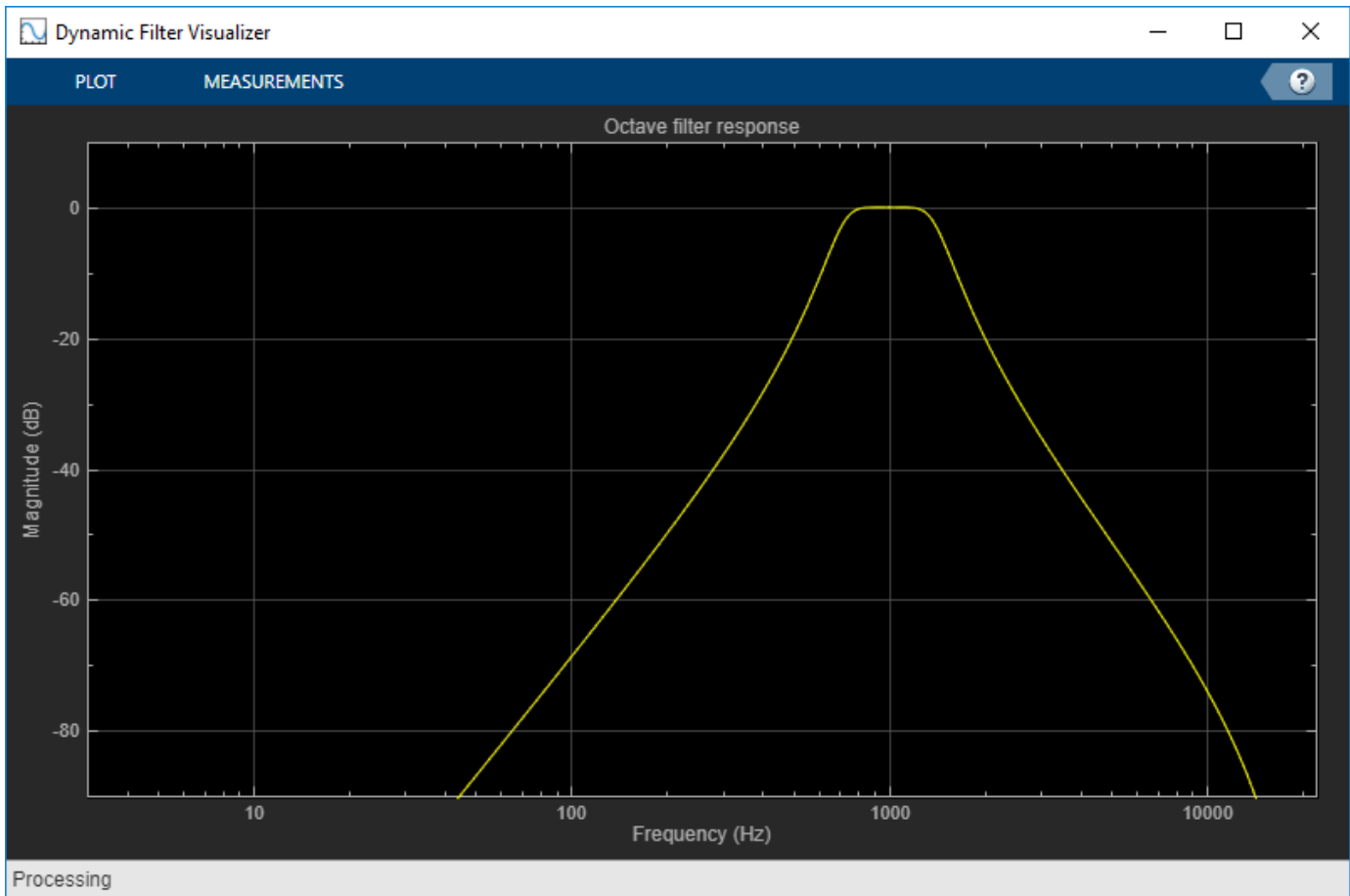


Tune Octave Filter Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create a `audioDeviceWriter` to write audio to your sound card. Create an `octaveFilter` to process the audio data. Call `visualize` to plot the frequency response of the octave filter.

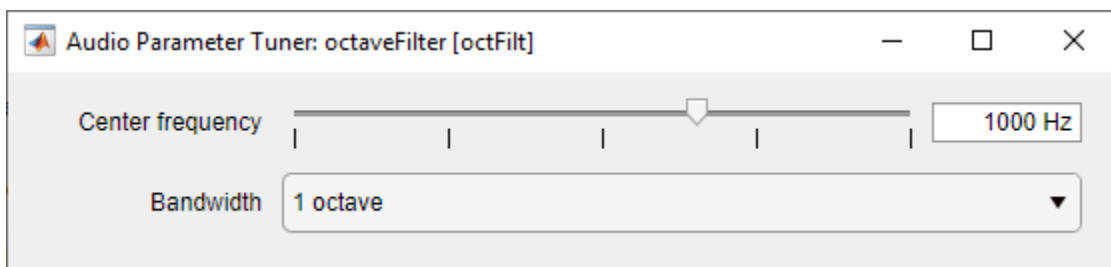
```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

octFilt = octaveFilter('SampleRate',fileReader.SampleRate);
visualize(octFilt)
```



Call `parameterTuner` to open a UI to tune parameters of the `octaveFilter` while streaming.

```
parameterTuner(octFilt)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply octave filtering.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the octave filter and listen to the effect.

```
while ~isDone(fileReader)
    audioIn = fileReader();
```

```

    audioOut = octFilt(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end

```

As a best practice, release your objects once done.

```

release(deviceWriter)
release(fileReader)
release(octFilt)

```

More About

Band Edge

A band edge frequency refers to the lower or upper edge of the passband of a bandpass filter.

Center Frequency of Octave Filter

The center frequency of an octave filter is the geometric mean of the lower and upper band edge frequencies.

Tips

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the `octaveFilter` to user-facing parameters:

Property	Range	Mapping	Units
CenterFrequency	[3, 22000]	log	Hz
Bandwidth	'1 octave', '2/3 octave', '1/2 octave', '1/3 octave', '1/6 octave', '1/12 octave', '1/24 octave', or '1/48 octave'	Your MIDI controller range is discretized into seven levels, corresponding to the seven Bandwidth choices.	--

Algorithms

Octave Bandwidth to Band Edge Conversion

The `octaveFilter` System object uses the specified center frequency and filter bandwidth in octaves to determine the normalized band edges [2].

The object computes the upper and lower band edge frequencies:

$$f_{pa} = f_c \times G^{-1/2b}$$

$$f_{pb} = f_c \times G^{1/2b}$$

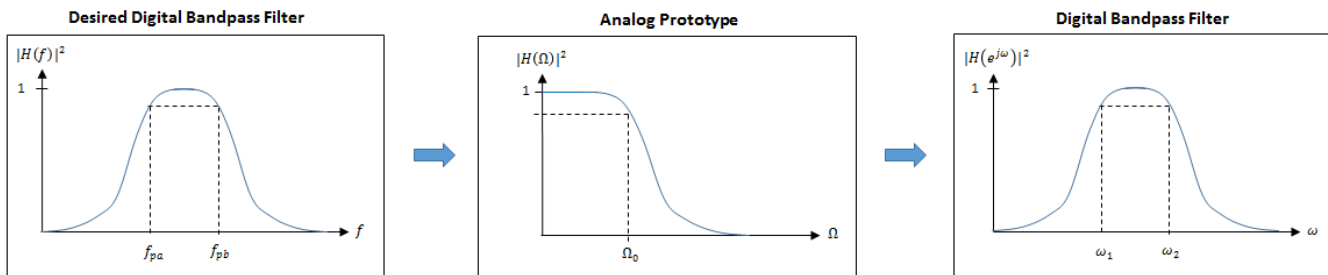
- f_c is the normalized center frequency specified by the CenterFrequency property.
- b is the octave bandwidth specified by the Bandwidth property. For example, if Bandwidth is specified as '1/3 octave', the value of b is 3.
- G is a conversion constant:

$$G = 10^{3/10}.$$

Digital Filter Design

The octaveFilter System object implements a higher-order digital bandpass filter design method specified in [1].

In this design method, a desired digital bandpass filter maps to a Butterworth lowpass analog prototype, which is then mapped back to a digital bandpass filter:



- 1 The analog Butterworth filter is expressed as a cascade of second-order sections:

$$H(s) = H_1(s)H_2(s)\cdots H_{2N}(s),$$

where:

$$H_i(s) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}}, \quad i = 1, 2, \dots, 2N$$

$$\theta_i = \frac{\pi}{2N}(N - 1 + 2i), \quad i = 1, 2, \dots, 2N$$

N is the filter order specified by the FilterOrder property.

- 2 The analog Butterworth filter is mapped to a digital filter using a bandpass version of the bilinear transformation:

$$s = \frac{1 - cz^{-1} + z^{-2}}{1 - z^{-2}},$$

where

$$c = \frac{\sin(\omega_{pa} + \omega_{pb})}{\sin\omega_{pa} + \sin\omega_{pb}}.$$

This mapping results in the following substitution:

$$\Omega_0 = \frac{c - \cos\omega_{pb}}{\sin\omega_{pb}}.$$

3 The analog prototype is evaluated:

$$H_i(z) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}} \Bigg|_s = \frac{1 - 2cz^{-1} + z^{-2}}{1 - z^{-2}}$$

Because s is second-order in z , the bandpass version of the bilinear transformation is fourth-order in z .

References

- [1] Orfanidis, Sophocles J. *Introduction to Signal Processing*. Englewood Cliffs, NJ: Prentice Hall, 2010.
- [2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters*. ANSI S1.11-2004. Melville, NY: Acoustical Society of America, 2009.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

Octave Filter | multibandParametricEQ | weightingFilter | dsp.BiquadFilter | octaveFilterBank

Topics

“Octave-Band and Fractional Octave-Band Filters”

Introduced in R2016b

getANSICenterFrequencies

Get the list of valid ANSI S1.11-2004 center frequencies

Syntax

```
centerFrequencies = getANSICenterFrequencies(octFilt)
```

Description

`centerFrequencies = getANSICenterFrequencies(octFilt)` returns a vector of valid center frequencies as specified by the ANSI S1.11-2004 standard.

Examples

Get ANSI Center Frequencies

Create an object of the `octaveFilter` System object™. Call `getANSICenterFrequencies` to get a list of valid center frequencies.

```
octFilt = octaveFilter;
centerFrequencies = getANSICenterFrequencies(octFilt)
```

```
centerFrequencies = 1×15
103 ×
```

```
    0.0005    0.0010    0.0020    0.0040    0.0079    0.0158    0.0316    0.0631    0.1259    0.2512
```

Input Arguments

octFilt — Object of octaveFilter

object

Object of the `octaveFilter` System object.

Output Arguments

centerFrequencies — Center frequencies

vector

Center frequencies specified by the ANSI S1.11-2004 standard, returned as a vector.

The range for computing valid center frequencies is 3 Hz to (Fs/2) Hz, where the `SampleRate` property of your octave filter defines Fs.

Data Types: `single` | `double`

See Also

Blocks

Octave Filter

Topics

“Octave-Band and Fractional Octave-Band Filters”

Introduced in R2016b

isStandardCompliant

Verify octave filter design is ANSI S1.11-2004 compliant

Syntax

```
complianceStatus = isStandardCompliant(octFilt,classType)
[complianceStatus,centerFreq] = isStandardCompliant(octFilt,classType)
```

Description

`complianceStatus = isStandardCompliant(octFilt,classType)` returns a logical scalar, `complianceStatus`, indicating whether the `complianceStatus` filter design is compliant with the ANSI S1.11-2004 standard for `classType`.

The mask used to determine compliance is centered on the nearest ANSI-compliant center frequency that ensures the center frequency of the object falls between the upper and lower band edges of the mask.

`[complianceStatus,centerFreq] = isStandardCompliant(octFilt,classType)` also returns the ANSI-compliant center frequency used to create the mask.

Examples

Verify Standard Compliance

Create an object of the `octaveFilter` System object™. Call `isStandardCompliant`, specifying the compliance class type to check as the second argument.

```
octFilt = octaveFilter;
complianceStatus = isStandardCompliant(octFilt,'class 2')

complianceStatus = logical
    1
```

Get ANSI-Compliant Center Frequency

Create an object of the `octaveFilter` System object. Check the compliance to class 0 status of your object, and get the center frequency used to create the compliance mask.

```
octFilt = octaveFilter('CenterFrequency',1266);
[compliant, centerFreq] = isStandardCompliant(octFilt,'class 0')

compliant = logical
    0

centerFreq = 1000
```

Input Arguments

octFilt — Object of octaveFilter

object

Object of the octaveFilter System object.

classType — Compliance class type

'class 0' | 'class 1' | 'class 2'

Compliance class type to verify, specified as 'class 0', 'class 1', or 'class 2'.

Data Types: char

Output Arguments

complianceStatus — Compliance status of filter design

scalar

Compliance status of filter design, returned as a logical scalar. The compliance status indicates whether the octFilt filter design is compliant with the ANSI S1.11-2004 standard for classType.

If your octave filter is noncompliant, try any of the following:

- Set the center frequency to one of the values returned by getANSICenterFrequencies
- Increase filter order
- Increase sample rate

Data Types: logical

centerFreq — Center frequency of mask

scalar

Center frequency used to create the compliance mask, returned as a scalar.

Data Types: single | double

See Also

Octave Filter | multibandParametricEQ | weightingFilter | dsp.BiquadFilter

Topics

“Octave-Band and Fractional Octave-Band Filters”

Introduced in R2016b

visualize

Visualize and validate filter response

Syntax

```
visualize(octFilt)
visualize(octFilt,N)
visualize( ____,mType)
hvsz = visualize( ____ )
```

Description

`visualize(octFilt)` plots the magnitude response of the octave-band filter `octFilt`. The plot is updated automatically when properties of the object change.

`visualize(octFilt,N)` uses an N-point FFT to calculate the magnitude response.

`visualize(____,mType)` creates a mask based on the class of filter specified by `mType`, using either of the previous syntaxes. Specify `mType` as 'class 0', 'class 1', or 'class 2'. The mask attenuation limits are defined in the ANSI S1.11-2004 standard. The mask center frequency is the ANSI standard center frequency, with band edge frequencies on either side of the `CenterFrequency` set in `octFilt`.

- If the mask is green, the design is compliant with the ANSI S1.11-2004 standard.
- If the mask is red, the design breaks compliance.

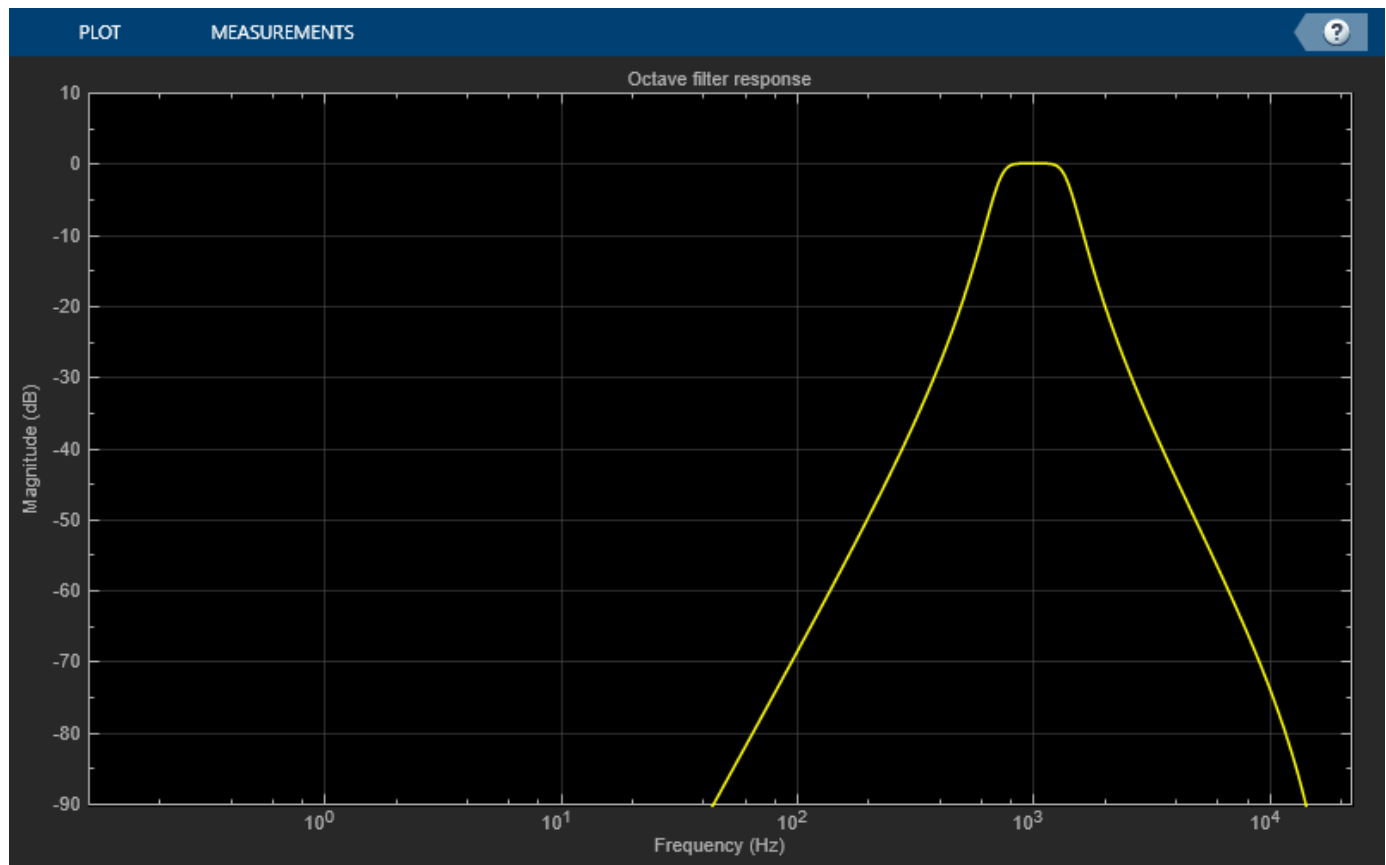
`hvsz = visualize(____)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when called with any of the previous syntaxes.

Examples

Plot Octave Filter Magnitude Response

Create an `octaveFilter` System object™ and then plot the magnitude response of the filter.

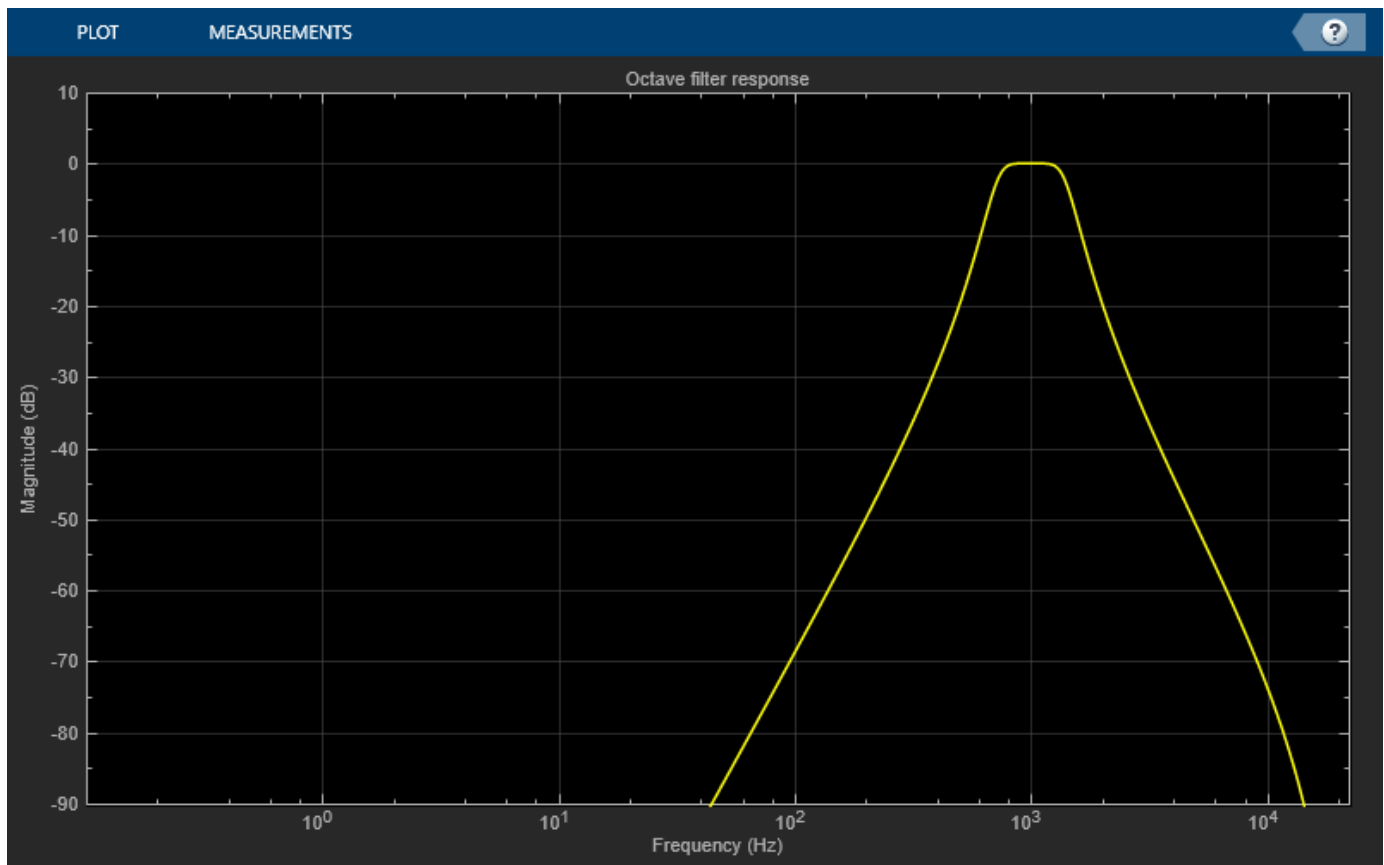
```
octFilt = octaveFilter;
visualize(octFilt)
```



Specify Number of Frequency Bins

Create an `octaveFilter` System object™. Plot a 5096-point frequency representation.

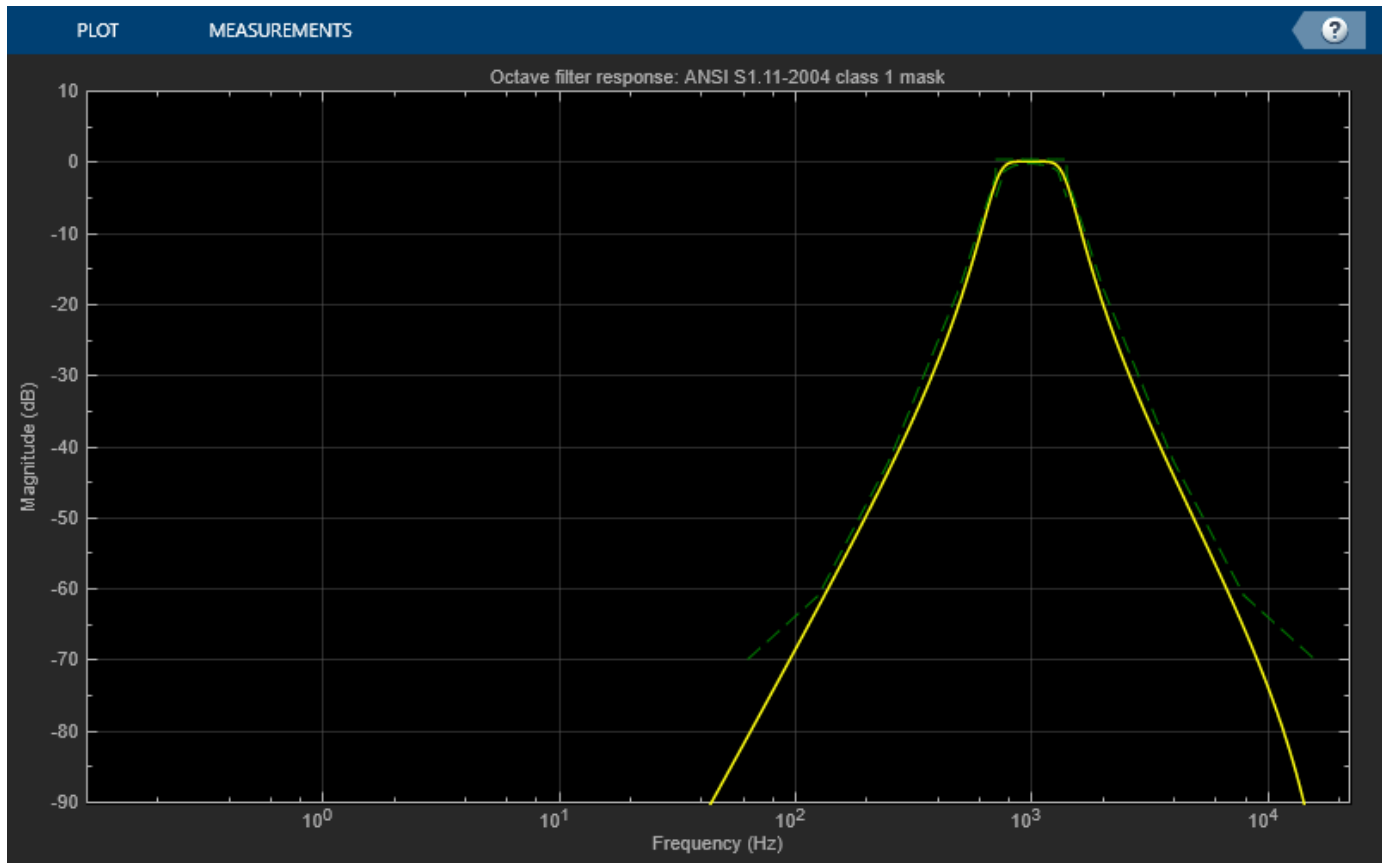
```
octFilt = octaveFilter;  
visualize(octFilt,5096)
```

Visualize Standard-Compliance Mask

Create an `octaveFilter` System object™. Visualize the class 1 compliance of the filter design.

```
octFilt = octaveFilter;  
visualize(octFilt, 'class 1')
```



Input Arguments

octFilt — Object of octaveFilter

object

Object of the octaveFilter System object.

N — Number of DFT bins

2048 | positive scalar

Number of DFT bins in frequency-domain representation, specified as a positive scalar. The default is 2048.

Data Types: single | double

mType — Type of mask

'class 0' | 'class 1' | 'class 2'

Type of mask, specified as 'class 0', 'class 1, or 'class 2'.

The mask attenuation limits are defined in the ANSI S1.11-2004 standard. The mask center frequency is the ANSI standard center frequency, with band edge frequencies on either side of the CenterFrequency set in octFilt.

- If the mask is green, the design is compliant with the ANSI S1.11-2004 standard.
- If the mask is red, the design breaks compliance.

Data Types: char

See Also

Topics

“Octave-Band and Fractional Octave-Band Filters”

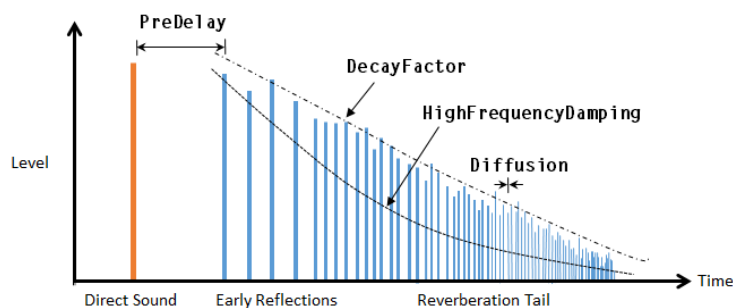
Introduced in R2016b

reverberator

Add reverberation to audio signal

Description

The reverberator System object adds reverberation to mono or stereo audio signals.



To add reverberation to your input:

- 1 Create the reverberator object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
reverb = reverberator
reverb = reverberator(Name, Value)
```

Description

`reverb = reverberator` creates a System object, `reverb`, that adds artificial reverberation to an audio signal.

`reverb = reverberator(Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `reverb = reverberator('PreDelay', 0.5, 'WetDryMix', 1)` creates a System object, `reverb`, with a 0.5 second pre-delay and a wet-to-dry mix ratio of one.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

PreDelay — Pre-delay for reverberation (s)

0 (default) | real positive scalar

Pre-delay for reverberation in seconds, specified as a real scalar in the range [0, 1].

Pre-delay for reverberation is the time between hearing direct sound and the first early reflection. The value of `PreDelay` is proportional to the size of the room being modeled.

Tunable: Yes

Data Types: `single` | `double`

HighCutFrequency — Lowpass filter cutoff (Hz)

20000 (default) | real positive scalar

Lowpass filter cutoff in Hz, specified as a real positive scalar in the range 0 to $\left(\frac{\text{SampleRate}}{2}\right)$.

Lowpass filter cutoff is the -3 dB cutoff frequency for the single-pole lowpass filter at the front of the reverberator structure. It prevents the application of reverberation to high-frequency components of the input.

Tunable: Yes

Data Types: `single` | `double`

Diffusion — Density of reverb tail

0.5 (default) | real scalar

Density of reverb tail, specified as a real positive scalar in the range [0, 1].

`Diffusion` is proportional to the rate at which the reverb tail builds in density. Increasing `Diffusion` pushes the reflections closer together, thickening the sound. Reducing `Diffusion` creates more discrete echoes.

Tunable: Yes

Data Types: `single` | `double`

DecayFactor — Decay factor of reverb tail

0.5 (default) | real scalar

Decay factor of reverb tail, specified as a real positive scalar in the range [0, 1].

`DecayFactor` is inversely proportional to the time it takes for reflections to run out of energy. To model a large room, use a long reverb tail (low decay factor). To model a small room, use a short reverb tail (high decay factor).

Tunable: Yes

Data Types: `single` | `double`

HighFrequencyDamping — High-frequency damping

`0.0005` (default) | real scalar

High-frequency damping, specified as a real positive scalar in the range [0, 1].

`HighFrequencyDamping` is proportional to the attenuation of high frequencies in the reverberation output. Setting `HighFrequencyDamping` to a large value makes high-frequency reflections decay faster than low-frequency reflections.

Tunable: Yes

Data Types: `single` | `double`

WetDryMix — Wet-dry mix

`0.3` (default) | real scalar

Wet-dry mix, specified as a real positive scalar in the range [0, 1].

Wet-dry mix is the ratio of wet (reverberated) to dry (original) signal that your reverberator System object outputs.

Tunable: Yes

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

`44100` (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: `single` | `double`

Usage

Syntax

```
audioOut = reverb(audioIn)
```

Description

`audioOut = reverb(audioIn)` adds reverberation to the input signal, `audioIn`, and returns the mixed signal, `audioOut`. The type of reverberation is specified by the algorithm and properties of the reverberator System object, `reverb`.

Input Arguments

audioIn — Audio input to reverberator

column vector | N -by-2 matrix

Audio input to the reverberator, specified as a column vector or two-column matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from reverberator

N-by-2 matrix

Audio output from the reverberator, returned as a two-column matrix.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to reverberator

<code>createAudioPluginClass</code>	Create audio plugin class that implements functionality of System object
<code>parameterTuner</code>	Tune object parameters while streaming

MIDI

<code>configureMIDI</code>	Configure MIDI connections between audio object and MIDI controller
<code>disconnectMIDI</code>	Disconnect MIDI controls from audio object
<code>getMIDIConnections</code>	Get MIDI connections of audio object

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm

Examples

Add Reverberation to Audio Signal

Use the reverberator System object™ to add artificial reverberation to an audio signal read from a file.

Create the `dsp.AudioFileReader` and `audioDeviceWriter` System objects. Use the sample rate of the reader as the sample rate of the writer.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3','SamplesPerFrame',1024);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

Play 10 seconds of the audio signal through your device.

```
tic
while toc < 10
    audio = fileReader();
    deviceWriter(audio);
end
release(fileReader)
```

Construct a reverberator System object with default settings.

```
reverb = reverberator

reverb =
    reverberator with properties:

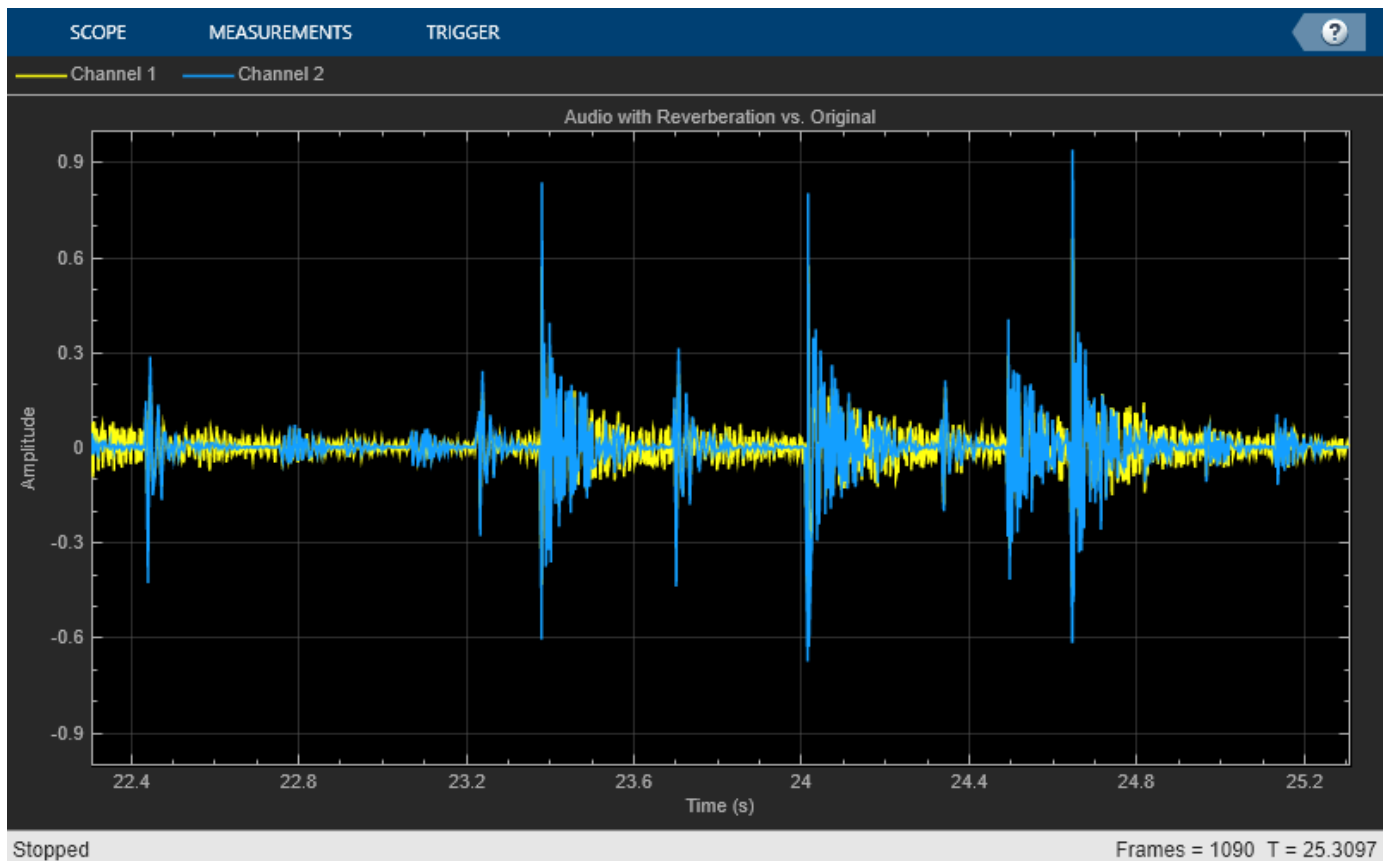
        PreDelay: 0
        HighCutFrequency: 20000
        Diffusion: 0.5000
        DecayFactor: 0.5000
        HighFrequencyDamping: 5.0000e-04
        WetDryMix: 0.3000
        SampleRate: 44100
```

Construct a time scope to visualize the original audio signal and the audio signal with added artificial reverberation.

```
scope = timescope( ...
    'SampleRate',fileReader.SampleRate,...
    'TimeSpanOvverrunAction','Scroll',...
    'TimeSpanSource','property',...
    'TimeSpan',3,...
    'BufferLength',3*fileReader.SampleRate*2, ...
    'YLimits',[-1,1],...
    'ShowGrid',true, ...
    'ShowLegend',true, ...
    'Title','Audio with Reverberation vs. Original');
```

Play the audio signal with artificial reverberation. Visualize the audio with reverberation and the original audio.

```
while ~isDone(fileReader)
    audio = fileReader();
    audioWithReverb = reverb(audio);
    deviceWriter(audioWithReverb);
    scope([audioWithReverb(:,1),audio(:,1)])
end
release(fileReader)
release(deviceWriter)
release(scope)
```

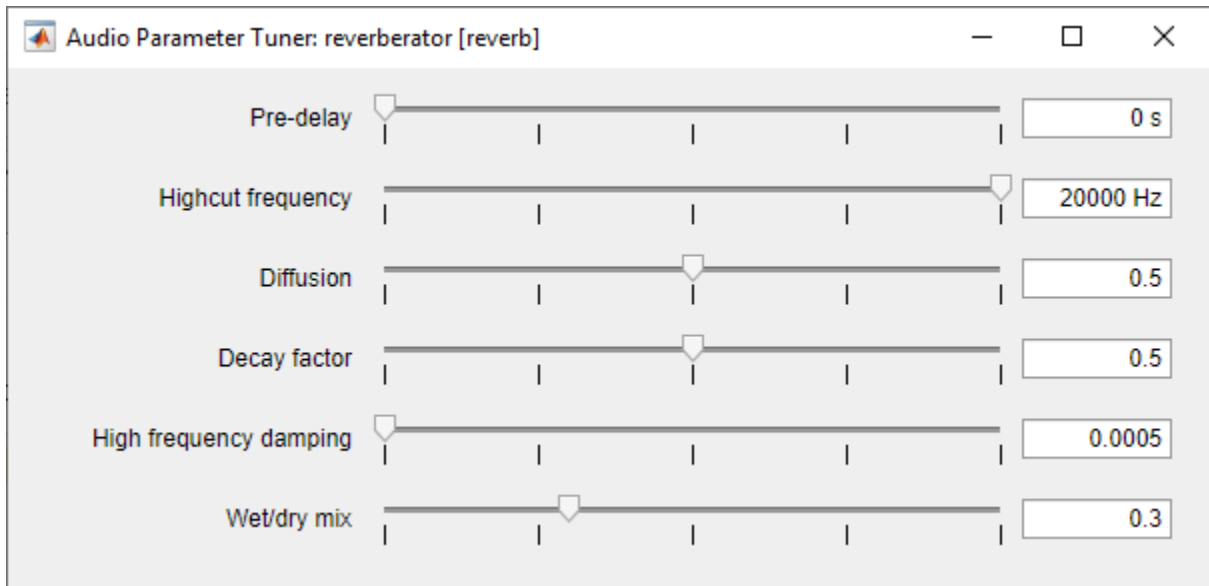
Tune Reverberator Parameters

Create a `dsp.AudioFileReader` to read in audio frame-by-frame. Create an `audioDeviceWriter` to write audio to your sound card. Create a `reverberator` to process the audio data.

```
frameLength = 1024;
fileReader = dsp.AudioFileReader('RockDrums-44p1-stereo-11secs.mp3', ...
    'SamplesPerFrame',frameLength,'PlayCount',2);
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
reverb = reverberator('SampleRate',fileReader.SampleRate);
```

Call `parameterTuner` to open a UI to tune parameters of the `octaveFilter` while streaming.

```
parameterTuner(reverb)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply reverberation.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the reverberator and listen to the effect.

```
while ~isDone(fileReader)
  audioIn = fileReader();
  audioOut = reverb(audioIn);
  deviceWriter(audioOut);
  drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(deviceWriter)
release(fileReader)
release(reverb)
```

Tips

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the compressor to user-facing parameters:

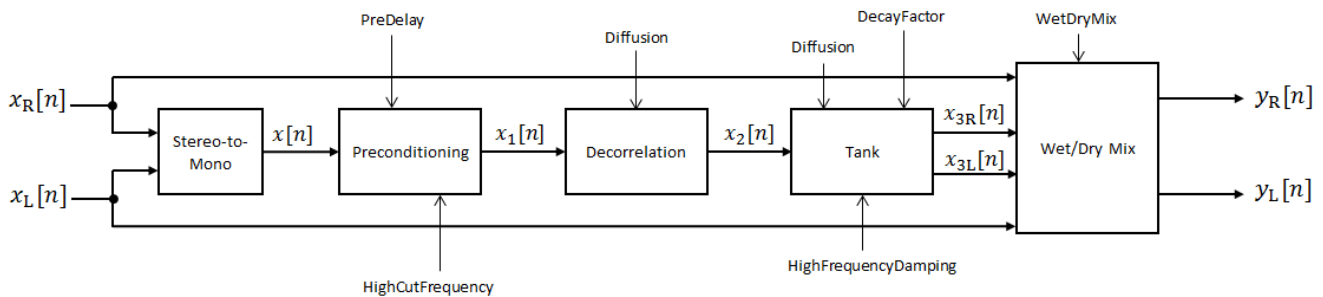
Property	Range	Mapping	Unit
PreDelay	[0, 1]	linear	s
HighCutFrequency	[20, 20000]	log	Hz
Diffusion	[0, 1]	linear	none
DecayFactor	[0, 1]	linear	none

Property	Range	Mapping	Unit
HighFrequencyDamping	[0, 1]	linear	none
WetDryMix	[0, 1]	linear	none

Algorithms

The algorithm to add reverberation follows the plate-class reverberation topology described in [1] and is based on a 29,761 Hz sample rate.

The algorithm has five stages.



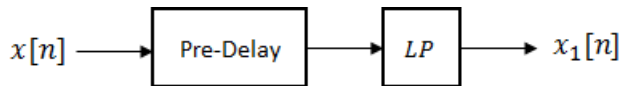
The description for the algorithm that follows is for a stereo input. A mono input is a simplified case.

Stereo-to-Mono

A stereo signal is converted to a mono signal: $x[n] = 0.5 \times (x_R[n] + x_L[n])$.

Preconditioning

A delay followed by a lowpass filter preconditions the mono signal.



- The pre-delay output is determined as $x_p[n] = x[n - k]$, where the PreDelay property determines the value of k .
- The signal is fed through a single-pole lowpass filter with transfer function

$$LP(z) = \frac{1 - \alpha}{1 - \alpha z^{-1}},$$

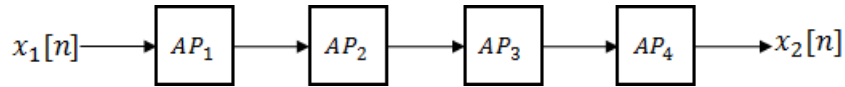
where

$$\alpha = \exp\left(-2\pi \times \frac{f_c}{f_s}\right).$$

- f_c is the cutoff frequency specified by the HighCutFrequency property.
- f_s is the sampling frequency specified by the SampleRate property.

Decorrelation

The signal is decorrelated by passing through a series of four allpass filters.



The allpass filters are of the form

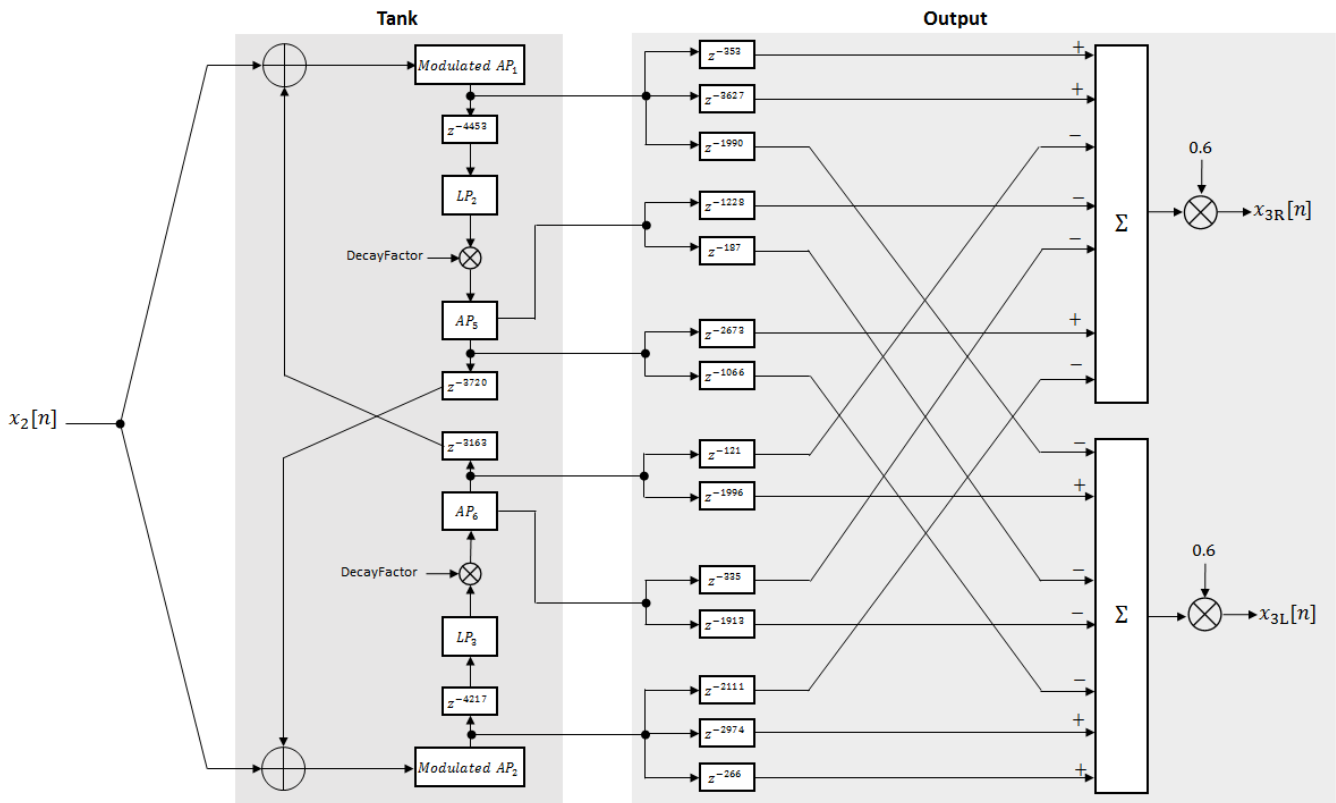
$$AP(z) = \frac{\beta + z^{-k}}{1 + \beta z^{-k}},$$

where β is the coefficient specified by the Diffusion property and k is the delay as follows:

- For AP_1 , $k = 142$.
- For AP_2 , $k = 107$.
- For AP_3 , $k = 379$.
- For AP_4 , $k = 277$.

Tank

The signal is fed into the tank, where it circulates to simulate the decay of a reverberation tail.



The following description tracks the signal as it progresses through the top of the tank. The signal progression through the bottom of the tank follows the same pattern, with different delay specifications.

- 1 The new signal enters the top of the tank and is added to the circulated signal from the bottom of the tank.
- 2 The signal passes through a modulated allpass filter:

$$\text{Modulated } AP_1(z) = \frac{-\beta + z^{-k}}{1 - \beta z^{-k}}$$

- β is the coefficient specified by the `Diffusion` property.
- k is the variable delay specified by a 1 Hz sinusoid with `amplitude = (8/29761) * SampleRate`. To account for fractional delay resulting from the modulating k , allpass interpolation is used [2].

- 3 The signal is delayed again, and then passes through a lowpass filter:

$$LP_2(z) = \frac{1 - \varphi}{1 - \varphi z^{-1}}$$

- φ is the coefficient specified by the `HighFrequencyDamping` property.

- 4 The signal is multiplied by a gain specified by the `DecayFactor` property. The signal then passes through an allpass filter:

$$AP_5(z) = \frac{\beta + z^{-k}}{1 + \beta z^{-k}}$$

- β is the coefficient specified by the `Diffusion` property.
- k is set to 1800 for the top of the tank and 2656 for the bottom of the tank.

- 5 The signal is delayed again and then circulated to the bottom half of the tank for the next iteration.

A similar pattern is executed in parallel for the bottom half of the tank. The output of the tank is calculated as the signed sum of delay lines picked off at various points from the tank. The summed output is multiplied by 0.6.

Wet/Dry Mix

The wet (processed) signal is then added to the dry (original) signal:

$$y_R[n] = (1 - \kappa)x_R[n] + \kappa x_{3R}[n],$$

$$y_L[n] = (1 - \kappa)x_L[n] + \kappa x_{3L}[n],$$

where the `WetDryMix` property determines κ .

References

- [1] Dattorro, Jon. "Effect Design, Part 1: Reverberator and Other Filters." *Journal of the Audio Engineering Society*. Vol. 45, Issue 9, 1997, pp. 660-684.

[2] Dattorro, Jon. "Effect Design, Part 2: Delay-Line Modulation and Chorus." *Journal of the Audio Engineering Society*. Vol. 45, Issue 10, 1997, pp. 764-788.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

Reverberator

Introduced in R2016a

shelvingFilter

Second-order IIR shelving filter

Description

The `shelvingFilter` System object implements a shelving filter, which boosts or cuts the frequency spectrum of the input signal above or below a given cutoff frequency.

To use a shelving filter:

- 1 Create the `shelvingFilter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
shelvFilt = shelvingFilter
shelvFilt = shelvingFilter(gain)
shelvFilt = shelvingFilter(gain,slope)
shelvFilt = shelvingFilter(gain,slope,cutoffFreq)
shelvFilt = shelvingFilter(gain,slope,cutoffFreq,type)
shelvFilt = shelvingFilter( ___,Name=Value)
```

Description

`shelvFilt = shelvingFilter` creates a shelving filter with default values.

`shelvFilt = shelvingFilter(gain)` sets the Gain property to `gain`.

`shelvFilt = shelvingFilter(gain,slope)` sets the Slope property to `slope`.

`shelvFilt = shelvingFilter(gain,slope,cutoffFreq)` sets the CutoffFrequency property to `cutoffFreq`.

`shelvFilt = shelvingFilter(gain,slope,cutoffFreq,type)` sets the FilterType property to `type`.

`shelvFilt = shelvingFilter(___,Name=Value)` sets “Properties” on page 3-366 using one or more name-value arguments in addition to the input arguments in previous syntaxes. For example, `shelvFilt = shelvingFilter(SampleRate=96000)` creates a shelving filter with a sample rate of 96,000 Hz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Gain — Peak gain (dB)

0 (default) | real scalar

Peak gain of the filter in dB, specified as a real scalar. The gain specifies how much the filter will boost (if the gain is positive) or cut (if the gain is negative) the frequency spectrum of the input signal.

Tunable: Yes

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Slope — Filter slope

1.5 (default) | positive scalar

Slope of the filter, specified as a positive scalar. The slope controls the width of the transition band in the filter response.

Tunable: Yes

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

CutoffFrequency — Cutoff frequency of filter

200 (default) | nonnegative scalar

Cutoff frequency of the filter in Hz, specified as a nonnegative scalar in the range $[0, \text{SampleRate}/2]$. The cutoff frequency specifies the frequency at half of the peak gain of the filter, $\text{Gain}/2$ dB.

Tunable: Yes

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

FilterType — Type of filter

"lowpass" (default) | "highpass"

Type of shelving filter, specified as "lowpass" or "highpass".

- "lowpass" -- Boost or cut the frequency spectrum below the cutoff frequency.
- "highpass" -- Boost or cut the frequency spectrum above the cutoff frequency.

Tunable: Yes

Data Types: `string` | `char`

SampleRate — Sample rate of the input (Hz)

44100 (default) | positive scalar

Sample rate of the input in Hz, specified as a positive scalar.

Tunable: No

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Usage

Syntax

```
audioOut = shelvFilt(audioIn)
```

Description

`audioOut = shelvFilt(audioIn)` applies the shelving filter to the input signal, `audioIn` and returns the output signal `audioOut`. The type of filtering applied by the function depends on the algorithm and properties of the `shelvingFilter` System object.

Input Arguments

audioIn — Audio input to shelving filter

`column vector` | `matrix`

Audio input to the shelving filter, specified as a column vector or a matrix. If the input is a matrix, the columns are treated as independent channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output of shelving filter

`column vector` | `matrix`

Audio output of the shelving filter, returned as a column vector or matrix with the same size and data type as the `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to shelvingFilter

<code>visualize</code>	Visualize magnitude response of shelving filter
<code>createAudioPluginClass</code>	Create audio plugin class that implements functionality of System object
<code>coeffs</code>	Get filter coefficients
<code>parameterTuner</code>	Tune object parameters while streaming

MIDI

<code>configureMIDI</code>	Configure MIDI connections between audio object and MIDI controller
<code>disconnectMIDI</code>	Disconnect MIDI controls from audio object

getMIDIConnections Get MIDI connections of audio object

Common to All System Objects

step Run System object algorithm
 release Release resources and allow changes to System object property values and input characteristics
 reset Reset internal states of System object

Examples

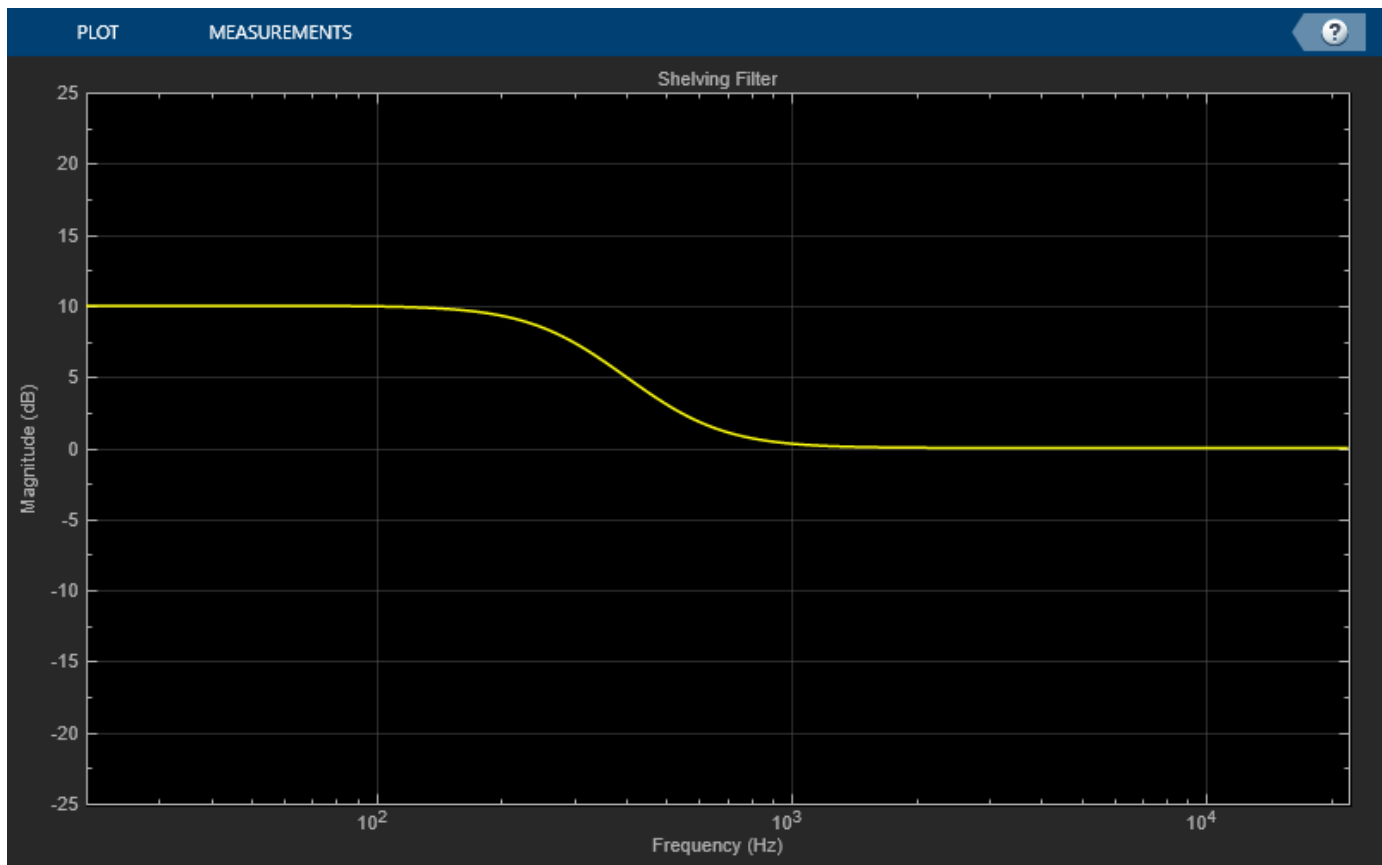
Filter Audio Using Shelving Filter

Create a lowpass shelvingFilter object with a gain of 10 dB, a slope of 1, and a cutoff frequency of 400 Hz.

```
shelvFilt = shelvingFilter(10,1,400,"lowpass");
```

Visualize the magnitude response of the filter.

```
visualize(shelvFilt)
```



Create a `dsp.AudioFileReader` object to read in the audio signal for filtering.

```
samplesPerFrame = 1024;  
reader = dsp.AudioFileReader( ...
```

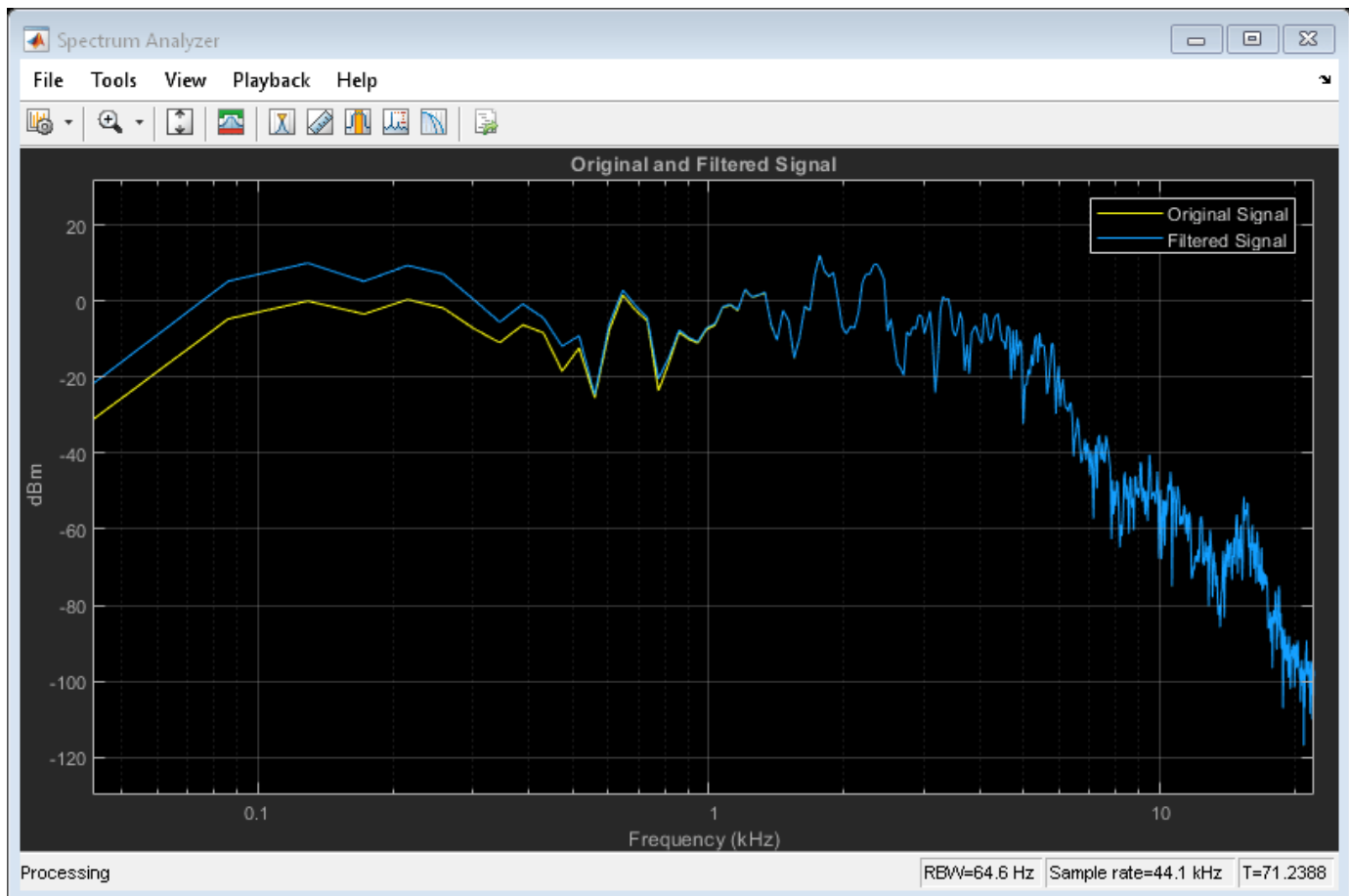
```
Filename="RockGuitar-16-44p1-stereo-72secs.wav", ...
SamplesPerFrame=samplesPerFrame);
```

Create a `dsp.SpectrumAnalyzer` object to visualize the spectrum of the original audio signal and the spectrum of the filtered signal.

```
scope = dsp.SpectrumAnalyzer( ...
    SampleRate=reader.SampleRate, ...
    PlotAsTwoSidedSpectrum=false, ...
    FrequencyScale="log", ...
    FrequencyResolutionMethod="WindowLength", ...
    WindowLength=samplesPerFrame, ...
    Title="Original and Filtered Signal", ...
    ShowLegend=true, ...
    ChannelNames={'Original Signal','Filtered Signal'});
```

Filter the audio signal and visualize the results.

```
while ~isDone(reader)
    audioIn = reader();
    filteredSignal = shelvFilt(audioIn);
    scope([audioIn(:,1),filteredSignal(:,1)]);
end
```



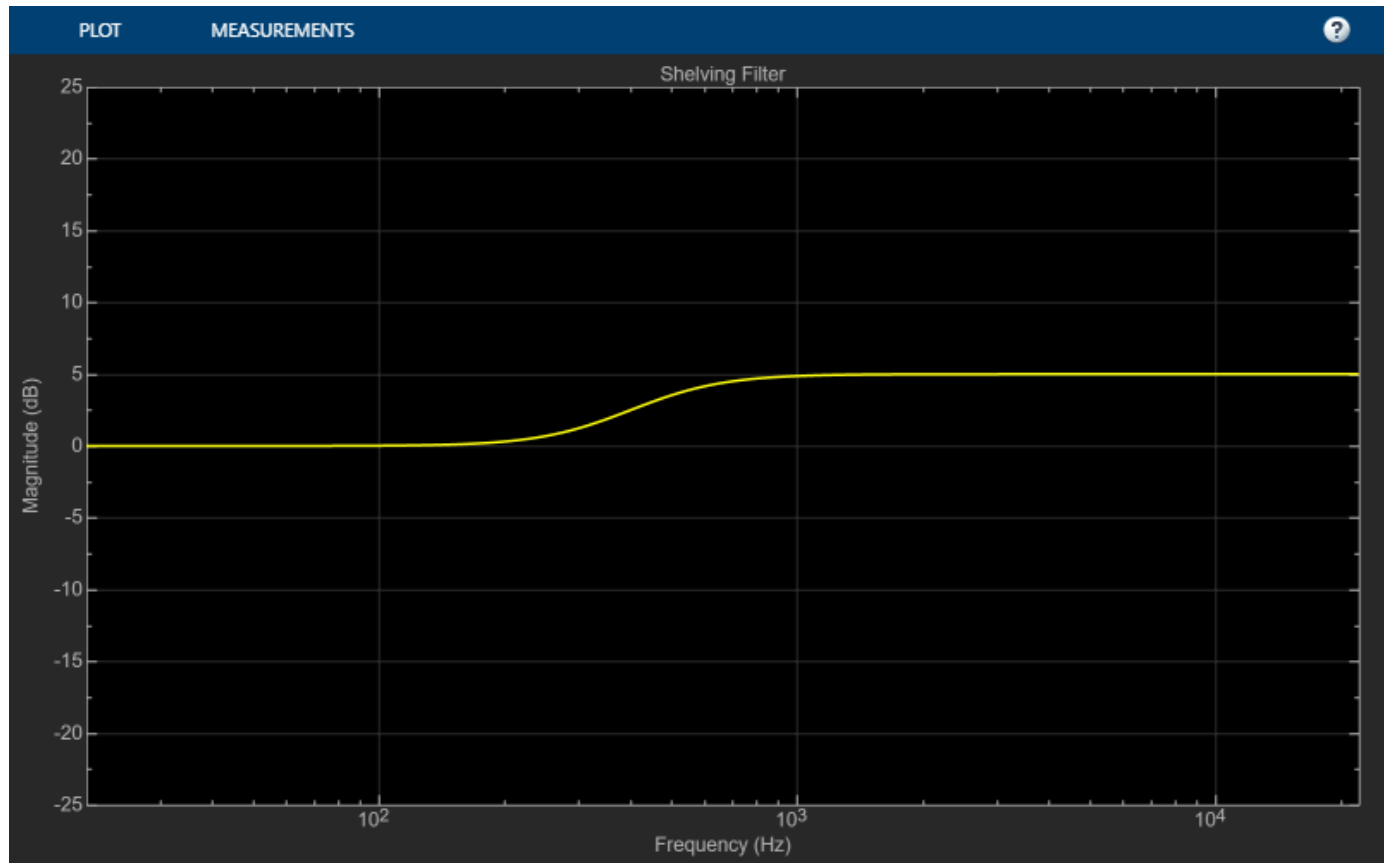
Tune Shelving Filter Parameters

Create a highpass shelvingFilter object with a gain of 5 dB, a slope of 1, and a cutoff frequency of 400 Hz.

```
shelvFilt = shelvingFilter(5,1,400,"highpass");
```

Visualize the magnitude response of the filter.

```
visualize(shelvFilt)
```

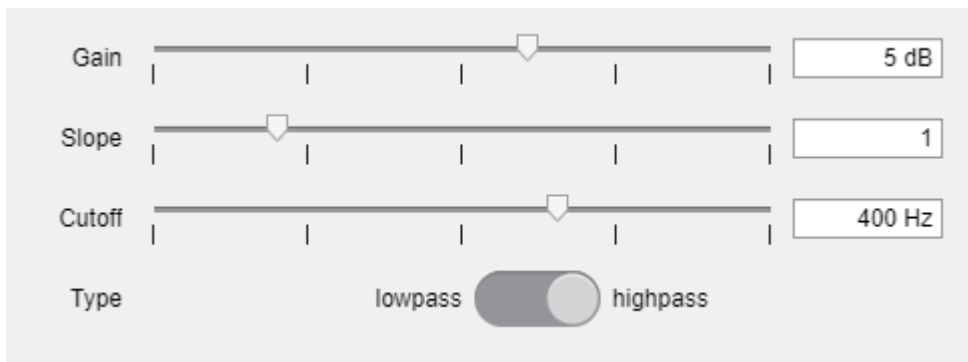


Create `dsp.AudioFileReader` and `audioDeviceWriter` objects to read in the audio signal and write the filtered signal to your audio device to listen to it.

```
samplesPerFrame = 1024;
reader = dsp.AudioFileReader( ...
    Filename="RockGuitar-16-44p1-stereo-72secs.wav", ...
    SamplesPerFrame=samplesPerFrame);
deviceWriter = audioDeviceWriter(SampleRate=reader.SampleRate);
```

Call `parameterTuner` to open a UI to tune the parameters of the shelving filter while streaming.

```
parameterTuner(shelvFilt)
```



In an audio stream loop:

- 1 Read in a frame of audio from the file.
- 2 Apply shelving filter.
- 3 Write the filtered frame of audio to your audio device for listening.

While streaming, tune the parameters of the shelving filter and listen to the effect.

```
while ~isDone(reader)
    audioIn = reader();
    audioOut = shelvFilt(audioIn);
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

As a best practice, release your objects once done.

```
release(reader)
release(shelvFilt)
release(deviceWriter)
```

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

Blocks

Shelving Filter | Graphic EQ | Multiband Parametric EQ

Functions

designParamEQ | designShelvingEQ | designVarSlopeFilter

Objects

dsp.SOSFilter | graphicEQ | multibandParametricEQ

Introduced in R2022a

visualize

Visualize magnitude response of shelving filter

Syntax

```
visualize(shelvFilt)
visualize(shelvFilt,NFFT)
hvsz = visualize( ___ )
```

Description

`visualize(shelvFilt)` plots the magnitude response of the shelving filter. The plot is updated automatically when you change the object properties.

`visualize(shelvFilt,NFFT)` specifies an N -point FFT to calculate the magnitude response.

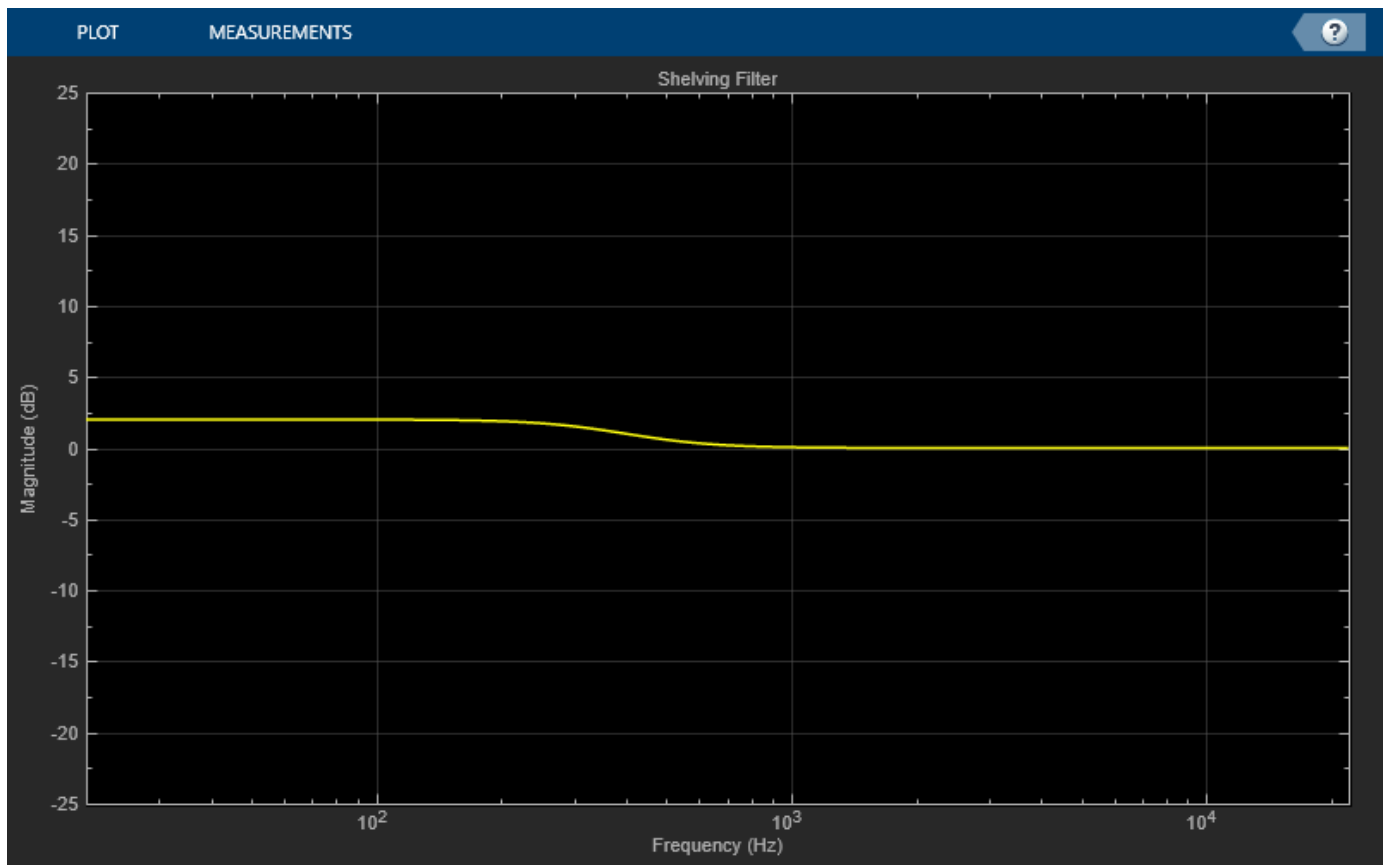
`hvsz = visualize(___)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when you call this syntax with any of the previous input arguments.

Examples

Visualize Magnitude Response of Shelving Filter

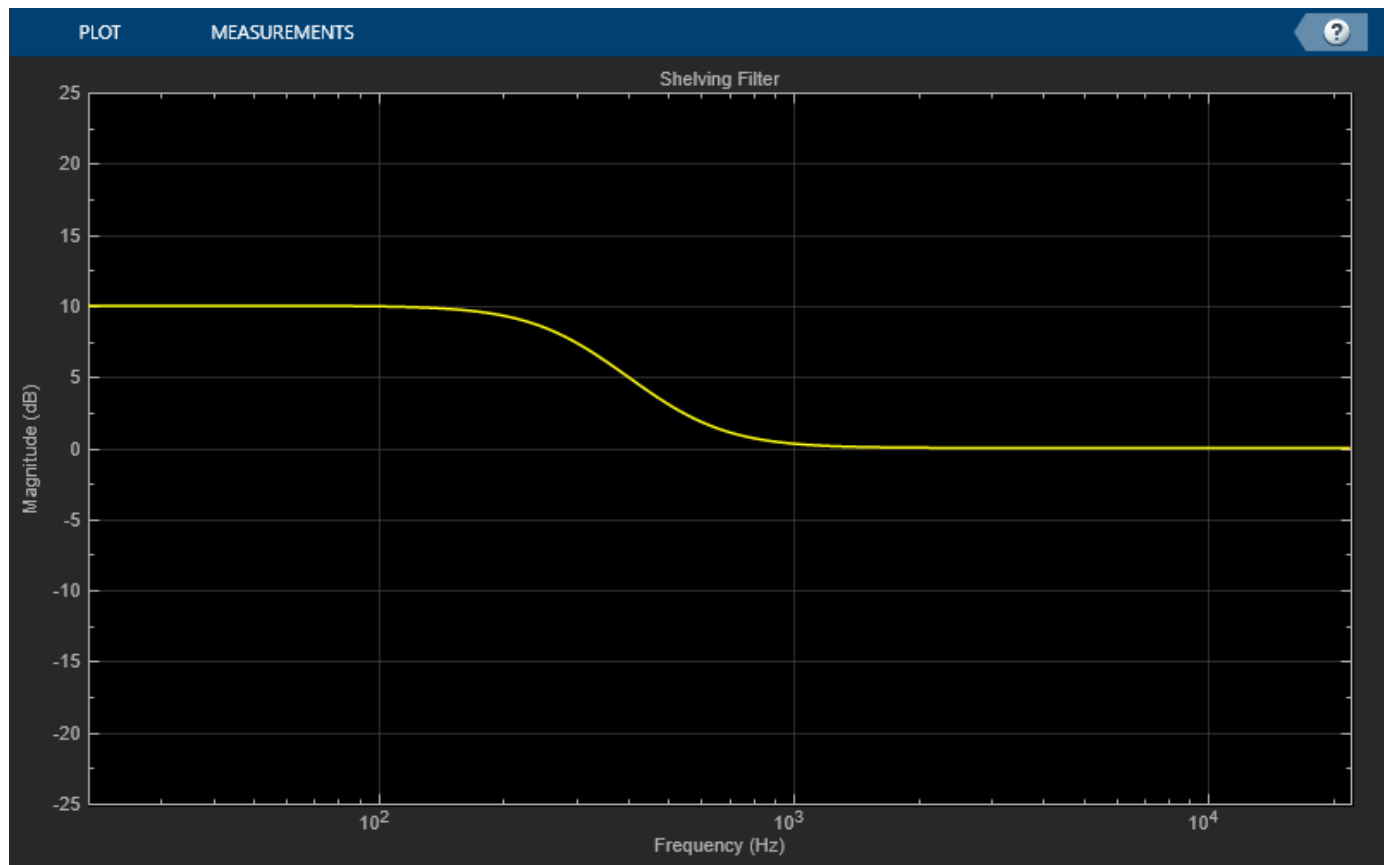
Create a `shelvingFilter` object, and then call `visualize` to plot the magnitude response of the filter.

```
shelvFilt = shelvingFilter(2,1,400,"lowpass");
visualize(shelvFilt)
```



Modify the gain and observe that the plot is updated automatically.

```
shelvFilt.Gain = 10;
```



Input Arguments

shelvFilt — Shelving filter
object

Shelving filter whose magnitude response you want to plot, specified as a `shelvingFilter` System object.

NFFT — N-point FFT
2048 (default) | positive scalar

Number of bins used to calculate the DFT, specified as a positive scalar.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also
`shelvingFilter`

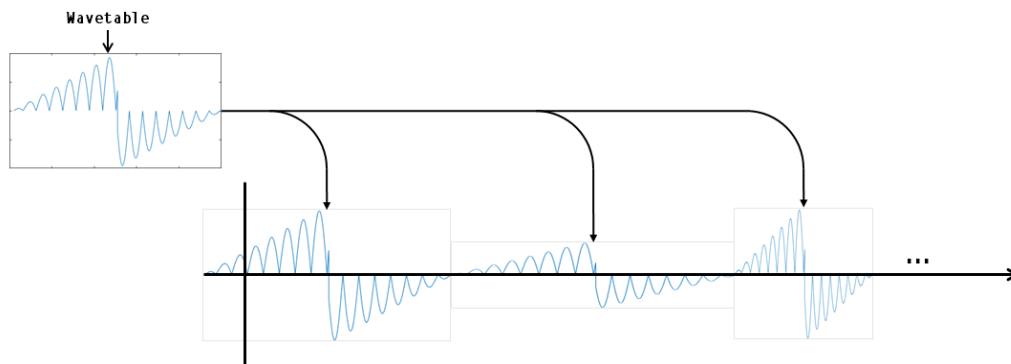
Introduced in R2022a

wavetableSynthesizer

Generate periodic signal from single-cycle waveforms

Description

The `wavetableSynthesizer` System object generates a periodic signal with tunable properties. The periodic signal is defined by a single-cycle waveform cached as the `Wavetable` property of your `wavetableSynthesizer` object.



To generate a periodic signal:

- 1 Create the `wavetableSynthesizer` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```

waveSynth = wavetableSynthesizer
waveSynth = wavetableSynthesizer(wavetableValue)
waveSynth = wavetableSynthesizer(wavetableValue, frequencyValue)
waveSynth = wavetableSynthesizer( ___, Name, Value)

```

Description

`waveSynth = wavetableSynthesizer` creates a wavetable synthesizer System object, `waveSynth`, with default property values.

`waveSynth = wavetableSynthesizer(wavetableValue)` sets the `Wavetable` property to `wavetableValue`.

`waveSynth = wavetableSynthesizer(wavetableValue, frequencyValue)` sets the `Frequency` property to `frequencyValue`.

`waveSynth = wavetableSynthesizer(___, Name, Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `waveSynth = wavetableSynthesizer('Amplitude',2,'DCOffset',2.5)` creates a System object, `waveSynth`, that generates the default sine waveform with an amplitude of 2 and a DC offset of 2.5.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see System Design in MATLAB Using System Objects.

Wavetable — Single-cycle waveform

`sin(2*pi*(0:511)/512)` (default) | vector of real values

Single-cycle waveform, specified as a vector of real values. The algorithm of the `wavetableSynthesizer` indexes into the single-cycle waveform to synthesize a periodic wave.

Tunable: Yes

Data Types: `single` | `double`

Frequency — Frequency of generated signal (Hz)

`100` (default) | real scalar

Frequency of generated signal in Hz, specified as a real scalar greater than or equal to 0.

Tunable: Yes

Data Types: `single` | `double`

Amplitude — Amplitude of generated signal

`1` (default) | real scalar

Amplitude of generated signal, specified as a real scalar greater than or equal to 0.

The generated signal is multiplied by the value specified by `Amplitude` at the output, before `DCOffset` is applied.

Tunable: Yes

Data Types: `single` | `double`

PhaseOffset — Normalized phase offset of generated signal

`0` (default) | real scalar

Normalized phase offset of generated signal, specified as a real scalar with values in the range `[0, 1]`. The range is a normalized 2π radians interval.

Tunable: No

Data Types: `single` | `double`

DCOffset — Value added to each element of generated signal

0 (default) | real scalar

Value added to each element of the generated signal, specified as a real scalar.

Tunable: Yes

Data Types: single | double

SamplesPerFrame — Number of samples per frame

512 (default) | positive integer

Number of samples per frame, specified as a positive integer in the range [1, 192000].

This property determines the vector length that your wavetableSynthesizer object outputs.

Tunable: Yes

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

SampleRate — Sample rate of generated signal (Hz)

44100 (default) | real positive scalar

Sample rate of generated signal in Hz, specified as a real positive scalar.

Tunable: Yes**OutputDataType — Data type of generated signal**

'double' (default) | 'single'

Data type of generated signal, specified as 'double' or 'single'.

Tunable: No

Data Types: char | string

Usage**Syntax**

```
waveform = waveSynth()
```

Description

`waveform = waveSynth()` generates a periodic signal, `waveform`. The type of signal is specified by the algorithm and properties of the `wavetableSynthesizer` System object, `waveSynth`.

Output Arguments**waveform — Waveform output from wavetable synthesizer**

column vector (default)

Waveform output from the wavetable synthesizer, returned as a column vector with length specified by the `SamplesPerFrame` property and data type specified by the `OutputDataType` property.

Data Types: single | double

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to wavetableSynthesizer

`createAudioPluginClass` Create audio plugin class that implements functionality of System object
`parameterTuner` Tune object parameters while streaming

MIDI

`configureMIDI` Configure MIDI connections between audio object and MIDI controller
`disconnectMIDI` Disconnect MIDI controls from audio object
`getMIDIConnections` Get MIDI connections of audio object

Common to All System Objects

`clone` Create duplicate System object
`isLocked` Determine if System object is in use
`release` Release resources and allow changes to System object property values and input characteristics
`reset` Reset internal states of System object
`step` Run System object algorithm

The `createAudioPluginClass` and `configureMIDI` functions map tunable properties of the `wavetableSynthesizer` System object to user-facing parameters:

Property	Range	Mapping	Unit
Frequency	[0.1, 20000]	log	Hz
Amplitude	[0, 10]	linear	none
DCOffset	[-10, 10]	linear	none

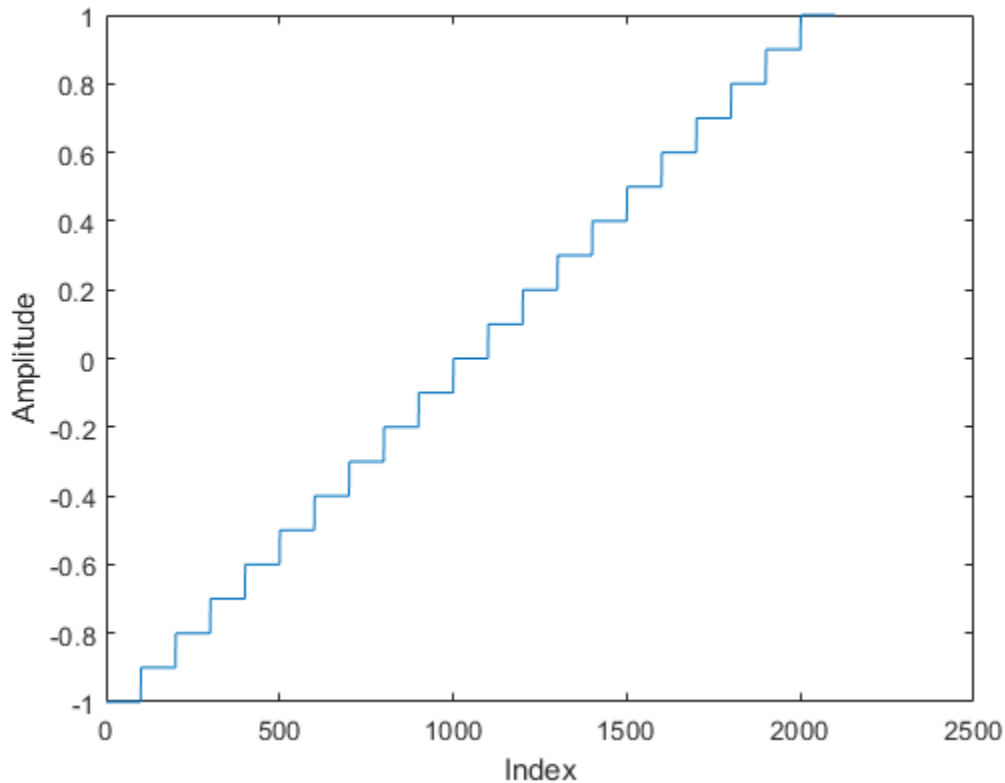
Examples

Generate Variable-Frequency Staircase Wave

Define and plot a single-cycle waveform.

```
values = -1:0.1:1;
singleCycleWave = ones(100,1) * values;
singleCycleWave = reshape(singleCycleWave,numel(singleCycleWave),1);

plot(singleCycleWave)
xlabel('Index')
ylabel('Amplitude')
```



Create a wavetable synthesizer, `waveSynth`, to generate a staircase wave using the single-cycle waveform. Specify a frequency of 10 Hz.

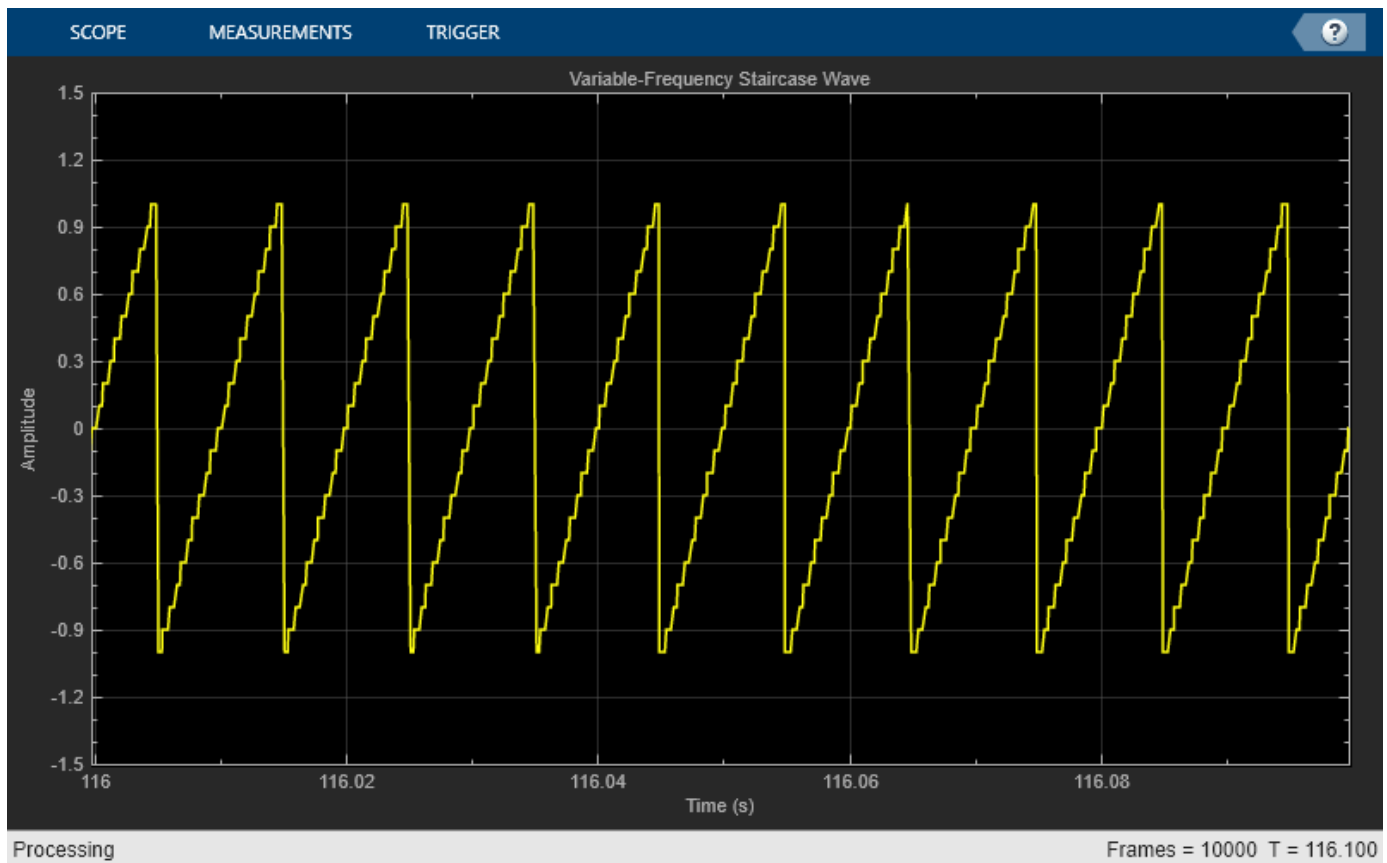
```
waveSynth = wavetableSynthesizer(singleCycleWave,10);
```

Create a time scope to visualize the staircase wave generated by `waveSynth`.

```
scope = timescope( ...
    'SampleRate',waveSynth.SampleRate, ...
    'TimeSpanSource','Property','TimeSpan',0.1, ...
    'YLimits',[-1.5,1.5], ...
    'TimeSpanOvverrunAction','Scroll', ...
    'ShowGrid',true, ...
    'Title','Variable-Frequency Staircase Wave');
```

Place the wavetable synthesizer in an audio stream loop. Increase the frequency of your staircase wave in 10 Hz increments.

```
counter = 0;
while (counter < 1e4)
    counter = counter + 1;
    staircaseWave = waveSynth();
    scope(staircaseWave)
    if mod(counter,1000)==0
        waveSynth.Frequency = waveSynth.Frequency + 10;
    end
end
```



Manipulate Audio Samples Using Wavetable Synthesizer

Sample an audio file and save it to the `Wavetable` property of a `wavetableSynthesizer` System object™. Use the wavetable synthesizer to manipulate your audio sample.

Read in an entire audio file. Clip out an interesting sound from the audio and then play it.

```
[audio,fs] = audioread('MainStreetOne-16-16-mono-12secs.wav');
aSound = audio(2.5e4:5e4);
sound(aSound,fs)
```

Create a wavetable synthesizer using your audio clip. The duration of the engine audio clip is `numel(aSound)/fs` seconds. In the `wavetableSynthesizer`, set the `Frequency` property to `1/(clip duration)`. The generated signal now plays back at the same rate it was recorded at.

```
duration = numel(aSound)/fs;
waveSynth = wavetableSynthesizer('Wavetable',aSound,'SampleRate',fs, ...
    'Frequency',1/duration);
```

Create an `audioDeviceWriter` to write to your audio device.

```
deviceWriter = audioDeviceWriter('SampleRate',fs);
```

In a loop, play the wavetable synthesizer to your device. After three seconds, begin increasing the frequency of the wavetable synthesizer. After six seconds, begin decreasing the frequency of the wavetable synthesizer.

```
timeElapsed = 0;
while timeElapsed < 9
    audioWave = waveSynth();
    deviceWriter(audioWave);

    if (timeElapsed > 3) && (timeElapsed < 6)
        waveSynth.Frequency = waveSynth.Frequency + 0.001;
    elseif timeElapsed > 6
        waveSynth.Frequency = waveSynth.Frequency - 0.002;
    end

    timeElapsed = timeElapsed + waveSynth.SamplesPerFrame*(1/fs);
end
```

Modify Wavetable While Stream Processing

Modify the Wavetable property of a wavetableSynthesizer object while stream processing. Visualize the wavetable and plot the resulting audio.

Create a single-cycle waveform for the wavetableSynthesizer to index into. Create a wavetable synthesizer object.

```
t = 0:0.001:1;
exponent = 5;
waveTable = [t.^exponent,fliplr(t.^exponent)] - 0.5;

waveSynth = wavetableSynthesizer('Wavetable',waveTable);
```

Create a dsp.ArrayPlot object to plot the wavetable as it is modified over time. Create an audioDeviceWriter object to listen to the signal output by your wavetable synthesizer.

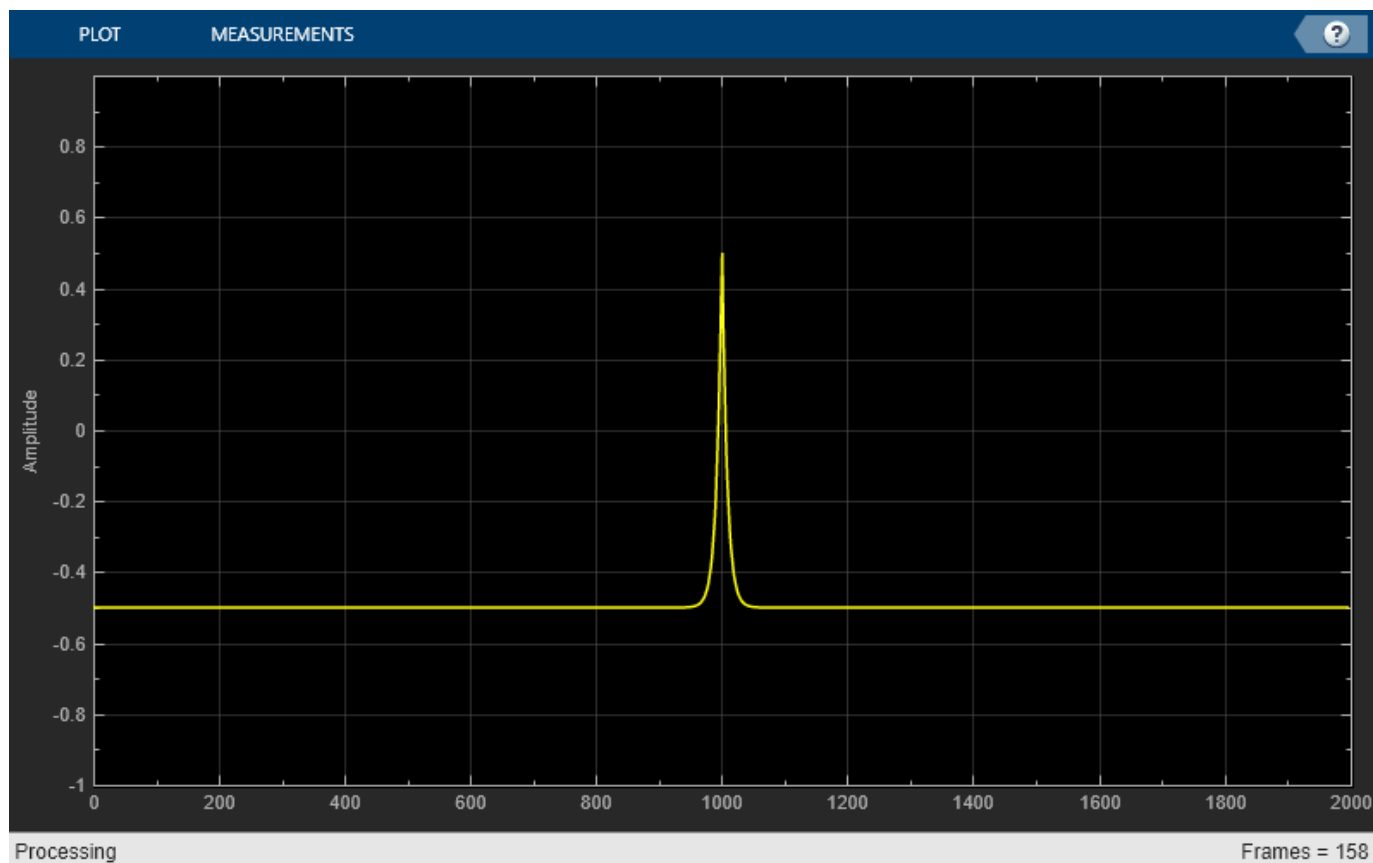
```
arrayPlotter = dsp.ArrayPlot('YLimits',[-1,1], 'PlotType', 'Line');
deviceWriter = audioDeviceWriter;
```

In an audio stream loop, incrementally modify the Wavetable property of the wavetable synthesizer and plot it. Call the synthesizer to output a waveform and play the waveform to your audio device.

```
tic
while toc < 10
    exponent = exponent - 0.01;
    waveSynth.Wavetable = [t.^abs(exponent),fliplr(t.^abs(exponent))] - 0.5;

    arrayPlotter(waveSynth.Wavetable')

    deviceWriter(waveSynth());
end
```



```
release(deviceWriter)
```

Tune Wavetable Synthesizer Parameters

Create a `wavetableSynthesizer` to generate a waveform. Create a `timescope` to visualize the waveform. Create an `audioDeviceWriter` to write audio to your sound card.

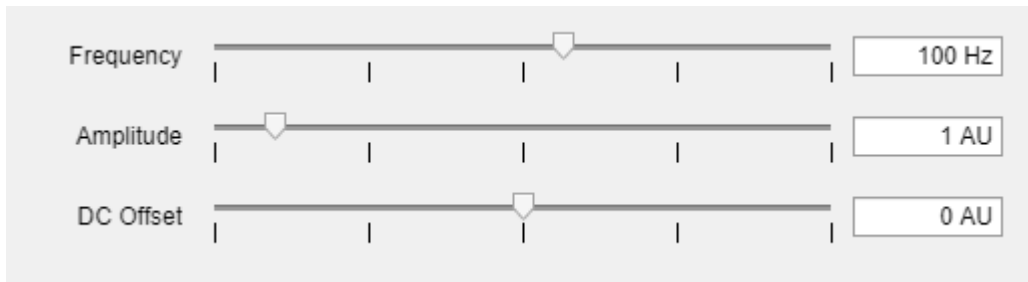
```
fs = 44.1e3;
wvSynth = wavetableSynthesizer('SampleRate', fs);
```

```
scope = timescope( ...
    'SampleRate', wvSynth.SampleRate, ...
    'TimeSpanSource', 'Property', 'TimeSpan', 1, ...
    'YLimits', [-2, 2], ...
    'TimeSpanOverrunAction', 'Scroll', ...
    'ShowGrid', true);
```

```
deviceWriter = audioDeviceWriter('SampleRate', wvSynth.SampleRate);
```

Call `parameterTuner` to open a UI to tune parameters of the wavetable synthesizer while streaming.

```
parameterTuner(wvSynth)
```

In an audio stream loop:

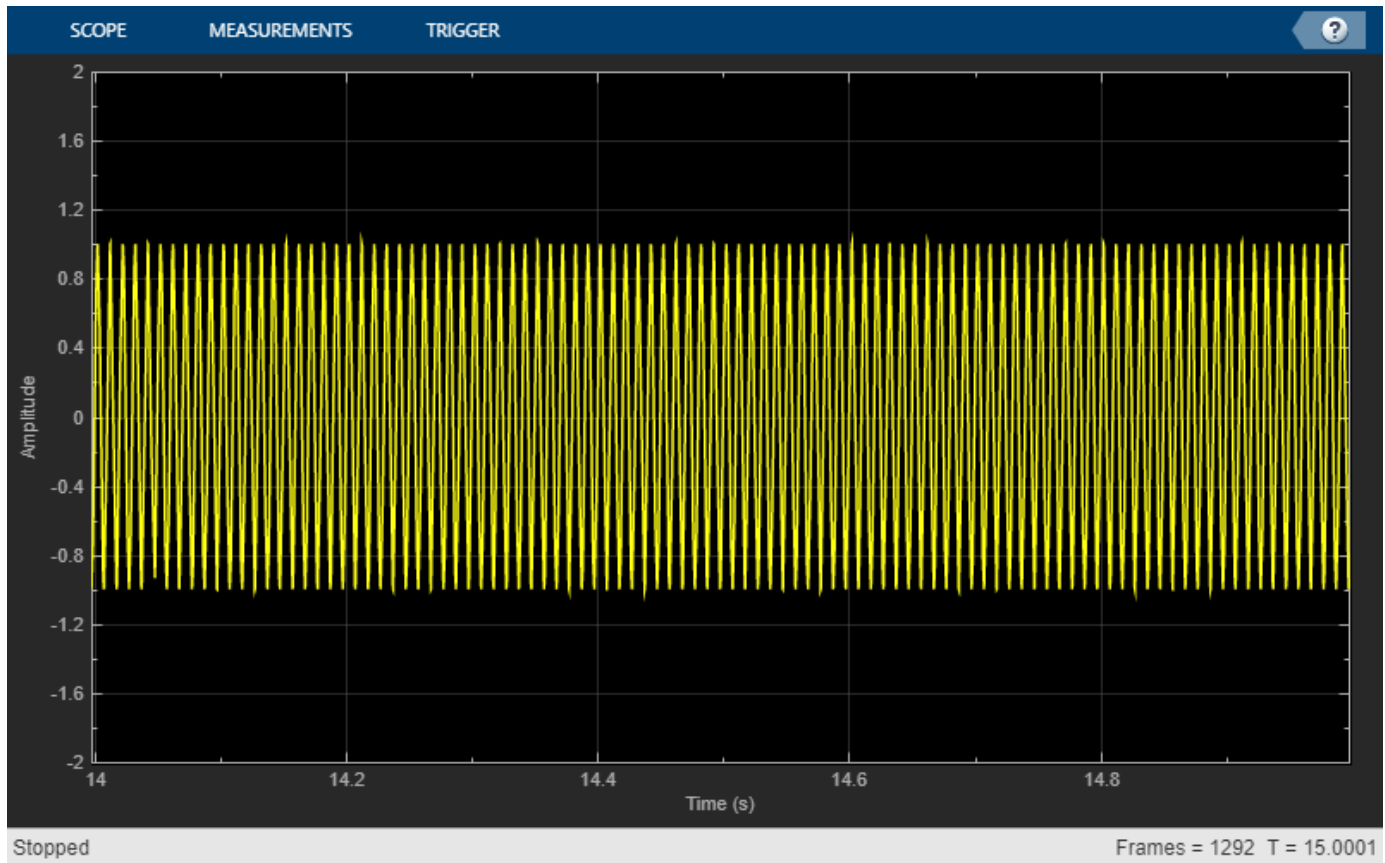
- 1 Call the wavetable synthesizer without arguments to output one frame of data.
- 2 Visualize the data using the time scope.
- 3 Write the frame of audio to your audio device for listening.

While streaming, tune parameters of the wavetable synthesizer and listen to the effect.

```
duration = 15;
numIterations = round(wvSynth.SampleRate*duration/wvSynth.SamplesPerFrame);
for i = 1:numIterations
    audioOut = wvSynth();
    scope(audioOut)
    deviceWriter(audioOut);
    drawnow limitrate % required to update parameter
end
```

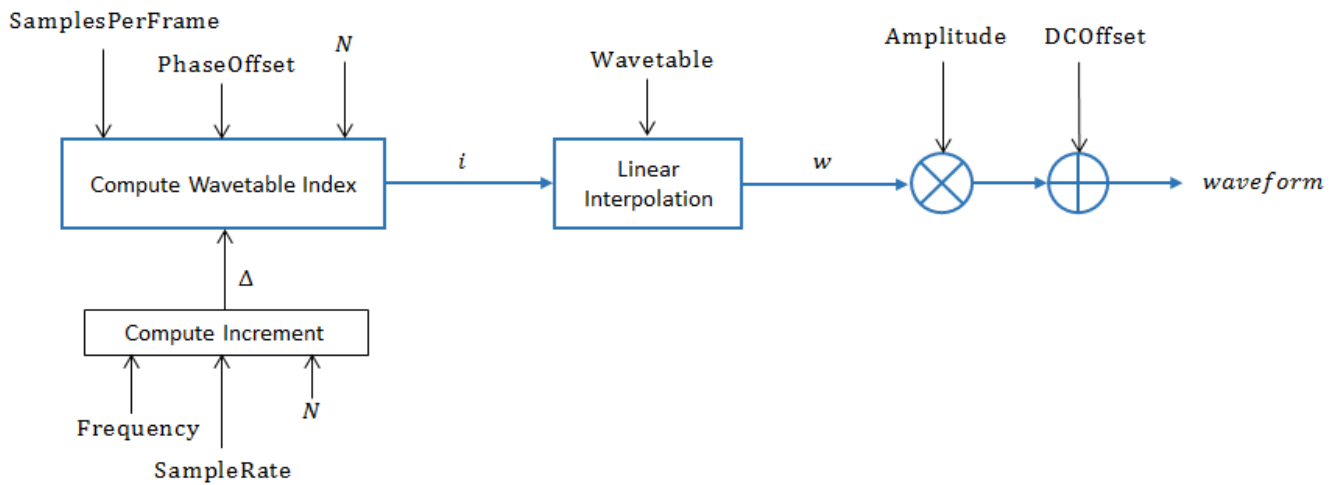
As a best practice, release your objects when done.

```
release(deviceWriter)
release(wvSynth)
release(scope)
```



Algorithms

The `wavetableSynthesizer` System object synthesizes periodic signals using a cached single-cycle waveform, specified waveform properties, and phase memory.



Compute Increment

Compute the increment step size:

$$\Delta = \frac{\text{Frequency}}{\text{SampleRate}} \times N,$$

where N is the number of elements in your wavetable.

Compute Wavetable Index

Compute Wavetable index,

$$i[n] = \begin{cases} i[n-1] + \Delta & i[n-1] < N \\ i[n-1] + \Delta - N & i[n-1] \geq N \end{cases}$$

for $2 \leq n \leq \text{SamplesPerFrame}$. The `PhaseOffset` property determines $i[n=1]$.

Linear Interpolation

Index into the `Wavetable` and perform linear interpolation:

$$w = \begin{cases} (\text{Wavetable}[1] - \text{Wavetable}[i_L]) \times \varepsilon + \text{Wavetable}[i_L] & i_H > N \\ (\text{Wavetable}[i_H] - \text{Wavetable}[i_L]) \times \varepsilon + \text{Wavetable}[i_L] & i_H \leq N \end{cases}$$

- $i_L = \text{floor}(i[n] + 1)$
- $i_H = i_L + 1$
- $\varepsilon = i - \text{floor}(i)$

Apply Amplitude and DC Offset

Multiply by `Amplitude` and add `DCOffset`.

$$\text{waveform} = w \times \text{Amplitude} + \text{DCOffset}$$

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

`audioOscillator` | Wavetable Synthesizer

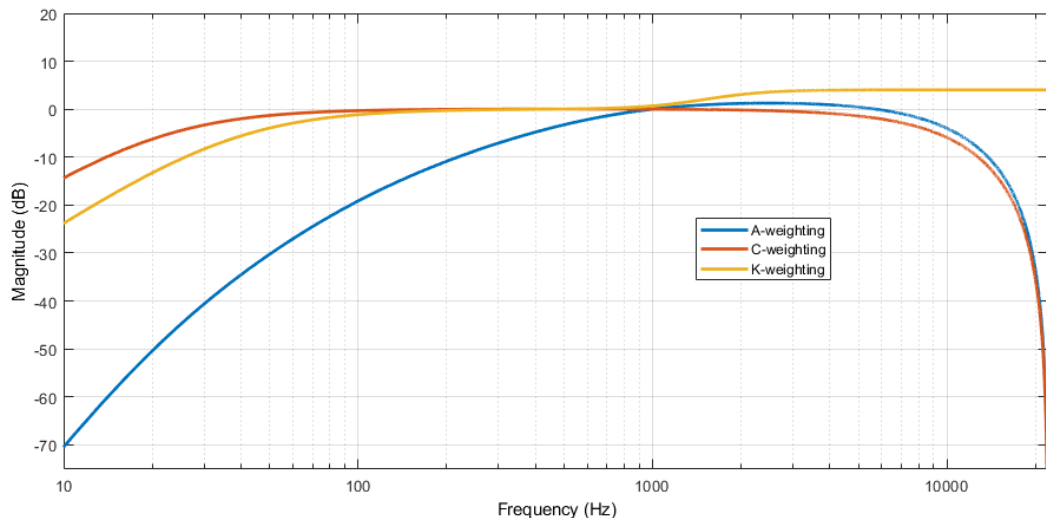
Introduced in R2016a

weightingFilter

Frequency-weighted filter

Description

The `weightingFilter` System object performs frequency-weighted filtering independently across each input channel.



To perform frequency-weighted filtering:

- 1 Create the `weightingFilter` object and set its properties.
- 2 Call the object with arguments, as if it were a function.

To learn more about how System objects work, see [What Are System Objects?](#)

Creation

Syntax

```
weightFilt = weightingFilter
weightFilt = weightingFilter(weightType)
weightFilt = weightingFilter(weightType,Fs)
weightFilt = weightingFilter( __ ,Name,Value)
```

Description

`weightFilt = weightingFilter` creates a System object, `weightFilt`, that performs frequency-weighted filtering independently across each input channel.

`weightFilt = weightingFilter(weightType)` sets the Method property to `weightType`.

`weightFilt = weightingFilter(weightType,Fs)` sets the `SampleRate` property to `Fs`.

`weightFilt = weightingFilter(____,Name,Value)` sets each property `Name` to the specified `Value`. Unspecified properties have default values.

Example: `weightFilt = weightingFilter('C-weighting','SampleRate',96000)` creates a C-weighting filter with a sample rate of 96,000 Hz.

Properties

Unless otherwise indicated, properties are *nontunable*, which means you cannot change their values after calling the object. Objects lock when you call them, and the `release` function unlocks them.

If a property is *tunable*, you can change its value at any time.

For more information on changing property values, see *System Design in MATLAB Using System Objects*.

Method — Type of weighting

'A-weighting' (default) | 'C-weighting' | 'K-weighting'

Type of weighting, specified as 'A-weighting', 'C-weighting', or 'K-weighting'. See “Algorithms” on page 3-398 for more information.

Tunable: No

Data Types: char | string

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Tunable: Yes

Data Types: single | double

Usage

Syntax

```
audioOut = weightFilt(audioIn)
```

Description

`audioOut = weightFilt(audioIn)` applies frequency-weighted filtering to the input signal, `audioIn`, and returns the filtered signal, `audioOut`. The type of filtering is specified by the algorithm and properties of the `weightingFilter` System object, `weightFilt`.

Input Arguments

audioIn — Audio input to weighting filter

matrix

Audio input to the weighting filter, specified as a matrix. The columns of the matrix are treated as independent audio channels.

Data Types: `single` | `double`

Output Arguments

audioOut — Audio output from weighting filter

matrix

Audio output from the weighting filter, returned as a matrix the same size as `audioIn`.

Data Types: `single` | `double`

Object Functions

To use an object function, specify the System object as the first input argument. For example, to release system resources of a System object named `obj`, use this syntax:

```
release(obj)
```

Specific to weightingFilter

<code>visualize</code>	Visualize and validate filter response
<code>getFilter</code>	Return biquad filter object with design parameters set
<code>createAudioPluginClass</code>	Create audio plugin class that implements functionality of System object
<code>isStandardCompliant</code>	Verify filter design is IEC 61672-1:2002 compliant

Common to All System Objects

<code>clone</code>	Create duplicate System object
<code>isLocked</code>	Determine if System object is in use
<code>release</code>	Release resources and allow changes to System object property values and input characteristics
<code>reset</code>	Reset internal states of System object
<code>step</code>	Run System object algorithm

Note `weightingFilter` supports additional filter analysis functions. See “Compare and Analyze Weighting Types” on page 3-394 for details.

Examples

Validate Filter Compliance

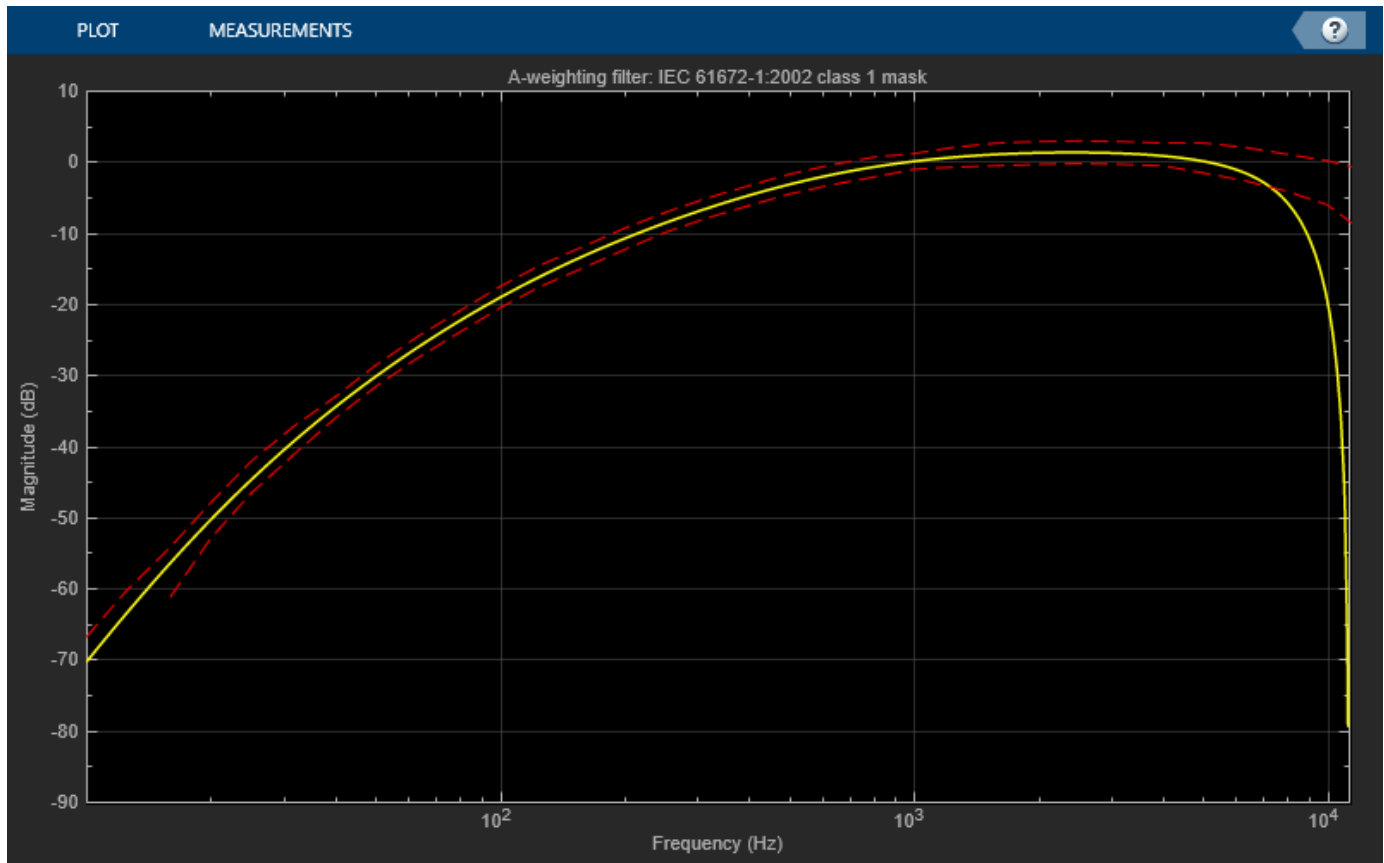
Check the compliance status of filter designs and visualize them.

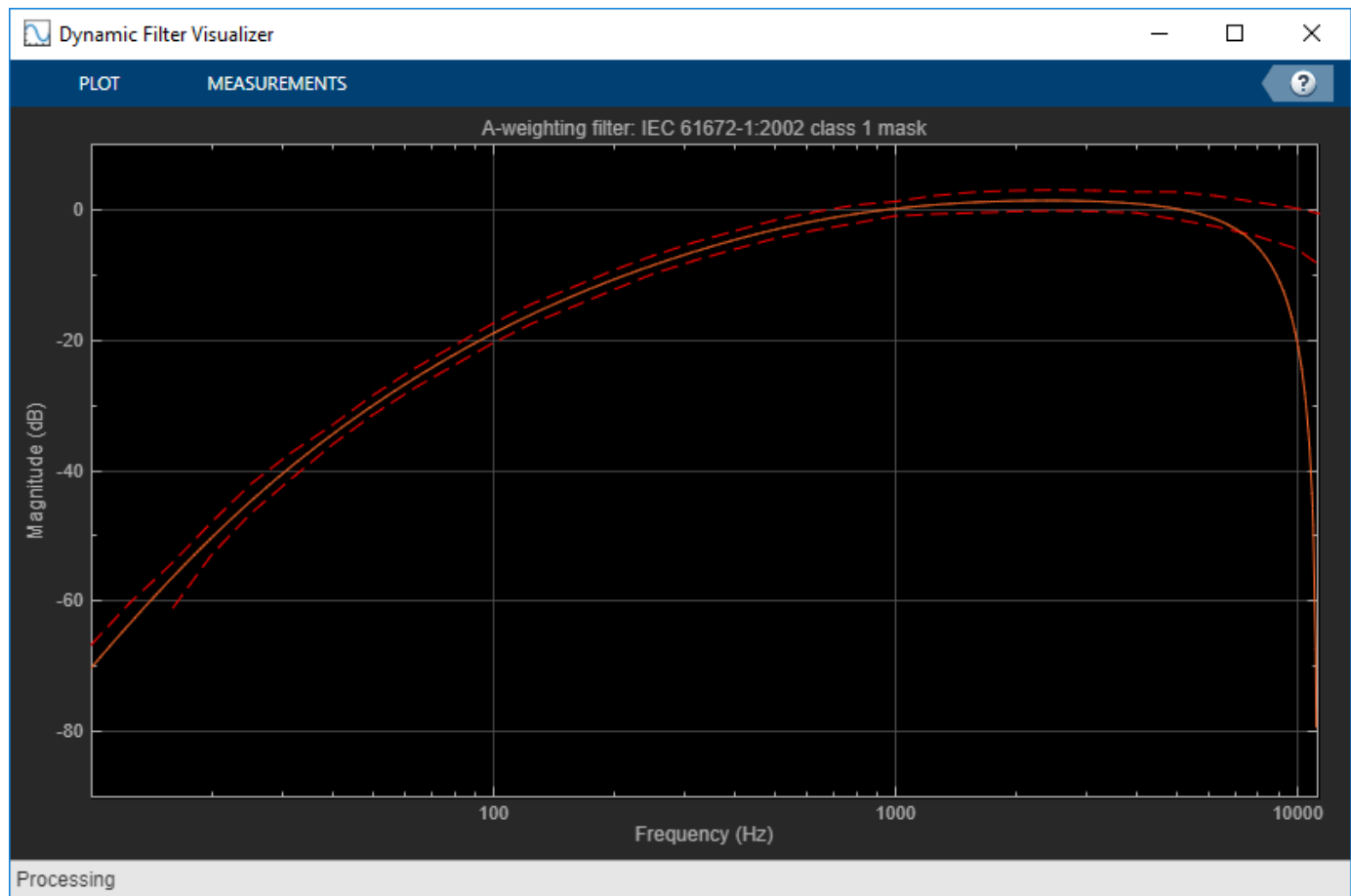
Create an A-weighting filter with a 22.5 kHz sample rate. Verify that the filter is standard compliant and visualize the filter design.

```
aWeight = weightingFilter('A-weighting','SampleRate',22500);  
complianceStatus = isStandardCompliant(aWeight,'class 1')
```

```
complianceStatus = logical  
0
```

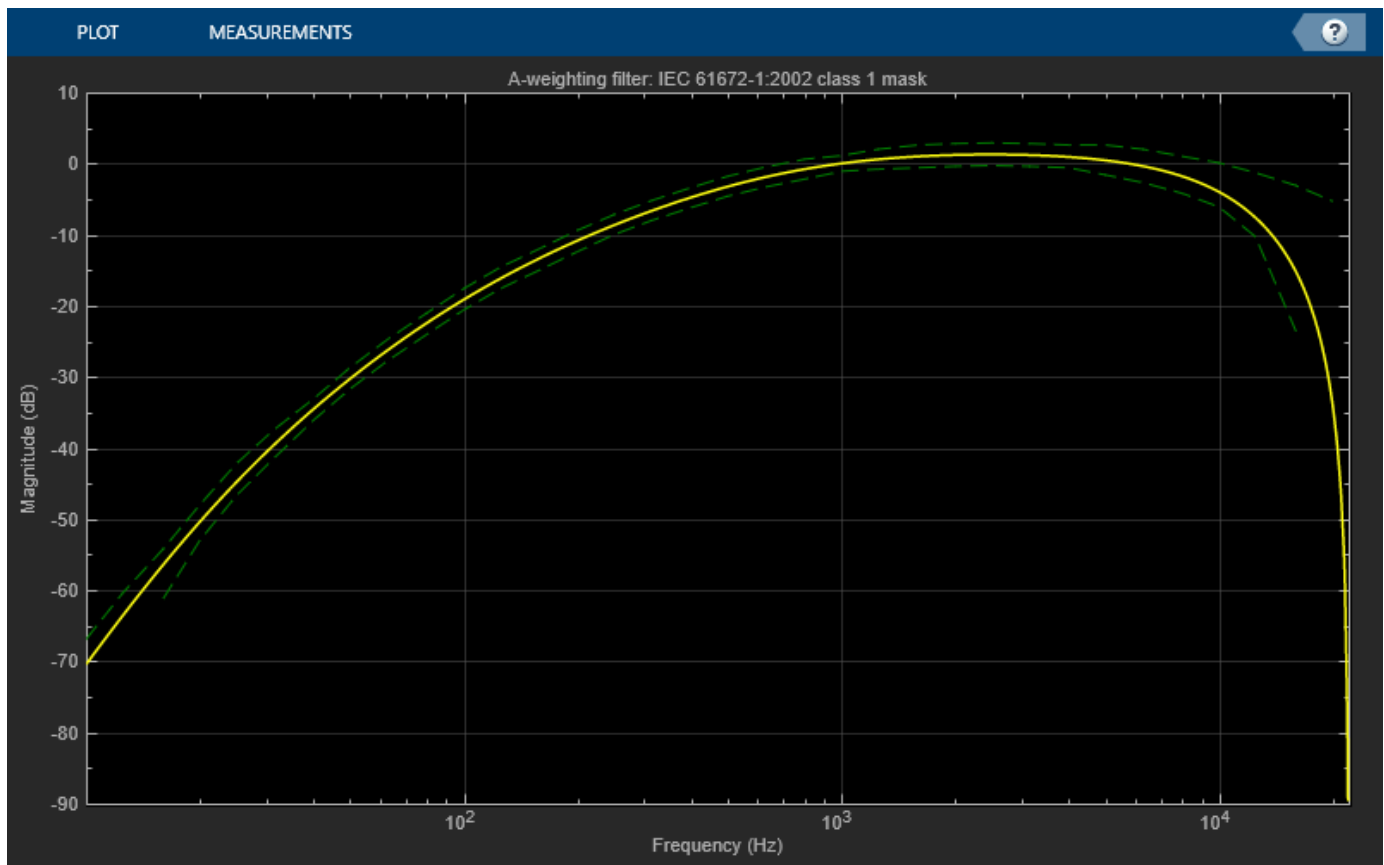
```
visualize(aWeight, 'class 1')
```





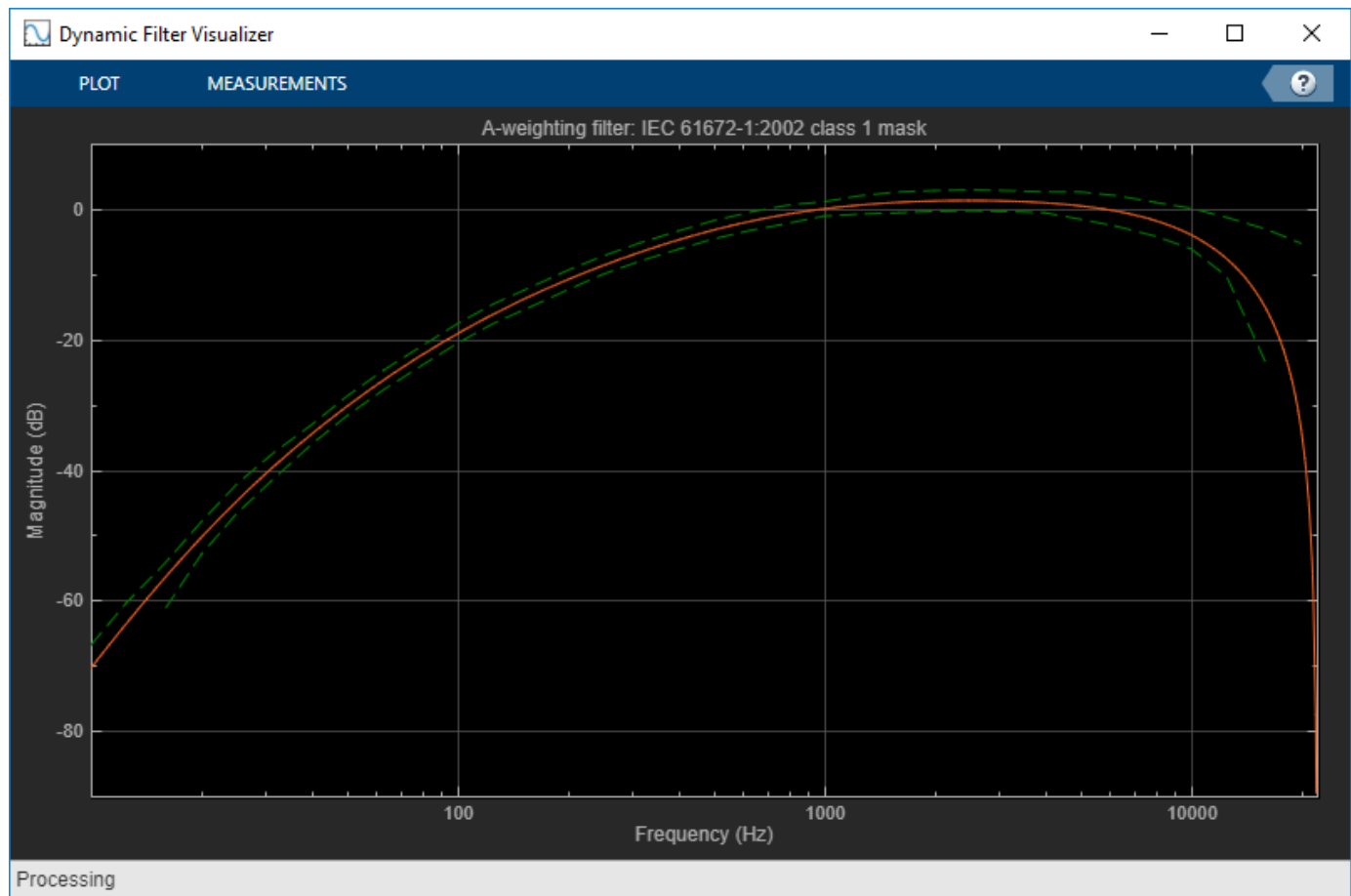
Change your A-weighting filter sample rate to 44.1 kHz. Verify that the filter is standard compliant and visualize the filter design.

```
aWeight.SampleRate = 44100;
```

```
complianceStatus = isStandardCompliant(aWeight, 'class 1')
```

```
complianceStatus = logical  
1
```



Perform A-Weighted Filtering

Use the `weightingFilter` System object™ to design an A-weighted filter, and then process an audio signal using your frequency-weighted filter design.

Create a `dsp.AudioFileReader` System object.

```
samplesPerFrame = 1024;
reader = dsp.AudioFileReader('Filename', ...
    'RockGuitar-16-44p1-stereo-72secs.wav', ...
    'SamplesPerFrame', samplesPerFrame, ...
    'PlayCount', Inf);
```

Create a `weightingFilter` System object. Use the sample rate of the reader as the sample rate of the weighting filter.

```
Fs = reader.SampleRate;
weightFilt = weightingFilter('A-weighting', Fs);
```

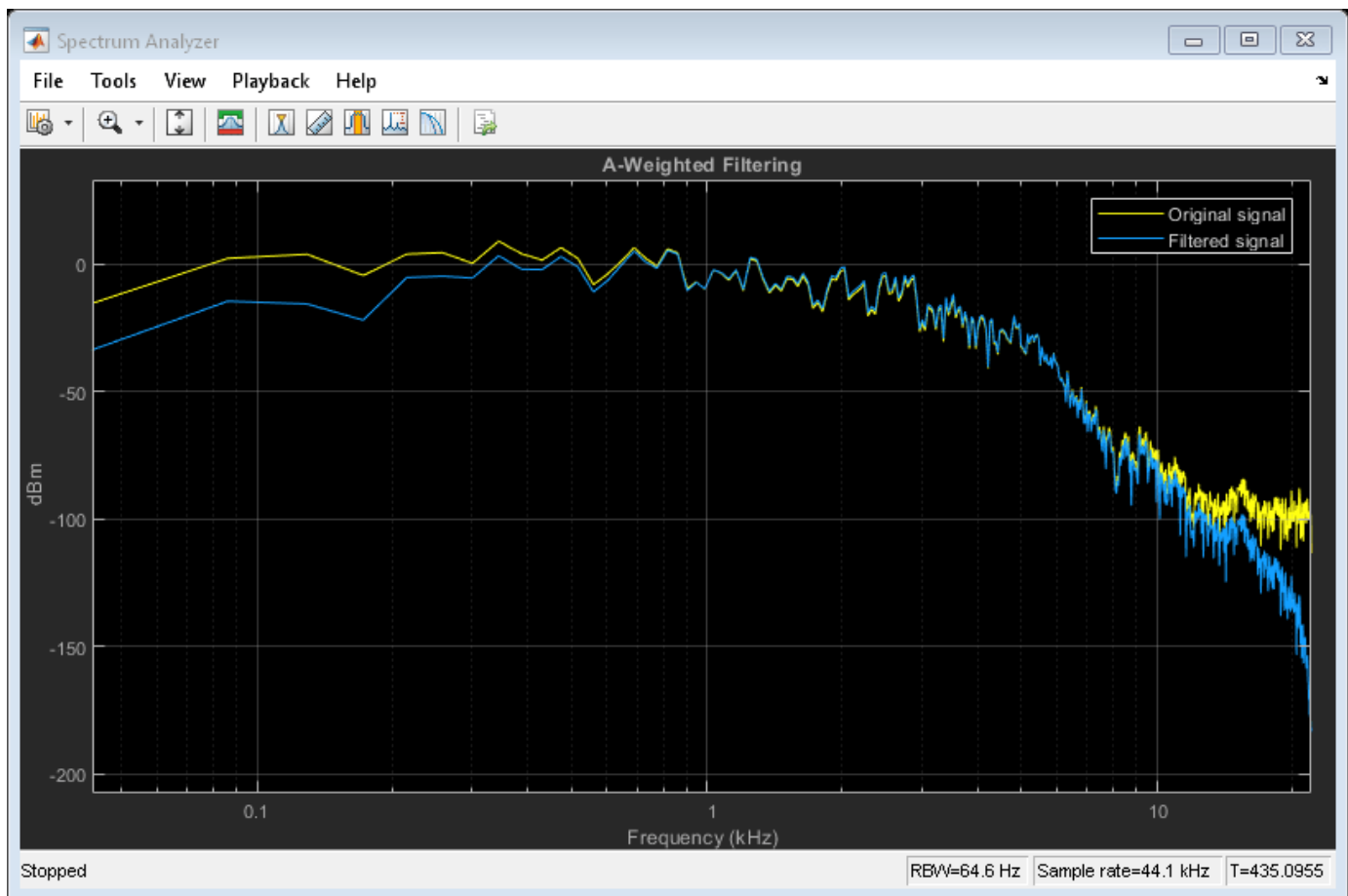
Create a spectrum analyzer to visualize the original audio signal and the audio signal after frequency-weighted filtering.

```
scope = dsp.SpectrumAnalyzer( ...
    'SampleRate',Fs, ...
    'PlotAsTwoSidedSpectrum',false, ...
    'FrequencyScale','Log', ...
    'FrequencyResolutionMethod','WindowLength', ...
    'WindowLength',samplesPerFrame, ...
    'Title','A-Weighted Filtering', ...
    'ShowLegend',true, ...
    'ChannelNames',{'Original signal','Filtered signal'});
```

Process the audio signal in an audio stream loop. Visualize the filtered audio and the original audio. As a best practice, release the System objects when complete.

```
tic
while toc < 20
    x = reader();
    y = weightFilt(x);
    scope([x(:,1),y(:,1)])
end

release(weightFilt)
release(reader)
release(scope)
```



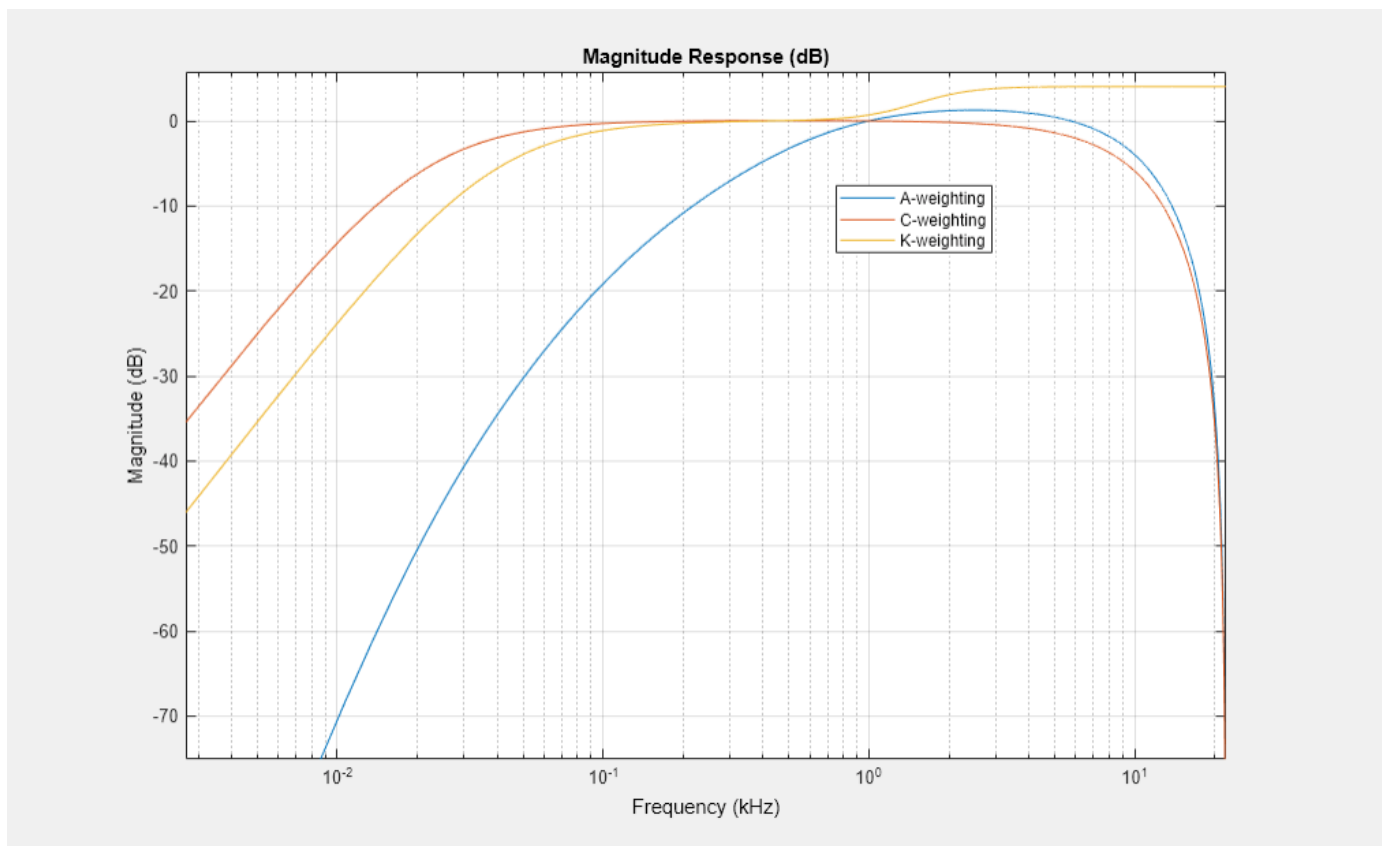
Compare and Analyze Weighting Types

Compare the A-weighted, C-weighted, and K-weighted filtering of an engine sound.

Create an A-weighting filter, a C-weighting filter, and a K-weighting filter. Compare and analyze the filters using FVTool.

```
wF{1} = weightingFilter;
wF{2} = weightingFilter('C-weighting');
wF{3} = weightingFilter('K-weighting');

fvtool(wF{1},wF{2},wF{3},'FrequencyScale','Log', ...
    'Fs',wF{1}.SampleRate);
legend(fvt,'A-weighting','C-weighting','K-weighting', ...
    Location="best")
```



The `weightingFilter` object supports several filter analysis methods. For more information, use `help` at the command line:

```
help weightingFilter.helpFilterAnalysis
```

The following analysis methods are available for discrete-time filter System objects:

```
fvtool    - Filter visualization tool
info      - Filter information
freqz     - Frequency response
```

phasez	- Phase response
zerophase	- Zero-phase response
grpdelay	- Group delay response
phasedelay	- Phase delay response
impz	- Impulse response
impzlength	- Length of impulse response
stepz	- Step response
zplane	- Pole/zero plot
cost	- Cost estimate for implementation of the filter System object
measure	- Measure characteristics of the frequency response
outputDelay	- Output delay value
order	- Filter order
coeffs	- Filter coefficients in a structure
firtype	- Determine the type (1-4) of a linear phase FIR filter System object
tf	- Convert to transfer function
zpk	- Convert to zero-pole-gain
ss	- Convert to state space representation
isallpass	- Verify if filter System object is allpass
isfir	- Verify if filter System object is FIR
islinphase	- Verify if filter System object is linear phase
ismaxphase	- Verify if filter System object is maximum phase
isminphase	- Verify if filter System object is minimum phase
isreal	- Verify if filter System object is minimum real
issos	- Verify if filter System object is in second-order sections form
isstable	- Verify if filter System object is stable
realizemdl	- Filter realization (Simulink diagram)
specifyall	- Fully specify fixed-point filter System object settings
cascade	- Create a FilterCascade System object

Second-order sections:

scale	- Scale second-order sections of BiquadFilter System object
scalecheck	- Check scaling of BiquadFilter System object
reorder	- Reorder second-order sections of BiquadFilter System object
cumsec	- Cumulative second-order section of BiquadFilter System object
scaleopts	- Create an options object for second-order section scaling
sos	- Convert to second-order-sections (for IIRFilter System objects only)

Fixed-Point (Fixed-Point Designer Required):

freqrespest	- Frequency response estimate via filtering
freqrespopts	- Create an options object for frequency response estimate
noisepsd	- Power spectral density of filter output due to roundoff noise
noisepsdopts	- Create an options object for output noise PSD computation

Multirate Analysis:

polyphase	- Polyphase decomposition of multirate filter System object
gain (CIC decimator)	- Gain of CIC decimator filter System object
gain (CIC interpolator)	- Gain of CIC interpolator filter System object

For decimator, interpolator, or rate change filter System objects the analysis tools perform computations relative to the rate at

which the filter is running. If a sampling frequency is specified, it is assumed that the filter is running at that rate.

Help for `weightingFilter.helpFilterAnalysis` is inherited from superclass `dsp.internal.FilterAnalysis`.

Create a `dsp.AudioFileReader` and specify a sound file. Create an `audioDeviceWriter` with default properties. In an audio stream loop, play the white noise, and then listen to it filtered through the A-weighted, C-weighted, and K-weighted filters, successively.

```
fileReader = dsp.AudioFileReader('Engine-16-44p1-stereo-20sec.wav');  
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
```

```
fprintf('No filtering...')
```

No filtering...

```
for i = 1:400  
    x = fileReader();  
    if i==100  
        index = 1;  
        fprintf('A-weighted filtering...')  
    elseif i==200  
        index = 2;  
        fprintf('C-weighted filtering...')  
    elseif i==300  
        index = 3;  
        fprintf('K-weighted filtering...\n')  
    end  
    if i>99  
        y = wF{index}(x);  
    else  
        y = x;  
    end  
    deviceWriter(y);  
end
```

A-weighted filtering...

C-weighted filtering...

K-weighted filtering...

As a best practice, release your objects once done.

```
release(deviceWriter)  
release(fileReader)
```

Use Weighting Filter Design with Biquad Filter

The `weightingFilter` object uses second-order sections (SOS) for filtering. To extract the weighting filter design, use `getFilter` to return a `dsp.BiquadFilter` object with the `SOSMatrix` and `ScaleValues` properties set.

Use `weightingFilter` to create C-weighted and A-weighted filter objects. Use `getFilter` to return corresponding `dsp.BiquadFilter` objects.

```

cFilt = weightingFilter('C-weighting');
aFilt = weightingFilter('A-weighting');
cSOSFilter = getFilter(cFilt);
aSOSFilter = getFilter(aFilt);

```

Create an audio file reader and audio device writer for audio input/output. Use the sample rate of your reader as the sample rate of your writer.

```

fileReader = dsp.AudioFileReader('JetAirplane-16-11p025-mono-16secs.wav');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);

```

In an audio stream loop, play the unfiltered signal. Release your file reader so that the next time you call it, it reads from the beginning of the file.

```

tic
while toc<8
    x = fileReader();
    deviceWriter(x);
end
release(fileReader)

```

Play the signal processed by the A-weighted filter. Then play the signal processed by the C-weighted filter. Cache the power in each frame of the original and filtered signals for analysis. As a best practice, release your file reader and device writer once complete.

```

y = [];
count = 1;
tic
while ~isDone(fileReader)
    x = fileReader();
    aFiltered = aSOSFilter(x);
    cFiltered = cSOSFilter(x);
    if toc>8
        deviceWriter(cFiltered);
    else
        deviceWriter(aFiltered);
    end
    xPower(count) = var(x);
    aPower(count) = var(aFiltered);
    cPower(count) = var(cFiltered);
    y = [y;x];
    count = count+1;
end

```

```

release(fileReader)
release(deviceWriter)

```

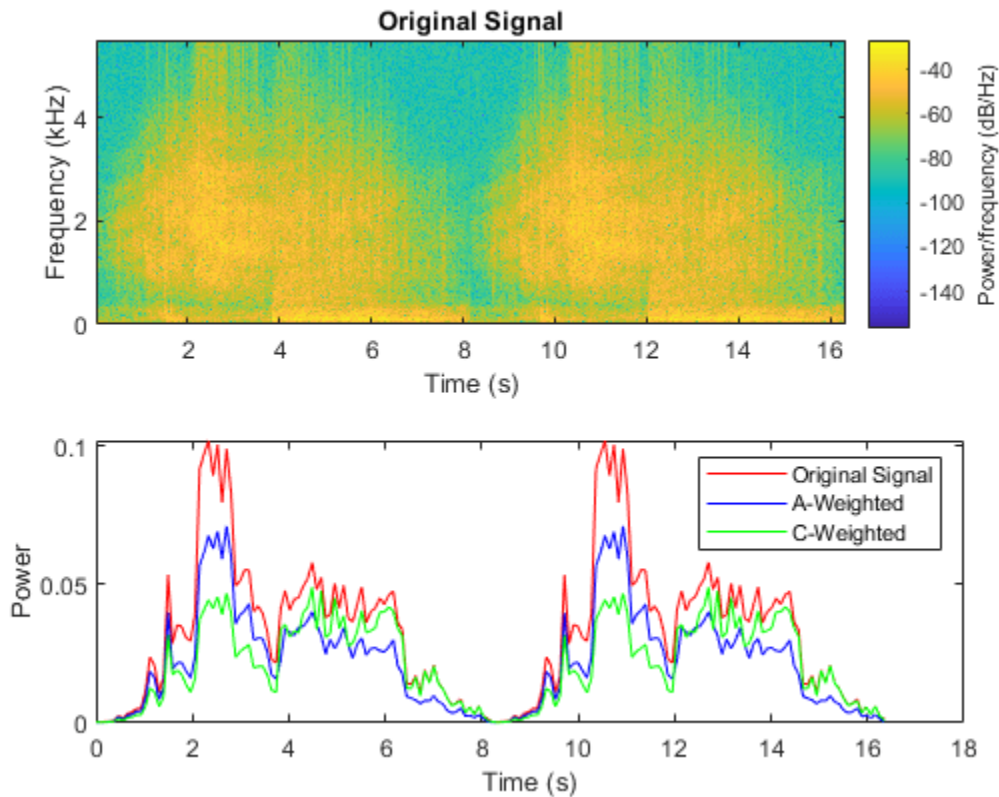
Plot the power of the original signal, the A-weighted signal, and the C-weighted signal over time.

```

subplot(2,1,1)
spectrogram(y,512,256,4096,fileReader.SampleRate,'yaxis')
title('Original Signal')

subplot(2,1,2)
t = linspace(0,16.3468,count-1);
plot(t,xPower,'r',t,aPower,'b',t,cPower,'g')
legend('Original Signal','A-Weighted','C-Weighted')
xlabel('Time (s)')
ylabel('Power')

```



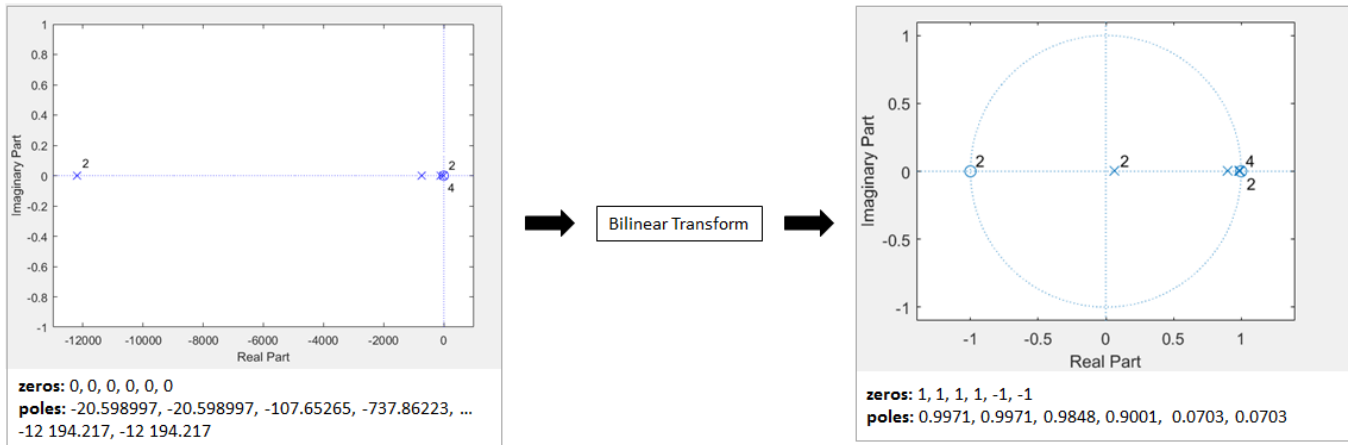
Algorithms

A-Weighting

The A-curve is a wide bandpass filter centered at 2.5 kHz, with approximately 20 dB attenuation at 100 Hz. A-weighted SPL measurements of noise level are increasingly found in sales literature for domestic appliances. In most countries, the use of A-weighting is mandated for the protection of workers against noise-induced deafness. The ISO and ICOA standards mandate A-weighting for all civil aircraft noise measurements.

The ANSI S1.42.2001 [1] defines this weighting curve. The IEC 61672-1:2002 [2] standard defines the minimum and maximum attenuation limits for an A-weighting filter.

ANSI S1.42.2001 defines the weighting curve by specifying analog poles and zeros. Audio Toolbox converts the specified poles and zeros to the digital domain using a bilinear transform:

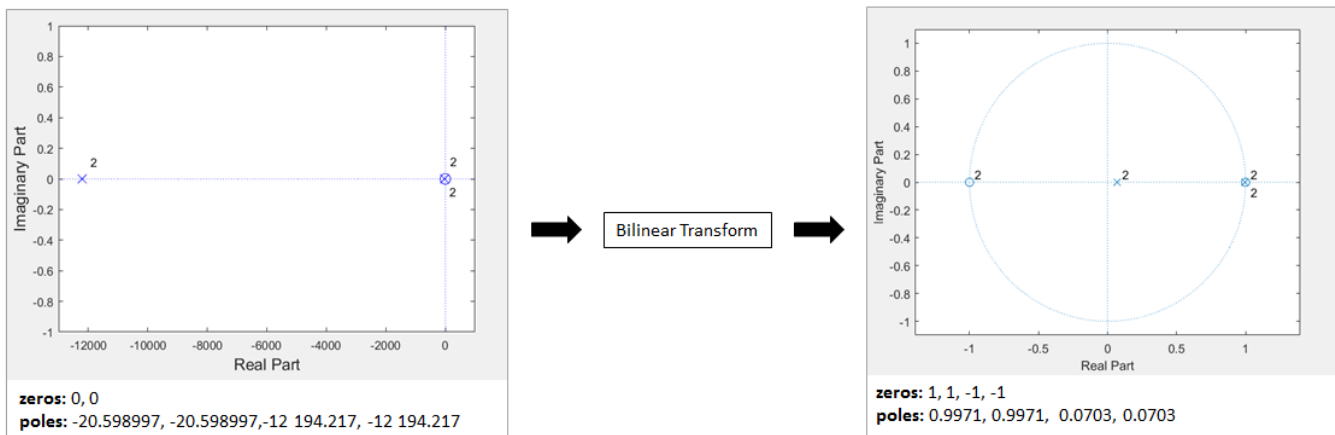


C-Weighting

The C-curve is "flat," but with limited bandwidth: It has -3 dB corners at 31.5 Hz and 8 kHz. C-curves are used in sound level meters for sounds that are louder than those intended for A-weighting filters.

The ANSI S1.42-2001 [1] defines the C-weighting curve. The IEC 61672-1:2002 [2] standard defines the minimum and maximum attenuation limits for C-weighting filters.

ANSI S1.42.2001 defines the weighting curve by specifying analog poles and zeros. Audio Toolbox converts the specified poles and zeros to the digital domain using a bilinear transform:

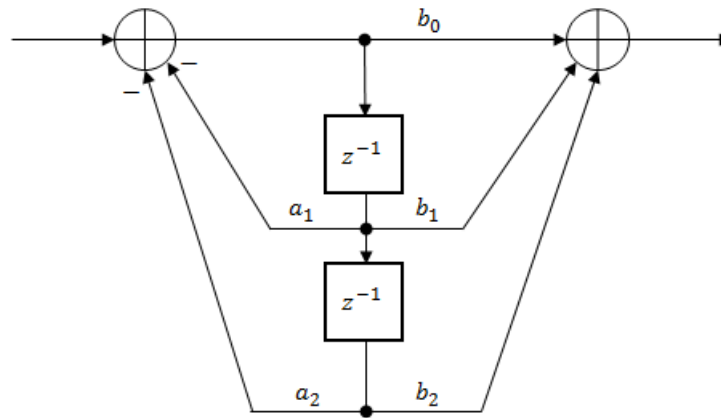


K-Weighting

The K-weighting filter is used for loudness normalization in broadcast. It is composed of two stages of filtering: a first stage shelving filter and a second stage highpass filter.

The ITU-R BS.1770-4 [3] standard defines this curve.

Assume a second-order filter.



The table shows the coefficients for the filters.

First Stage Shelving Coefficients	Second Stage Highpass Coefficients
$a_1 = -1.69065929318241$	$a_1 = -1.99004745483398$
$a_2 = 0.73248077421585$	$a_2 = 0.99007225036621$
$b_0 = 1.53512485958697$	$b_0 = 1.0$
$b_1 = -2.6916918940638$	$b_1 = -2.0$
$b_2 = 1.19839281085285$	$b_2 = 1.0$

The coefficients presented by ITU-R BS.1770-4 are defined for 48 kHz. These coefficients are recomputed for nonstandard sample rates using the algorithm described in [4].

References

- [1] Acoustical Society of America. *Design Response of Weighting Networks for Acoustical Measurements*. ANSI S1.42-2001. New York, NY: American National Standards Institute, 2001.
- [2] International Electrotechnical Commission. *Electroacoustics Sound Level Meters Part 1: Specifications*. First Edition. IEC 61672-1. 2002-2005.
- [3] International Telecommunication Union. *Algorithms to measure audio programme loudness and true-peak audio level*. ITU-R BS.1770-4. 2015.
- [4] Mansbridge, Stuart, Saoirse Finn, and Joshua D. Reiss. "Implementation and Evaluation of Autonomous Multi-track Fader Control." Paper presented at the 132nd Audio Engineering Society Convention, Budapest, Hungary, 2012.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

“System Objects in MATLAB Code Generation” (MATLAB Coder)

See Also

Weighting Filter | multibandParametricEQ | octaveFilter | dsp.BiquadFilter

Topics

“Audio Weighting Filters”

“Sound Pressure Measurement of Octave Frequency Bands”

Introduced in R2016b

isStandardCompliant

Verify filter design is IEC 61672-1:2002 compliant

Syntax

```
complianceStatus = isStandardCompliant(weightFilt,classType)
complianceStatus = isStandardCompliant( ____,freqRange)
```

Description

`complianceStatus = isStandardCompliant(weightFilt,classType)` returns a logical scalar, `complianceStatus`, indicating whether the `weightFilt` filter design is compliant with the minimum and maximum attenuation specifications for the `classType` design specified in IEC 61672-1:2002. You can check compliance for A-weighting and C-weighting filters only.

`complianceStatus = isStandardCompliant(____,freqRange)` specifies the range of frequencies checked for compliance.

Examples

Verify Class 1 Standard Compliance

Create an object of the `weightingFilter` System object™. Call `isStandardCompliant`, specifying the compliance class type to check as the second argument.

```
weightFilt = weightingFilter;
complianceStatus = isStandardCompliant(weightFilt,'class 1')

complianceStatus = logical
    1
```

Specify Frequency Range Checked for Compliance

Create an object of the `weightingFilter` System object™. Check the 'class 2' compliance status of the filter design over a specified frequency range.

```
weightFilt = weightingFilter;
isStandardCompliant(weightFilt,'class 2',[120,2000])

ans = logical
    1
```

Input Arguments

weightFilt — Object of weightingFilter

object

Object of the weightingFilter System object.

classType — Compliance class type

'class 1' | 'class 2'

Compliance class type to verify, specified as 'class 1' or 'class 2'.

Data Types: char

freqRange — Frequency range checked for compliance (Hz)

[minFreq,maxFreq] | two-element vector of increasing values

Specify the frequency range, in Hz, checked for compliance as a two-element vector of increasing values: [minFreq,maxFreq].

Data Types: single | double

Output Arguments

complianceStatus — Compliance status of filter design

scalar

Compliance status of filter design, returned as a logical scalar. The compliance status indicates whether the weightFilt filter design is compliant with the minimum and maximum attenuation specifications for the class type design specified by IEC 61672-1:2002 standard. Compliance can only be checked for A-weighting and C-weighting filters.

Data Types: logical

Note The pole-zero values defined in the ANSI S1.42-2001 standard are used for designing the A-weighted and C-weighted filters. The pole-zero values are based on analog filters, so the design can break compliance for lower sample rates.

See Also

Topics

“Audio Weighting Filters”

“Sound Pressure Measurement of Octave Frequency Bands”

Introduced in R2016b

visualize

Visualize and validate filter response

Syntax

```
visualize(weightFilt)
visualize(weightFilt,N)
visualize( ____,mType)
hvsz = visualize( ____)
```

Description

`visualize(weightFilt)` plots the magnitude response of the frequency-weighted filter `weightFilt`. The plot is updated automatically when properties of the object change.

`visualize(weightFilt,N)` uses an N-point FFT to calculate the magnitude response.

`visualize(____,mType)` creates a mask based on the class of filter specified by `mType`, using either of the previous syntaxes.

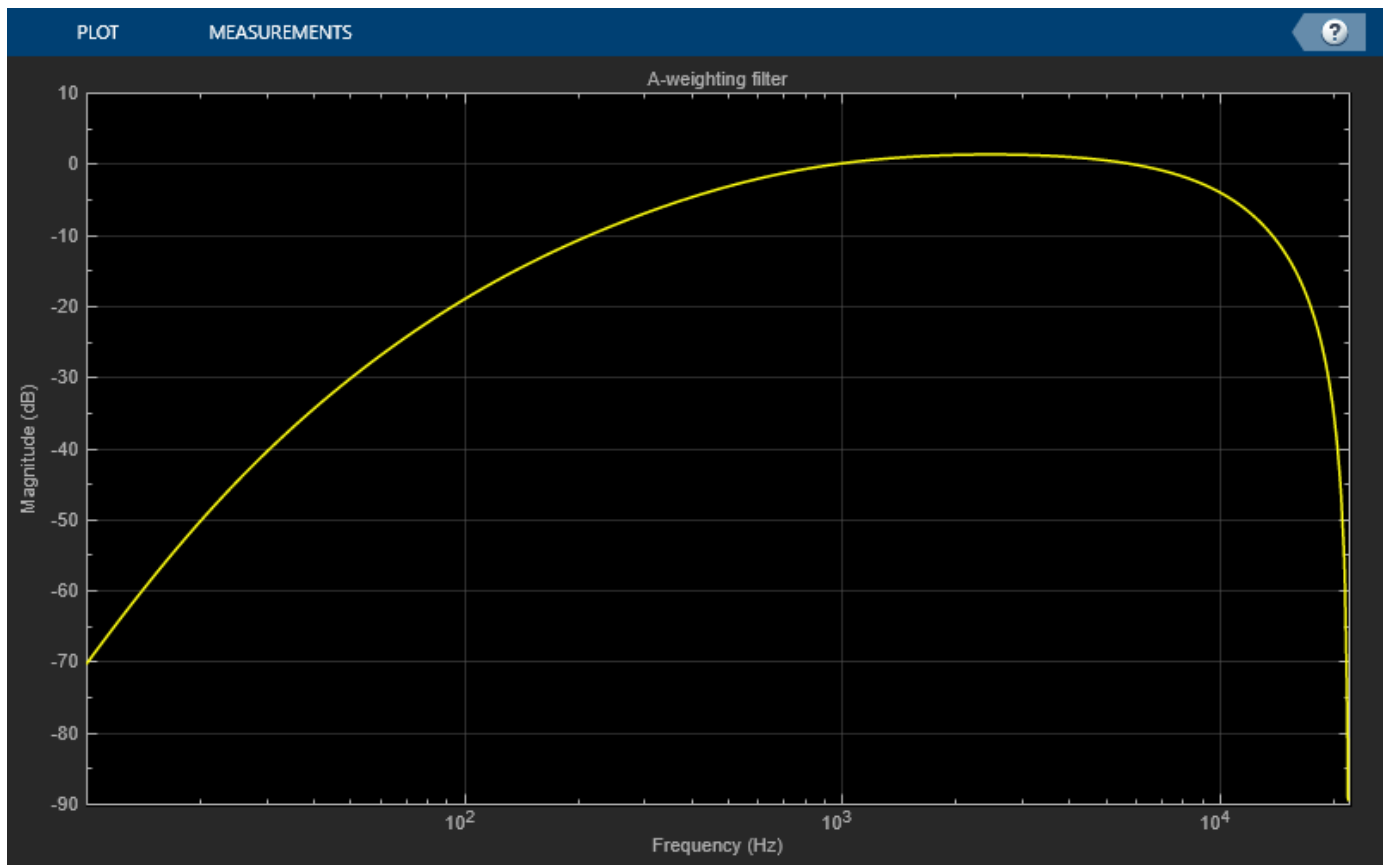
`hvsz = visualize(____)` returns a handle to the visualizer as a `dsp.DynamicFilterVisualizer` object when called with any of the previous syntaxes.

Examples

Plot Weighting Filter Magnitude Response

Create a `weightingFilter` System object™ and then plot the magnitude response of the filter.

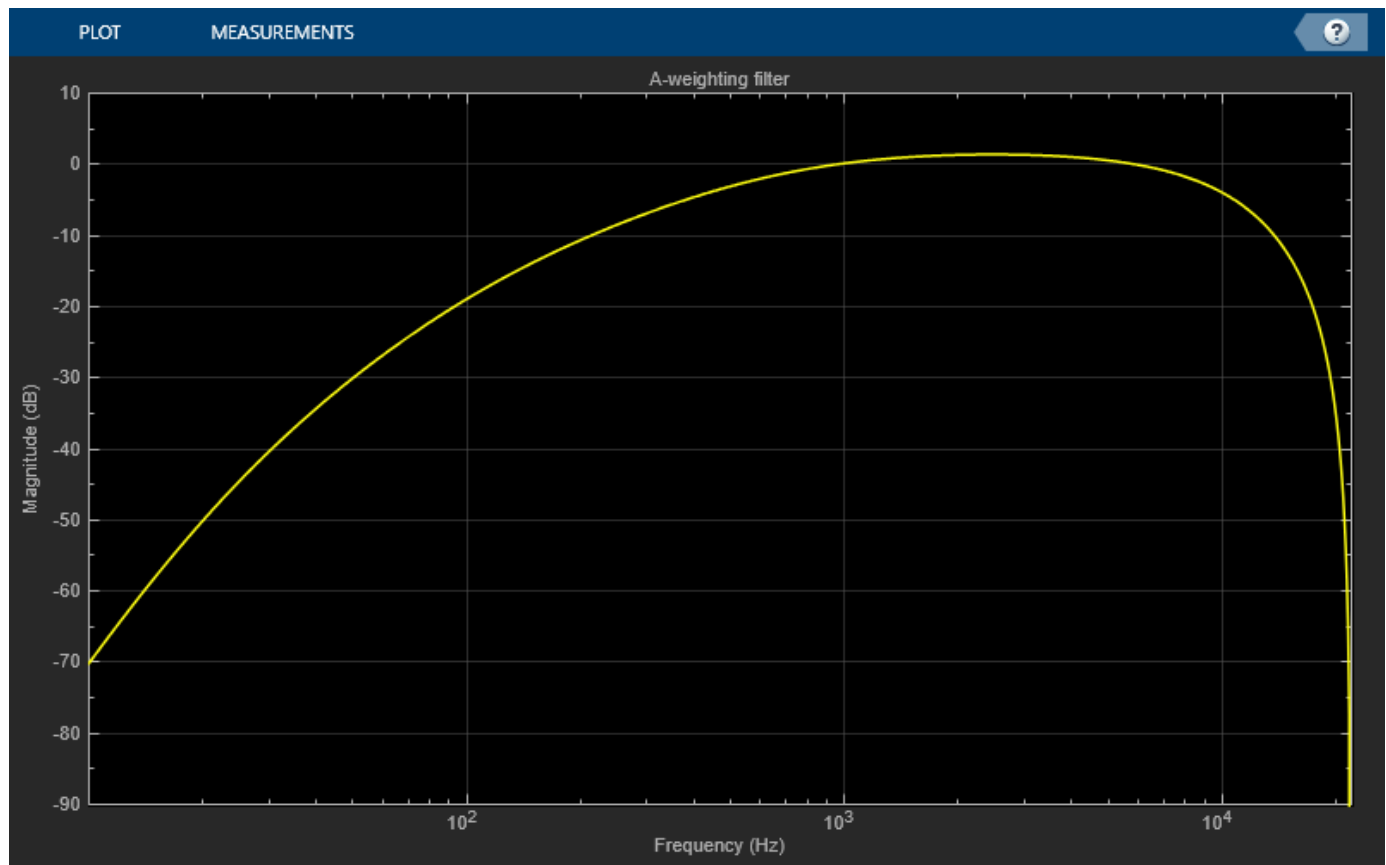
```
weightFilt = weightingFilter;
visualize(weightFilt)
```



Specify Number of Frequency Bins in FFT Calculation

Create a `weightingFilter` System object™. Plot a 1024-point frequency representation.

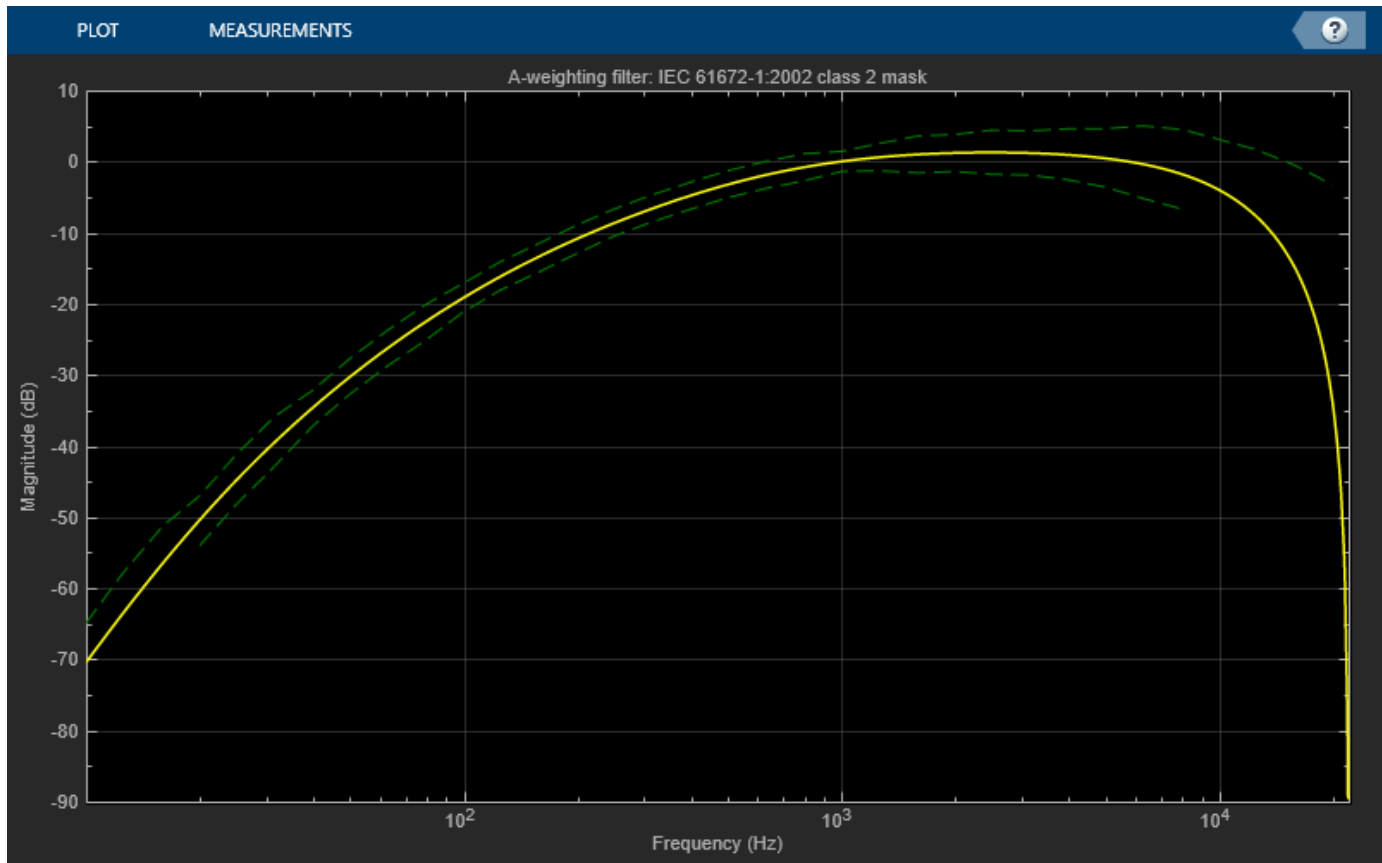
```
weightFilt = weightingFilter;  
visualize(weightFilt,1024)
```



Visualize Class 2 Standard-Compliance Mask

Create a `weightingFilter` System object™. Visualize the class 2 compliance of the filter design.

```
weightFilt = weightingFilter;  
visualize(weightFilt, 'class 2')
```

Input Arguments

weightFilt — Object of `weightingFilter`
object

Object of the `weightingFilter` System object.

N — Number of DFT bins
2048 | positive scalar

Number of DFT bins in frequency-domain representation, specified as a positive scalar. The default is 2048.

Data Types: `single` | `double`

mType — Type of mask
'class 1' (default) | 'class 2'

Type of mask, specified as 'class 1' or 'class 2'.

The mask attenuation limits are defined in the IEC 61672-1:2002 standard. The mask is defined for A-weighting and C-weighting filters only.

- If the mask is green, the design is compliant with the IEC 61672-1:2002 standard.

- If the mask is red, the design breaks compliance.

Note The pole-zero values defined in the ANSI S1.42-2001 standard are used for designing the A-weighted and C-weighted filters. The pole-zero values are based on analog filters, so the design can break compliance for lower sample rates.

Data Types: char

See Also

Topics

“Audio Weighting Filters”

“Sound Pressure Measurement of Octave Frequency Bands”

Introduced in R2016b

Classes

generateMATLABFunction

Create MATLAB function compatible with C/C++ code generation

Syntax

```
generateMATLABFunction(afe)
generateMATLABFunction(afe, fileName)

generateMATLABFunction( ____, 'IsStreaming', TF)
```

Description

Generate Equivalent MATLAB Function

`generateMATLABFunction(afe)` generates code and opens an untitled file containing a function named `extractAudioFeatures`. The generated MATLAB function has the signature:

```
featureVector = extractAudioFeatures(audioIn)
```

The signature is equivalent to:

```
featureVector = extract(afe, audioIn)
```

`generateMATLABFunction(afe, fileName)` generates code and saves the resulting function to the file specified by `fileName`. The generated MATLAB function has the signature:

```
featureVector = functionName(audioIn)
```

The signature is equivalent to:

```
featureVector = extract(afe, audioIn)
```

Generate MATLAB Function for Stream Processing

`generateMATLABFunction(____, 'IsStreaming', TF)` specifies whether the function is intended for stream (single-frame) processing. If `TF` is specified as `true`, the resulting function requires single-frame input of length `numel(afe.Window)`. If individual feature extractors have state, the resulting function maintains the state between calls. If unspecified, `TF` defaults to `false`. The streaming function has the signature:

```
featureVector = functionName(audioIn, varargin)
```

The size of `featureVector` depends on the value of `IsStreaming`.

- If `IsStreaming` was set to `true`, then `featureVector` is returned as an M -by- N matrix, where M is the number of features extracted and N is the number of channels.
- If `IsStreaming` was set to `false`, then `featureVector` is returned as an L -by- M -by- N array, where L is the number of hops, M is the number of feature vectors, and N is the number of channels.

The possible values of `varargin` depends on the configuration of your `audioFeatureExtractor` object, `afe`.

- If the features your `audioFeatureExtractor` object extracts do not require state, then `varargin` must be empty.
- If the features your `audioFeatureExtractor` object extracts require state, then `varargin` can be the optional name-value pair `'Reset'` and either `true` or `false`. If you call the function with `'Reset'` set to `true`, then the function clears any state before calculating and returning the feature vector.

Examples

Generate Equivalent MATLAB® Function

You can use the `audioFeatureExtractor` object while developing a feature extraction pipeline in MATLAB. Once you are ready to deploy your system to a device or integrate it into a larger system, use `generateMATLABFunction` to create a MATLAB function suitable for C/C++ code generation. Then use MATLAB Coder™ to generate equivalent C/C++ code.

Read in an audio file. You will use this audio file to verify the equivalency of the `audioFeatureExtractor` object and the generated MATLAB function.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
```

Create an `audioFeatureExtractor` object to extract the Bark spectrum, the delta gammatone cepstral coefficients (GTCC), and the harmonic ratio.

```
afe = audioFeatureExtractor("Window",hann(512,"periodic"), ...
    "OverlapLength",256, ...
    "SampleRate",fs, ...
    "FFTLength",1024, ...
    'barkSpectrum',true, ...
    "gtccDelta",true, ...
    "harmonicRatio",true)
```

```
afe =
    audioFeatureExtractor with properties:
```

Properties

```
Window: [512x1 double]
OverlapLength: 256
SampleRate: 44100
FFTLength: 1024
SpectralDescriptorInput: 'linearSpectrum'
FeatureVectorLength: 46
```

Enabled Features

```
barkSpectrum, gtccDelta, harmonicRatio
```

Disabled Features

```
linearSpectrum, melSpectrum, erbSpectrum, mfcc, mfccDelta, mfccDeltaDelta
gtcc, gtccDeltaDelta, spectralCentroid, spectralCrest, spectralDecrease, spectralEntropy
spectralFlatness, spectralFlux, spectralKurtosis, spectralRolloffPoint, spectralSkewness, s
spectralSpread, pitch, zerocrossrate, shortTimeEnergy
```

To extract a feature, set the corresponding property to `true`.

For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

Call `generateMATLABFunction` on the object and specify a name for the generated MATLAB function.

```
functionName = 'extractAudioFeatures';
generateMATLABFunction(afe,functionName)
```

The generated function is saved to your current folder.

type `extractAudioFeatures`

```
function featureVector = extractAudioFeatures(x)
%extractAudioFeatures Extract multiple features from batch audio
% featureVector = extractAudioFeatures(audioIn) returns audio features
% extracted from audioIn.
%
% Parameters of the audioFeatureExtractor used to generate this
% function must be honored when calling this function.
% - Sample rate of the input should be 44100 Hz.
% - Input frame length should be greater than or equal to 512 samples.
%
%
% EXAMPLE 1: Extract features
% source = dsp.ColoredNoise("SamplesPerFrame",44100);
% for ii = 1:10
%     audioIn = source();
%     featureArray = extractAudioFeatures(audioIn);
%     % ... do something with featureArray ...
% end
%
% EXAMPLE 2: Generate code
% targetDataType = "single";
% codegen extractAudioFeatures -args {ones(44100,1,targetDataType)}
% source = dsp.ColoredNoise("SamplesPerFrame",44100, ...
%     "OutputDataType",targetDataType);
% for ii = 1:10
%     audioIn = source();
%     featureArray = extractAudioFeatures_mex(audioIn);
%     % ... do something with featureArray ...
% end
%
% See also audioFeatureExtractor, dsp.AsyncBuffer, codegen.
%
% Generated by audioFeatureExtractor on 26-Feb-2022 17:32:06 -0500
%#codegen

dataType = underlyingType(x);
[numSamples,numChannels] = size(x);

props = coder.const(getProps(dataType));

persistent config outputIndex
if isempty(outputIndex)
    [config, outputIndex] = coder.const(@getConfig,dataType,props);
end
```

```

% Preallocate feature vector
numHops = floor((numSamples-numel(props.Window))/(numel(props.Window) - props.OverlapLength)) + 1;
featureVector = coder.nullcopy(zeros(numHops,props.NumFeatures,numChannels,dataType));

% Short-time Fourier transform
Y = stft(x,"Window",props.Window,"OverlapLength",props.OverlapLength,"FFTLength",props.FFTLength);
Z = reshape(Y,[],numHops*numChannels);
Zpower = real(Z.*conj(Z));

% Bark spectrum
barkSpectrum = reshape(config.barkSpectrum.FilterBank*Zpower,[],numHops,numChannels);
featureVector(:,outputIndex.barkSpectrum,:) = permute(barkSpectrum,[2,1,3]);

% ERB spectrum
erbSpectrum = reshape(config.erbSpectrum.FilterBank*Zpower,[],numHops,numChannels);

% Gammatone-frequency cepstral coefficients (GTCC)
gammacc = cepstralCoefficients(erbSpectrum,"NumCoeffs",13,"Rectification","log");
featureVector(:,outputIndex.gtccDelta,:) = audioDelta(gammacc,9);

% Periodicity features
featureVector(:,outputIndex.harmonicRatio,:) = harmonicRatio(x,props.SampleRate,"Window",props.Window);
end

function props = getProps(dataType)
props.Window = cast([0;3.764908042774850471801073581446e-05;0.0001505906518978750163739732670364],dataType);
props.OverlapLength = cast(256,dataType);
props.SampleRate = cast(44100,dataType);
props.FFTLength = uint16(1024);
props.NumFeatures = uint8(46);
end

function [config, outputIndex] = getConfig(dataType, props)
powerNormalizationFactor = 1/(sum(props.Window)^2);

barkFilterbank = designAuditoryFilterBank(props.SampleRate, ...
    "FrequencyScale","bark", ...
    "FFTLength",props.FFTLength, ...
    "OneSided",true, ...
    "FrequencyRange",[0 22050], ...
    "NumBands",32, ...
    "Normalization","bandwidth", ...
    "FilterBankDesignDomain","linear");
barkFilterbank = barkFilterbank*powerNormalizationFactor;
config.barkSpectrum.FilterBank = cast(barkFilterbank,dataType);

erbFilterbank = coder.const(@feval,'designAuditoryFilterBank',props.SampleRate, ...
    "FrequencyScale","erb", ...
    "FFTLength",props.FFTLength, ...
    "OneSided",true, ...
    "FrequencyRange",[0 22050], ...
    "NumBands",43, ...
    "Normalization","bandwidth");
erbFilterbank = erbFilterbank*powerNormalizationFactor;
config.erbSpectrum.FilterBank = cast(erbFilterbank,dataType);

outputIndex.barkSpectrum = uint8(1:32);

```

```
outputIndex.gtccDelta = uint8(33:45);
outputIndex.harmonicRatio = uint8(46);
end
```

Calling the generated function is equivalent to calling `extract` on the `audioFeatureExtractor` object. You can replace calls to `extract` with calls to the generated function in your code. Verify the equivalency between the object and the function.

```
a = extract(afe, audioIn);
b = extractAudioFeatures(audioIn);
isequal(a, b)
```

```
ans = logical
     1
```

The generated function contains help text that indicates any requirements on the input. In this example, the only requirement is that the input sample rate should be 44.1 kHz. The help text also contains custom examples. These examples show how to use the function directly in MATLAB and how to generate C/C++ code.

`help extractAudioFeatures`

```
extractAudioFeatures Extract multiple features from batch audio
featureVector = extractAudioFeatures(audioIn) returns audio features
extracted from audioIn.
```

```
Parameters of the audioFeatureExtractor used to generate this
function must be honored when calling this function.
- Sample rate of the input should be 44100 Hz.
- Input frame length should be greater than or equal to 512 samples.
```

```
% EXAMPLE 1: Extract features
source = dsp.ColoredNoise("SamplesPerFrame", 44100);
for ii = 1:10
    audioIn = source();
    featureArray = extractAudioFeatures(audioIn);
    % ... do something with featureArray ...
end

% EXAMPLE 2: Generate code
targetDataType = "single";
codegen extractAudioFeatures -args {ones(44100, 1, targetDataType)}
source = dsp.ColoredNoise("SamplesPerFrame", 44100, ...
    "OutputDataType", targetDataType);

for ii = 1:10
    audioIn = source();
    featureArray = extractAudioFeatures_mex(audioIn);
    % ... do something with featureArray ...
end
```

See also `audioFeatureExtractor`, `dsp.AsyncBuffer`, `codegen`.

Run the first example to see how to use the function to extract features in MATLAB.

```
source = dsp.ColoredNoise("SamplesPerFrame", 44100);
for ii = 1:10
```



```

    audioIn = source();
    featureArray = extractAudioFeatures(audioIn);
    % ... do something with featureArray ...
end

```

Run the second example to see how to generate a MATLAB executable from the function. Then use the MEX file to extract features while working in MATLAB. MATLAB Coder™ is required to run the following code.

```

targetDataType = "single";
codegen extractAudioFeatures -args {ones(44100,1,targetDataType)}

```

Code generation successful.

```

source = dsp.ColoredNoise("SamplesPerFrame",44100, ...
    "OutputDataType",targetDataType);
for ii = 1:10
    audioIn = source();
    featureArray = extractAudioFeatures_mex(audioIn);
    % ... do something with featureArray ...
end

```

Generate MATLAB® Function for Stream Processing

You can use the `audioFeatureExtractor` object to develop a feature extraction pipeline in MATLAB. The `audioFeatureExtractor` is optimized to extract features from audio signals that contain several windows of data. Typically, audio features are extracted on time scales from 5 ms to 100 ms, depending on the application. When you are ready to deploy your system to a device or to integrate it into a larger system, you can use `generateMATLABFunction` to create a MATLAB function suitable for C/C++ code generation. Deployed systems are often concerned with minimizing latency. You can set the `IsStreaming` parameter to `true` when calling `generateMATLABFunction` to generate a MATLAB function that is optimized for stream processing. The generated MATLAB function assumes that the input has already been buffered and requires a fixed input frame size. The generated MATLAB function also maintains any required state for you between calls.

Read in an audio file. You will use this audio file to verify the approximate equivalency of the `audioFeatureExtractor` object and the generated MATLAB function.

```

[audioToVerify,fs] = audioread('Counting-16-44p1-mono-15secs.wav');

```

Create an `audioFeatureExtractor` object to extract the mel frequency cepstral coefficients (MFCC), the delta and delta-delta MFCC, the spectral centroid, and the pitch. Extract features from 30 ms windows with 20 ms overlap between windows.

```

afe = audioFeatureExtractor("Window",hann(round(0.03*fs),'periodic'), ...
    "OverlapLength",round(0.02*fs), ...
    "SampleRate",fs, ...
    "mfcc",true, ...
    "mfccDelta",true, ...
    "mfccDeltaDelta",true, ...
    "spectralCentroid",true, ...
    "pitch",true)

```

```

afe =
    audioFeatureExtractor with properties:

```

Properties

```

    Window: [1323x1 double]
    OverlapLength: 882
    SampleRate: 44100
    FFTLength: []
    SpectralDescriptorInput: 'linearSpectrum'
    FeatureVectorLength: 41

```

Enabled Features

```
mfcc, mfccDelta, mfccDeltaDelta, spectralCentroid, pitch
```

Disabled Features

```

linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, gtcc, gtccDelta
gtccDeltaDelta, spectralCrest, spectralDecrease, spectralEntropy, spectralFlatness, spectral
spectralKurtosis, spectralRolloffPoint, spectralSkewness, spectralSlope, spectralSpread, ha
zerocrossrate, shortTimeEnergy

```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

Call `generateMATLABFunction` on the object and specify a name and the full path for the generated MATLAB function. Set `IsStreaming` to true to generate a MATLAB function optimized for stream processing.

```
filename = fullfile(tempdir,"extractAudioFeatures");
generateMATLABFunction(afe,filename,'IsStreaming',true);
```

The generated function is saved to the `tempdir` folder. Because the `mfccDelta` and `mfccDeltaDelta` features require state, the generated function includes the ability to reset states using the optional name-value pair `"Reset"` and either `true` or `false`. If you generate a function that does not require state, the `"Reset"` parameter is not included in the generated function.

```
cd(tempdir)
```

```
type extractAudioFeatures
```

```

function featureVector = extractAudioFeatures(x, varargin)
%extractAudioFeatures Extract multiple features from streaming audio
% featureVector = extractAudioFeatures(audioIn) returns audio features
% extracted from audioIn.
%
% featureVector = extractAudioFeatures(audioIn,"Reset",TF) returns feature extractors
% to their initial conditions before extracting features.
%
% Parameters of the audioFeatureExtractor used to generate this
% function must be honored when calling this function.
% - Sample rate of the input should be 44100 Hz.
% - Frame length of the input should be 1323 samples.
% - Successive frames of the input should be overlapped by
% 882 samples before calling extractAudioFeatures.
%
%
%
% EXAMPLE 1: Extract features
% source = dsp.ColoredNoise();
% inputBuffer = dsp.AsyncBuffer;
% for ii = 1:10

```

```

%         audioIn = source();
%         write(inputBuffer,audioIn);
%         while inputBuffer.NumUnreadSamples > 441
%             x = read(inputBuffer,1323,882);
%             featureVector = extractAudioFeatures(x);
%             % ... do something with featureVector ...
%         end
%     end
%
%
% % EXAMPLE 2: Extract features from speech regions only
% [audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
% audioIn = resample(audioIn,44100,fs);
% source = dsp.AsyncBuffer(size(audioIn,1));
% write(source,audioIn);
% TF = false;
% while source.NumUnreadSamples > 441
%     x = read(source,1323,882);
%     isSilence = var(x) < 0.01;
%     if ~isSilence
%         featureVector = extractAudioFeatures(x,"Reset",TF);
%         TF = false;
%     else
%         TF = true;
%     end
%     % ... do something with featureVector ...
% end
%
%
% % EXAMPLE 3: Generate code that does not use reset
% targetDataType = "single";
% codegen extractAudioFeatures -args {ones(1323,1,targetDataType)}
% source = dsp.ColoredNoise('OutputDataType',targetDataType);
% inputBuffer = dsp.AsyncBuffer;
% for ii = 1:10
%     audioIn = source();
%     write(inputBuffer,audioIn);
%     while inputBuffer.NumUnreadSamples > 441
%         x = read(inputBuffer,1323,882);
%         featureVector = extractAudioFeatures_mex(x);
%         % ... do something with featureVector ...
%     end
% end
%
%
% % EXAMPLE 4: Generate code that uses reset
% targetDataType = "single";
% codegen extractAudioFeatures -args {ones(1323,1,targetDataType),'Reset',true}
% [audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
% audioIn = resample(audioIn,44100,fs);
% source = dsp.AsyncBuffer(size(audioIn,1));
% write(source,cast(audioIn,targetDataType));
% TF = false;
% while source.NumUnreadSamples > 441
%     x = read(source,1323,882);
%     isSilence = var(x) < 0.01;
%     if ~isSilence
%         featureVector = extractAudioFeatures_mex(x,'Reset',TF);

```

```
%             TF = false;
%             else
%             TF = true;
%             end
%             % ... do something with featureVector ...
%         end
%
% See also audioFeatureExtractor, dsp.AsyncBuffer, codegen.

% Generated by audioFeatureExtractor on 26-Feb-2022 17:33:11 -0500
%#codegen

dataType = underlyingType(x);
numChannels = size(x,2);

props = coder.const(getProps(dataType));

persistent config outputIndex state
if isempty(outputIndex)
    [config, outputIndex] = coder.const(@getConfig,dataType,props);
    state = getState(dataType,numChannels);
else
    assert(state.NumChannels == numChannels)
end
if nargin==3
    if strcmpi(varargin{1},"Reset") && varargin{2}
        state = reset(state);
    end
end

% Preallocate feature vector
featureVector = coder.nullcopy(zeros(props.NumFeatures,numChannels,dataType));

% Fourier transform
Y = fft(bsxfun(@times,x,props.Window),props.FFTLength);
Z = Y(config.OneSidedSpectrumBins,:);
Zpower = real(Z.*conj(Z));

% Linear spectrum
linearSpectrum = Zpower(config.linearSpectrum.FrequencyBins,:)*config.linearSpectrum.Normalization;
linearSpectrum(1,:) = 0.5*linearSpectrum(1,:);
linearSpectrum = reshape(linearSpectrum,[],1,numChannels);

% Mel spectrum
melSpectrum = reshape(config.melSpectrum.FilterBank*Zpower,[],1,numChannels);

% Mel-frequency cepstral coefficients (MFCC)
melcc = cepstralCoefficients(melSpectrum,"NumCoeffs",13,"Rectification","log");
featureVector(outputIndex.mfcc,:) = melcc;
[melccDelta,state.mfccDelta] = audioDelta(melcc,9,state.mfccDelta);
featureVector(outputIndex.mfccDelta,:) = melccDelta;
[featureVector(outputIndex.mfccDeltaDelta,:),state.mfccDeltaDelta] = audioDelta(melccDelta,9,sta

% Spectral descriptors
featureVector(outputIndex.spectralCentroid,:) = spectralCentroid(linearSpectrum,config.SpectralDe

% Periodicity features
featureVector(outputIndex.pitch,:) = pitch(x,props.SampleRate,"WindowLength",numel(props.Window)
```

```
end
```

```
function props = getProps(dataType)
props.Window = cast([0;5.6387032669191761158344888826832e-06;2.2554685887743453065468202112243e-06],dataType);
props.OverlapLength = cast(882,dataType);
props.SampleRate = cast(44100,dataType);
props.FFTLength = uint16(1323);
props.NumFeatures = uint8(41);
end
```

```
function [config, outputIndex] = getConfig(dataType, props)
powerNormalizationFactor = 1/(sum(props.Window)^2);
```

```
config.OneSidedSpectrumBins = uint16(1:662);
```

```
linearSpectrumFrequencyBins = 1:662;
config.linearSpectrum.FrequencyBins = uint16(linearSpectrumFrequencyBins);
config.linearSpectrum.NormalizationFactor = cast(2*powerNormalizationFactor,dataType);
```

```
melFilterbank = designAuditoryFilterBank(props.SampleRate, ...
    "FrequencyScale","mel", ...
    "FFTLength",props.FFTLength, ...
    "OneSided",true, ...
    "FrequencyRange",[0 22050], ...
    "NumBands",32, ...
    "Normalization","bandwidth", ...
    "FilterBankDesignDomain","linear");
```

```
melFilterbank = melFilterbank*powerNormalizationFactor;
config.melSpectrum.FilterBank = cast(melFilterbank,dataType);
```

```
FFTLength = cast(props.FFTLength,'like',props.SampleRate);
w = (props.SampleRate/FFTLength)*(linearSpectrumFrequencyBins-1);
w(end) = props.SampleRate*(FFTLength-1)/(2*FFTLength);
config.SpectralDescriptorInput.FrequencyVector = cast(w(:),dataType);
```

```
outputIndex.mfcc = uint8(1:13);
outputIndex.mfccDelta = uint8(14:26);
outputIndex.mfccDeltaDelta = uint8(27:39);
outputIndex.spectralCentroid = uint8(40);
outputIndex.pitch = uint8(41);
end
```

```
function state = getState(dataType, numChannels)
state.NumChannels = numChannels;
state.mfccDelta = zeros(8,13,numChannels,dataType);
state.mfccDeltaDelta = zeros(8,13,numChannels,dataType);
end
```

```
function state = reset(state)
state.mfccDelta(:,:,:) = 0;
state.mfccDeltaDelta(:,:,:) = 0;
end
```

The generated function contains help text that indicates any requirements on the input. In this example, the sample rate of the input should be 44.1 kHz, the frame input to the function should be 1323 samples, and successive frames should be overlapped by 882 samples before calling the function. The differences between the `audioFeatureExtractor` object and the function are

described in more detail in [Approximate Equivalency Between audioFeatureExtractor and Generated Function on page 4-0](#) .

help [extractAudioFeatures](#)

```
extractAudioFeatures Extract multiple features from streaming audio
    featureVector = extractAudioFeatures(audioIn) returns audio features
    extracted from audioIn.

    featureVector = extractAudioFeatures(audioIn,"Reset",TF) returns feature extractors
    to their initial conditions before extracting features.

Parameters of the audioFeatureExtractor used to generate this
function must be honored when calling this function.
- Sample rate of the input should be 44100 Hz.
- Frame length of the input should be 1323 samples.
- Successive frames of the input should be overlapped by
  882 samples before calling extractAudioFeatures.

% EXAMPLE 1: Extract features
source = dsp.ColoredNoise();
inputBuffer = dsp.AsyncBuffer;
for ii = 1:10
    audioIn = source();
    write(inputBuffer,audioIn);
    while inputBuffer.NumUnreadSamples > 441
        x = read(inputBuffer,1323,882);
        featureVector = extractAudioFeatures(x);
        % ... do something with featureVector ...
    end
end

% EXAMPLE 2: Extract features from speech regions only
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
audioIn = resample(audioIn,44100,fs);
source = dsp.AsyncBuffer(size(audioIn,1));
write(source,audioIn);
TF = false;
while source.NumUnreadSamples > 441
    x = read(source,1323,882);
    isSilence = var(x) < 0.01;
    if ~isSilence
        featureVector = extractAudioFeatures(x,"Reset",TF);
        TF = false;
    else
        TF = true;
    end
    % ... do something with featureVector ...
end

% EXAMPLE 3: Generate code that does not use reset
targetDataType = "single";
codegen extractAudioFeatures -args {ones(1323,1,targetDataType)}
source = dsp.ColoredNoise('OutputDataType',targetDataType);
inputBuffer = dsp.AsyncBuffer;
```

```

for ii = 1:10
    audioIn = source();
    write(inputBuffer, audioIn);
    while inputBuffer.NumUnreadSamples > 441
        x = read(inputBuffer, 1323, 882);
        featureVector = extractAudioFeatures_mex(x);
        % ... do something with featureVector ...
    end
end

% EXAMPLE 4: Generate code that uses reset
targetDataType = "single";
codegen extractAudioFeatures -args {ones(1323,1,targetDataType), 'Reset', true}
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
audioIn = resample(audioIn, 44100, fs);
source = dsp.AsyncBuffer(size(audioIn, 1));
write(source, cast(audioIn, targetDataType));
TF = false;
while source.NumUnreadSamples > 441
    x = read(source, 1323, 882);
    isSilence = var(x) < 0.01;
    if ~isSilence
        featureVector = extractAudioFeatures_mex(x, 'Reset', TF);
        TF = false;
    else
        TF = true;
    end
    % ... do something with featureVector ...
end
end

```

See also `audioFeatureExtractor`, `dsp.AsyncBuffer`, `codegen`.

The examples in the help show how to use the function directly in MATLAB and how to generate C/C++ code. Run the first example to see how to use the function to extract features in MATLAB.

```

source = dsp.ColoredNoise();
inputBuffer = dsp.AsyncBuffer;
for ii = 1:10
    audioIn = source();
    write(inputBuffer, audioIn);
    while inputBuffer.NumUnreadSamples > 441
        x = read(inputBuffer, 1323, 882);
        featureVector = extractAudioFeatures(x);
        % ... do something with featureVector ...
    end
end
end

```

Run the second example to see how to extract features in MATLAB while using the optional "Reset" name-value pair. The `Reset` name-value pair enables you to reset states on the function. For example, if you are only concerned with extracting features from regions of voiced speech and want to avoid the overhead of extracting features constantly, you can use the "Reset" parameter to avoid bleeding feature information between regions.

```

[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
source = dsp.AsyncBuffer(size(audioIn, 1));
write(source, audioIn);
TF = false;

```

```

while source.NumUnreadSamples > 441
    x = read(source,1323,882);
    isSilence = var(x) < 0.01;
    if ~isSilence
        featureVector = extractAudioFeatures(x,"Reset",TF);
        TF = false;
    else
        TF = true;
    end
    % ... do something with featureVector ...
end

```

Run the third example to see how to generate code that does not include the ability to reset state. When generating code that does not use the 'Reset' parameter, only specify a prototype for the audio input argument. The following code requires MATLAB Coder™.

```

targetDataType = "single";
codegen extractAudioFeatures -args {ones(1323,1,targetDataType)}

```

Code generation successful.

```

source = dsp.ColoredNoise('OutputDataType',targetDataType);
inputBuffer = dsp.AsyncBuffer;
for ii = 1:10
    audioIn = source();
    write(inputBuffer,audioIn);
    while inputBuffer.NumUnreadSamples > 441
        x = read(inputBuffer,1323,882);
        featureVector = extractAudioFeatures_mex(x);
        % ... do something with featureVector ...
    end
end

```

Run the fourth example to see how to generate code that can reset state. When generating code that uses the 'Reset' parameter, specify prototype input arguments for the full function signature. The following code requires MATLAB Coder™.

```

targetDataType = "single";
codegen extractAudioFeatures -args {ones(1323,1,targetDataType),'Reset',true}

```

Code generation successful.

```

[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
source = dsp.AsyncBuffer(size(audioIn,1));
write(source,cast(audioIn,targetDataType));
TF = false;
while source.NumUnreadSamples > 441
    x = read(source,1323,882);
    isSilence = var(x) < 0.01;
    if ~isSilence
        featureVector = extractAudioFeatures_mex(x,'Reset',TF);
        TF = false;
    else
        TF = true;
    end
    % ... do something with featureVector ...
end

```


Approximate Equivalency Between audioFeatureExtractor and Generated Function

When you call `extract` using `audioFeatureExtractor`, the input is buffered internally prior to feature extraction. The output from `extract` is an L -by- M -by- N array, where L is the number of feature vectors and is equal to the number of analysis windows. M is the number of features extracted per analysis window. N is the number of channels.

```
featuresA = extract(afe, audioToVerify);
[L,M,N] = size(featuresA)
```

```
L = 1551
```

```
M = 41
```

```
N = 1
```

When you call the generated function, `extractAudioFeatures`, the input should represent a single frame of audio data. The output from the generated function is an M -by- N matrix, where M is the number of features extracted and N is the number of channels. Use the generated function to extract features from the audio signal `audioIn`. Use the `dsp.AsyncBuffer` object to buffer the input into the required frame length and overlap length prior to calling `extractAudioFeatures`. Reshape the extracted feature vectors to match the orientation output from `audioFeatureExtractor`.

```
frameLength = 1323;
overlapLength = 882;
hopLength = frameLength - overlapLength;
```

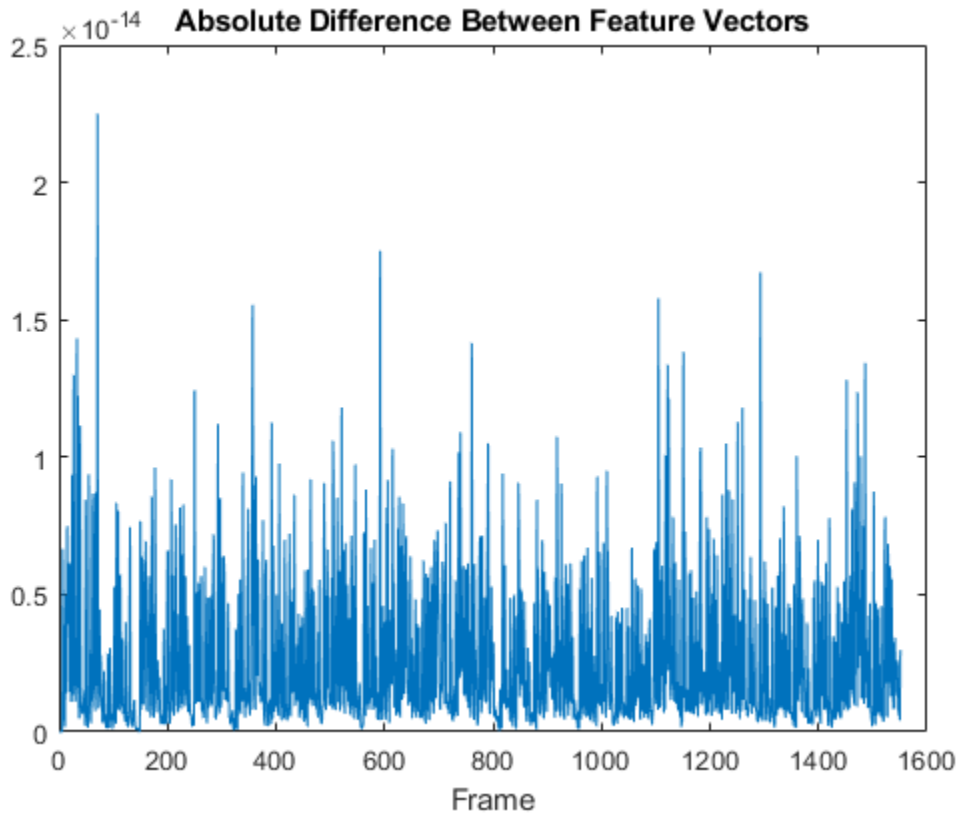
```
featuresB = zeros(L,M,N);
```

```
buff = dsp.AsyncBuffer('Capacity', numel(audioToVerify));
write(buff, audioToVerify);
```

```
hop = 1;
while buff.NumUnreadSamples > hopLength
    if hop==1
        x = read(buff, frameLength);
        features = extractAudioFeatures(x, 'Reset', true);
    else
        x = read(buff, frameLength, overlapLength);
        features = extractAudioFeatures(x);
    end
    featuresB(hop, :, :) = reshape(features, [1, M, N]);
    hop = hop + 1;
end
```

Visualize the difference between the output from `audioFeatureExtractor` and the generated function. The differences between frames are less than $1.8e-14$ and are due to the different code paths being optimized for batch versus stream processing.

```
differenceBetweenFrames = sum(abs(featuresA - featuresB), 2);
plot(differenceBetweenFrames)
xlabel('Frame')
title('Absolute Difference Between Feature Vectors')
```



Input Arguments

afe – Input object

audioFeatureExtractor object

Input object, specified as an audioFeatureExtractor object.

fileName – File name

character vector | string scalar

File name where the generated function is saved, specified as a character vector or string scalar.

Data Types: char | string

TF – Flag to specify if function is for streaming

false (default) | true

Flag to specify if generated function is intended for stream processing, specified as true or false.

Data Types: logical

See Also

codegen | dsp.AsyncBuffer | audioFeatureExtractor | vggishEmbeddings

Introduced in R2020b

setExtractorParameters

Set nondefault parameter values for individual feature extractors

Syntax

```
setExtractorParameters(aFE, featureName, params)  
setExtractorParameters(aFE, featureName)
```

Description

`setExtractorParameters(aFE, featureName, params)` specifies parameters used to extract `featureName`.

`setExtractorParameters(aFE, featureName)` returns the parameters used to extract `featureName` to default values.

Examples

Extract Pitch Using the LHS Method

Read in an audio signal.

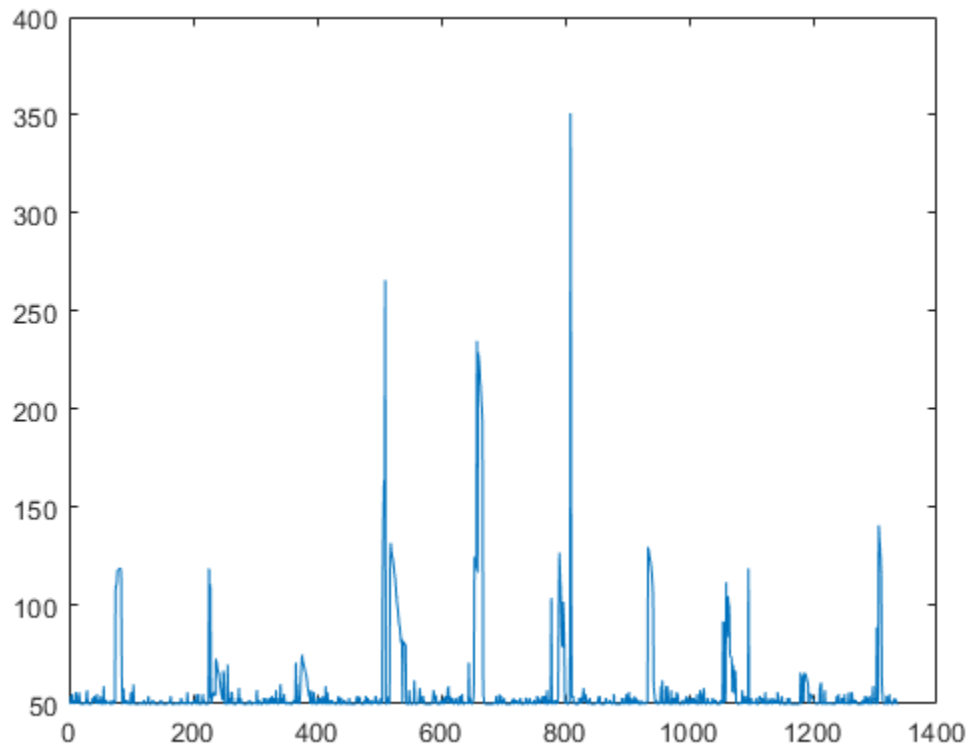
```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioFeatureExtractor` object to extract pitch. Set the method of pitch extraction to "LHS".

```
aFE = audioFeatureExtractor(SampleRate=fs, pitch=true);  
setExtractorParameters(aFE, "pitch", Method="LHS")
```

Call `extract` and plot the results.

```
f0 = extract(aFE, audioIn);  
plot(f0)
```



Modify Spectral Rolloff Threshold and Mel Spectrum Parameters

Read in an audio signal.

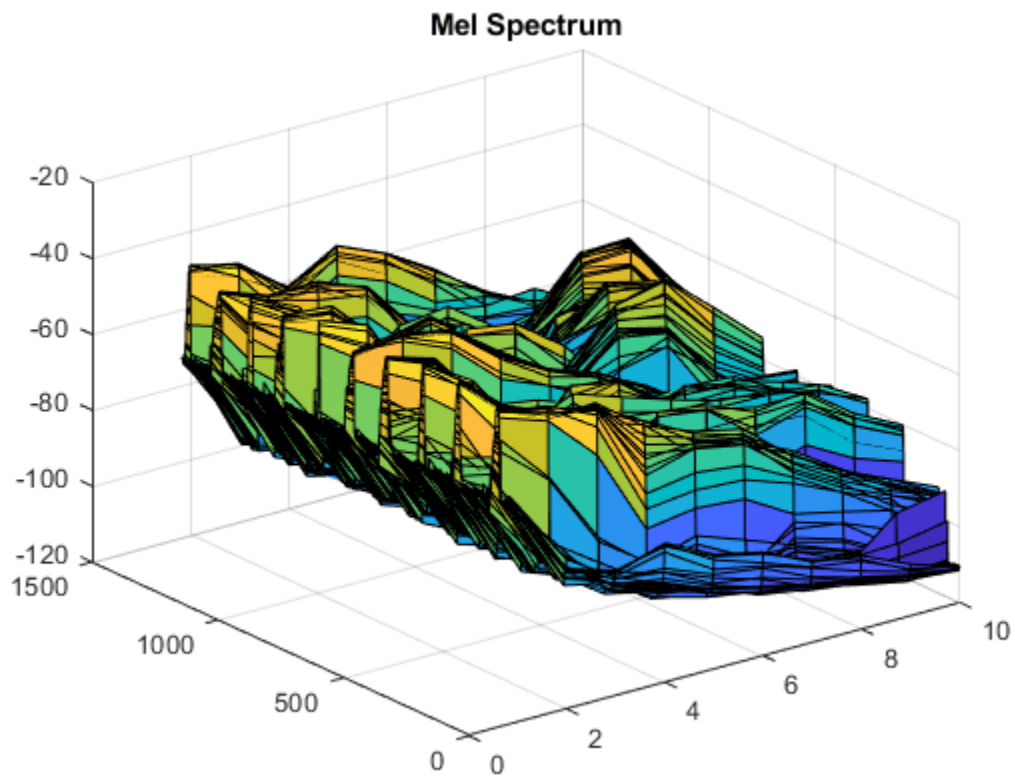
```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioFeatureExtractor` object to extract the `melSpectrum` and `spectralRolloffPoint`. Specify ten bands for the mel spectrum and set the threshold for the rolloff point to 50% of the total energy.

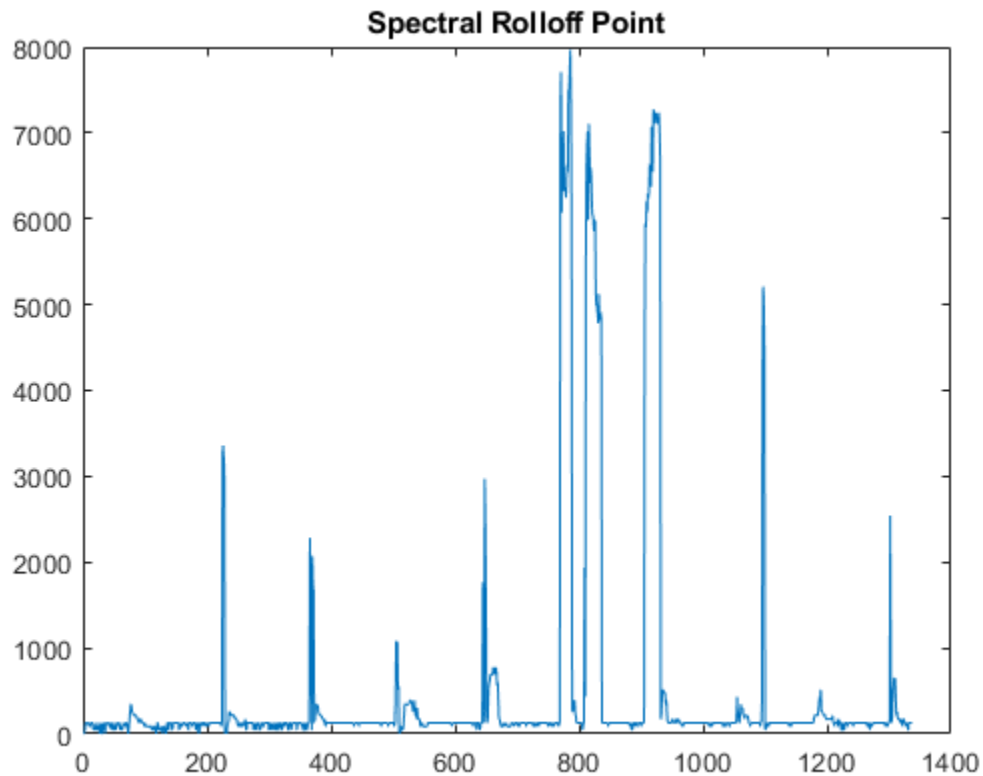
```
aFE = audioFeatureExtractor(SampleRate=fs, melSpectrum=true, spectralRolloffPoint=true);  
setExtractorParameters(aFE, "melSpectrum", NumBands=10)  
setExtractorParameters(aFE, "spectralRolloffPoint", Threshold=0.5)
```

Call `extract` and plot the results.

```
features = extract(aFE, audioIn);  
idx = info(aFE);  
  
surf(10*log10(features(:, idx.melSpectrum)))  
title("Mel Spectrum")
```



```
plot(features(:,idx.spectralRolloffPoint))  
title("Spectral Rolloff Point")
```

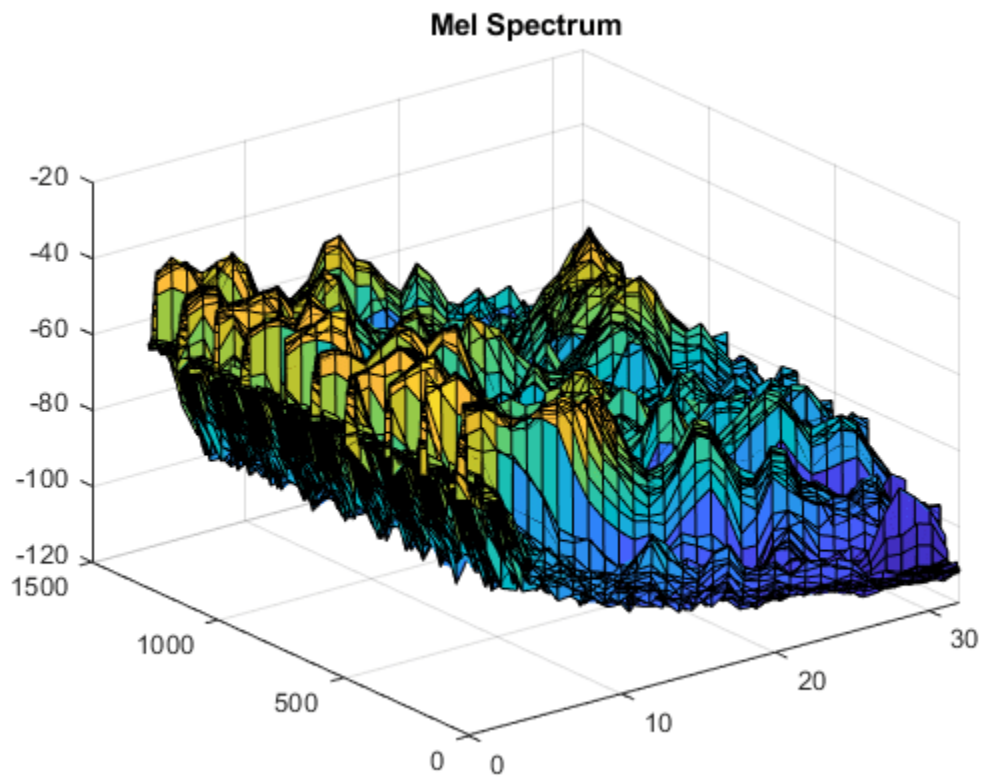


To return individual audio feature extractors to their default values, call `setExtractorParameters` without specifying any parameters to set.

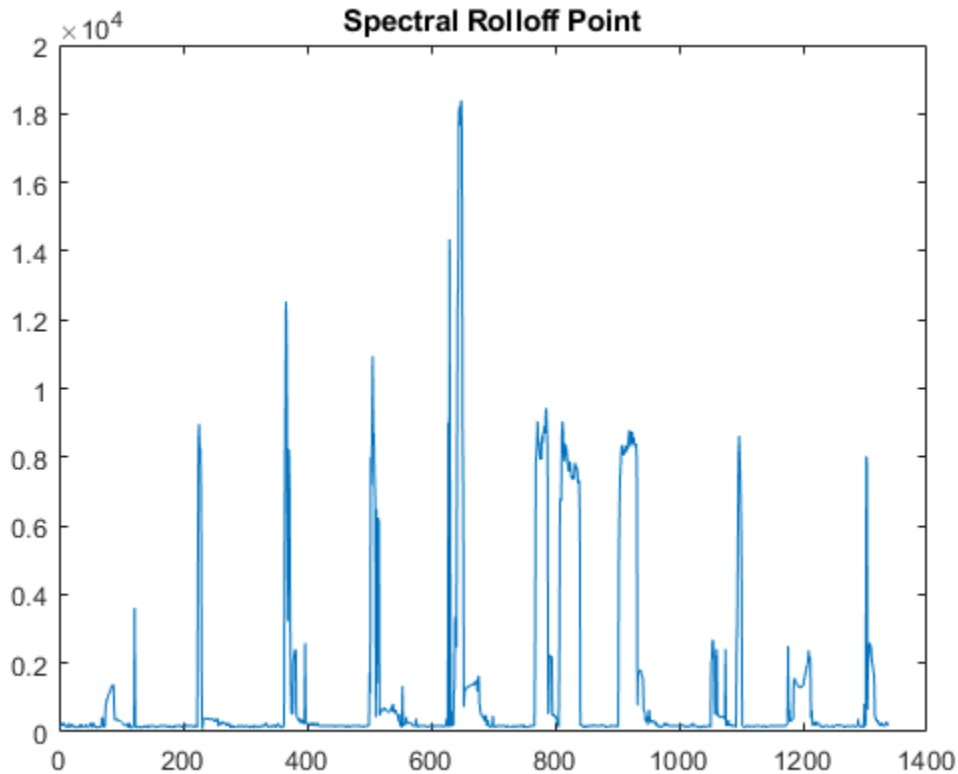
```
setExtractorParameters(aFE, "melSpectrum")  
setExtractorParameters(aFE, "spectralRolloffPoint")
```

Call `extract` and plot the results.

```
features = extract(aFE, audioIn);  
idx = info(aFE);  
  
surf(10*log10(features(:, idx.melSpectrum)))  
title("Mel Spectrum")
```



```
plot(features(:,idx.spectralRolloffPoint))  
title("Spectral Rolloff Point")
```



Input Arguments

aFE — Input object

audioFeatureExtractor object

Input object, specified as an audioFeatureExtractor object.

featureName — Name of feature extractor

character array | string

Name of feature extractor, specified as a character array or string.

Data Types: char | string

params — Parameters to set

name-value arguments | struct

Parameters to set, specified as name-value arguments or a struct.

See Also

Objects

audioFeatureExtractor

Introduced in R2022a

setExtractorParams

(To be removed) Set nondefault parameter values for individual feature extractors

Note The `setExtractorParams` function will be removed in a future release. Use `setExtractorParameters` instead. For more information, see “Compatibility Considerations”.

Syntax

```
setExtractorParams(aFE, featureName, params)
setExtractorParams(aFE, featureName)
```

Description

`setExtractorParams(aFE, featureName, params)` specifies parameters used to extract `featureName`.

`setExtractorParams(aFE, featureName)` returns the parameters used to extract `featureName` to default values.

Examples

Extract Pitch Using the LHS Method

Read in an audio signal.

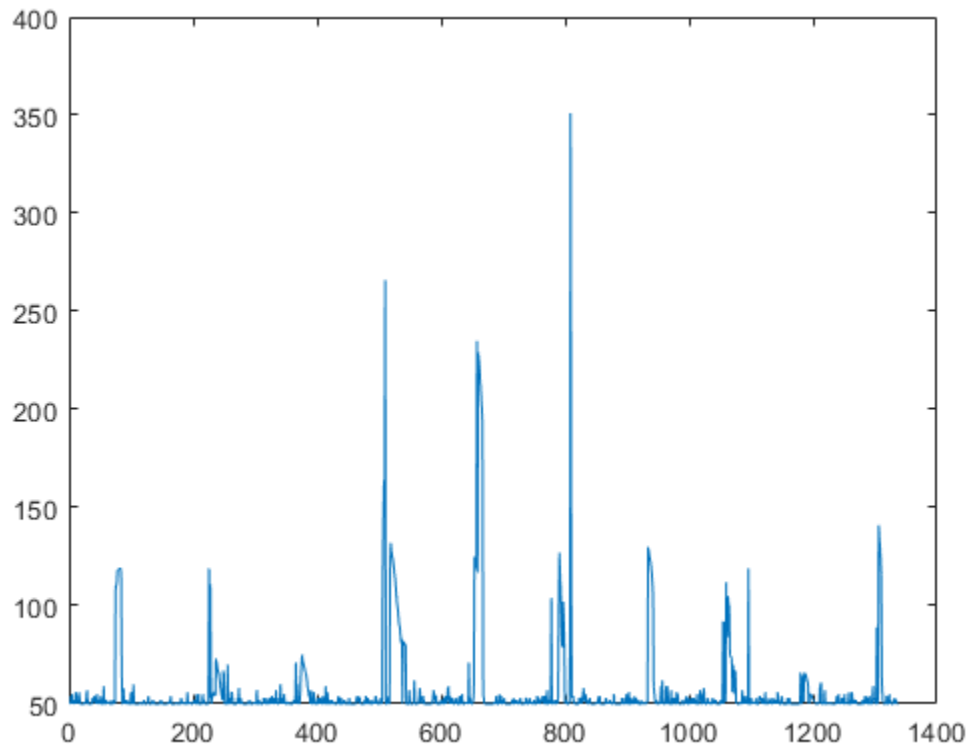
```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioFeatureExtractor` object to extract pitch. Set the method of pitch extraction to "LHS".

```
aFE = audioFeatureExtractor(SampleRate=fs, pitch=true);
setExtractorParameters(aFE, "pitch", Method="LHS")
```

Call `extract` and plot the results.

```
f0 = extract(aFE, audioIn);
plot(f0)
```



Modify Spectral Rolloff Threshold and Mel Spectrum Parameters

Read in an audio signal.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

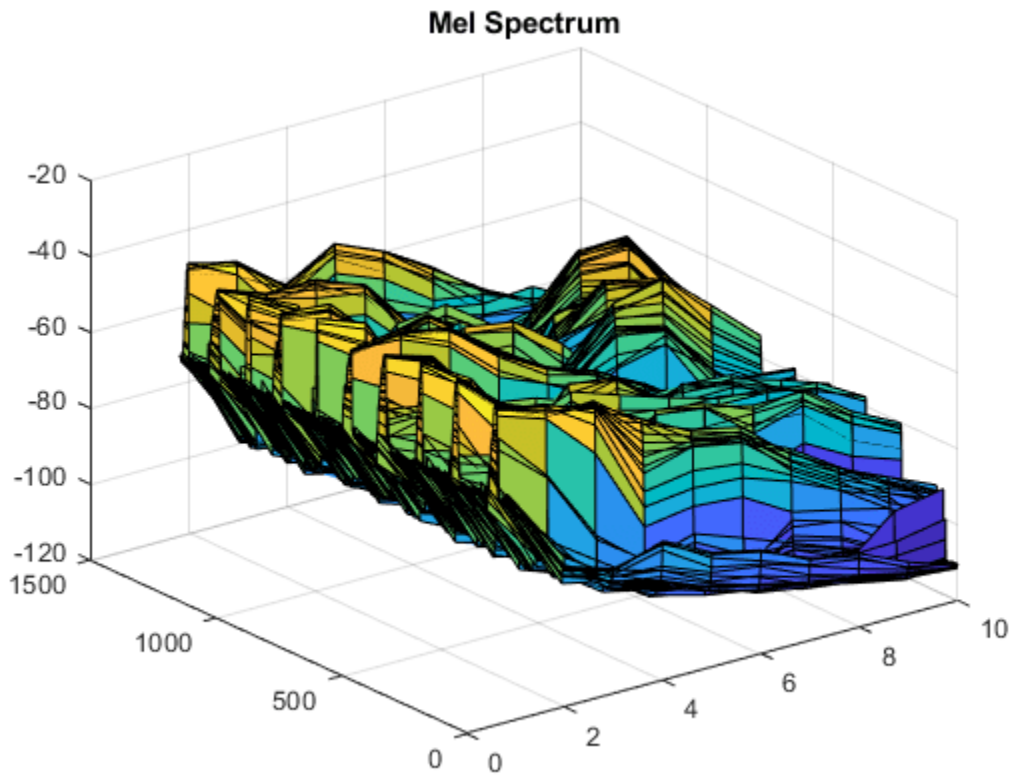
Create an `audioFeatureExtractor` object to extract the `melSpectrum` and `spectralRolloffPoint`. Specify ten bands for the mel spectrum and set the threshold for the rolloff point to 50% of the total energy.

```
aFE = audioFeatureExtractor(SampleRate=fs,melSpectrum=true,spectralRolloffPoint=true);
setExtractorParameters(aFE,"melSpectrum",NumBands=10)
setExtractorParameters(aFE,"spectralRolloffPoint",Threshold=0.5)
```

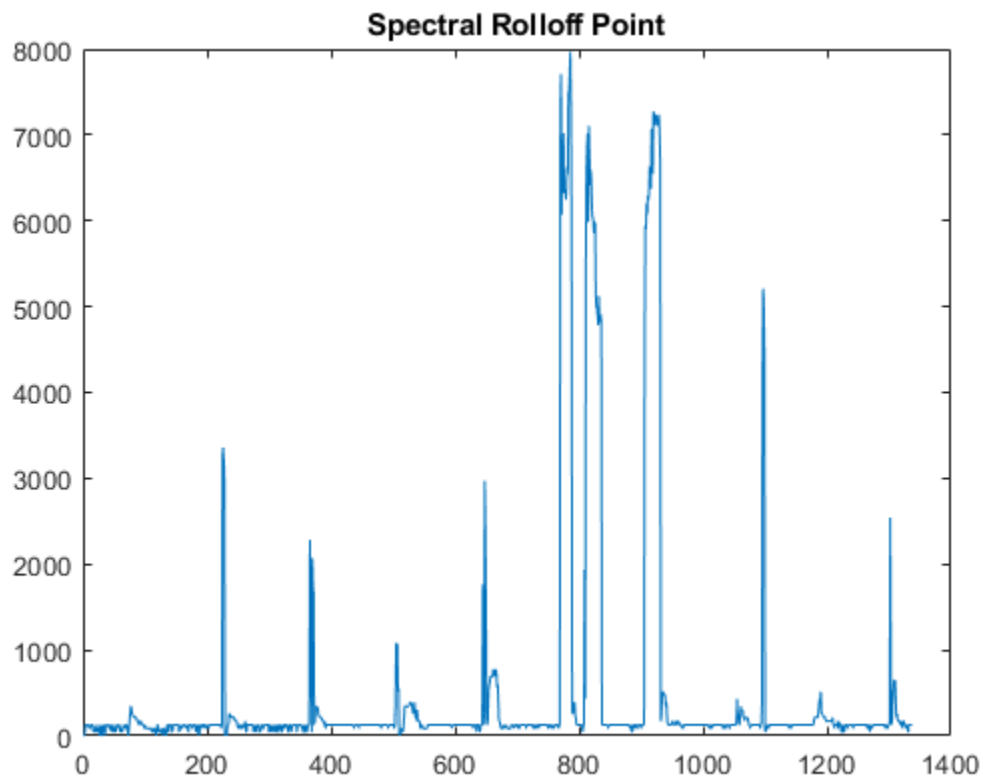
Call `extract` and plot the results.

```
features = extract(aFE,audioIn);
idx = info(aFE);

surf(10*log10(features(:,idx.melSpectrum)))
title("Mel Spectrum")
```



```
plot(features(:,idx.spectralRolloffPoint))  
title("Spectral Rolloff Point")
```



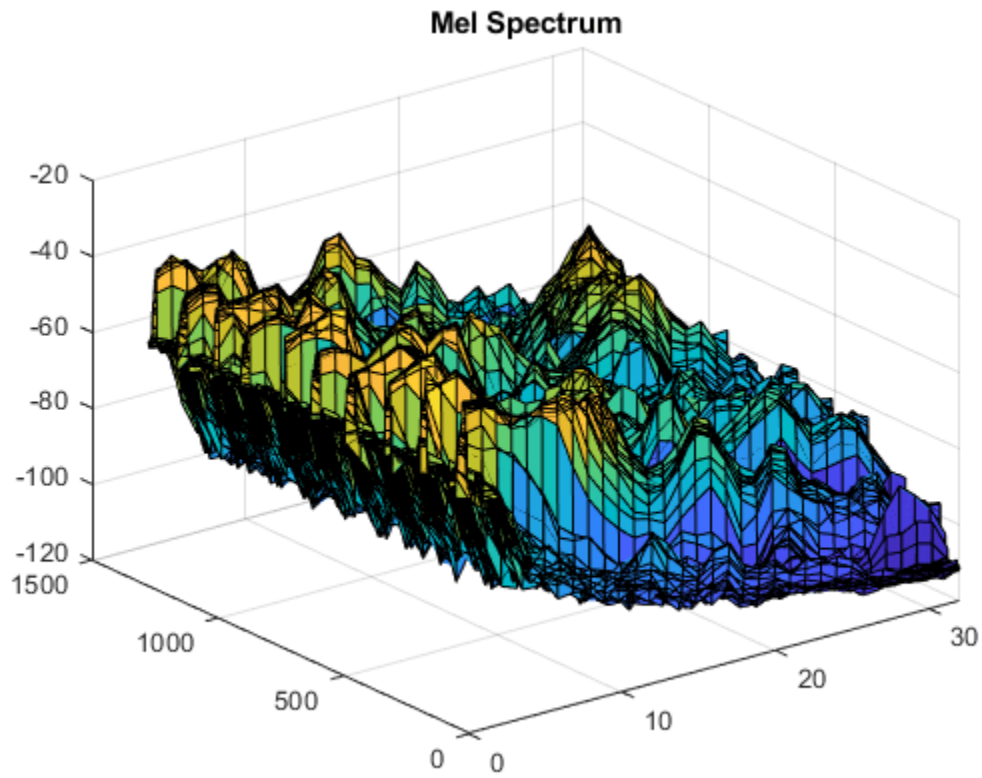
To return individual audio feature extractors to their default values, call `setExtractorParameters` without specifying any parameters to set.

```
setExtractorParameters(aFE, "melSpectrum")
setExtractorParameters(aFE, "spectralRolloffPoint")
```

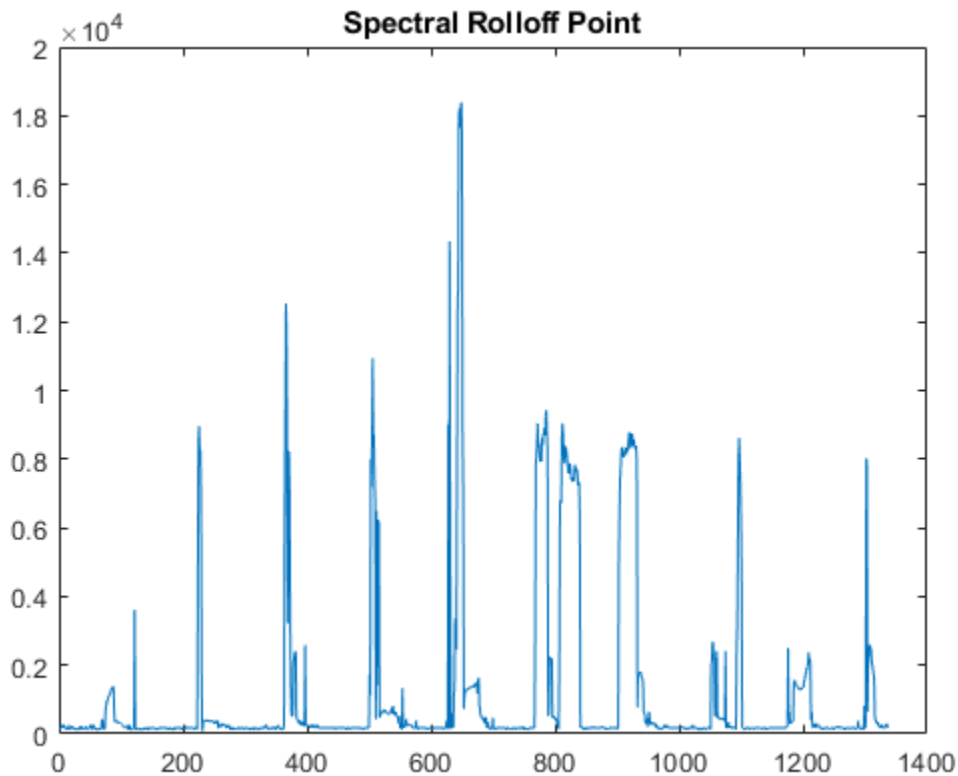
Call `extract` and plot the results.

```
features = extract(aFE, audioIn);
idx = info(aFE);

surf(10*log10(features(:, idx.melSpectrum)))
title("Mel Spectrum")
```



```
plot(features(:,idx.spectralRolloffPoint))  
title("Spectral Rolloff Point")
```



Input Arguments

aFE — Input object

audioFeatureExtractor object

audioFeatureExtractor object.

featureName — Name of feature extractor

character array | string

Name of feature extractor, specified as a character array or string.

Data Types: char | string

params — Parameters to set

comma-separated name-value pairs | struct

Parameters to set, specified as comma-separated name-value pairs or as a struct.

Compatibility Considerations

setExtractorParams will be removed

Not recommended starting in R2022a

The `setExtractorParams` function will be removed in a future release. Use `setExtractorParameters` instead. Existing calls to `setExtractorParams` continue to run.

See Also

Objects

`audioFeatureExtractor`

Functions

`setExtractorParameters`

Introduced in R2019b

info

Output mapping and individual feature extractor parameters

Syntax

```
idx = info(aFE)
idx = info(aFE,"all")
[idx,params] = info( __ )
```

Description

`idx = info(aFE)` returns a struct with field names corresponding to enabled feature extractors. The field values correspond to the column indices that the extracted features occupy in the output from `extract`.

`idx = info(aFE,"all")` returns a struct with field names corresponding to all available feature extractors. If the feature extractor is disabled, the field value is empty.

`[idx,params] = info(__)` returns a second struct, `params`. The field names of `params` correspond to the feature extractors with settable parameters. If the "all" flag is specified, `params` contains all feature extractors with settable parameters. If the "all" flag is not specified, `params` contains only the enabled feature extractors with settable parameters. You can set parameters using `setExtractorParameters`.

Examples

Interpret Output from `extract`

Extract the mel spectrum, mel spectral centroid, and mel spectral skewness from concatenated white and pink noise.

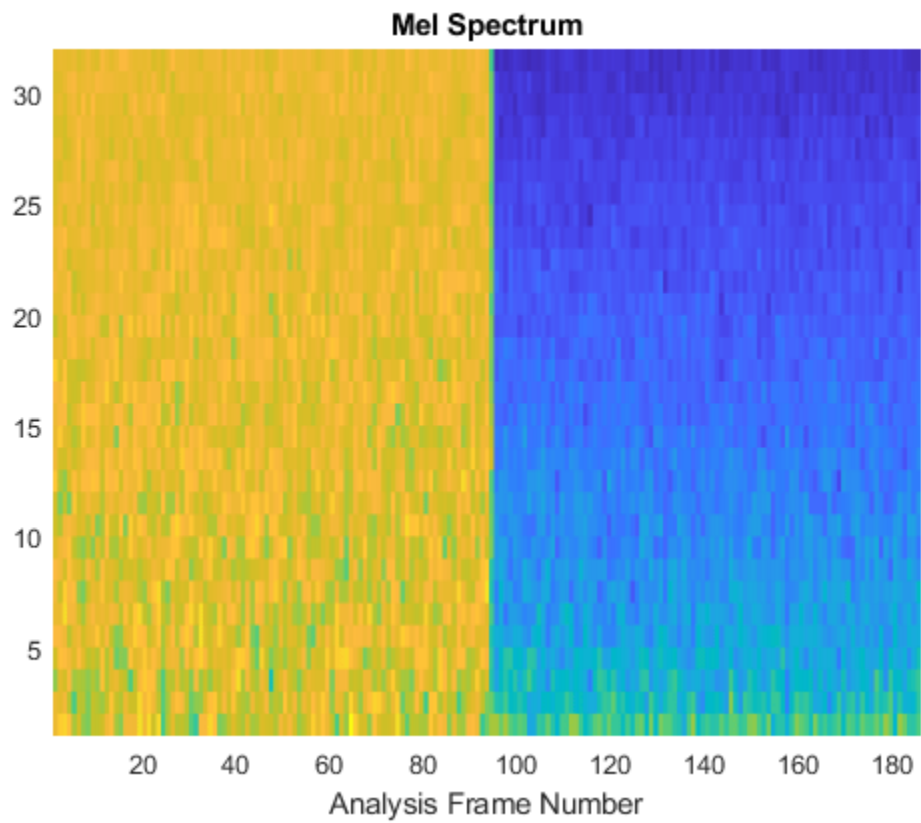
```
fs = 48e3;
aFE = audioFeatureExtractor("SampleRate",fs, ...
    "melSpectrum",true, ...
    "SpectralDescriptorInput","melSpectrum", ...
    "spectralCentroid",true, ...
    "spectralSkewness",true);
```

```
features = extract(aFE,[2*rand(fs,1)-1;pinknoise(fs,1)]);
```

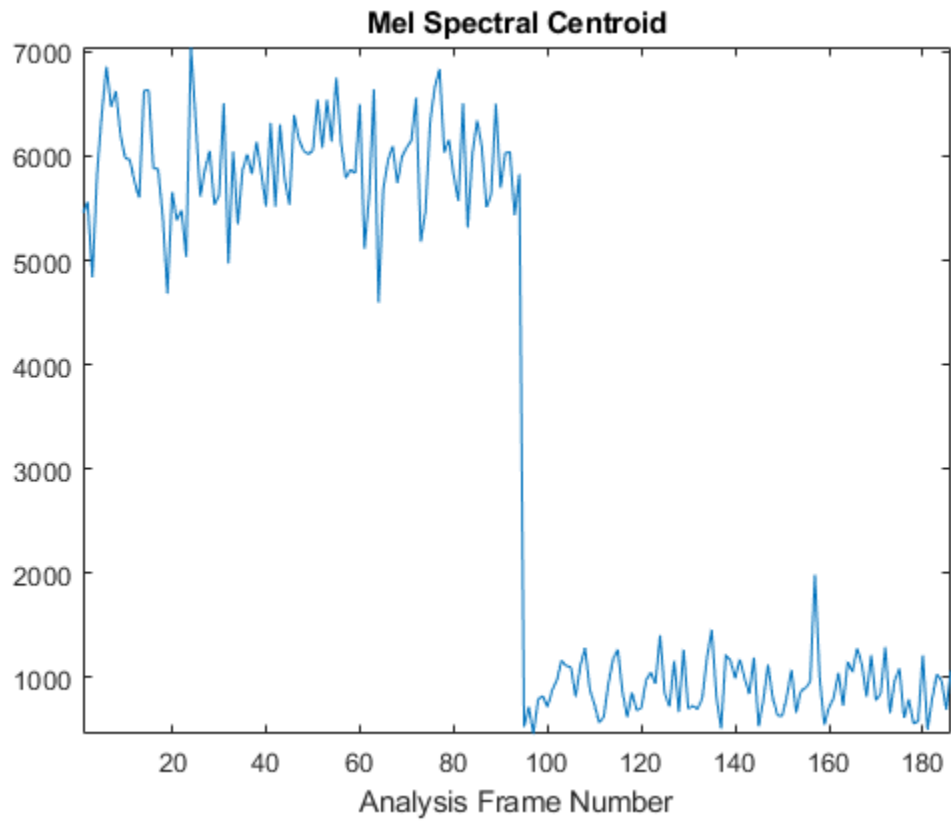
Use `info` to determine which columns of the output correspond to which feature. Plot the features separately.

```
idx = info(aFE);

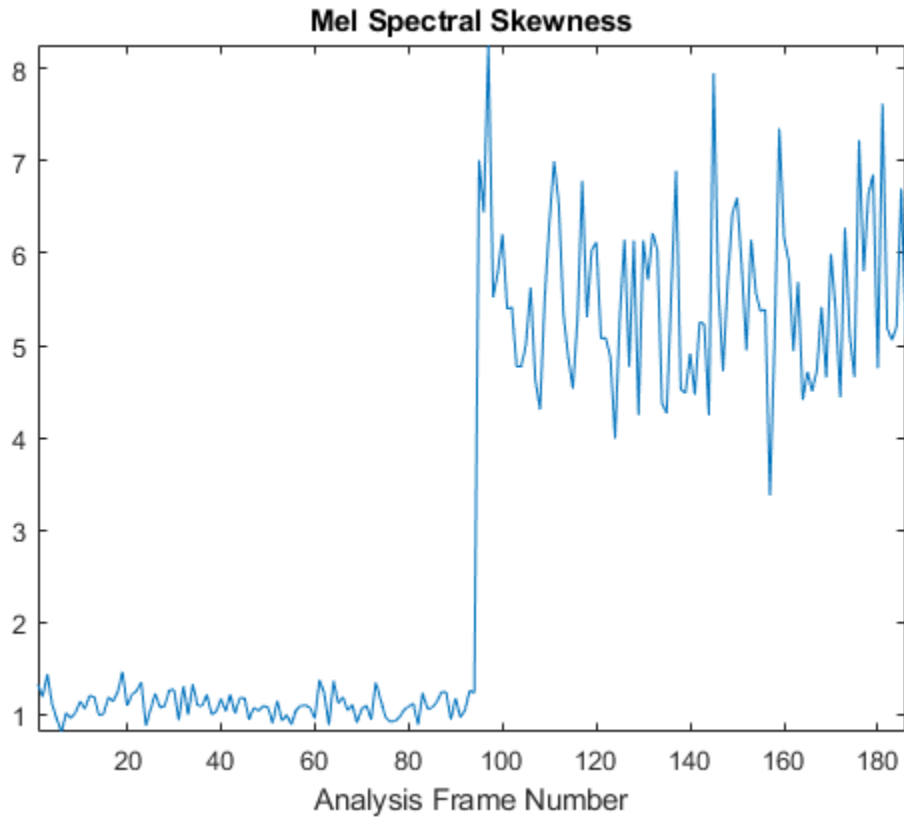
surf(log10(features(:,idx.melSpectrum)),"EdgeColor","none");
view([90,-90])
axis tight
title("Mel Spectrum")
ylabel("Analysis Frame Number")
```



```
plot(features(:,idx.spectralCentroid))  
axis tight  
title("Mel Spectral Centroid")  
xlabel("Analysis Frame Number")
```



```
plot(features(:,idx.spectralSkewness))  
axis tight  
title("Mel Spectral Skewness")  
xlabel("Analysis Frame Number")
```



Get List of All Features audioFeatureExtractor Provides

Create a default audioFeatureExtractor object. By default, all feature extractors are disabled.

```
aFE = audioFeatureExtractor
```

```
aFE =  
audioFeatureExtractor with properties:
```

```
Properties
```

```
Window: [1024x1 double]  
OverlapLength: 512  
SampleRate: 44100  
FFTLength: []  
SpectralDescriptorInput: 'linearSpectrum'  
FeatureVectorLength: 0
```

```
Enabled Features
```

```
none
```

```
Disabled Features
```

```
linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta  
mfccDeltaDelta, gtcc, gtccDelta, gtccDeltaDelta, spectralCentroid, spectralCrest  
spectralDecrease, spectralEntropy, spectralFlatness, spectralFlux, spectralKurtosis, spectralSkewness, spectralSlope, spectralSpread, pitch, harmonicRatio, zerocrossrate
```

```
shortTimeEnergy
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds mfcc to the list of enabled features.

The `info` function returns information about enabled feature extractors. To view information about all feature extractors, call `info` using the "all" flag.

```
[idx,params] = info(aFE,"all")
```

```
idx = struct with fields:
    linearSpectrum: [1x0 double]
    melSpectrum: [1x0 double]
    barkSpectrum: [1x0 double]
    erbSpectrum: [1x0 double]
    mfcc: [1x0 double]
    mfccDelta: [1x0 double]
    mfccDeltaDelta: [1x0 double]
    gtcc: [1x0 double]
    gtccDelta: [1x0 double]
    gtccDeltaDelta: [1x0 double]
    spectralCentroid: [1x0 double]
    spectralCrest: [1x0 double]
    spectralDecrease: [1x0 double]
    spectralEntropy: [1x0 double]
    spectralFlatness: [1x0 double]
    spectralFlux: [1x0 double]
    spectralKurtosis: [1x0 double]
    spectralRolloffPoint: [1x0 double]
    spectralSkewness: [1x0 double]
    spectralSlope: [1x0 double]
    spectralSpread: [1x0 double]
    pitch: [1x0 double]
    harmonicRatio: [1x0 double]
    zerocrossrate: [1x0 double]
    shortTimeEnergy: [1x0 double]
```

```
params = struct with fields:
    linearSpectrum: [1x1 struct]
    melSpectrum: [1x1 struct]
    barkSpectrum: [1x1 struct]
    erbSpectrum: [1x1 struct]
    mfcc: [1x1 struct]
    gtcc: [1x1 struct]
    spectralFlux: [1x1 struct]
    spectralRolloffPoint: [1x1 struct]
    pitch: [1x1 struct]
    zerocrossrate: [1x1 struct]
```

Use the `idx` struct to enable all feature extractors on the `audioFeatureExtractor` object.

```
features = fieldnames(idx);
for i = 1:numel(features)
    aFE.(features{i}) = true;
```

```
end
aFE

aFE =
  audioFeatureExtractor with properties:

  Properties
      Window: [1024x1 double]
      OverlapLength: 512
      SampleRate: 44100
      FFTLength: []
      SpectralDescriptorInput: 'linearSpectrum'
      FeatureVectorLength: 713

  Enabled Features
      linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
      mfccDeltaDelta, gtcc, gtccDelta, gtccDeltaDelta, spectralCentroid, spectralCrest
      spectralDecrease, spectralEntropy, spectralFlatness, spectralFlux, spectralKurtosis, spectral
      spectralSkewness, spectralSlope, spectralSpread, pitch, harmonicRatio, zerocrossrate
      shortTimeEnergy

  Disabled Features
      none
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

Determine Settable Parameters of Individual Feature Extractors

Create an `audioFeatureExtractor` to extract the ERB spectrum.

```
aFE = audioFeatureExtractor(erbSpectrum=true)
```

```
aFE =
  audioFeatureExtractor with properties:

  Properties
      Window: [1024x1 double]
      OverlapLength: 512
      SampleRate: 44100
      FFTLength: []
      SpectralDescriptorInput: 'linearSpectrum'
      FeatureVectorLength: 43

  Enabled Features
      erbSpectrum

  Disabled Features
      linearSpectrum, melSpectrum, barkSpectrum, mfcc, mfccDelta, mfccDeltaDelta
      gtcc, gtccDelta, gtccDeltaDelta, spectralCentroid, spectralCrest, spectralDecrease
      spectralEntropy, spectralFlatness, spectralFlux, spectralKurtosis, spectralRolloffPoint, sp
      spectralSlope, spectralSpread, pitch, harmonicRatio, zerocrossrate, shortTimeEnergy
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

The second output argument from `info` is a `struct` that contains the settable parameters of the individual feature extractors and their current value.

```
[~,params] = info(aFE)
```

```
params = struct with fields:
  erbSpectrum: [1x1 struct]
```

```
params.erbSpectrum
```

```
ans = struct with fields:
  NumBands: 43
  FrequencyRange: [0 22050]
  FilterBankNormalization: "bandwidth"
  WindowNormalization: 1
  SpectrumType: "power"
```

If you are using the default parameter values, then the parameters are dynamic and updated when properties they depend on are updated. For example, the default frequency range of the ERB filter bank and the default number of bandpass filters in the ERB filter bank depends on the sample rate. Decrease the sample rate of the `audioFeatureExtractor` object and then call `info` again.

```
aFE.SampleRate = 16e3;
[~,params] = info(aFE);
params.erbSpectrum
```

```
ans = struct with fields:
  NumBands: 34
  FrequencyRange: [0 8000]
  FilterBankNormalization: "bandwidth"
  WindowNormalization: 1
  SpectrumType: "power"
```

You can modify the individual feature extractor parameters using `setExtractorParameters`. Set the number of bands to 40 and the spectrum type to "magnitude". Call `info` to confirm that the parameters are updated.

```
params.erbSpectrum.NumBands = 40;
params.erbSpectrum.SpectrumType = "magnitude";
setExtractorParameters(aFE,erbSpectrum=params.erbSpectrum)
[~,params] = info(aFE);
params.erbSpectrum
```

```
ans = struct with fields:
  NumBands: 40
  FrequencyRange: [0 8000]
  FilterBankNormalization: "bandwidth"
  WindowNormalization: 1
  SpectrumType: "magnitude"
```

When you set individual feature extractor parameters, they remain at the set value until you set them to another value or return them to defaults. Return the sample rate of the `audioFeatureExtractor` object to its initial value and then call `info`. The parameters remain at their set value.

```
aFE.SampleRate = 44.1e3;

[~,params] = info(aFE);
params.erbSpectrum

ans = struct with fields:
    NumBands: 40
    FrequencyRange: [0 8000]
    FilterBankNormalization: "bandwidth"
    WindowNormalization: 1
    SpectrumType: "magnitude"
```

To return parameters to their default values, call `setExtractorParameters` and specify no parameters.

```
setExtractorParameters(aFE, "erbSpectrum")
[~,params] = info(aFE);
params.erbSpectrum

ans = struct with fields:
    NumBands: 43
    FrequencyRange: [0 22050]
    FilterBankNormalization: "bandwidth"
    WindowNormalization: 1
    SpectrumType: "power"
```

Input Arguments

aFE — Input object

`audioFeatureExtractor` object

`audioFeatureExtractor` object.

Output Arguments

idx — Mapping of requested features with output from extract

struct

Mapping of requested features with output from `extract`, returned as a struct with field names corresponding to individual feature extractors and field values corresponding to column indices.

params — Settable parameters of individual feature extractors

struct

Settable parameters of individual feature extractors, returned as a struct with field names corresponding to individual feature extractors and field values containing parameter specification structs. The parameter specification structs have field names corresponding to settable parameter names and field values corresponding to the current parameter setting.

See Also

audioFeatureExtractor

Introduced in R2019b

extract

Extract audio features

Syntax

```
features = extract(aFE, audioIn)
```

Description

`features = extract(aFE, audioIn)` returns an array containing features of the audio input.

Examples

Extract and Normalize Audio Features

Read in an audio signal.

```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioFeatureExtractor` to extract the centroid of the Bark spectrum, the kurtosis of the Bark spectrum, and the pitch of an audio signal.

```
aFE = audioFeatureExtractor("SampleRate", fs, ...  
    "SpectralDescriptorInput", "barkSpectrum", ...  
    "spectralCentroid", true, ...  
    "spectralKurtosis", true, ...  
    "pitch", true)
```

```
aFE =  
audioFeatureExtractor with properties:
```

Properties

```
Window: [1024x1 double]  
OverlapLength: 512  
SampleRate: 44100  
FFTLength: []  
SpectralDescriptorInput: 'barkSpectrum'  
FeatureVectorLength: 3
```

Enabled Features

```
spectralCentroid, spectralKurtosis, pitch
```

Disabled Features

```
linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta  
mfccDeltaDelta, gtcc, gtccDelta, gtccDeltaDelta, spectralCrest, spectralDecrease  
spectralEntropy, spectralFlatness, spectralFlux, spectralRolloffPoint, spectralSkewness, sp  
spectralSpread, harmonicRatio, zerocrossrate, shortTimeEnergy
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

Call `extract` to extract the features from the audio signal. Normalize the features by their mean and standard deviation.

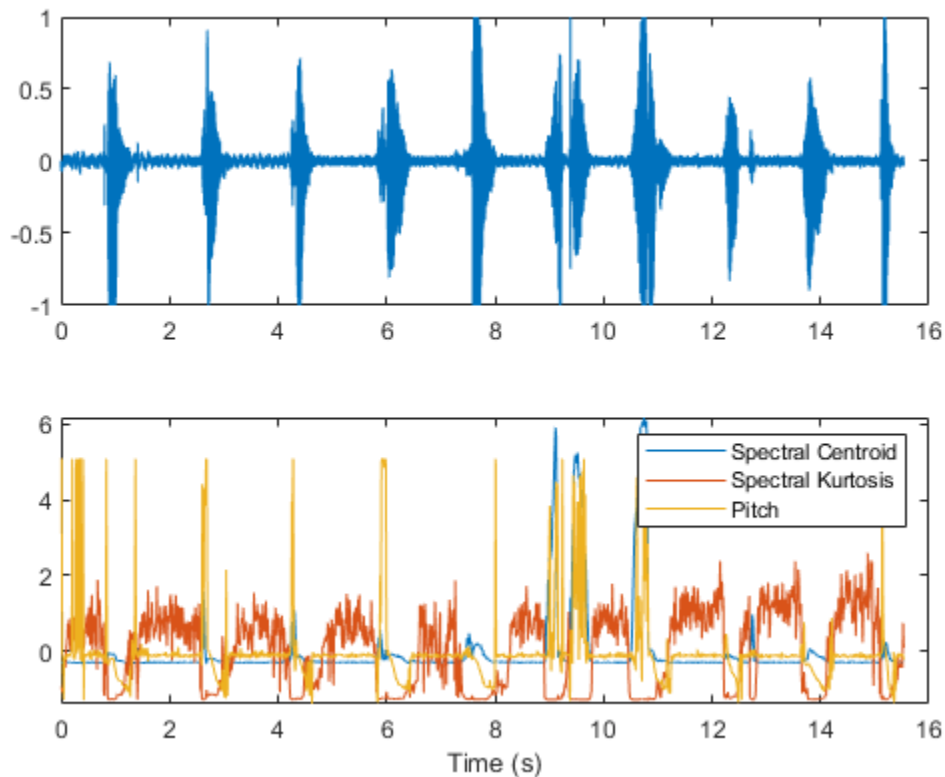
```
features = extract(aFE, audioIn);
features = (features - mean(features,1))./std(features,[],1);
```

Plot the normalized features over time.

```
idx = info(aFE);
duration = size(audioIn,1)/fs;

subplot(2,1,1)
t = linspace(0,duration,size(audioIn,1));
plot(t, audioIn)

subplot(2,1,2)
t = linspace(0,duration,size(features,1));
plot(t, features(:,idx.spectralCentroid), ...
      t, features(:,idx.spectralKurtosis), ...
      t, features(:,idx.pitch));
legend("Spectral Centroid", "Spectral Kurtosis", "Pitch")
xlabel("Time (s)")
```



Input Arguments

aFE — Input object

audioFeatureExtractor object

audioFeatureExtractor object.

audioIn — Input audio

column vector | matrix

Input audio, specified as a column vector or matrix of independent channels (columns).

Data Types: single | double

Output Arguments

features — Extracted audio features

vector | matrix | 3-D array

Extracted audio features, returned as an L -by- M -by- N array, where:

- L -- Number of feature vectors (hops)
- M -- Number of features extracted per analysis window
- N -- Number of channels

Data Types: single | double

See Also

audioFeatureExtractor | **Extract Audio Features**

Introduced in R2019b

audioFeatureExtractor

Streamline audio feature extraction

Description

`audioFeatureExtractor` encapsulates multiple audio feature extractors into a streamlined and modular implementation.

Creation

Syntax

```
aFE = audioFeatureExtractor()  
aFE = audioFeatureExtractor(Name=Value)
```

Description

`aFE = audioFeatureExtractor()` creates an audio feature extractor with default property values.

`aFE = audioFeatureExtractor(Name=Value)` specifies nondefault properties for `aFE` using one or more name-value arguments.

Properties

Main Properties

Window — Analysis window

`hamming(1024, "periodic")` (default) | real vector

Analysis window, specified as a real vector.

Data Types: `single` | `double`

OverlapLength — Overlap length of adjacent analysis windows

512 (default) | integer in the range `[0, numel(Window))`

Overlap length of adjacent analysis windows, specified as an integer in the range `[0, numel(Window))`.

Data Types: `single` | `double`

FFTLength — FFT length

`[]` (default) | positive integer

FFT length, specified as an integer. The default value of `[]` means that the FFT length is equal to the window length `numel(Window)`.

Data Types: `single` | `double`

SampleRate — Input sample rate (Hz)

44100 (default) | positive scalar

Input sample rate in Hz, specified as a positive scalar.

Data Types: single | double

SpectralDescriptorInput — Input to spectral descriptors

"linearSpectrum" (default) | "melSpectrum" | "barkSpectrum" | "erbSpectrum"

Input to spectral descriptors, specified as "linearSpectrum", "melSpectrum", "barkSpectrum", or "erbSpectrum".

Spectral descriptors affected by this property are:

- spectralCentroid
- spectralCrest
- spectralDecrease
- spectralEntropy
- spectralFlatness
- spectralFlux
- spectralKurtosis
- spectralRolloffPoint
- spectralSkewness
- spectralSlope
- spectralSpread

The spectrum input to the spectral descriptors is the same as output from the corresponding feature:

- linearSpectrum
- melSpectrum
- barkSpectrum
- erbSpectrum

For example, if you set `SpectralDescriptorInput` to "barkSpectrum", and `spectralCentroid` to true, then `aFE` returns the centroid of the default Bark spectrum.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
aFE = audioFeatureExtractor(SampleRate=fs, ...
    SpectralDescriptorInput="barkSpectrum", ...
    spectralCentroid=true);
barkSpectralCentroid = extract(aFE,audioIn);
```

If you specify a nondefault `barkSpectrum` using `setExtractorParameters`, then the nondefault Bark spectrum is the input to the spectral descriptors. For example, if you call `setExtractorParameters(aFE, "barkSpectrum", NumBands=40)`, then `aFE` returns the centroid of a 40-band Bark spectrum.

```
setExtractorParameters(aFE, "barkSpectrum", NumBands=40)
bark40SpectralCentroid = extract(aFE,audioIn);
```

Data Types: char | string

FeatureVectorLength — Number of features output from extract

positive integer

This property is read-only.

Total number of features output from `extract` for the current object configuration, specified as a positive integer. `FeatureVectorLength` is equal to the second dimension of the output from the `extract` function.

Data Types: `single` | `double`**Features to Extract****LinearSpectrum — Extract linear spectrum**`false` (default) | `true`

Extract the one-sided linear spectrum, specified as `true` or `false`.

To set parameters of the linear spectrum extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "LinearSpectrum", Name=Value)
```

Settable parameters for the linear spectrum extraction are:

- `FrequencyRange` -- Frequency range of the extracted spectrum in Hz, specified as a two-element vector of increasing numbers in the range $[0, \text{SampleRate}/2]$. If unspecified, `FrequencyRange` defaults to $[0, \text{SampleRate}/2]$.
- `SpectrumType` -- Spectrum type, specified as "power" or "magnitude". If unspecified, `SpectrumType` defaults to "power".
- `WindowNormalization` -- Apply window normalization, specified as `true` or `false`. If unspecified, `WindowNormalization` defaults to `true`.

Data Types: `logical`**melSpectrum — Extract mel spectrum**`false` (default) | `true`

Extract the one-sided mel spectrum, specified as `true` or `false`.

To set parameters of the mel spectrum extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "melSpectrum", Name=Value)
```

Settable parameters for the mel spectrum extraction are:

- `FrequencyRange` -- Frequency range of the extracted spectrum in Hz, specified as a two-element vector of increasing numbers in the range $[0, \text{SampleRate}/2]$. If unspecified, `FrequencyRange` defaults to $[0, \text{SampleRate}/2]$.
- `SpectrumType` -- Spectrum type, specified as "power" or "magnitude". If unspecified, `SpectrumType` defaults to "power".
- `NumBands` -- Number of mel bands, specified as an integer. If unspecified, `NumBands` defaults to 32.
- `FilterBankNormalization` -- Normalization applied to bandpass filters, specified as "bandwidth", "area", or "none". If unspecified, `FilterBankNormalization` defaults to "bandwidth".

- `WindowNormalization` -- Apply window normalization, specified as `true` or `false`. If unspecified, `WindowNormalization` defaults to `true`.
- `FilterBankDesignDomain` -- Domain in which the filter bank is designed, specified as either `"linear"` or `"warped"`. If unspecified, `FilterBankDesignDomain` defaults to `"linear"`.

Data Types: `logical`

barkSpectrum — Extract Bark spectrum

`false` (default) | `true`

Extract the one-sided Bark spectrum, specified as `true` or `false`.

To set parameters of the Bark spectrum extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "barkSpectrum", Name=Value)
```

Settable parameters for the Bark spectrum extraction are:

- `FrequencyRange` -- Frequency range of the extracted spectrum in Hz, specified as a two-element vector of increasing numbers in the range $[0, \text{SampleRate}/2]$. If unspecified, `FrequencyRange` defaults to $[0, \text{SampleRate}/2]$.
- `SpectrumType` -- Spectrum type, specified as `"power"` or `"magnitude"`. If unspecified, `SpectrumType` defaults to `"power"`.
- `NumBands` -- Number of Bark bands, specified as an integer. If unspecified, `NumBands` defaults to 32.
- `FilterBankNormalization` -- Normalization applied to bandpass filters, specified as `"bandwidth"`, `"area"`, or `"none"`. If unspecified, `FilterBankNormalization` defaults to `"bandwidth"`.
- `WindowNormalization` -- Apply window normalization, specified as `true` or `false`. If unspecified, `WindowNormalization` defaults to `true`.
- `FilterBankDesignDomain` -- Domain in which the filter bank is designed, specified as either `"linear"` or `"warped"`. If unspecified, `FilterBankDesignDomain` defaults to `"linear"`.

Data Types: `logical`

erbSpectrum — Extract ERB spectrum

`false` (default) | `true`

Extract the one-sided ERB spectrum, specified as `true` or `false`.

To set parameters of the ERB spectrum extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "erbSpectrum", Name=Value)
```

Settable parameters for the ERB spectrum extraction are:

- `FrequencyRange` -- Frequency range of the extracted spectrum in Hz, specified as a two-element vector of increasing numbers in the range $[0, \text{SampleRate}/2]$. If unspecified, `FrequencyRange` defaults to $[0, \text{SampleRate}/2]$.
- `SpectrumType` -- Spectrum type, specified as `"power"` or `"magnitude"`. If unspecified, `SpectrumType` defaults to `"power"`.
- `NumBands` -- Number of ERB bands, specified as an integer. If unspecified, `NumBands` defaults to $\text{ceil}(\text{hz2erb}(\text{FrequencyRange}(2)) - \text{hz2erb}(\text{FrequencyRange}(1)))$.

- `FilterBankNormalization` -- Normalization applied to bandpass filters, specified as "bandwidth", "area", or "none". If unspecified, `FilterBankNormalization` defaults to "bandwidth".
- `WindowNormalization` -- Apply window normalization, specified as `true` or `false`. If unspecified, `WindowNormalization` defaults to `true`.

Data Types: `logical`

mfcc — Extract mel-frequency cepstral coefficients (MFCC)

`false` (default) | `true`

Extract mel-frequency cepstral coefficients (MFCC), specified as `true` or `false`.

To set parameters of the MFCC extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "mfcc", Name=Value)
```

Settable parameters for the MFCC extraction are:

- `NumCoeffs` -- Number of coefficients returned for each window, specified as a positive integer. If unspecified, `NumCoeffs` defaults to 13.
- `DeltaWindowLength` -- Delta window length, specified as an odd integer greater than 2. If unspecified, `DeltaWindowLength` defaults to 9. This parameter affects the `mfccDelta` and `mfccDeltaDelta` features.
- `Rectification` -- Type of nonlinear rectification, specified as "log" or "cubic-root".

The mel-frequency cepstral coefficients are calculated using the `melSpectrum`.

Data Types: `logical`

mfccDelta — Extract delta of MFCC

`false` (default) | `true`

Extract delta of MFCC, specified as `true` or `false`.

The delta MFCC is calculated based on the extracted MFCC. Parameters set on `mfcc` affect `mfccDelta`.

Data Types: `logical`

mfccDeltaDelta — Extract delta-delta of MFCC

`false` (default) | `true`

Extract delta-delta of MFCC, specified as `true` or `false`.

The delta-delta MFCC is calculated based on the extracted MFCC. Parameters set on `mfcc` affect `mfccDeltaDelta`.

Data Types: `logical`

gtcc — Extract gammatone cepstral coefficients (GTCC)

`false` (default) | `true`

Extract gammatone cepstral coefficients (GTCC), specified as `true` or `false`.

To set parameters of the GTCC extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "gtcc", Name=Value)
```

Settable parameters for the GTCC extraction are:

- `NumCoeffs` -- Number of coefficients returned for each window, specified as a positive integer. If unspecified, `NumCoeffs` defaults to 13.
- `DeltaWindowLength` -- Delta window length, specified as an odd integer greater than 2. If unspecified, `DeltaWindowLength` defaults to 9. This parameter affects the `gtccDelta` and `gtccDeltaDelta` features.
- `Rectification` -- Type of nonlinear rectification, specified as "log" or "cubic-root".

The gammatone cepstral coefficients are calculated using the `erbSpectrum`.

Data Types: `logical`

gtccDelta — Extract delta of GTCC

`false` (default) | `true`

Extract delta of GTCC, specified as `true` or `false`.

The delta GTCC is calculated based on the extracted GTCC. Parameters set on `gtcc` affect `gtccDelta`.

Data Types: `logical`

gtccDeltaDelta — Extract delta-delta of GTCC

`false` (default) | `true`

Extract delta-delta of GTCC, specified as `true` or `false`.

The delta-delta GTCC is calculated based on the extracted GTCC. Parameters set on `gtcc` affect `gtccDeltaDelta`.

Data Types: `logical`

spectralCentroid — Extract spectral centroid

`false` (default) | `true`

Extract spectral centroid, specified as `true` or `false`.

The spectral centroid is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralCrest — Extract spectral crest

`false` (default) | `true`

Extract spectral crest, specified as `true` or `false`.

The spectral crest is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralDecrease — Extract spectral decrease

`false` (default) | `true`

Extract spectral decrease, specified as `true` or `false`.

The spectral decrease is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralEntropy — Extract spectral entropy

`false` (default) | `true`

Extract spectral entropy, specified as `true` or `false`.

The spectral entropy is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralFlatness — Extract spectral flatness

`false` (default) | `true`

Extract spectral flatness, specified as `true` or `false`.

The spectral flatness is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`

- `erbSpectrum`

Data Types: `logical`

spectralFlux — Extract spectral flux

`false` (default) | `true`

Extract spectral flux, specified as `true` or `false`.

The spectral flux is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

To set parameters of the spectral flux extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "spectralFlux", Name=Value)
```

Settable parameters for the spectral flux extraction are:

- `NormType` -- Norm type used to calculate the spectral flux, specified as 1 or 2. If unspecified, `NormType` defaults to 2.

Data Types: `logical`

spectralKurtosis — Extract spectral kurtosis

`false` (default) | `true`

Extract spectral kurtosis, specified as `true` or `false`.

The spectral kurtosis is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralRolloffPoint — Extract spectral rolloff point

`false` (default) | `true`

Extract spectral rolloff point, specified as `true` or `false`.

The spectral rolloff point is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`

- barkSpectrum
- erbSpectrum

To set parameters of the spectral rolloff point extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "spectralRolloffPoint", Name=Value)
```

Settable parameters for the spectral flux extraction are:

- `Threshold` -- Threshold of the rolloff point, specified as a scalar in the range (0, 1). If unspecified, `Threshold` defaults to `0.95`.

Data Types: `logical`

spectralSkewness — Extract spectral skewness

`false` (default) | `true`

Extract spectral skewness, specified as `true` or `false`.

The spectral skewness is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralSlope — Extract spectral slope

`false` (default) | `true`

Extract spectral slope, specified as `true` or `false`.

The spectral slope is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`
- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

spectralSpread — Extract spectral spread

`false` (default) | `true`

Extract spectral spread, specified as `true` or `false`.

The spectral spread is calculated on one of the following spectral representations, as specified by the `SpectralDescriptorInput` property:

- `linearSpectrum`

- `melSpectrum`
- `barkSpectrum`
- `erbSpectrum`

Data Types: `logical`

pitch — Extract pitch

`false` (default) | `true`

Extract pitch, specified as `true` or `false`.

To set parameters of the pitch extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "pitch", Name=Value)
```

Settable parameters for the pitch extraction are:

- **Method** -- Method used to calculate the pitch, specified as "PEF", "NCF", "CEP", "LHS", or "SRH". If unspecified, **Method** defaults to "NCF". For a description of available pitch extraction methods, see `pitch`.
- **Range** -- Range within to search for the pitch in Hz, specified as a two-element row vector of increasing values. If unspecified, **Range** defaults to `[50, 400]`.
- **MedianFilterLength** -- Median filter length used to smooth pitch estimates over time, specified as a positive integer. If unspecified, **MedianFilterLength** defaults to 1 (no median filtering).

Data Types: `logical`

harmonicRatio — Extract harmonic ratio

`false` (default) | `true`

Extract harmonic ratio, specified as `true` or `false`.

Data Types: `logical`

zerocrossrate — Extract zero-crossing rate

`false` (default) | `true`

Extract zero-crossing rate, specified as `true` or `false`.

To set parameters of the zero-crossing rate extraction, use `setExtractorParameters`:

```
setExtractorParameters(aFE, "zerocrossrate", Name=Value)
```

Settable parameters for the zero-crossing rate extraction are:

- **Method** -- Method for computing the zero-crossing rate, specified as "difference" or "comparison". If unspecified, **Method**, defaults to "difference". For more information, see `zerocrossrate`.
- **Level** -- Signal level for which the crossing rate is computed, specified as a real scalar. `audioFeatureExtractor` subtracts the **Level** value from the signal and then finds the zero crossings. If unspecified, **Level** defaults to 0.
- **Threshold** -- Threshold above and below the **Level** value over which the crossing rate is computed, specified as a real scalar. `audioFeatureExtractor` sets all the values of the input in the range `[-Threshold, Threshold]` to 0 and then finds the zero crossings. If unspecified, **Threshold** defaults to 0.

- **TransitionEdge** — Transitions to include when counting zero crossings, specified as "falling", "rising", or "both". If you specify "falling", only negative-going transitions are counted. If you specify "rising", only positive-going transitions are counted. If unspecified, **TransitionEdge** defaults to "both".
- **ZeroPositive** — Sign convention, specified as a logical scalar. If you specify **ZeroPositive** as true, then 0 is considered positive. If you specify **ZeroPositive** as false, then **audioFeatureExtractor** considers 0, -1, and +1 to have distinct signs following the convention of the **sign** function. If unspecified, **ZeroPositive** defaults to false.

Data Types: logical

shortTimeEnergy — Extract short-time energy

false (default) | true

Extract short-time energy, specified as true or false. The short-time energy is computed using

$$sTE = \text{sum}(xbw.^2, 1),$$

where **xbw** is the buffered and windowed signal.

Example: Chirp Function

Generate a chirp sampled at 1 kHz for 3 seconds. The instantaneous frequency is 100 Hz at $t = 0$ and crosses 200 Hz at $t = 1$ second. Divide the signal into 103-sample segments with 43 samples of overlap between adjoining segments. Window each segment with a periodic Hamming window.

```
fs = 1e3;
x = chirp(0:1/fs:3,100,1,200)';

win = hamming(103,"periodic");
nover = 43;

[xb,~] = buffer(x,length(win),nover,"nodelay");
xbw = xb.*win;
```

Compute the short-time energy using the definition.

```
Edef = sum(xbw.^2,1)';
```

Use **audioFeatureExtractor** to compute the short-time energy.

```
EaFE = extract(audioFeatureExtractor(shortTimeEnergy=true, ...
    SampleRate=fs,Window=win,OverlapLength=nover),x);
```

Verify that both procedures give the same short-time energy.

```
dff = max(abs(EaFE-Edef))
```

```
dff = 0
```

Data Types: logical

Object Functions

extract	Extract audio features
setExtractorParameters	Set nondefault parameter values for individual feature extractors
info	Output mapping and individual feature extractor parameters
generateMATLABFunction	Create MATLAB function compatible with C/C++ code generation

Examples

Extract Multiple Audio Features

Read in an audio signal.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioFeatureExtractor` object that extracts the MFCC, delta MFCC, delta-delta MFCC, pitch, spectral centroid, zero-crossing rate, and short-time energy of the signal. Use a 30 ms analysis window with 20 ms overlap.

```
aFE = audioFeatureExtractor( ...
    SampleRate=fs, ...
    Window=hamming(round(0.03*fs),"periodic"), ...
    OverlapLength=round(0.02*fs), ...
    mfcc=true, ...
    mfccDelta=true, ...
    mfccDeltaDelta=true, ...
    pitch=true, ...
    spectralCentroid=true, ...
    zerocrossrate=true, ...
    shortTimeEnergy=true);
```

Call `extract` to extract the audio features from the audio signal.

```
features = extract(aFE,audioIn);
```

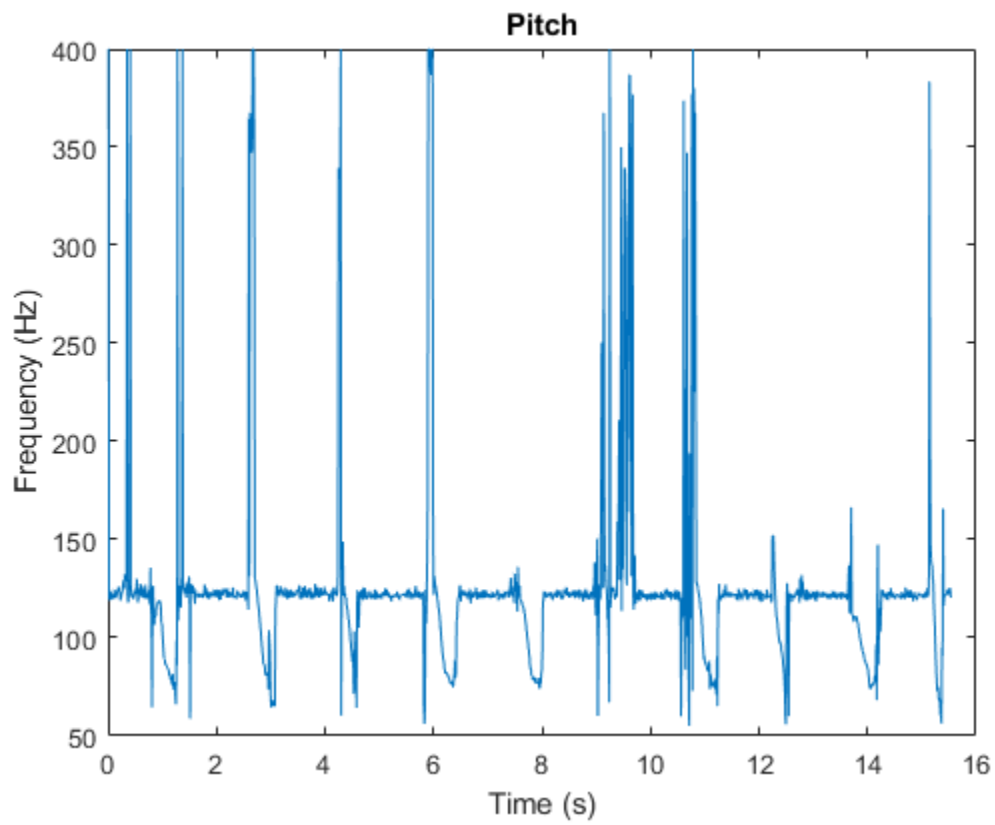
Use `info` to determine which column of the feature extraction matrix corresponds to the requested pitch extraction.

```
idx = info(aFE)
```

```
idx = struct with fields:
    mfcc: [1 2 3 4 5 6 7 8 9 10 11 12 13]
    mfccDelta: [14 15 16 17 18 19 20 21 22 23 24 25 26]
    mfccDeltaDelta: [27 28 29 30 31 32 33 34 35 36 37 38 39]
    spectralCentroid: 40
    pitch: 41
    zerocrossrate: 42
    shortTimeEnergy: 43
```

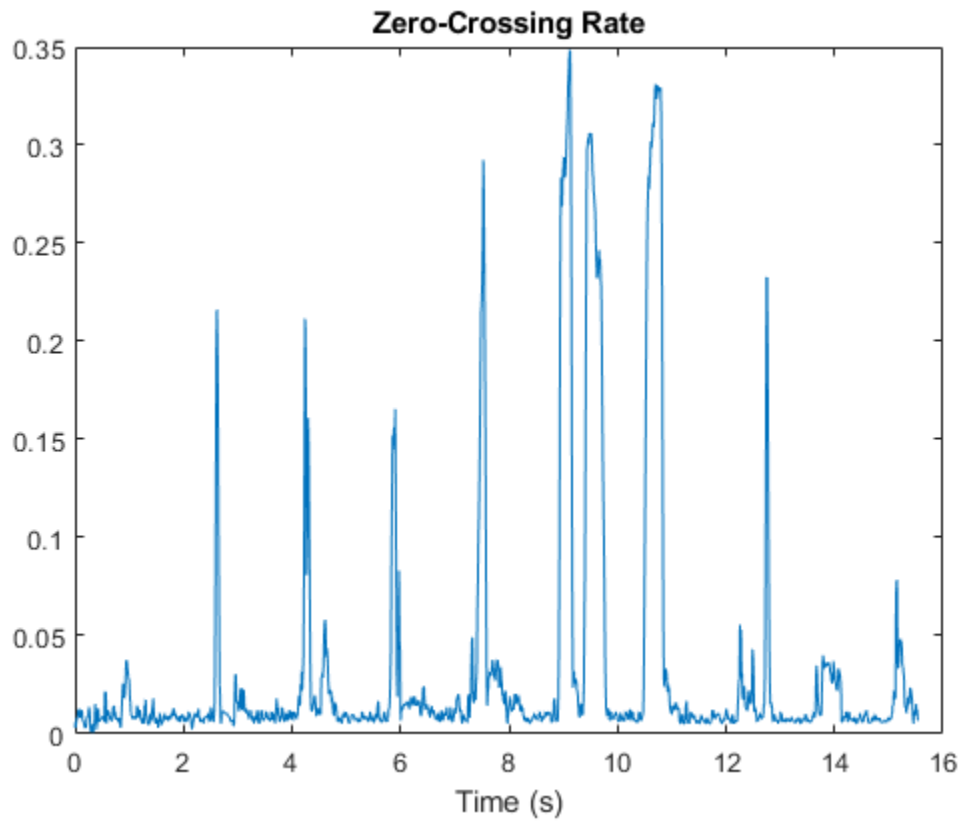
Plot the detected pitch over time.

```
t = linspace(0,size(audioIn,1)/fs,size(features,1));
plot(t,features(:,idx.pitch))
title("Pitch")
xlabel("Time (s)")
ylabel("Frequency (Hz)")
```

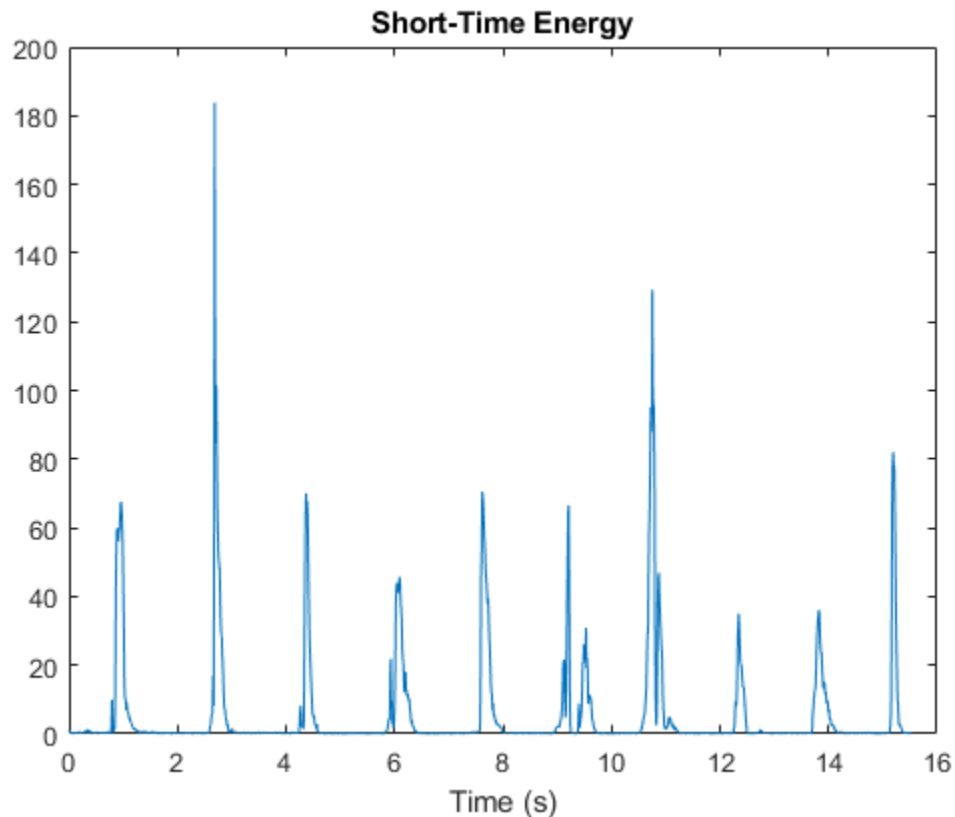
Plot the zero-crossing rate over time.

```
plot(t, features(:, idx.zerocrossrate))  
title("Zero-Crossing Rate")  
xlabel("Time (s)")
```



Plot the short-time energy over time.

```
plot(t, features(:, idx.shortTimeEnergy))  
title("Short-Time Energy")  
xlabel("Time (s)")
```



Extract Features from Dataset

Create an audio datastore that points to audio samples included with Audio Toolbox®.

```
folder = fullfile(matlabroot, "toolbox", "audio", "samples");
ads = audioDatastore(folder);
```

Find all files that correspond to a sample rate of 44.1 kHz and then subset the datastore.

```
keepFile = cellfun(@(x)contains(x, "44p1"), ads.Files);
ads = subset(ads, keepFile);
```

Convert the data to a tall array. Tall arrays are evaluated only when you request them explicitly using `gather`. MATLAB® automatically optimizes the queued calculations by minimizing the number of passes through the data. If you have Parallel Computing Toolbox™, you can spread the calculations across multiple workers. The audio data is represented as an M -by-1 tall cell array, where M is the number of files in the audio datastore.

```
adsTall = tall(ads)
```

```
Starting parallel pool (parpool) using the 'local' profile ...
Connected to the parallel pool (number of workers: 6).
```

```
adsTall =
```

```

M×1 tall cell array

{ 539648×1 double}
{ 227497×1 double}
{  8000×1 double}
{ 685056×1 double}
{ 882688×2 double}
{1115760×2 double}
{ 505200×2 double}
{3195904×2 double}
      :      :
      :      :

```

Create an `audioFeatureExtractor` object to extract the mel spectrum, Bark spectrum, ERB spectrum, and linear spectrum from each audio file. Use the default analysis window and overlap length for the spectrum extraction.

```

aFE = audioFeatureExtractor(SampleRate=44.1e3, ...
    melSpectrum=true, ...
    barkSpectrum=true, ...
    erbSpectrum=true, ...
    linearSpectrum=true);

```

Define a `cellfun` function so that audio features are extracted from each cell of the tall array. Call `gather` to evaluate the tall array.

```

specsTall = cellfun(@(x)extract(aFE,x),adsTall,UniformOutput=false);
specs = gather(specsTall);

```

```

Evaluating tall expression using the Parallel Pool 'local':
- Pass 1 of 1: Completed in 14 sec
Evaluation completed in 14 sec

```

The `specs` variable returned from `gather` is a *numFiles*-by-1 cell array, where *numFiles* is the number of files in the datastore. Each element of the cell array is a *numHops*-by-*numFeatures*-by-*numChannels* array, where the number of hops and number of channels depends on the length and number of channels of the audio file, and the number of features is the requested number of features from the audio data.

```

numFiles = numel(specs)

numFiles = 12

[numHops1,numFeaturesFile1,numChannelsFile1] = size(specs{1})

numHops1 = 1053

numFeaturesFile1 = 620

numChannelsFile1 = 1

[numHops2,numFeaturesFile2,numChannelsFile2] = size(specs{2})

numHops2 = 443

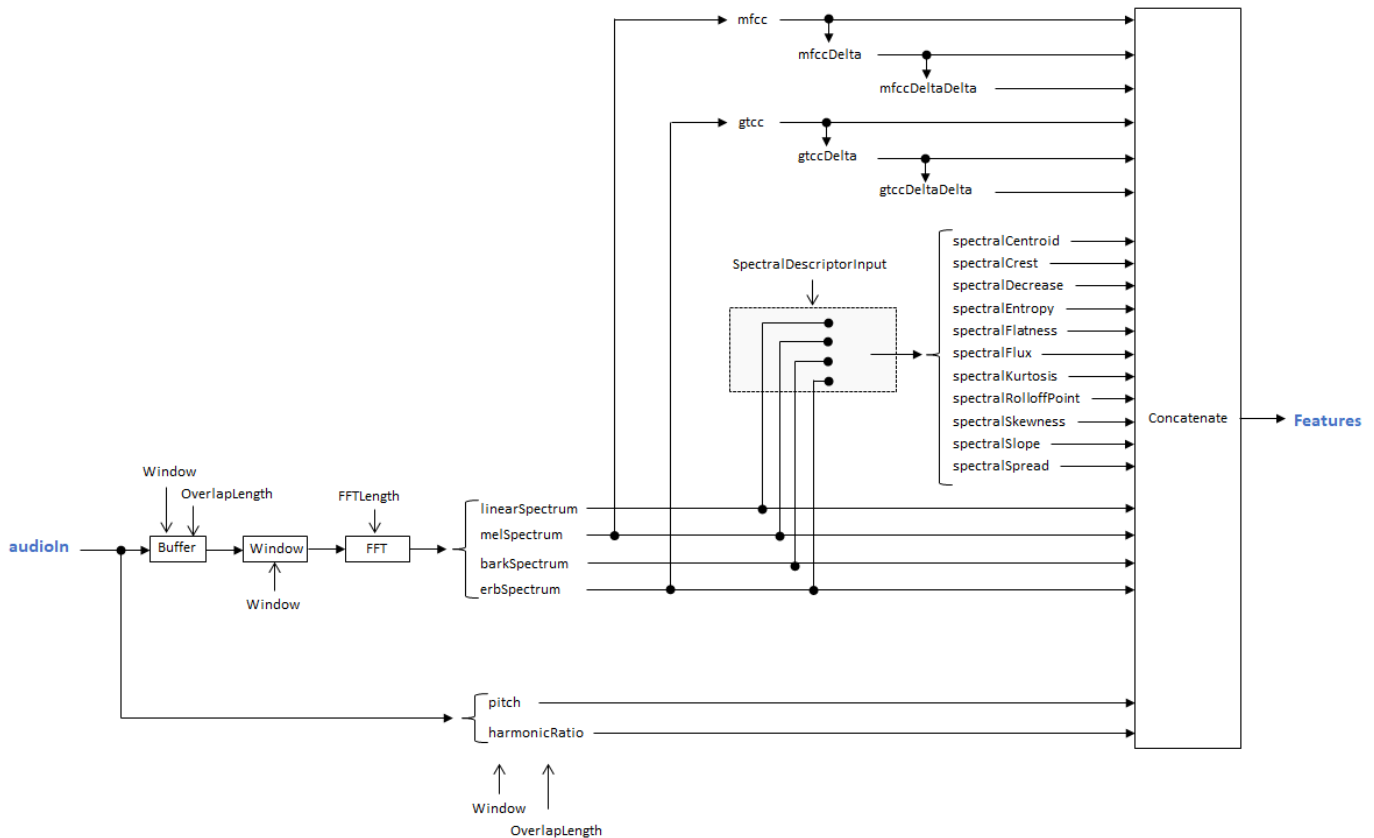
numFeaturesFile2 = 620

numChannelsFile2 = 1

```

Algorithms

The `audioFeatureExtractor` creates a feature extraction pipeline based on your selected features. To reduce computations, `audioFeatureExtractor` reuses intermediary representations and outputs some intermediate representations as features.



For example, to create an object that extracts the centroid of the Bark spectrum, the flux of the Bark spectrum, the pitch, the harmonic ratio, and the delta-delta of the MFCC, specify the `audioFeatureExtractor` as follows.

```
aFE = audioFeatureExtractor( ...
    SpectralDescriptorInput="barkSpectrum", ...
    spectralCentroid=true, ...
    spectralFlux=true, ...
    pitch=true, ...
    harmonicRatio=true, ...
    mfccDeltaDelta=true)
```

aFE =

```
audioFeatureExtractor with properties:
    Properties
        Window: [1024x1 double]
        OverlapLength: 512
        SampleRate: 44100
        FFTLength: []
        SpectralDescriptorInput: 'barkSpectrum'
    Enabled Features
```

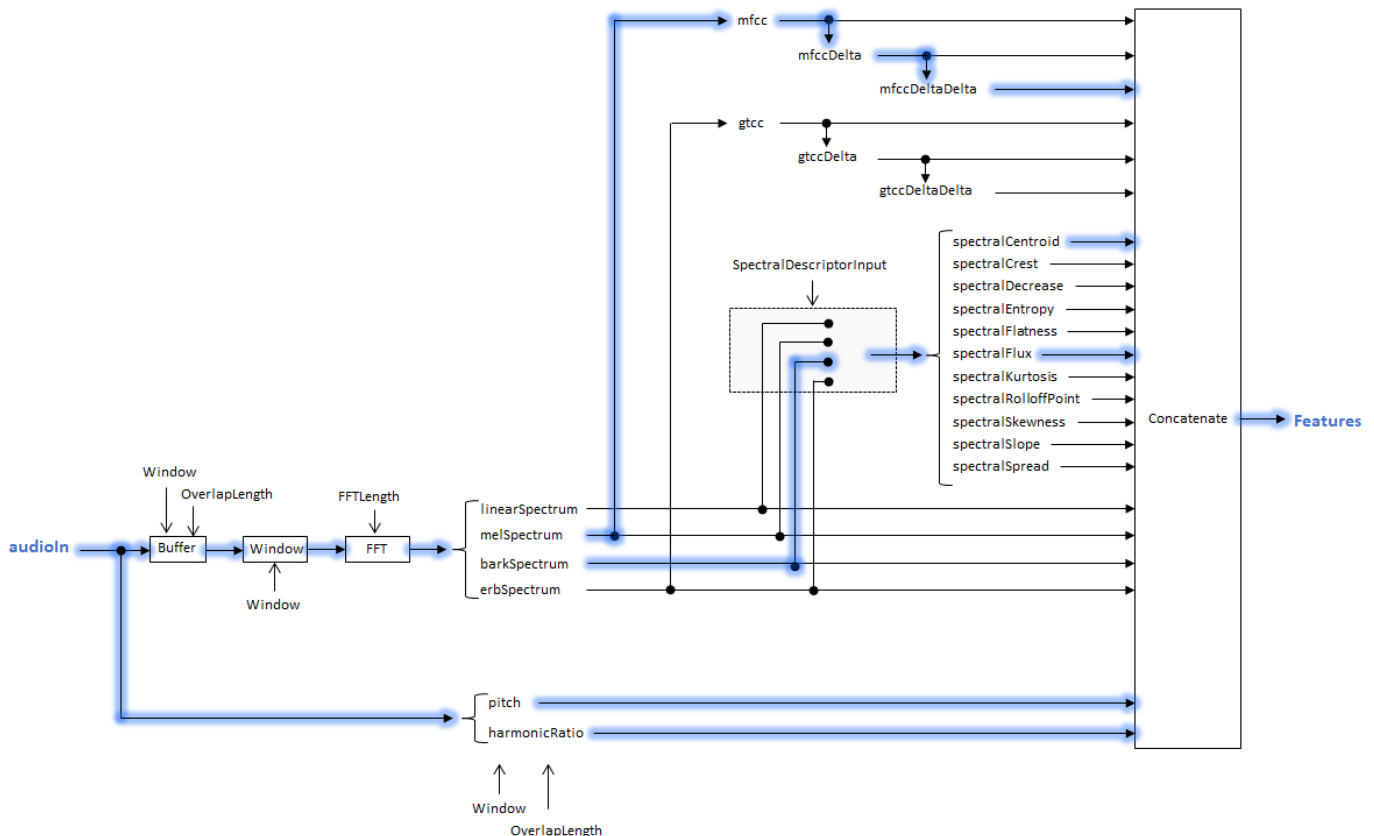
```
mfccDeltaDelta, spectralCentroid, spectralFlux, pitch, harmonicRatio
```

Disabled Features

```
linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
gtcc, gtccDelta, gtccDeltaDelta, spectralCrest, spectralDecrease, spectralEntropy
spectralFlatness, spectralKurtosis, spectralRolloffPoint, spectralSkewness, spectralSlope, spectralSpread
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

This configuration corresponds to the highlighted feature extraction pipeline.



Note Because `audioFeatureExtractor` reuses intermediary representations, the features output from `audioFeatureExtractor` might not correspond with the default configuration of features output by corresponding individual feature extractors.

Compatibility Considerations

Computation of deltas and delta-deltas

Behavior changed in R2020b

The `audioDelta` function is now used to compute `mfccDelta`, `mfccDeltaDelta`, `gtccDelta`, and `gtccDeltaDelta`. The `audioDelta` algorithm has a different startup behavior than the previous algorithm. The default window length used to compute the deltas has changed from 2 to 9. A delta window length of 2 is no longer supported.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

Usage notes and limitations:

- You cannot generate code directly from `audioFeatureExtractor`. You can generate C/C++ code from the function returned by `generateMATLABFunction`.
- `zerocrossrate` code generation does not support disabling dynamic memory allocation when the input is multichannel.

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

Usage notes and limitations:

- `zerocrossrate` is not supported.

For more information, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

Extract Audio Features | `audioDatastore` | `audioDataAugmenter` | **Signal Labeler** | `vggishEmbeddings`

Introduced in R2019b

removeAugmentationMethod

Remove custom augmentation method

Syntax

```
removeAugmentationMethod(aug,algorithmName)
```

Description

`removeAugmentationMethod(aug,algorithmName)` removes the custom augmentation algorithm from an `audioDataAugmenter` object.

Examples

Remove Augmentation Method

Create a default `audioDataAugmenter` object.

```
aug = audioDataAugmenter
aug =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
      NumAugmentations: 1
      TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
      PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
      VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
      AddNoiseProbability: 0.5000
      SNRRange: [0 10]
      TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]
```

Add a custom augmentation method that applies a random DC offset.

```
algorithmName = 'DCOffset';
algorithmHandle = @(x)x+rand(1,'like',x);
addAugmentationMethod(aug,algorithmName,algorithmHandle)
aug
aug =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
      NumAugmentations: 1
```



```

TimeStretchProbability: 0.5000
  SpeedupFactorRange: [0.8000 1.2000]
PitchShiftProbability: 0.5000
  SemitoneShiftRange: [-2 2]
VolumeControlProbability: 0.5000
  VolumeGainRange: [-3 3]
AddNoiseProbability: 0.5000
  SNRRange: [0 10]
TimeShiftProbability: 0.5000
  TimeShiftRange: [-0.0050 0.0050]
DCOffsetProbability: 0.5000

```

Remove the custom augmentation method.

```
removeAugmentationMethod(aug,algorithmName)
aug
```

```

aug =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
      AugmentationParameterSource: 'random'
      NumAugmentations: 1
      TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
      PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
      VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
      AddNoiseProbability: 0.5000
      SNRRange: [0 10]
      TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]

```

Input Arguments

aug — Audio data augmenter

audioDataAugmenter object

audioDataAugmenter object.

algorithmName — Algorithm name

character vector | string

Algorithm name, specified as a character vector or string. `algorithmName` must match the algorithm name you used to add the algorithm using `addAugmentationMethod`.

Data Types: char | string

See Also

`addAugmentationMethod` | `audioDataAugmenter`

Introduced in R2019b

augment

Augment audio data

Syntax

```
data = augment(aug, audioIn)
data = augment(aug, audioIn, fs)
```

Description

`data = augment(aug, audioIn)` returns a table containing augmented audio data and information about the augmentation applied.

`data = augment(aug, audioIn, fs)` specifies the sample rate of the audio input.

Examples

Apply Random Sequential Augmentations

Read in an audio signal and listen to it.

```
[audioIn, fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn, fs)
```

Create an `audioDataAugmenter` object that applies time stretching, volume control, and time shifting in cascade. Apply each of the augmentations with 80% probability. Set `NumAugmentations` to 5 to output five independently augmented signals. To skip pitch shifting and noise addition for each augmentation, set the respective probabilities to 0. Define parameter ranges for each relevant augmentation algorithm.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode", "sequential", ...
    "NumAugmentations", 5, ...
    ...
    "TimeStretchProbability", 0.8, ...
    "SpeedupFactorRange", [1.3, 1.4], ...
    ...
    "PitchShiftProbability", 0, ...
    ...
    "VolumeControlProbability", 0.8, ...
    "VolumeGainRange", [-5, 5], ...
    ...
    "AddNoiseProbability", 0, ...
    ...
    "TimeShiftProbability", 0.8, ...
    "TimeShiftRange", [-500e-3, 500e-3])
```

```
augmenter =
    audioDataAugmenter with properties:
```

```
    AugmentationMode: "sequential"
```

```

AugmentationParameterSource: 'random'
  NumAugmentations: 5
  TimeStretchProbability: 0.8000
  SpeedupFactorRange: [1.3000 1.4000]
  PitchShiftProbability: 0
  VolumeControlProbability: 0.8000
  VolumeGainRange: [-5 5]
  AddNoiseProbability: 0
  TimeShiftProbability: 0.8000
  TimeShiftRange: [-0.5000 0.5000]

```

Call `augment` on the audio to create 5 augmentations. The augmented audio is returned in a table with variables `Audio` and `AugmentationInfo`. The number of rows in the table is defined by `NumAugmentations`.

```
data = augment(augmenter, audioIn, fs)
```

```

data=5x2 table
      Audio          AugmentationInfo
-----
{685056x1 double}  1x1 struct
{685056x1 double}  1x1 struct
{505183x1 double}  1x1 struct
{685056x1 double}  1x1 struct
{490728x1 double}  1x1 struct

```

In the current augmentation pipeline, augmentation parameters are assigned randomly from within the specified ranges. To determine the exact parameters used for an augmentation, inspect `AugmentationInfo`.

```

augmentationToInspect = ;
data.AugmentationInfo(augmentationToInspect)

ans = struct with fields:
  SpeedupFactor: 1
  VolumeGain: 4.3399
  TimeShift: 0.4502

```

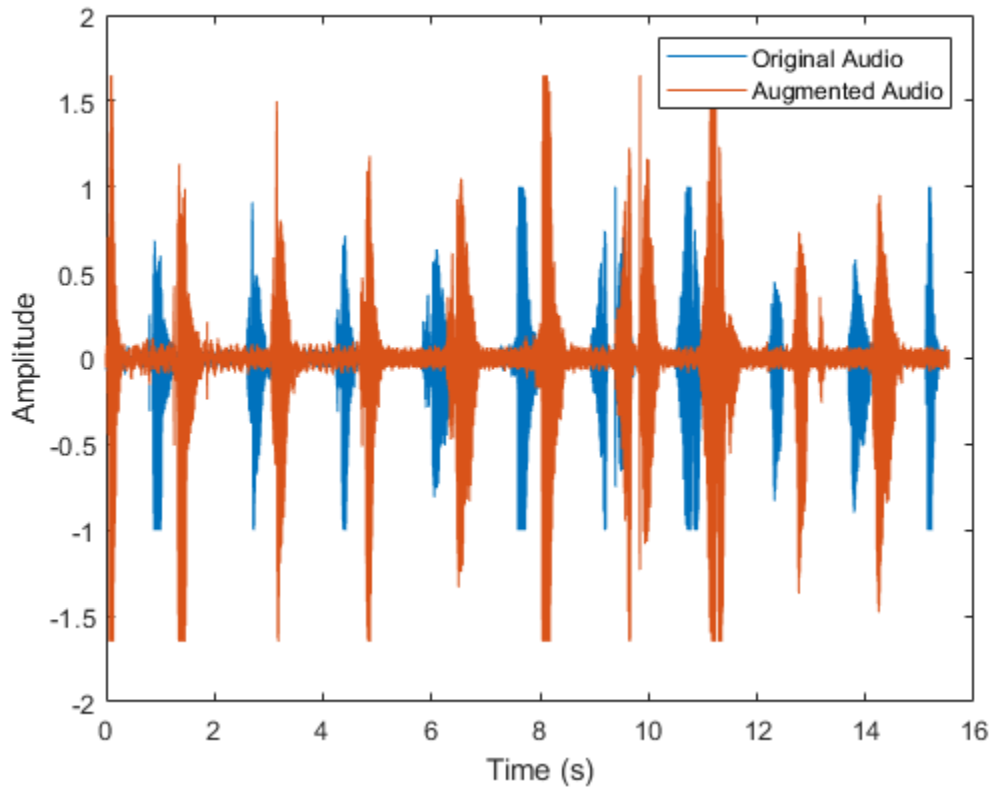
Listen to the augmentation you are inspecting. Plot time representation of the original and augmented signals.

```

augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Apply Specified Sequential Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn,fs)
```

Create an `audioDataAugmenter` object that applies time stretching, pitch shifting, and noise corruption in cascade. Specify the time stretch speedup factors as 0.9, 1.1, and 1.2. Specify the pitch shifting in semitones as -2, -1, 1, and 2. Specify the noise corruption SNR as 10 dB and 15 dB.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode","sequential", ...
    "AugmentationParameterSource","specify", ...
    "SpeedupFactor",[0.9,1.1,1.2], ...
    "ApplyTimeStretch",true, ...
    "ApplyPitchShift",true, ...
    "SemitoneShift",[-2,-1,1,2], ...
    "SNR",[10,15], ...
    "ApplyVolumeControl",false, ...
    "ApplyTimeShift",false)
```

```
augmenter =
    audioDataAugmenter with properties:
```

```

        AugmentationMode: "sequential"
AugmentationParameterSource: "specify"
        ApplyTimeStretch: 1
            SpeedupFactor: [0.9000 1.1000 1.2000]
        ApplyPitchShift: 1
            SemitoneShift: [-2 -1 1 2]
        ApplyVolumeControl: 0
            ApplyAddNoise: 1
                SNR: [10 15]
        ApplyTimeShift: 0

```

Call `augment` on the audio to create 24 augmentations. The augmentations represent every combination of the specified augmentation parameters ($3 \times 4 \times 2 = 24$).

```
data = augment(augmenter, audioIn, fs)
```

```

data=24x2 table
      Audio          AugmentationInfo
-----
{761243x1 double}   1x1 struct
{622888x1 double}   1x1 struct
{571263x1 double}   1x1 struct
{761243x1 double}   1x1 struct
{622888x1 double}   1x1 struct
{571263x1 double}   1x1 struct
{761243x1 double}   1x1 struct
{622888x1 double}   1x1 struct
{571263x1 double}   1x1 struct
{761243x1 double}   1x1 struct
{622888x1 double}   1x1 struct
{571263x1 double}   1x1 struct
{761243x1 double}   1x1 struct
{622888x1 double}   1x1 struct
{571263x1 double}   1x1 struct
{761243x1 double}   1x1 struct
:

```

You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```

augmentationToInspect = ;
data.AugmentationInfo(augmentationToInspect)

```

```

ans = struct with fields:
    SpeedupFactor: 0.9000
    SemitoneShift: -2
    SNR: 10

```

Listen to the augmentation you are inspecting. Plot the time-domain representation of the original and augmented signals.

```

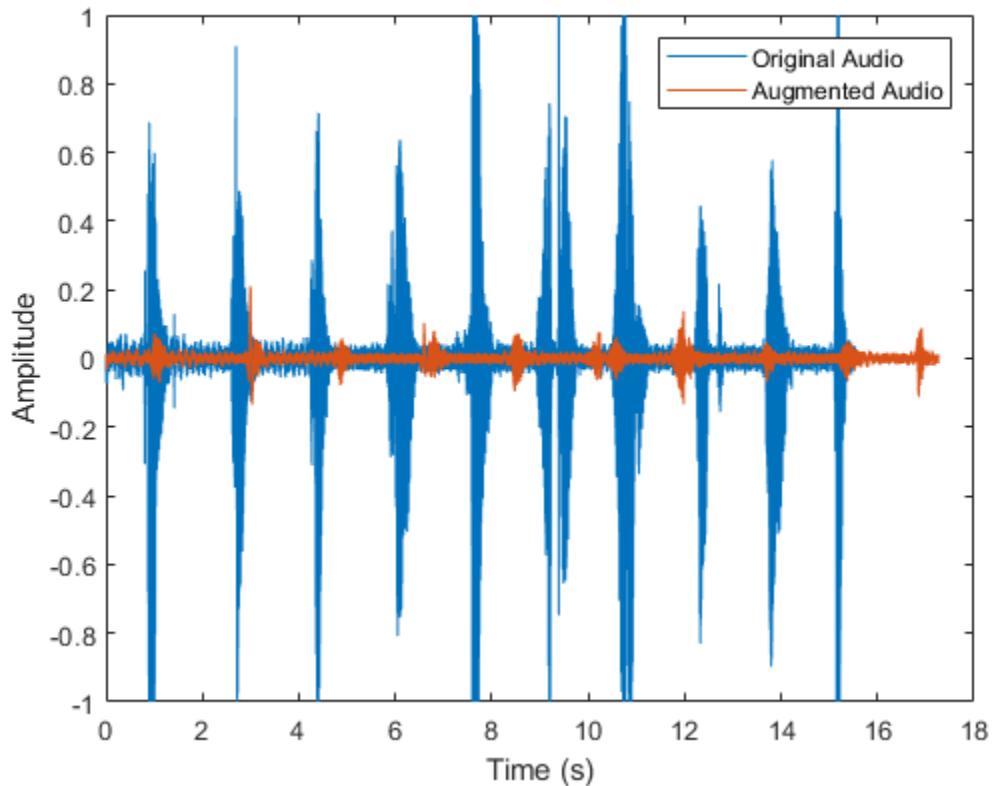
augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)

```

```

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t,audioIn,taug,augmentation)
legend("Original Audio","Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Apply Random Independent Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioDataAugmenter` object that applies noise corruption, and time shifting in parallel branches. For the noise corruption branch, randomly apply noise with an SNR in the range 0 dB to 20 dB. For the time shifting branch, randomly apply time shifting in the range -300 ms to 300 ms. Apply augmentation 2 times for each branch, for 4 total augmentations.

```

augmenter = audioDataAugmenter( ...
    "AugmentationMode","independent", ...
    "AugmentationParameterSource","random", ...
    "NumAugmentations",2, ...
    "ApplyTimeStretch",false, ...
    "ApplyPitchShift",false, ...

```

```

    "ApplyVolumeControl",false, ...
    "SNRRange",[0,20], ...
    "TimeShiftRange",[-300e-3,300e-3])
augmenter =
  audioDataAugmenter with properties:
      AugmentationMode: "independent"
      AugmentationParameterSource: "random"
      NumAugmentations: 2
      ApplyTimeStretch: 0
      ApplyPitchShift: 0
      ApplyVolumeControl: 0
      ApplyAddNoise: 1
          SNRRange: [0 20]
      ApplyTimeShift: 1
      TimeShiftRange: [-0.3000 0.3000]

```

Call `augment` on the audio to create 3 augmentations.

```
data = augment(augmenter, audioIn, fs);
```

You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```

augmentationToInspect = ;
data.AugmentationInfo{augmentationToInspect}

ans = struct with fields:
    TimeShift: 0.0016

```

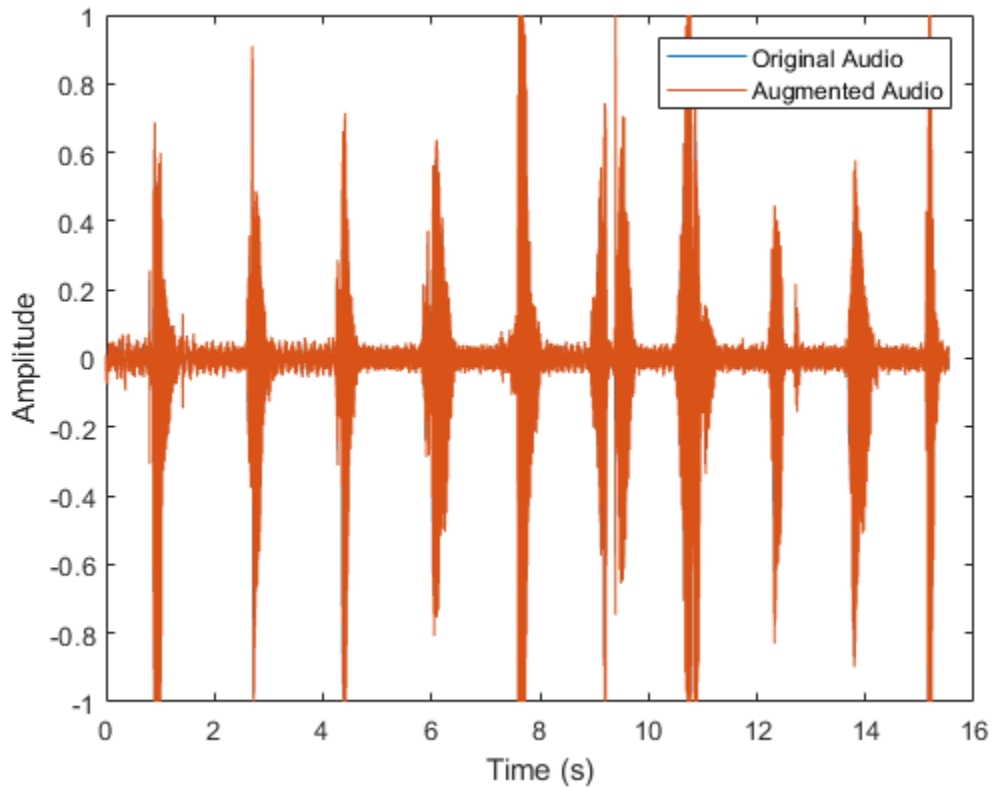
Listen to the audio you are inspecting. Plot the time-domain representation of the original and augmented signals.

```

augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```

Apply Specified Independent Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioDataAugmenter` object that applies volume control, noise corruption, and time shifting in parallel branches.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode","independent", ...
    "AugmentationParameterSource","specify", ...
    "ApplyTimeStretch",false, ...
    "ApplyPitchShift",false, ...
    "VolumeGain",2, ...
    "SNR",0, ...
    "TimeShift",2)
```

```
augmenter =
    audioDataAugmenter with properties:
```

```
    AugmentationMode: "independent"
    AugmentationParameterSource: "specify"
    ApplyTimeStretch: 0
    ApplyPitchShift: 0
```

```

    ApplyVolumeControl: 1
        VolumeGain: 2
    ApplyAddNoise: 1
        SNR: 0
    ApplyTimeShift: 1
        TimeShift: 2

```

Call `augment` on the audio to create 3 augmentations.

```
data = augment(augmenter, audioIn, fs)
```

```

data=3x2 table
      Audio      AugmentationInfo
-----
{685056x1 double}  {1x1 struct}
{685056x1 double}  {1x1 struct}
{685056x1 double}  {1x1 struct}

```

You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```

augmentationToInspect = ;
data.AugmentationInfo{augmentationToInspect}

ans = struct with fields:
    TimeShift: 2

```

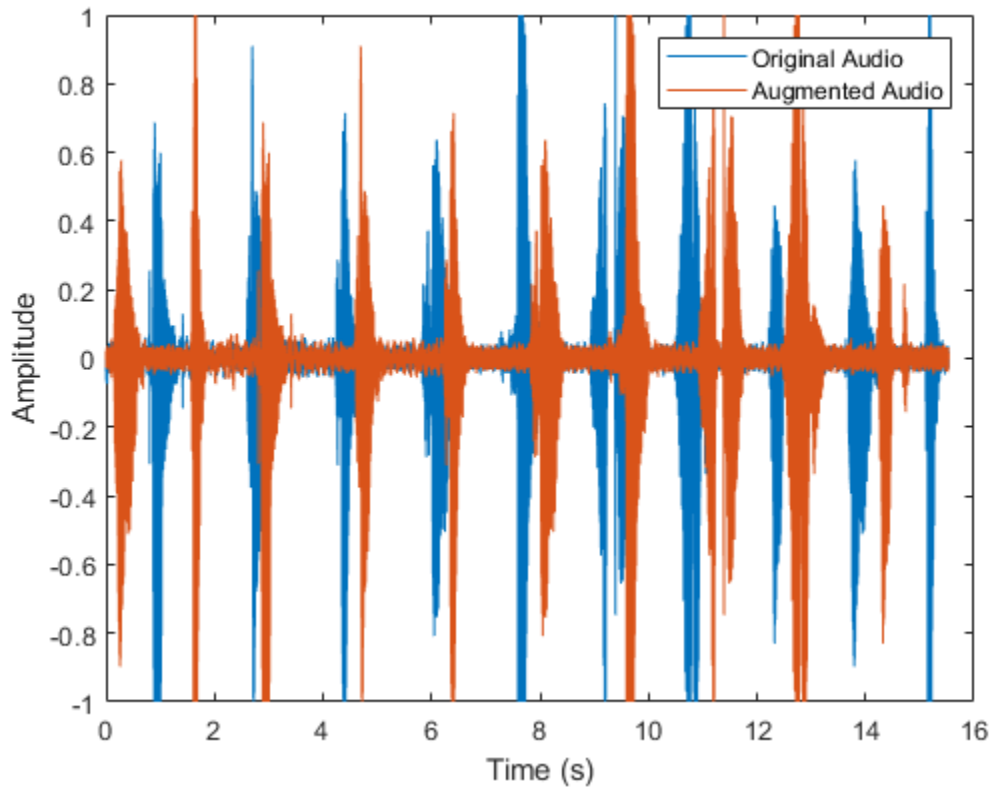
Listen to the audio you are inspecting. Plot the time-domain representations of the original and augmented signals.

```

augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Augment Audio Dataset

The `audioDataAugmenter` supports multiple workflows for augmenting your datastore, including:

- Offline augmentation
- Augmentation using tall arrays
- Augmentation using transform datastores

In each workflow, begin by creating an audio datastore to point to your audio data. In this example, you create an audio datastore that points to audio samples included with Audio Toolbox™. Count the number of files in the dataset.

```
folder = fullfile(matlabroot,"toolbox","audio","samples");
ADS = audioDatastore(folder)
```

```
ADS =
  audioDatastore with properties:
```

```
Files: {
    '..\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
    '..\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20sec'
    '..\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5sec'
    ... and 26 more
}
```

```

AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}

```

```
numFilesInDataset = numel(ADS.Files)
```

```
numFilesInDataset = 29
```

Create an `audioDataAugmenter` that applies random sequential augmentations. Set `NumAugmentations` to 2.

```
aug = audioDataAugmenter('NumAugmentations',2)
```

```

aug =
    audioDataAugmenter with properties:
        AugmentationMode: 'sequential'
        AugmentationParameterSource: 'random'
        NumAugmentations: 2
        TimeStretchProbability: 0.5000
        SpeedupFactorRange: [0.8000 1.2000]
        PitchShiftProbability: 0.5000
        SemitoneShiftRange: [-2 2]
        VolumeControlProbability: 0.5000
        VolumeGainRange: [-3 3]
        AddNoiseProbability: 0.5000
        SNRRange: [0 10]
        TimeShiftProbability: 0.5000
        TimeShiftRange: [-0.0050 0.0050]

```

Offline Augmentation

To augment the audio dataset, create two augmentations of each file and then write the augmentations as WAV files.

```

while hasdata(ADS)
    [audioIn,info] = read(ADS);

    data = augment(aug,audioIn,info.SampleRate);

    [~,fn] = fileparts(info.FileName);
    for i = 1:size(data,1)
        augmentedAudio = data.Audio{i};

        % If augmentation caused an audio signal to have values outside of -1 and 1,
        % normalize the audio signal to avoid clipping when writing.
        if max(abs(augmentedAudio),[],'all')>1
            augmentedAudio = augmentedAudio/max(abs(augmentedAudio),[],'all');
        end

        audiowrite(sprintf('%s_aug%d.wav',fn,i),augmentedAudio,info.SampleRate)
    end
end

```

Create an `audioDatastore` that points to the augmented dataset and confirm that the number of files in the dataset is double the original number of files.

```
augmentedADS = audioDatastore(pwd)
```

```
augmentedADS =
    audioDatastore with properties:
```

```

        Files: {
            ' ...\Examples\audio-ex28074079\Ambiance-16-44p1-mono-12secs_aug1.v
            ' ...\Examples\audio-ex28074079\Ambiance-16-44p1-mono-12secs_aug2.v
            ' ...\Examples\audio-ex28074079\AudioArray-16-16-4channels-20secs_
            ... and 55 more
        }
    AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
```

```
numFilesInAugmentedDataset = numel(augmentedADS.Files)
```

```
numFilesInAugmentedDataset = 58
```

Augment Using Tall Arrays

When augmenting a dataset using tall arrays, the input data to the augments should be sampled at a consistent rate. Subset the original audio dataset to only include files with a sample rate of 44.1 kHz. Most datasets are already cleaned to have a consistent sample rate.

```
keepFile = cellfun(@(x)contains(x,'44p1'),ADS.Files);
ads44p1 = subset(ADS,keepFile);
fs = 44.1e3;
```

Convert the audio datastore to a tall array. Tall arrays are evaluated only when you request them explicitly using `gather`. MATLAB® automatically optimizes the queued calculations by minimizing the number of passes through the data. If you have the Parallel Computing Toolbox™, you can spread the calculations across multiple machines. The audio data is represented as an M -by-1 tall cell array, where M is the number of files in the audio datastore.

```
adsTall = tall(ads44p1)
```

```
Starting parallel pool (parpool) using the 'local' profile ...
Connected to the parallel pool (number of workers: 6).
```

```
adsTall =
```

```
M×1 tall cell array
```

```

    { 539648×1 double}
    { 227497×1 double}
    {   8000×1 double}
    { 685056×1 double}
    { 882688×2 double}
    {1115760×2 double}
    { 505200×2 double}
    {3195904×2 double}
    :
    :
```

Define a `cellfun` function so that augmentation is applied to each cell of the tall array. Call `gather` to evaluate the tall array.

```
augTall = cellfun(@(x)augment(aug,x,fs),adsTall,"UniformOutput",false);
augmentedDataset = gather(augTall)
```

```
Evaluating tall expression using the Parallel Pool 'local':
- Pass 1 of 1: Completed in 1 min 34 sec
Evaluation completed in 1 min 34 sec
```

```
augmentedDataset=12x1 cell array
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
```

The augmented dataset is returned as a *numFiles*-by-1 cell array, where *numFiles* is the number of files in the datastore. Each element of the cell array is a *numAugmentationsPerFile*-by-2 table, where *numAugmentationsPerFile* is the number of augmentations returned per file.

```
numFiles = numel(augmentedDataset)

numFiles = 12

numAugmentationsPerFile = size(augmentedDataset{1},1)

numAugmentationsPerFile = 2
```

Augment Using Transform Datastore

You can perform online data augmentation while you train your machine learning application using a transform datastore. Call `transform` to create a new datastore that applies data augmentation while reading.

```
transformADS = transform(ADS,@(x,info)augment(aug,x,info),'IncludeInfo',true)

transformADS =
    TransformedDatastore with properties:

        UnderlyingDatastore: [1x1 audioDatastore]
        Transforms: {@(x,info)augment(aug,x,info)}
        IncludeInfo: 1
```

Call `read` to return the augmented first file from the transform datastore.

```
augmentedRead = read(transformADS)

augmentedRead=2x2 table
    Audio      AugmentationInfo
    _____  _____
    {539648x1 double}  [1x1 struct]
```

{586683×1 double} [1×1 struct]

Input Arguments

aug — Audio data augmenter

audioDataAugmenter object

audioDataAugmenter object.

audioIn — Audio input

vector | matrix

Audio input, specified as a column vector or matrix of independent channels (columns).

Data Types: single | double

fs — Sample rate (Hz)

44100 (default) | positive scalar

Sample rate in Hz, specified as a positive scalar. The allowable range of `fs` depends on the properties of the `audioDataAugmenter` object.

Data Types: single | double

Output Arguments

data — Augmented audio and augmentation information

table

Augmented audio and augmentation information, returned as a two-column table. The first column holds the augmented audio signal. The second column holds information about the applied augmentation methods. The number of rows in `data` corresponds to the number of output augmented signals. The number of output augmented signals depends on the property values of the object.

See Also

audioDataAugmenter | addAugmentationMethod | removeAugmentationMethod | table

Introduced in R2019b

addAugmentationMethod

Add custom augmentation method

Syntax

```
addAugmentationMethod(aug, algorithmName, algorithmHandle)
addAugmentationMethod(aug, algorithmName, algorithmHandle, Name, Value)
```

Description

`addAugmentationMethod(aug, algorithmName, algorithmHandle)` adds a custom augmentation algorithm to an `audioDataAugmenter` object.

`addAugmentationMethod(aug, algorithmName, algorithmHandle, Name, Value)` specifies options using one or more `Name, Value` pair arguments.

Examples

Add Custom Augmentation Method

You can expand the capabilities of `audioDataAugmenter` by adding custom augmentation methods.

Read in an audio signal and listen to it.

```
[audioIn, fs] = audioread('Counting-16-44p1-mono-15secs.wav');
sound(audioIn, fs)
```

Create an `audioDataAugmenter` object. Set the probability of applying white noise to 0.

```
augmenter = audioDataAugmenter('AddNoiseProbability', 0)
```

```
augmenter =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
      NumAugmentations: 1
  TimeStretchProbability: 0.5000
  SpeedupFactorRange: [0.8000 1.2000]
  PitchShiftProbability: 0.5000
  SemitoneShiftRange: [-2 2]
  VolumeControlProbability: 0.5000
  VolumeGainRange: [-3 3]
  AddNoiseProbability: 0
  TimeShiftProbability: 0.5000
  TimeShiftRange: [-0.0050 0.0050]
```

Specify a custom augmentation algorithm that applies pink noise. The `AddPinkNoise` algorithm is added to the `augmenter` properties.


```

algorithmName = 'AddPinkNoise';
algorithmHandle = @(x)x+pinknoise(size(x),'like',x);
addAugmentationMethod(augmenter,algorithmName,algorithmHandle)

```

```
augmenter
```

```

augmenter =
  audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
        NumAugmentations: 1
    TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
    PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
  VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
      AddNoiseProbability: 0
    TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]
    AddPinkNoiseProbability: 0.5000

```

Set the probability of adding pink noise to 1.

```
augmenter.AddPinkNoiseProbability = 1
```

```

augmenter =
  audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
        NumAugmentations: 1
    TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
    PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
  VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
      AddNoiseProbability: 0
    TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]
    AddPinkNoiseProbability: 1

```

Augment the original signal and listen to the result. Inspect parameters of the augmentation algorithms applied.

```

data = augment(augmenter, audioIn, fs);
sound(data.Audio{1}, fs)

```

```
data.AugmentationInfo(1)
```

```

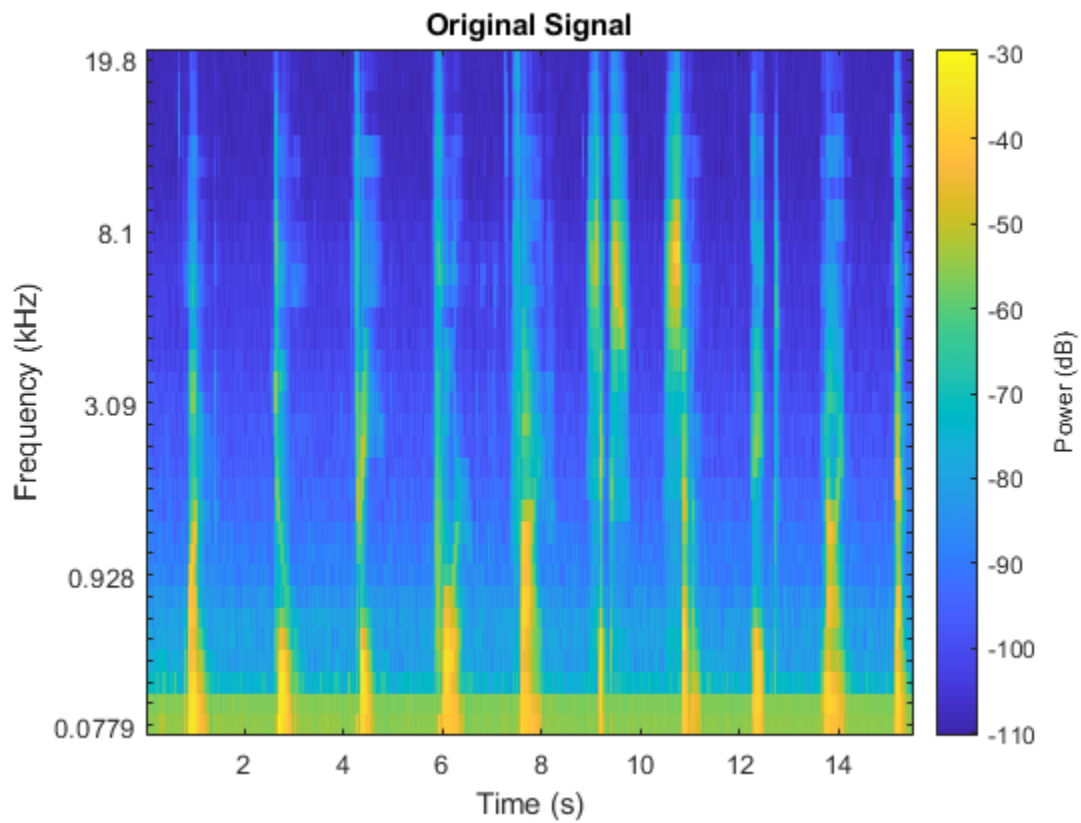
ans = struct with fields:
  SpeedupFactor: 1
  SemitoneShift: 0
  VolumeGain: 2.4803
  TimeShift: -0.0022

```

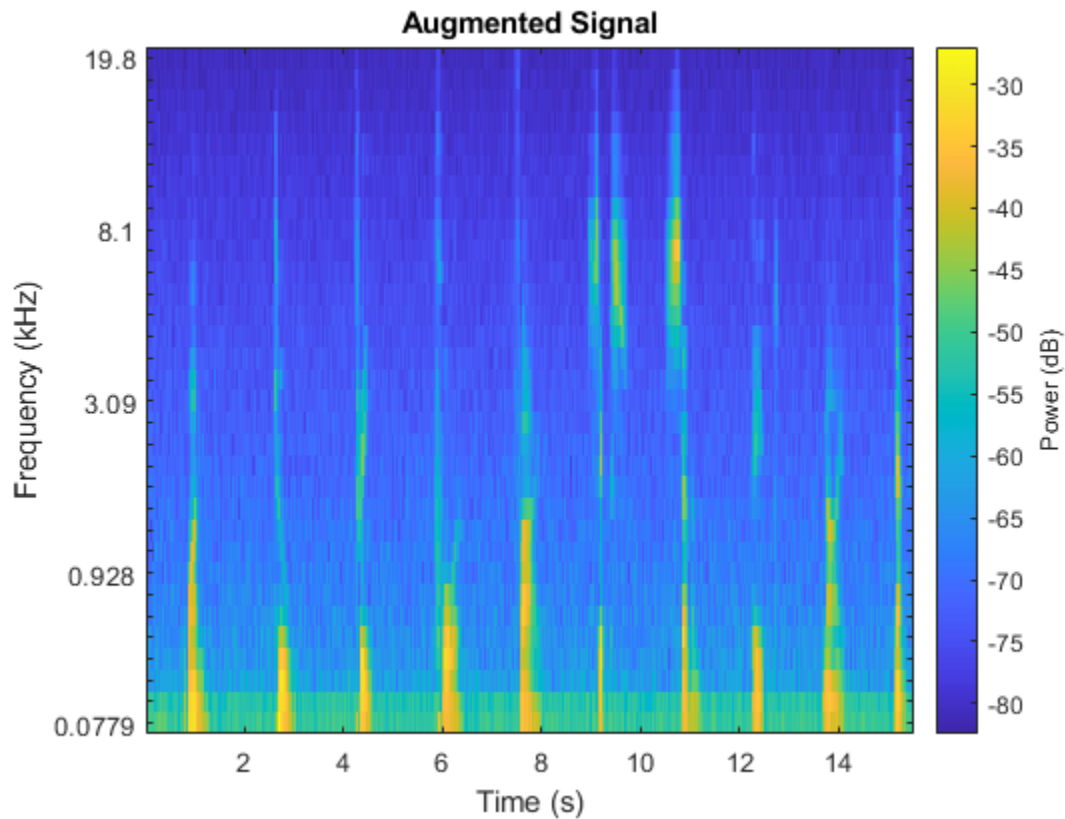
```
AddPinkNoise: 'Applied'
```

Plot the mel spectrograms of the original and augmented signals.

```
melSpectrogram(audioIn, fs)  
title('Original Signal')
```



```
melSpectrogram(data.Audio{1}, fs)  
title('Augmented Signal')
```



Specify Parameters of Custom Augmentation Method

In this example, you add a custom augmentation method that applies median filtering to your audio.

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn,fs)
```

Create a random sequential augmenter that adds noise with an SNR range of 5 dB to 10 dB. Set the probability of applying volume control, time stretching, pitch shifting, and time shifting to 0. Set NumAugmentations to 4 to create 4 separate augmentations.

```
aug = audioDataAugmenter('NumAugmentations',4, ...
    "AddNoiseProbability",1, ...
    "SNRRange",[5,10], ...
    "VolumeControlProbability",0, ...
    "TimeStretchProbability",0, ...
    "TimeShiftProbability",0, ...
    "PitchShiftProbability",0)
```

```
aug =
    audioDataAugmenter with properties:
        AugmentationMode: 'sequential'
```

```

AugmentationParameterSource: 'random'
    NumAugmentations: 4
    TimeStretchProbability: 0
    PitchShiftProbability: 0
    VolumeControlProbability: 0
    AddNoiseProbability: 1
        SNRRange: [5 10]
    TimeShiftProbability: 0

```

Call `addAugmentationMethod` with an algorithm name and function handle. Specify the algorithm name as `MedianFilter` and the function handle as `movmedian` with a 3-element window length. The augmentation is added to the properties of your `audioDataAugmenter` object.

```

algorithmName = 'MedianFilter';
algorithmHandle = @(x)(movmedian(x,100));
addAugmentationMethod(aug,algorithmName,algorithmHandle)

```

```
aug
```

```

aug =
    audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
    AugmentationParameterSource: 'random'
        NumAugmentations: 4
        TimeStretchProbability: 0
        PitchShiftProbability: 0
    VolumeControlProbability: 0
        AddNoiseProbability: 1
            SNRRange: [5 10]
        TimeShiftProbability: 0
    MedianFilterProbability: 0.5000

```

Set the probability of applying median filtering to 80%.

```
aug.MedianFilterProbability = 0.8
```

```

aug =
    audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
    AugmentationParameterSource: 'random'
        NumAugmentations: 4
        TimeStretchProbability: 0
        PitchShiftProbability: 0
    VolumeControlProbability: 0
        AddNoiseProbability: 1
            SNRRange: [5 10]
        TimeShiftProbability: 0
    MedianFilterProbability: 0.8000

```

Call `augment` on the audio to create 4 augmentations.

```
data = augment(aug, audioIn, fs);
```

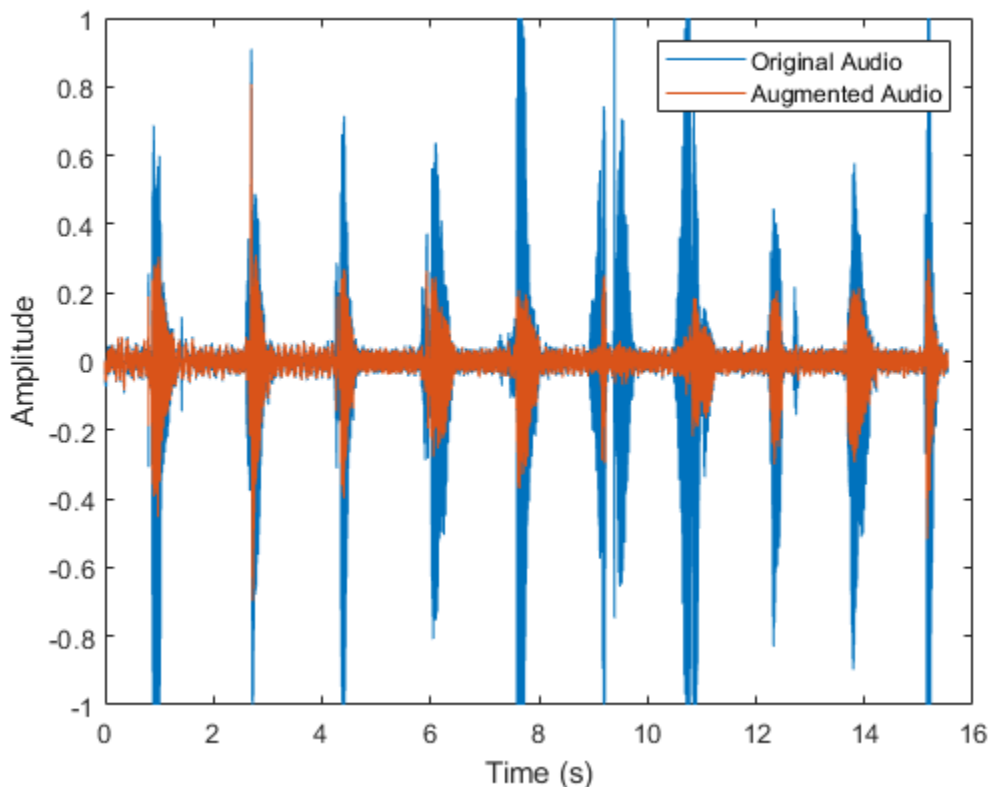
You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable. If median filtering was applied for an augmentation, then `AugmentationInfo` lists the parameter as 'Applied'. If median filtering was not applied for an augmentation, then `AugmentationInfo` lists the parameter as 'Bypassed'.

```
augmentationToInspect = 2;
data.AugmentationInfo(augmentationToInspect)

ans = struct with fields:
    SNR: 9.5787
    MedianFilter: 'Applied'
```

Listen to the audio you are inspecting. Plot the time-domain representation of the original and augmented signals.

```
augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)
t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")
```



You can specify additional parameters and corresponding parameter ranges (for use when `AugmentationParameterSource` is set to 'random') and parameter values (for use when

AugmentationParameterSource is set to 'specify'). You must specify additional parameters, parameter ranges, and parameter values during your call to addAugmentationMethod.

Call removeAugmentationMethod to remove the MedianFilter augmentation method. Call addAugmentationMethod again, this time specifying an augmentation parameter, parameter range, and parameter value. The augmentation and parameter range is added to the properties of your audioDataAugmenter object.

```
removeAugmentationMethod(aug, 'MedianFilter')

algorithmName = 'MedianFilter';
augmentationParameter = 'MedianFilterWindowLength';
parameterRange = [1,200];
parameterValue = 100;

algorithmHandle = @(x,k)(movmedian(x,k));
addAugmentationMethod(aug,algorithmName,algorithmHandle, ...
    'AugmentationParameter',augmentationParameter, ...
    'ParameterRange',parameterRange, ...
    'ParameterValue',parameterValue)

aug
```

```
aug =
  audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
        NumAugmentations: 4
    TimeStretchProbability: 0
    PitchShiftProbability: 0
  VolumeControlProbability: 0
    AddNoiseProbability: 1
                SNRRange: [5 10]
    TimeShiftProbability: 0
    MedianFilterProbability: 0.5000
  MedianFilterWindowLengthRange: [1 200]
```

In the current augmentation pipeline configuration, the parameter value is not applicable. ParameterValue is applicable when AugmentationParameterSource is set to 'specify'. Set AugmentationParameterSource to 'specify' to enable the current parameter value.

```
aug.AugmentationParameterSource = 'specify'

aug =
  audioDataAugmenter with properties:

        AugmentationMode: 'sequential'
  AugmentationParameterSource: 'specify'
    ApplyTimeStretch: 1
        SpeedupFactor: 0.8000
    ApplyPitchShift: 1
        SemitoneShift: -3
  ApplyVolumeControl: 1
        VolumeGain: -3
    ApplyAddNoise: 1
                SNR: 5
```

```

        ApplyTimeShift: 1
          TimeShift: 0.0050
    ApplyMedianFilter: 1
MedianFilterWindowLength: 100

```

Set `AugmentationParameterSource` to `random` and then call `augment`.

```

aug.AugmentationParameterSource = "random";
data = augment(aug, audioIn, fs);

```

If median filtering was applied for an augmentation, then `AugmentationInfo` lists the value applied.

```

augmentationToInspect = ;
data.AugmentationInfo(augmentationToInspect)

```

```

ans = struct with fields:
    SNR: 8.7701
    MedianFilter: 117.9847

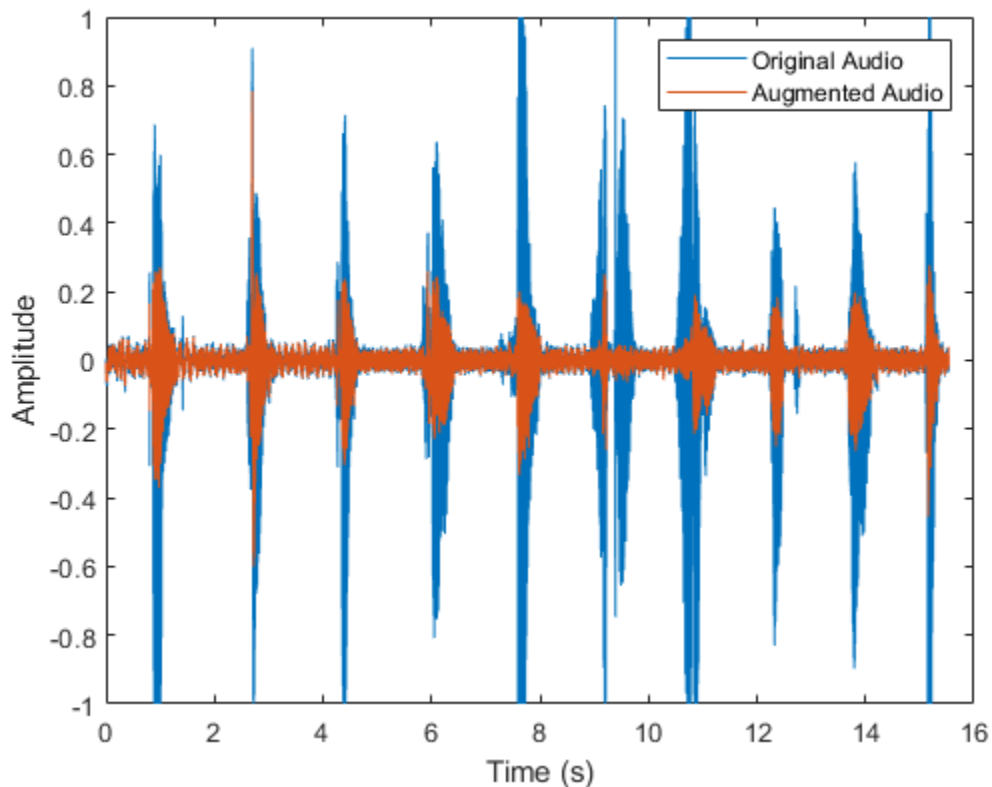
```

Listen to the audio you are inspecting. Plot the time-domain representation of the original and augmented signals.

```

augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)
t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Specify Multiple Parameters of Custom Augmentation Method

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread('RockDrums-44p1-stereo-11secs.mp3');
sound(audioIn,fs)
```

Create an `audioDataAugmenter` object that outputs 5 augmentations. Set the `AddNoiseProbability` to 0.

```
aug = audioDataAugmenter('NumAugmentations',5,'AddNoiseProbability',0);
```

Add reverberation as a custom augmentation algorithm. The `applyReverb` function creates a `reverbObject`, updates the sample rate, pre-delay, and wet/dry mix as indicated, and then applies reverberation. To minimize computational overhead, the `reverbObject` is persistent. The object is reset on every call to avoid mixing the reverberation tail between audio files.

type `applyReverb.m`

```
function audioOut = applyReverb(audio,preDelay,wetDryMix,sampleRate)
    persistent reverbObject
    if isempty(reverbObject)
        reverbObject = reverbator;
    end
    reverbObject.SampleRate = sampleRate;
```



```

    reverbObject.PreDelay = preDelay;
    reverbObject.WetDryMix = wetDryMix;

    audioOut = reverbObject(audio);
    reset(reverbObject)
end

```

Add `applyReverb` as a custom augmentation method. To specify multiple parameters for a custom method, specify the parameters, parameter ranges, and parameter values as cell arrays with the same number of cells. Set the probability of applying reverberation to 1.

```

algorithmName = 'Reverb';
algorithmHandle = @(x,preDelay,weDryMix)applyReverb(x,preDelay,weDryMix,fs);
parameters = {'PreDelay','WetDryMix'};
parameterRanges = {[0,1],[0,1]};
parameterValues = {0,0.3};

```

```

addAugmentationMethod(aug,algorithmName,algorithmHandle, ...
    'AugmentationParameter',parameters, ...
    'ParameterRange',parameterRanges, ...
    'ParameterValue',parameterValues)

```

```
aug.ReverbProbability = 1
```

```

aug =
  audioDataAugmenter with properties:

    AugmentationMode: 'sequential'
    AugmentationParameterSource: 'random'
    NumAugmentations: 5
    TimeStretchProbability: 0.5000
    SpeedupFactorRange: [0.8000 1.2000]
    PitchShiftProbability: 0.5000
    SemitoneShiftRange: [-2 2]
    VolumeControlProbability: 0.5000
    VolumeGainRange: [-3 3]
    AddNoiseProbability: 0
    TimeShiftProbability: 0.5000
    TimeShiftRange: [-0.0050 0.0050]
    ReverbProbability: 1
    PreDelayRange: [0 1]
    WetDryMixRange: [0 1]

```

Call `augment` to create 5 augmentations.

```
data = augment(aug,audioIn,fs);
```

Check the configuration of each augmentation using `AugmentationInfo`.

```

augmentationToInspect = ;
data.AugmentationInfo(augmentationToInspect)

```

```

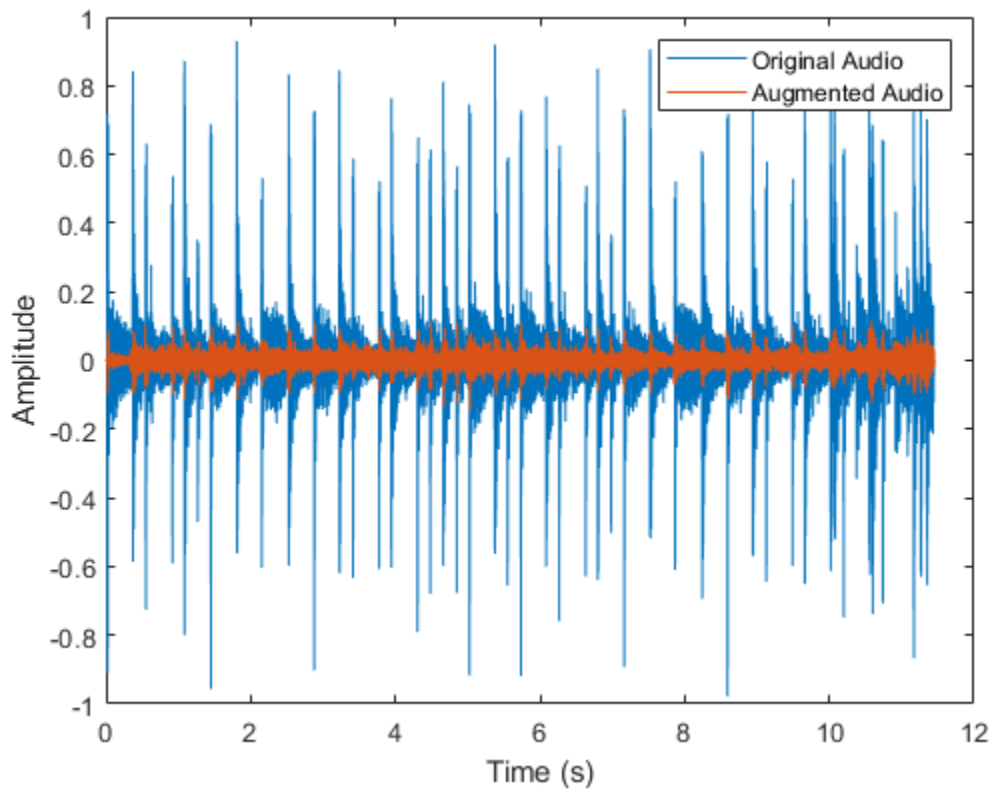
ans = struct with fields:
    SpeedupFactor: 1
    SemitoneShift: -1.4325
    VolumeGain: 0
    TimeShift: 0

```

```
Reverb: [0.2760 0.4984]
```

Listen to the audio you are inspecting. Plot the time-domain representation of the original and augmented signals.

```
augmentation = data.Audio{augmentationToInspect};  
sound(augmentation,fs)  
t = (0:(size(audioIn,1)-1))/fs;  
taug = (0:(size(augmentation,1)-1))/fs;  
plot(t,audioIn(:,1),taug,augmentation(:,1))  
legend("Original Audio","Augmented Audio")  
ylabel("Amplitude")  
xlabel("Time (s)")
```



Input Arguments

aug — Audio data augmenter

audioDataAugmenter object

audioDataAugmenter object.

algorithmName — Algorithm name

character vector | string

Algorithm name, specified as a character vector or string. `algorithmName` must be a unique property name on the `audioDataAugmenter`, `aug`.

Data Types: `char` | `string`

algorithmHandle — Handle to function that implements custom augmentation algorithm
`function_handle`

Handle to function that implements custom augmentation algorithm, specified as a `function_handle`.

Data Types: `function_handle`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `'AugmentationParameter','PreDelay'`

AugmentationParameter — Augmentation parameter

`character vector` | `string` | `cell array of character vectors` | `cell array of strings`

Augmentation parameter, specified as a character vector, string, cell array of character vectors, or cell array of strings.

Use cell arrays to create multiple augmentation parameters. If you create multiple augmentation parameters, you must also specify `ParameterRange` and `ParameterValue` as cell arrays containing information for each augmentation parameter.

Example: `'AugmentationParameter','PreDelay'`

Example: `'AugmentationParameter',{'PreDelay','HighCutFrequency'}`

Data Types: `char` | `string`

ParameterRange — Parameter range

`[0,1]` (default) | `two-element vector of nondecreasing values` | `cell array of two-element vectors of nondecreasing values`

Parameter range, specified as a two-element vector of nondecreasing values (for a single parameter) or a cell array of two-element vectors of nondecreasing values (for multiple parameters).

Example: `'ParameterRange',[0,1]`

Example: `'ParameterRange',{'[0,1]','[20,20000]'}`

Dependencies

To enable this property, set the `AugmentationParameterSource` property of your `audioDataAugmenter` object to `'random'`.

Data Types: `single` | `double` | `cell`

ParameterValue — Parameter value

`0` (default) | `scalar` | `vector` | `cell array of scalars or vectors`

Parameter value, specified as a scalar, vector, or cell array of scalars or vectors.

Example: 'ParameterValue',0

Example: 'ParameterValue',[0,0.5,1]

Example: 'ParameterValue',{0,20000}

Example: 'ParameterValue',{[0,0.5,1],20000}

Dependencies

To enable this property, set the `AugmentationParameterSource` property of your `audioDataAugmenter` to 'specify'.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Complex Number Support: Yes

See Also

`removeAugmentationMethod` | `audioDataAugmenter` | `reverberator`

Introduced in R2019b

setAugmenterParams

Set parameters of augmentation algorithm

Syntax

```
setAugmenterParams(aug, algorithmName, params)
setAugmenterParams(aug, algorithmName)
```

Description

`setAugmenterParams(aug, algorithmName, params)` sets parameters of the augmentation algorithm associated with the `audioDataAugmenter` object.

`setAugmenterParams(aug, algorithmName)` without the `params` argument restores the `algorithmName` parameters to their default values.

Examples

Set Augmenter Parameters

Modify the default parameters of the `shiftPitch` and `stretchAudio` augmentation algorithms.

Read in an audio signal and listen to it.

```
[audioIn, fs] = audioread('FemaleSpeech-16-8-mono-3secs.wav');
soundsc(audioIn, fs)
```

Create an `audioDataAugmenter` object that applies a pitch shift of 3 semitones and a time stretch with a `SpeedupFactor` of 1.5.

```
aug = audioDataAugmenter('AugmentationParameterSource', 'specify', ...
    'ApplyPitchShift', true, ...
    'SemitoneShift', 3, ...
    'ApplyTimeStretch', true, ...
    'SpeedupFactor', 1.5, ...
    'ApplyVolumeControl', false, ...
    'ApplyAddNoise', false, ...
    'ApplyTimeShift', false)
```

```
aug =
    audioDataAugmenter with properties:
```

```
    AugmentationMode: 'sequential'
    AugmentationParameterSource: 'specify'
    ApplyTimeStretch: 1
    SpeedupFactor: 1.5000
    ApplyPitchShift: 1
    SemitoneShift: 3
    ApplyVolumeControl: 0
    ApplyAddNoise: 0
```

```
ApplyTimeShift: 0
```

Call `setAugmenterParams` to set the `LockPhase` and `PreserveFormants` parameters of the `shiftPitch` augmentation algorithm to `false`. Set the `LockPhase` parameter of the `stretchAudio` augmentation algorithm to `false`. Set the `CepstralOrder` parameter of the `shiftPitch` algorithm to 30.

Augment the original signal and listen to the result. The resulting file has an audible distortion that sounds unnatural. View the parameters of the augmentation algorithms.

```
setAugmenterParams(aug, 'shiftPitch', 'LockPhase', false, 'PreserveFormants', false, 'CepstralOrder', 30);
setAugmenterParams(aug, 'stretchAudio', 'LockPhase', false);
data = augment(aug, audioIn, fs);
```

```
pause(3)
```

```
augmentationPre = data.Audio{1};
soundsc(augmentationPre, fs)
```

```
data.AugmentationInfo(1)
```

```
ans = struct with fields:
    SpeedupFactor: 1.5000
    SemitoneShift: 3
```

```
augmenterParamsPre = getAugmenterParams(aug);
augmenterParamsPre.stretchAudio
```

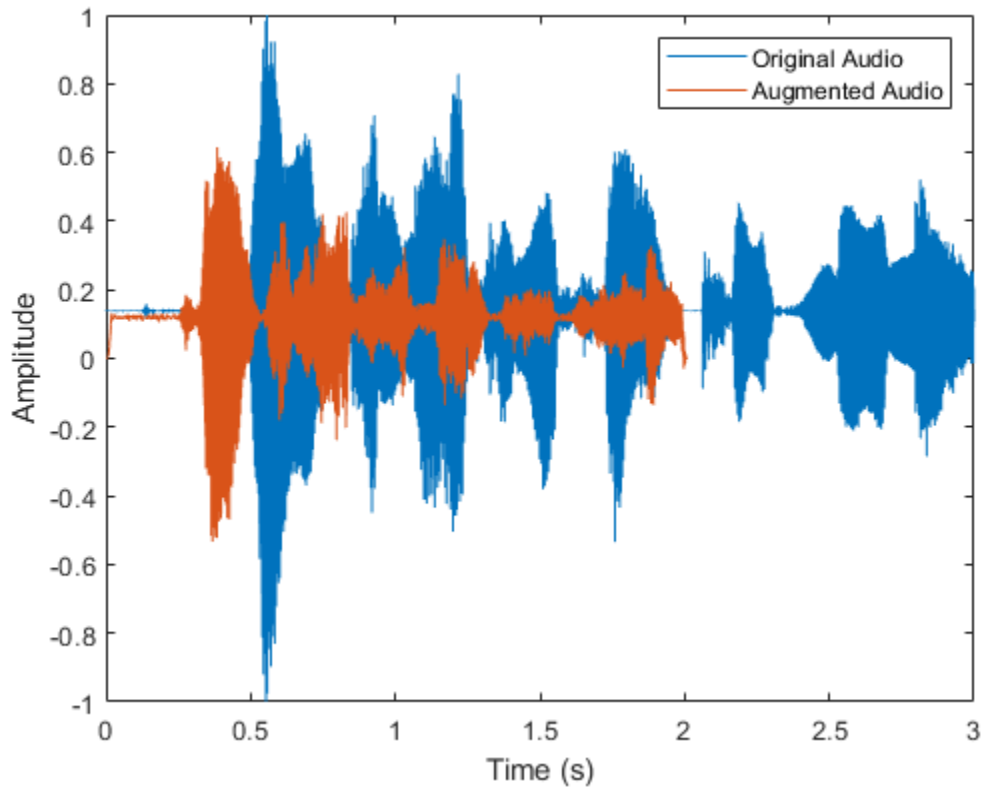
```
ans = struct with fields:
    LockPhase: 0
```

```
augmenterParamsPre.shiftPitch
```

```
ans = struct with fields:
    LockPhase: 0
    PreserveFormants: 0
    CepstralOrder: 30
```

Plot the time-domain representation of the original and the augmented signals.

```
t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentationPre)-1))/fs;
plot(t, audioIn, taug, augmentationPre)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")
```



To partially compensate for the audible distortion and increase the fidelity of the augmentation algorithms, apply formant preservation to the `shiftPitch` algorithm, apply phase-locking to both algorithms, and change the cepstral order of the `shiftPitch` algorithm to 25. Listen to the processed audio.

```
setAugmenterParams(aug, 'shiftPitch', 'LockPhase', true, 'PreserveFormants', true, 'CepstralOrder', 25)
setAugmenterParams(aug, 'stretchAudio', 'LockPhase', true);
data = augment(aug, audioIn, fs);
```

```
augmentationPost = data.Audio{1};
soundsc(augmentationPost, fs)
```

```
data.AugmentationInfo(1)
```

```
ans = struct with fields:
  SpeedupFactor: 1.5000
  SemitoneShift: 3
```

```
augmenterParamsPost = getAugmenterParams(aug);
augmenterParamsPost.stretchAudio
```

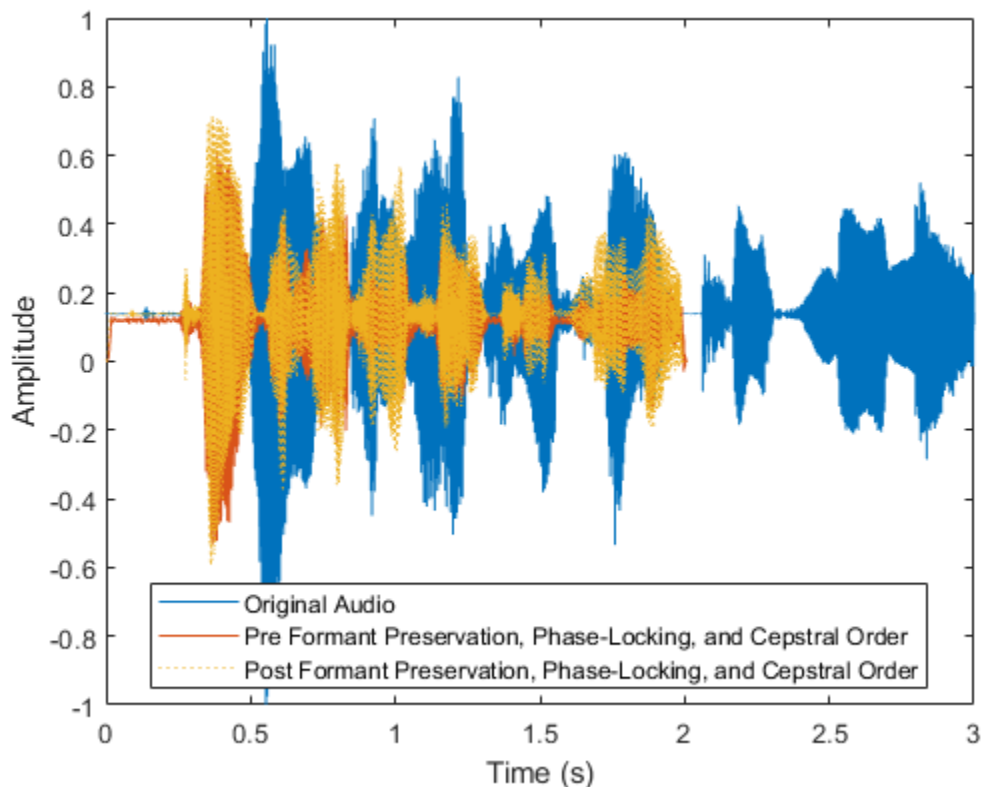
```
ans = struct with fields:
  LockPhase: 1
```

```
augmenterParamsPost.shiftPitch
```

```
ans = struct with fields:
    LockPhase: 1
    PreserveFormants: 1
    CepstralOrder: 25
```

Plot the original audio as well as the augmented data before and after formant preservation, phase-locking, and cepstral order modification.

```
taug = (0:(numel(augmentationPost)-1))/fs;
plot(t, audioIn, taug, augmentationPre)
hold on
plot(taug, augmentationPost, 'LineStyle', ':')
legend("Original Audio", "Pre Formant Preservation, Phase-Locking, and Cepstral Order", ...
       "Post Formant Preservation, Phase-Locking, and Cepstral Order")
ylabel("Amplitude")
xlabel("Time (s)")
legend('Location', 'best')
```



Return the augmentation algorithm parameters to their default values. Call `getAugmenterParams` to display the current parameter values for the `audioAugmenter` object.

```
setAugmenterParams(aug, 'shiftPitch')
setAugmenterParams(aug, 'stretchAudio')
augmenterParamsDefault = getAugmenterParams(aug);
augmenterParamsDefault.stretchAudio
```



```
ans = struct with fields:
    LockPhase: 0
```

```
augmenterParamsDefault.shiftPitch
```

```
ans = struct with fields:
    LockPhase: 0
    PreserveFormants: 0
    CepstralOrder: 30
```

Input Arguments

aug — Audio data augmenter

audioDataAugmenter object

Audio data augmenter, specified as an audioDataAugmenter object.

algorithmName — Algorithm name

'stretchAudio' | 'shiftPitch'

Algorithm name, specified as 'stretchAudio' or 'shiftPitch'.

Note Augmentation algorithms must be modified independently using separate calls to setAugmenterParams for each algorithm.

Data Types: char | string

params — Parameter used with augmentation algorithm

character vector | string | structure array

Parameter name, specified as a character vector, string, or structure array. Parameter values depend on algorithmName. Specify params as one of these:

- When you set algorithmName to 'stretchAudio', specify params as 'LockPhase' and true or false.
- When you set algorithmName to 'shiftPitch', specify params as one or all of these:
 - 'LockPhase' and true or false
 - 'PreserveFormants' and true or false
 - 'CepstralOrder' and a positive integer

Example:

```
setAugmenterParams(aug, 'shiftPitch', 'LockPhase', true, 'PreserveFormants', false, 'CepstralOrder', 15) enables the LockPhase parameter, disables the PreserveFormants parameter, and sets a cepstral order of 15 for the shiftPitch augmentation algorithm.
```

Data Types: char | string | struct

See Also

removeAugmentationMethod | augment | getAugmenterParams | addAugmentationMethod | audioDataAugmenter

Introduced in R2021a

getAugmenterParams

Get parameters of augmentation algorithm

Syntax

```
augmenterParams = getAugmenterParams(aug,algorithmName)
augmenterParams = getAugmenterParams(aug)
```

Description

`augmenterParams = getAugmenterParams(aug,algorithmName)` returns parameters of the augmentation algorithm associated with the `audioDataAugmenter` object.

`augmenterParams = getAugmenterParams(aug)` returns the parameters of all augmentation algorithms associated with the `audioDataAugmenter` object.

Examples

Set Augmenter Parameters

Modify the default parameters of the `shiftPitch` and `stretchAudio` augmentation algorithms.

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread('FemaleSpeech-16-8-mono-3secs.wav');
soundsc(audioIn,fs)
```

Create an `audioDataAugmenter` object that applies a pitch shift of 3 semitones and a time stretch with a `SpeedupFactor` of 1.5.

```
aug = audioDataAugmenter('AugmentationParameterSource','specify', ...
    'ApplyPitchShift',true, ...
    'SemitoneShift',3, ...
    'ApplyTimeStretch',true, ...
    'SpeedupFactor',1.5, ...
    'ApplyVolumeControl',false, ...
    'ApplyAddNoise',false, ...
    'ApplyTimeShift',false)
```

```
aug =
    audioDataAugmenter with properties:
```

```
    AugmentationMode: 'sequential'
AugmentationParameterSource: 'specify'
    ApplyTimeStretch: 1
    SpeedupFactor: 1.5000
    ApplyPitchShift: 1
    SemitoneShift: 3
    ApplyVolumeControl: 0
    ApplyAddNoise: 0
```

```
ApplyTimeShift: 0
```

Call `setAugmenterParams` to set the `LockPhase` and `PreserveFormants` parameters of the `shiftPitch` augmentation algorithm to `false`. Set the `LockPhase` parameter of the `stretchAudio` augmentation algorithm to `false`. Set the `CepstralOrder` parameter of the `shiftPitch` algorithm to 30.

Augment the original signal and listen to the result. The resulting file has an audible distortion that sounds unnatural. View the parameters of the augmentation algorithms.

```
setAugmenterParams(aug, 'shiftPitch', 'LockPhase', false, 'PreserveFormants', false, 'CepstralOrder', 30);
setAugmenterParams(aug, 'stretchAudio', 'LockPhase', false);
data = augment(aug, audioIn, fs);
```

```
pause(3)
```

```
augmentationPre = data.Audio{1};
soundsc(augmentationPre, fs)
```

```
data.AugmentationInfo(1)
```

```
ans = struct with fields:
    SpeedupFactor: 1.5000
    SemitoneShift: 3
```

```
augmenterParamsPre = getAugmenterParams(aug);
augmenterParamsPre.stretchAudio
```

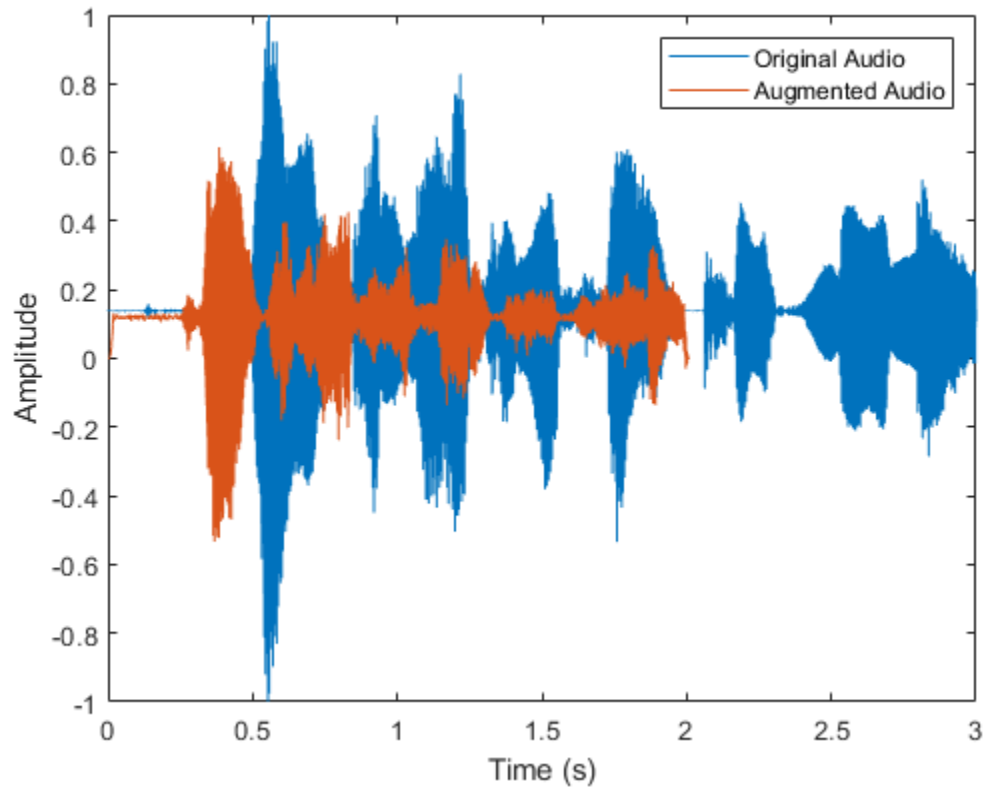
```
ans = struct with fields:
    LockPhase: 0
```

```
augmenterParamsPre.shiftPitch
```

```
ans = struct with fields:
    LockPhase: 0
    PreserveFormants: 0
    CepstralOrder: 30
```

Plot the time-domain representation of the original and the augmented signals.

```
t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentationPre)-1))/fs;
plot(t, audioIn, taug, augmentationPre)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")
```



To partially compensate for the audible distortion and increase the fidelity of the augmentation algorithms, apply formant preservation to the `shiftPitch` algorithm, apply phase-locking to both algorithms, and change the cepstral order of the `shiftPitch` algorithm to 25. Listen to the processed audio.

```
setAugmenterParams(aug, 'shiftPitch', 'LockPhase', true, 'PreserveFormants', true, 'CepstralOrder', 25)
setAugmenterParams(aug, 'stretchAudio', 'LockPhase', true);
data = augment(aug, audioIn, fs);
```

```
augmentationPost = data.Audio{1};
soundsc(augmentationPost, fs)
```

```
data.AugmentationInfo(1)
```

```
ans = struct with fields:
  SpeedupFactor: 1.5000
  SemitoneShift: 3
```

```
augmenterParamsPost = getAugmenterParams(aug);
augmenterParamsPost.stretchAudio
```

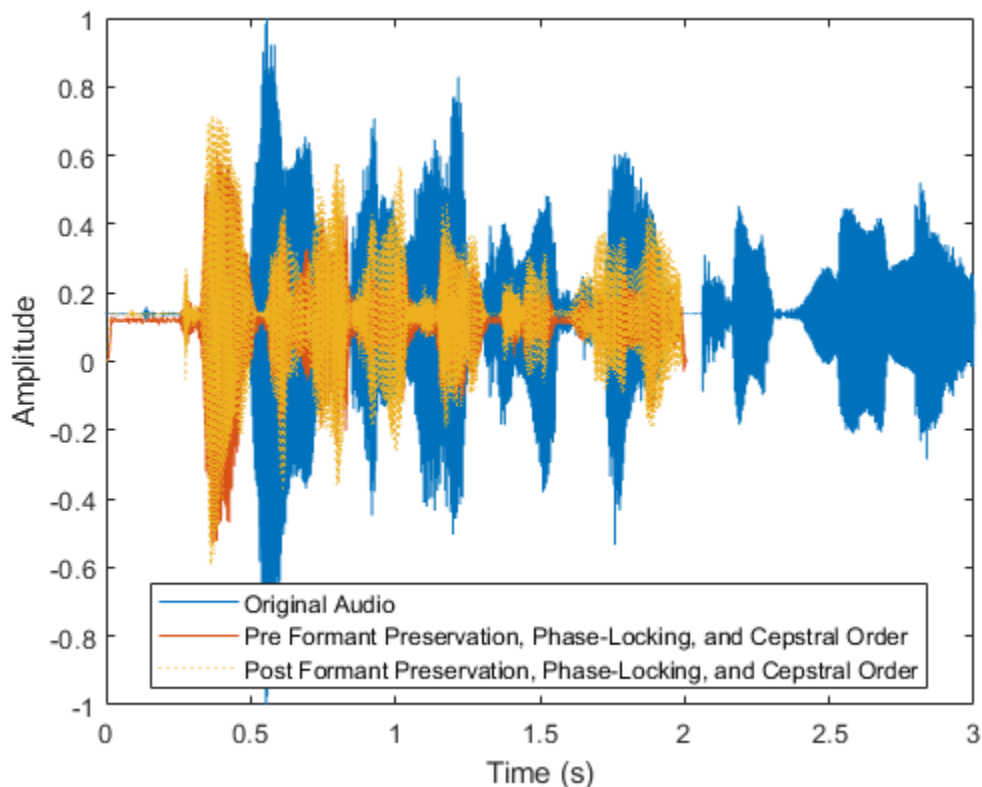
```
ans = struct with fields:
  LockPhase: 1
```

```
augmenterParamsPost.shiftPitch
```

```
ans = struct with fields:
    LockPhase: 1
    PreserveFormants: 1
    CepstralOrder: 25
```

Plot the original audio as well as the augmented data before and after formant preservation, phase-locking, and cepstral order modification.

```
taug = (0:(numel(augmentationPost)-1))/fs;
plot(t, audioIn, taug, augmentationPre)
hold on
plot(taug, augmentationPost, 'LineStyle', ':')
legend("Original Audio", "Pre Formant Preservation, Phase-Locking, and Cepstral Order", ...
       "Post Formant Preservation, Phase-Locking, and Cepstral Order")
ylabel("Amplitude")
xlabel("Time (s)")
legend('Location', 'best')
```



Return the augmentation algorithm parameters to their default values. Call `getAugmenterParams` to display the current parameter values for the `audioAugmenter` object.

```
setAugmenterParams(aug, 'shiftPitch')
setAugmenterParams(aug, 'stretchAudio')
augmenterParamsDefault = getAugmenterParams(aug);
augmenterParamsDefault.stretchAudio
```

```
ans = struct with fields:  
    LockPhase: 0
```

```
augmenterParamsDefault.shiftPitch
```

```
ans = struct with fields:  
    LockPhase: 0  
    PreserveFormants: 0  
    CepstralOrder: 30
```

Input Arguments

aug — Audio data augmenter

audioDataAugmenter object

Audio data augmenter, specified as an audioDataAugmenter object.

algorithmName — Algorithm name

'stretchAudio' | 'shiftPitch'

Algorithm name, specified as 'stretchAudio' or 'shiftPitch'.

Data Types: char | string

Output Arguments

augmenterParams — Audio augmenter parameters

structure array

Audio augmenter parameters, returned as a structure array.

Data Types: struct

See Also

removeAugmentationMethod | augment | setAugmenterParams | addAugmentationMethod | audioDataAugmenter

Introduced in R2021a

audioDataAugmenter

Augment audio data

Description

Enlarge your audio dataset using audio-specific augmentation techniques like pitch shifting, time-scale modification, time shifting, noise addition, and volume control. You can create cascaded or parallel augmentation pipelines to apply multiple algorithms deterministically or probabilistically.

Creation

Syntax

```
aug = audioDataAugmenter()  
aug = audioDataAugmenter(Name, Value)
```

Description

`aug = audioDataAugmenter()` creates an audio data augmenter object with default property values.

`aug = audioDataAugmenter(Name, Value)` specifies nondefault properties for `aug` using one or more name-value arguments.

Properties

Augmentation Pipeline

AugmentationMode — Augmentation mode

'sequential' (default) | 'independent'

Augmentation mode, specified as 'sequential' or 'independent'.

- 'sequential' -- Augmentation algorithms are applied sequentially (in series).
- 'independent' -- Augmentation algorithms are applied independently (in parallel).

Data Types: char | string

AugmentationParameterSource — Source of augmentation parameters

'random' (default) | 'specify'

Source of augmentation parameters, specified as 'random' or 'specify'.

- 'random' -- Augmentation algorithms are applied probabilistically using a probability parameter and a range parameter.

For example, to create an `audioDataAugmenter` that applies time-stretching using a speedup factor between 0.5 and 1.5 with a 60% probability, enter the following in the Command Window:


```
aug = audioDataAugmenter('AugmentationParameterSource','random', ...
                        'TimeStretchProbability',0.6, ...
                        'SpeedupFactorRange',[0.5,1.5]);
```

When time-stretching is applied, the speedup factor is drawn from a uniform distribution centered at 1 (the mean of the range) with a minimum of 0.5 and a maximum of 1.5.

- 'specify' -- Augmentation algorithms are applied deterministically using a logical parameter and a specified parameter value. For example, to create an `audioDataAugmenter` that applies time-stretching using a 1.5 speedup factor with a 100% probability, enter the following in the Command Window:

```
aug = audioDataAugmenter('AugmentationParameterSource','specify', ...
                        'ApplyTimeStretch',true, ...
                        'SpeedupFactor',1.5);
```

Data Types: char | string

NumAugmentations — Number of augmented signals to output

1 (default) | positive integer

Number of augmented signals to output, specified as a positive integer.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'random'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Stretch Time

TimeStretchProbability — Probability of applying time stretch

0.5 (default) | scalar in the range [0, 1]

Probability of applying time stretch, specified as a scalar in the range [0, 1]. Set the probability to 1 to apply time stretching every time you call `augment`. Set the probability to 0 to skip time stretching every time you call `augment`.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'random' and `AugmentationMode` to 'sequential'.

Data Types: single | double

SpeedupFactorRange — Range of time stretch speedup factor

[0.8 1.2] (default) | two-element row vector of positive nondecreasing values

Range of time stretch speedup factor, specified as a two-element row vector of positive nondecreasing values.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'random'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

ApplyTimeStretch — Apply time stretch

true (default) | false

Apply time stretch, specified as `true` or `false`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `logical`

SpeedupFactor — Time stretch speedup factor

0.8 (default) | real positive scalar | real positive vector

Time stretch speedup factor, specified as a scalar or vector of real positive values.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Shift Pitch**PitchShiftProbability — Probability of applying pitch shift**

0.5 (default) | scalar in the range [0, 1]

Probability of applying pitch shift, specified as a scalar in the range [0, 1]. Set the probability to 1 to apply pitch shifting every time you call `augment`. Set the probability to 0 to skip pitch shifting every time you call `augment`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'random'` and `AugmentationMode` to `'sequential'`.

Data Types: `single` | `double`

SemitoneShiftRange — Range of pitch shift (semitones)

[-2, 2] (default) | two-element row vector of nondecreasing values

Range of pitch shift in semitones, specified as a two-element row vector of nondecreasing values.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'random'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ApplyPitchShift — Apply pitch shift

`true` (default) | `false`

Apply pitch shift, specified as `true` or `false`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `logical`

SemitoneShift — Pitch shift (semitones)

-3 (default) | real scalar | real vector

Pitch shift in semitones, specified as a real scalar or vector.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Control Volume

VolumeControlProbability — Probability of applying volume control

0.5 (default) | scalar in the range [0, 1]

Probability of applying volume control, specified as a scalar in the range [0, 1]. Set the probability to 1 to apply volume control every time you call `augment`. Set the probability to 0 to skip volume control every time you call `augment`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'random'` and `AugmentationMode` to `'sequential'`.

Data Types: `single` | `double`

VolumeGainRange — Range of volume gain (dB)

[-3, 3] (default) | two-element row vector of nondecreasing values

Range of volume gain in dB, specified as a two-element row vector of nondecreasing values.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'random'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ApplyVolumeControl — Apply volume gain

true (default) | false

Apply volume gain, specified as `true` or `false`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `logical`

VolumeGain — Volume gain (dB)

-3 (default) | scalar | vector

Volume gain in dB, specified as a scalar or vector.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Add Noise

AddNoiseProbability — Probability of applying noise addition

0.5 (default) | scalar in the range [0, 1]

Probability of applying Gaussian white noise addition, specified as a scalar in the range [0, 1]. Set the probability to 1 to add noise every time you call `augment`. Set the probability to 0 to skip adding noise every time you call `augment`.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'random' and `AugmentationMode` to 'sequential'.

Data Types: `single` | `double`

SNRRange — Range of noise addition SNR (dB)

[0, 10] (default) | two-element row vector of nondecreasing values

Range of noise addition SNR in dB, specified as a two-element row vector of nondecreasing values.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'range'.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ApplyAddNoise — Apply noise addition

true (default) | false

Apply Gaussian white noise addition, specified as true or false.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'specify'.

Data Types: `logical`

SNR — Noise addition SNR (dB)

5 (default) | scalar | vector

Noise addition SNR in dB, specified as a scalar or vector.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Shift Time**TimeShiftProbability — Probability of applying time shift**

0.5 (default) | scalar in the range [0, 1]

Probability of applying time shift, specified as a scalar in the range [0, 1]. Set the probability to 1 to apply time shifting every time you call `augment`. Set the property to 0 to skip time shifting every time you call `augment`.

Time-shifting applies a circular shift on the time-domain audio data.

Dependencies

To enable this property, set `AugmentationParameterSource` to 'random' and `AugmentationMode` to 'sequential'.

Data Types: `single` | `double`

TimeShiftRange — Range of time shift (s)

[-5e-3, 5e3] (default) | two-element row vector of nondecreasing values.

Range of time shift in seconds, specified as a two-element row vector of nondecreasing values.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'random'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ApplyTimeShift — Apply time shift

`true` (default) | `false`

Apply time shift, specified as `true` or `false`.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Time-shifting applies a circular shift on the time-domain audio data.

Data Types: `logical`

TimeShift — Time shift (s)

`5e-3` (default) | `scalar` | `vector`

Time shift in seconds, specified as a scalar or vector.

Dependencies

To enable this property, set `AugmentationParameterSource` to `'specify'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Object Functions

<code>addAugmentationMethod</code>	Add custom augmentation method
<code>removeAugmentationMethod</code>	Remove custom augmentation method
<code>augment</code>	Augment audio data
<code>setAugmenterParams</code>	Set parameters of augmentation algorithm
<code>getAugmenterParams</code>	Get parameters of augmentation algorithm

Examples

Apply Random Sequential Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn,fs)
```

Create an `audioDataAugmenter` object that applies time stretching, volume control, and time shifting in cascade. Apply each of the augmentations with 80% probability. Set `NumAugmentations` to 5 to output five independently augmented signals. To skip pitch shifting and noise addition for each augmentation, set the respective probabilities to 0. Define parameter ranges for each relevant augmentation algorithm.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode","sequential", ...
```

```

    "NumAugmentations",5, ...
    ...
    "TimeStretchProbability",0.8, ...
    "SpeedupFactorRange", [1.3,1.4], ...
    ...
    "PitchShiftProbability",0, ...
    ...
    "VolumeControlProbability",0.8, ...
    "VolumeGainRange",[-5,5], ...
    ...
    "AddNoiseProbability",0, ...
    ...
    "TimeShiftProbability",0.8, ...
    "TimeShiftRange", [-500e-3,500e-3])

augmenter =
    audioDataAugmenter with properties:

        AugmentationMode: "sequential"
        AugmentationParameterSource: 'random'
        NumAugmentations: 5
        TimeStretchProbability: 0.8000
        SpeedupFactorRange: [1.3000 1.4000]
        PitchShiftProbability: 0
        VolumeControlProbability: 0.8000
        VolumeGainRange: [-5 5]
        AddNoiseProbability: 0
        TimeShiftProbability: 0.8000
        TimeShiftRange: [-0.5000 0.5000]

```

Call `augment` on the audio to create 5 augmentations. The augmented audio is returned in a table with variables `Audio` and `AugmentationInfo`. The number of rows in the table is defined by `NumAugmentations`.

```

data = augment(augmenter, audioIn, fs)

data=5x2 table
      Audio          AugmentationInfo
-----
{685056x1 double}   1x1 struct
{685056x1 double}   1x1 struct
{505183x1 double}   1x1 struct
{685056x1 double}   1x1 struct
{490728x1 double}   1x1 struct

```

In the current augmentation pipeline, augmentation parameters are assigned randomly from within the specified ranges. To determine the exact parameters used for an augmentation, inspect `AugmentationInfo`.

```

augmentationToInspect = ;
data.AugmentationInfo(augmentationToInspect)

ans = struct with fields:
    SpeedupFactor: 1

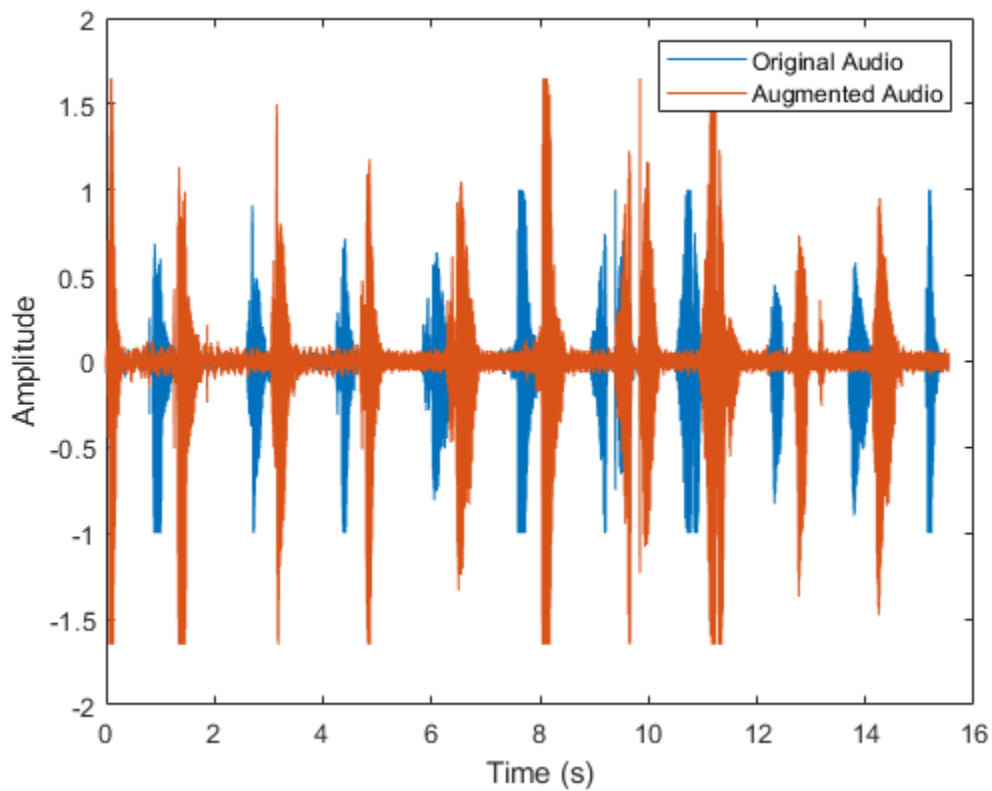
```

```
VolumeGain: 4.3399
TimeShift: 0.4502
```

Listen to the augmentation you are inspecting. Plot time representation of the original and augmented signals.

```
augmentation = data.Audio{augmentationToInspect};
sound(augmentation,fs)
```

```
t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t,audioIn,taug,augmentation)
legend("Original Audio","Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")
```



Apply Specified Sequential Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
sound(audioIn,fs)
```

Create an `audioDataAugmenter` object that applies time stretching, pitch shifting, and noise corruption in cascade. Specify the time stretch speedup factors as 0.9, 1.1, and 1.2. Specify the pitch shifting in semitones as -2, -1, 1, and 2. Specify the noise corruption SNR as 10 dB and 15 dB.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode", "sequential", ...
    "AugmentationParameterSource", "specify", ...
    "SpeedupFactor", [0.9, 1.1, 1.2], ...
    "ApplyTimeStretch", true, ...
    "ApplyPitchShift", true, ...
    "SemitoneShift", [-2, -1, 1, 2], ...
    "SNR", [10, 15], ...
    "ApplyVolumeControl", false, ...
    "ApplyTimeShift", false)
```

```
augmenter =
    audioDataAugmenter with properties:
```

```

    AugmentationMode: "sequential"
    AugmentationParameterSource: "specify"
    ApplyTimeStretch: 1
    SpeedupFactor: [0.9000 1.1000 1.2000]
    ApplyPitchShift: 1
    SemitoneShift: [-2 -1 1 2]
    ApplyVolumeControl: 0
    ApplyAddNoise: 1
    SNR: [10 15]
    ApplyTimeShift: 0
```

Call `augment` on the audio to create 24 augmentations. The augmentations represent every combination of the specified augmentation parameters ($3 \times 4 \times 2 = 24$).

```
data = augment(augmenter, audioIn, fs)
```

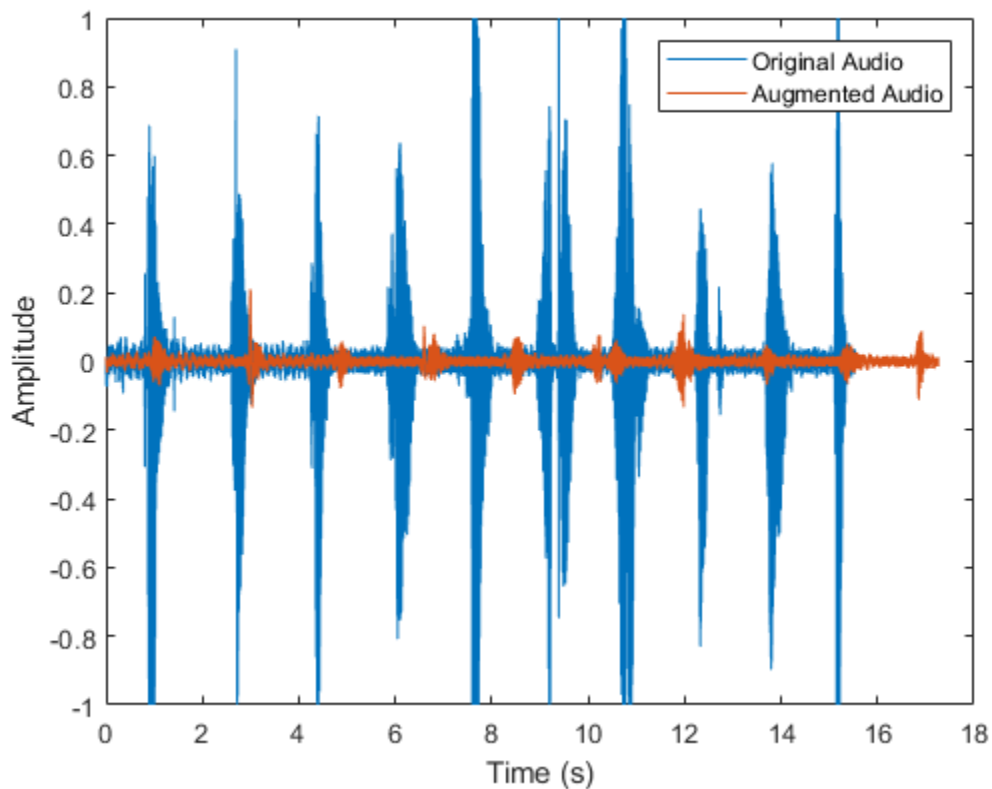
```
data=24x2 table
    Audio          AugmentationInfo
-----
{761243x1 double} 1x1 struct
{622888x1 double} 1x1 struct
{571263x1 double} 1x1 struct
{761243x1 double} 1x1 struct
{622888x1 double} 1x1 struct
{571263x1 double} 1x1 struct
{761243x1 double} 1x1 struct
{622888x1 double} 1x1 struct
{571263x1 double} 1x1 struct
{761243x1 double} 1x1 struct
{622888x1 double} 1x1 struct
{571263x1 double} 1x1 struct
{761243x1 double} 1x1 struct
{622888x1 double} 1x1 struct
{571263x1 double} 1x1 struct
{761243x1 double} 1x1 struct
:
```


You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```
augmentationToInspect = 1;  
data.AugmentationInfo(augmentationToInspect)  
  
ans = struct with fields:  
    SpeedupFactor: 0.9000  
    SemitoneShift: -2  
    SNR: 10
```

Listen to the augmentation you are inspecting. Plot the time-domain representation of the original and augmented signals.

```
augmentation = data.Audio{augmentationToInspect};  
sound(augmentation,fs)  
  
t = (0:(numel(audioIn)-1))/fs;  
taug = (0:(numel(augmentation)-1))/fs;  
plot(t,audioIn,taug,augmentation)  
legend("Original Audio","Augmented Audio")  
ylabel("Amplitude")  
xlabel("Time (s)")
```



Apply Random Independent Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an `audioDataAugmenter` object that applies noise corruption, and time shifting in parallel branches. For the noise corruption branch, randomly apply noise with an SNR in the range 0 dB to 20 dB. For the time shifting branch, randomly apply time shifting in the range -300 ms to 300 ms. Apply augmentation 2 times for each branch, for 4 total augmentations.

```
augmenter = audioDataAugmenter( ...
    "AugmentationMode","independent", ...
    "AugmentationParameterSource","random", ...
    "NumAugmentations",2, ...
    "ApplyTimeStretch",false, ...
    "ApplyPitchShift",false, ...
    "ApplyVolumeControl",false, ...
    "SNRRange",[0,20], ...
    "TimeShiftRange",[-300e-3,300e-3])
```

```
augmenter =
    audioDataAugmenter with properties:
```

```
        AugmentationMode: "independent"
    AugmentationParameterSource: "random"
        NumAugmentations: 2
        ApplyTimeStretch: 0
        ApplyPitchShift: 0
    ApplyVolumeControl: 0
        ApplyAddNoise: 1
            SNRRange: [0 20]
        ApplyTimeShift: 1
        TimeShiftRange: [-0.3000 0.3000]
```

Call `augment` on the audio to create 3 augmentations.

```
data = augment(augmenter,audioIn,fs);
```

You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```
augmentationToInspect = ;
data.AugmentationInfo{augmentationToInspect}
```

```
ans = struct with fields:
    TimeShift: 0.0016
```

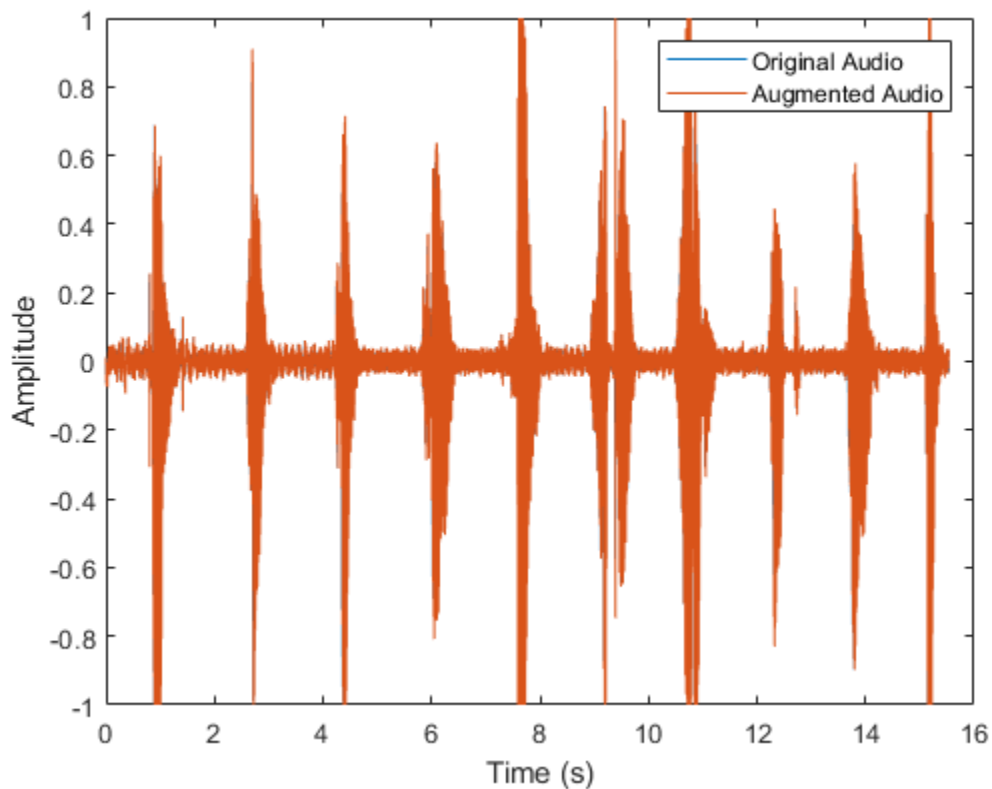
Listen to the audio you are inspecting. Plot the time-domain representation of the original and augmented signals.

```
augmentation = data.Audio{augmentationToInspect};
sound(augmentation,fs)
```

```

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t,audioIn,taug,augmentation)
legend("Original Audio","Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Apply Specified Independent Augmentations

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread("Counting-16-44p1-mono-15secs.wav");
```

Create an audioDataAugmenter object that applies volume control, noise corruption, and time shifting in parallel branches.

```

augmenter = audioDataAugmenter( ...
    "AugmentationMode","independent", ...
    "AugmentationParameterSource","specify", ...
    "ApplyTimeStretch",false, ...
    "ApplyPitchShift",false, ...
    "VolumeGain",2, ...
    "SNR",0, ...
    "TimeShift",2)

```

```

augmenter =
  audioDataAugmenter with properties:

      AugmentationMode: "independent"
  AugmentationParameterSource: "specify"
      ApplyTimeStretch: 0
      ApplyPitchShift: 0
      ApplyVolumeControl: 1
          VolumeGain: 2
      ApplyAddNoise: 1
          SNR: 0
      ApplyTimeShift: 1
          TimeShift: 2

```

Call `augment` on the audio to create 3 augmentations.

```

data = augment(augmenter, audioIn, fs)

data=3x2 table
      Audio          AugmentationInfo
-----
{685056x1 double}  {1x1 struct}
{685056x1 double}  {1x1 struct}
{685056x1 double}  {1x1 struct}

```

You can check the parameter configuration of each augmentation using the `AugmentationInfo` table variable.

```

augmentationToInspect = ;
data.AugmentationInfo{augmentationToInspect}

ans = struct with fields:
    TimeShift: 2

```

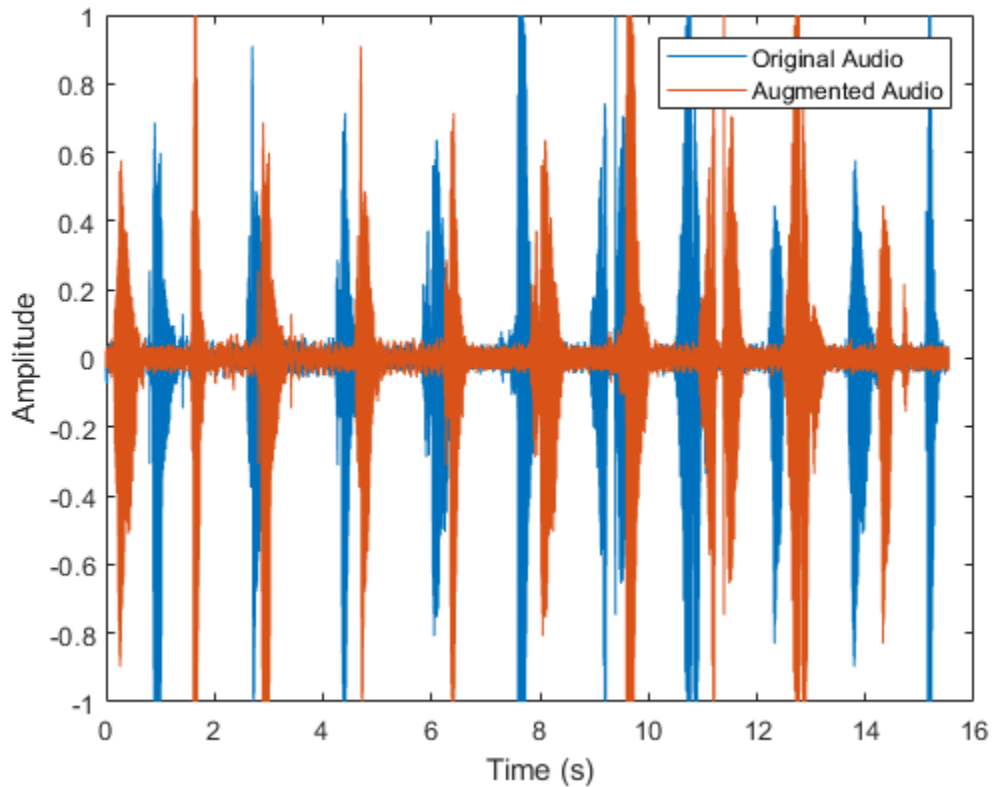
Listen to the audio you are inspecting. Plot the time-domain representations of the original and augmented signals.

```

augmentation = data.Audio{augmentationToInspect};
sound(augmentation, fs)

t = (0:(numel(audioIn)-1))/fs;
taug = (0:(numel(augmentation)-1))/fs;
plot(t, audioIn, taug, augmentation)
legend("Original Audio", "Augmented Audio")
ylabel("Amplitude")
xlabel("Time (s)")

```



Augment Audio Dataset

The `audioDataAugmenter` supports multiple workflows for augmenting your datastore, including:

- Offline augmentation
- Augmentation using tall arrays
- Augmentation using transform datastores

In each workflow, begin by creating an audio datastore to point to your audio data. In this example, you create an audio datastore that points to audio samples included with Audio Toolbox™. Count the number of files in the dataset.

```
folder = fullfile(matlabroot,"toolbox","audio","samples");
ADS = audioDatastore(folder)
```

```
ADS =
  audioDatastore with properties:
```

```
Files: {
    '..\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
    '..\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20sec'
    '..\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5sec'
    ... and 26 more
}
```

```

AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}

```

```
numFilesInDataset = numel(ADS.Files)
```

```
numFilesInDataset = 29
```

Create an `audioDataAugmenter` that applies random sequential augmentations. Set `NumAugmentations` to 2.

```
aug = audioDataAugmenter('NumAugmentations',2)
```

```

aug =
    audioDataAugmenter with properties:
        AugmentationMode: 'sequential'
        AugmentationParameterSource: 'random'
        NumAugmentations: 2
        TimeStretchProbability: 0.5000
        SpeedupFactorRange: [0.8000 1.2000]
        PitchShiftProbability: 0.5000
        SemitoneShiftRange: [-2 2]
        VolumeControlProbability: 0.5000
        VolumeGainRange: [-3 3]
        AddNoiseProbability: 0.5000
        SNRRange: [0 10]
        TimeShiftProbability: 0.5000
        TimeShiftRange: [-0.0050 0.0050]

```

Offline Augmentation

To augment the audio dataset, create two augmentations of each file and then write the augmentations as WAV files.

```

while hasdata(ADS)
    [audioIn,info] = read(ADS);

    data = augment(aug,audioIn,info.SampleRate);

    [~,fn] = fileparts(info.FileName);
    for i = 1:size(data,1)
        augmentedAudio = data.Audio{i};

        % If augmentation caused an audio signal to have values outside of -1 and 1,
        % normalize the audio signal to avoid clipping when writing.
        if max(abs(augmentedAudio),[],'all')>1
            augmentedAudio = augmentedAudio/max(abs(augmentedAudio),[],'all');
        end

        audiowrite(sprintf('%s_aug%d.wav',fn,i),augmentedAudio,info.SampleRate)
    end
end

```

Create an `audioDatastore` that points to the augmented dataset and confirm that the number of files in the dataset is double the original number of files.

```
augmentedADS = audioDatastore(pwd)
```

```
augmentedADS =
  audioDatastore with properties:
```

```

      Files: {
        ' ...\Examples\audio-ex28074079\Ambiance-16-44p1-mono-12secs_aug1.v
        ' ...\Examples\audio-ex28074079\Ambiance-16-44p1-mono-12secs_aug2.v
        ' ...\Examples\audio-ex28074079\AudioArray-16-16-4channels-20secs_
        ... and 55 more
      }
  AlternateFileSystemRoots: {}
      OutputDataType: 'double'
      Labels: {}
```

```
numFilesInAugmentedDataset = numel(augmentedADS.Files)
```

```
numFilesInAugmentedDataset = 58
```

Augment Using Tall Arrays

When augmenting a dataset using tall arrays, the input data to the augmenter should be sampled at a consistent rate. Subset the original audio dataset to only include files with a sample rate of 44.1 kHz. Most datasets are already cleaned to have a consistent sample rate.

```
keepFile = cellfun(@(x)contains(x,'44p1'),ADS.Files);
ads44p1 = subset(ADS,keepFile);
fs = 44.1e3;
```

Convert the audio datastore to a tall array. `tall` arrays are evaluated only when you request them explicitly using `gather`. MATLAB® automatically optimizes the queued calculations by minimizing the number of passes through the data. If you have the Parallel Computing Toolbox™, you can spread the calculations across multiple machines. The audio data is represented as an M -by-1 tall cell array, where M is the number of files in the audio datastore.

```
adsTall = tall(ads44p1)
```

```
Starting parallel pool (parpool) using the 'local' profile ...
Connected to the parallel pool (number of workers: 6).
```

```
adsTall =
```

```
  M×1 tall cell array
```

```

    { 539648×1 double}
    { 227497×1 double}
    {   8000×1 double}
    { 685056×1 double}
    { 882688×2 double}
    {1115760×2 double}
    { 505200×2 double}
    {3195904×2 double}
      :
      :
```

Define a `cellfun` function so that augmentation is applied to each cell of the tall array. Call `gather` to evaluate the tall array.

```
augTall = cellfun(@(x)augment(aug,x,fs),adsTall,"UniformOutput",false);
augmentedDataset = gather(augTall)
```

```
Evaluating tall expression using the Parallel Pool 'local':
- Pass 1 of 1: Completed in 1 min 34 sec
Evaluation completed in 1 min 34 sec
```

```
augmentedDataset=12x1 cell array
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
    {2x2 table}
```

The augmented dataset is returned as a *numFiles*-by-1 cell array, where *numFiles* is the number of files in the datastore. Each element of the cell array is a *numAugmentationsPerFile*-by-2 table, where *numAugmentationsPerFile* is the number of augmentations returned per file.

```
numFiles = numel(augmentedDataset)

numFiles = 12

numAugmentationsPerFile = size(augmentedDataset{1},1)

numAugmentationsPerFile = 2
```

Augment Using Transform Datastore

You can perform online data augmentation while you train your machine learning application using a transform datastore. Call `transform` to create a new datastore that applies data augmentation while reading.

```
transformADS = transform(ADS,@(x,info)augment(aug,x,info),'IncludeInfo',true)

transformADS =
    TransformedDatastore with properties:

        UnderlyingDatastore: [1x1 audioDatastore]
           Transforms: {@(x,info)augment(aug,x,info)}
           IncludeInfo: 1
```

Call `read` to return the augmented first file from the transform datastore.

```
augmentedRead = read(transformADS)

augmentedRead=2x2 table
      Audio      AugmentationInfo
      -----      -----
    {539648x1 double}    [1x1 struct]
```



```
{586683×1 double}      [1×1 struct]
```

Add Custom Augmentation Method

You can expand the capabilities of `audioDataAugmenter` by adding custom augmentation methods.

Read in an audio signal and listen to it.

```
[audioIn,fs] = audioread('Counting-16-44p1-mono-15secs.wav');
sound(audioIn,fs)
```

Create an `audioDataAugmenter` object. Set the probability of applying white noise to 0.

```
augmenter = audioDataAugmenter('AddNoiseProbability',0)
```

```
augmenter =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
      NumAugmentations: 1
  TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
  PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
  VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
  AddNoiseProbability: 0
  TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]
```

Specify a custom augmentation algorithm that applies pink noise. The `AddPinkNoise` algorithm is added to the `augmenter` properties.

```
algorithmName = 'AddPinkNoise';
algorithmHandle = @(x)x+pinknoise(size(x),'like',x);
addAugmentationMethod(augmenter,algorithmName,algorithmHandle)
```

```
augmenter
```

```
augmenter =
  audioDataAugmenter with properties:
      AugmentationMode: 'sequential'
  AugmentationParameterSource: 'random'
      NumAugmentations: 1
  TimeStretchProbability: 0.5000
      SpeedupFactorRange: [0.8000 1.2000]
  PitchShiftProbability: 0.5000
      SemitoneShiftRange: [-2 2]
  VolumeControlProbability: 0.5000
      VolumeGainRange: [-3 3]
  AddNoiseProbability: 0
  TimeShiftProbability: 0.5000
      TimeShiftRange: [-0.0050 0.0050]
```

```
AddPinkNoiseProbability: 0.5000
```

Set the probability of adding pink noise to 1.

```
augmenter.AddPinkNoiseProbability = 1
```

```
augmenter =
```

```
  audioDataAugmenter with properties:
```

```
      AugmentationMode: 'sequential'  
AugmentationParameterSource: 'random'  
      NumAugmentations: 1  
      TimeStretchProbability: 0.5000  
      SpeedupFactorRange: [0.8000 1.2000]  
      PitchShiftProbability: 0.5000  
      SemitoneShiftRange: [-2 2]  
VolumeControlProbability: 0.5000  
      VolumeGainRange: [-3 3]  
      AddNoiseProbability: 0  
      TimeShiftProbability: 0.5000  
      TimeShiftRange: [-0.0050 0.0050]  
AddPinkNoiseProbability: 1
```

Augment the original signal and listen to the result. Inspect parameters of the augmentation algorithms applied.

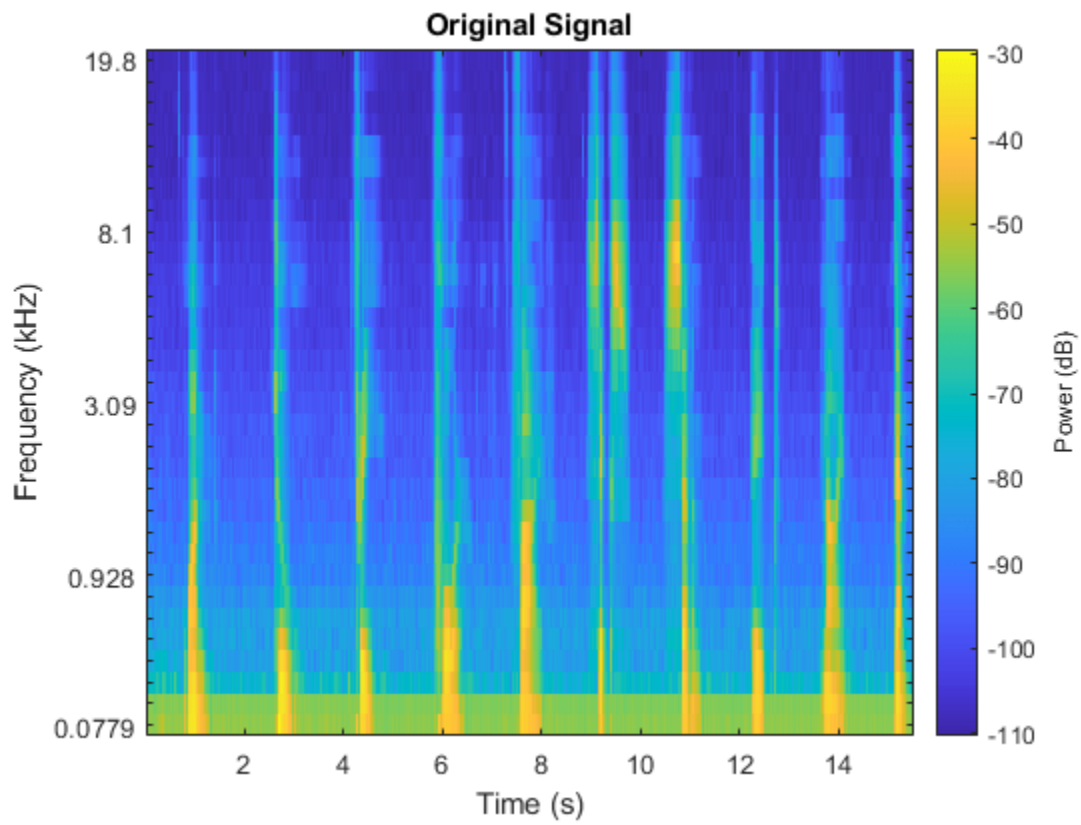
```
data = augment(augmenter, audioIn, fs);  
sound(data.Audio{1}, fs)
```

```
data.AugmentationInfo(1)
```

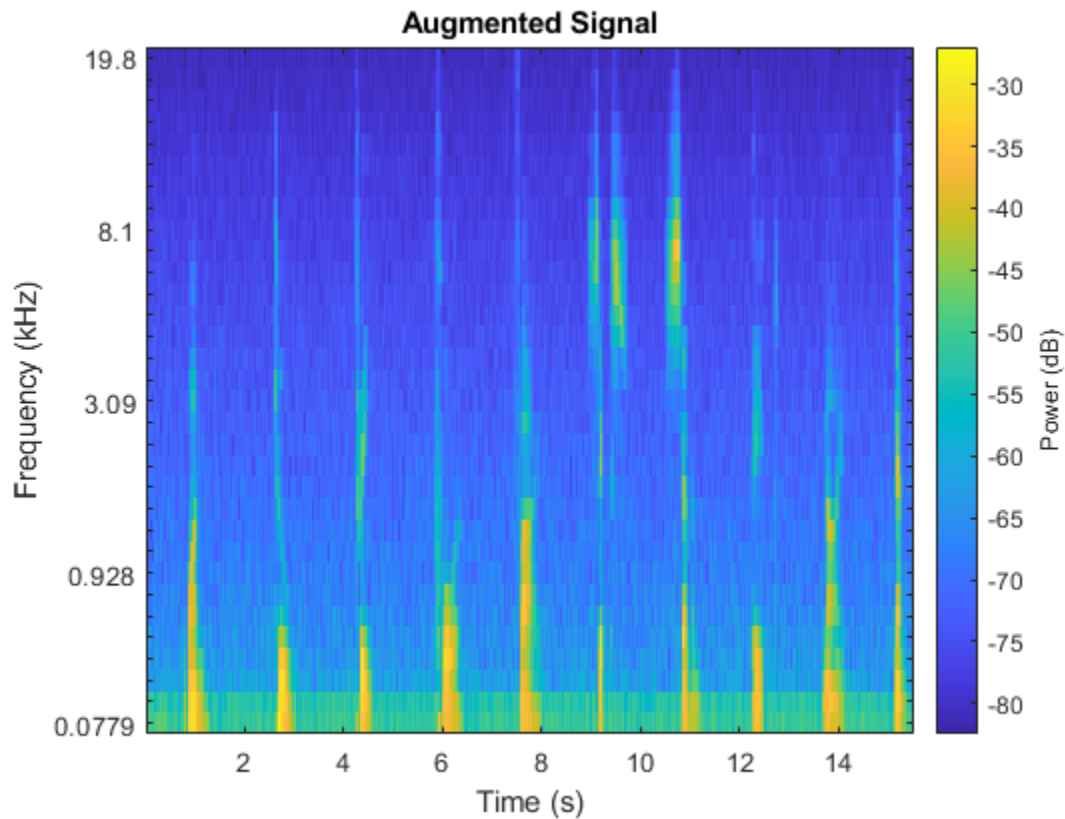
```
ans = struct with fields:  
  SpeedupFactor: 1  
  SemitoneShift: 0  
  VolumeGain: 2.4803  
  TimeShift: -0.0022  
  AddPinkNoise: 'Applied'
```

Plot the mel spectrograms of the original and augmented signals.

```
melSpectrogram(audioIn, fs)  
title('Original Signal')
```



```
melSpectrogram(data.Audio{1}, fs)  
title('Augmented Signal')
```



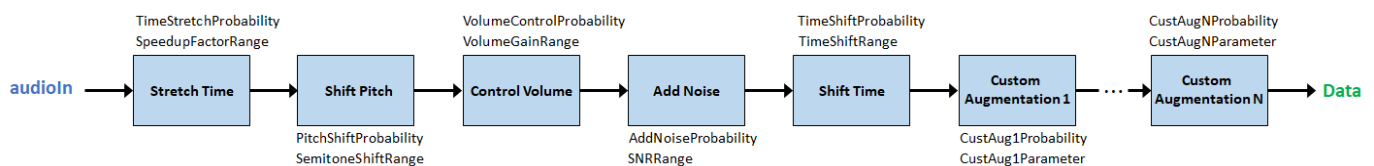
Algorithms

The `audioDataAugmenter` object enables you to configure your augmentation pipeline as deterministic or probabilistic using the `AugmentationParameterSource` property. You can also choose to apply the augmentations in series or in parallel using the `AugmentationMode` property. The following sections describe the pipelines you can create and the applicable properties for each architecture.

Random Sequential Augmentations

To define your augmentation as a sequence of probabilistically applied augmentations, set `AugmentationParameterSource` to `'random'` and `AugmentationMode` to `'sequential'`.

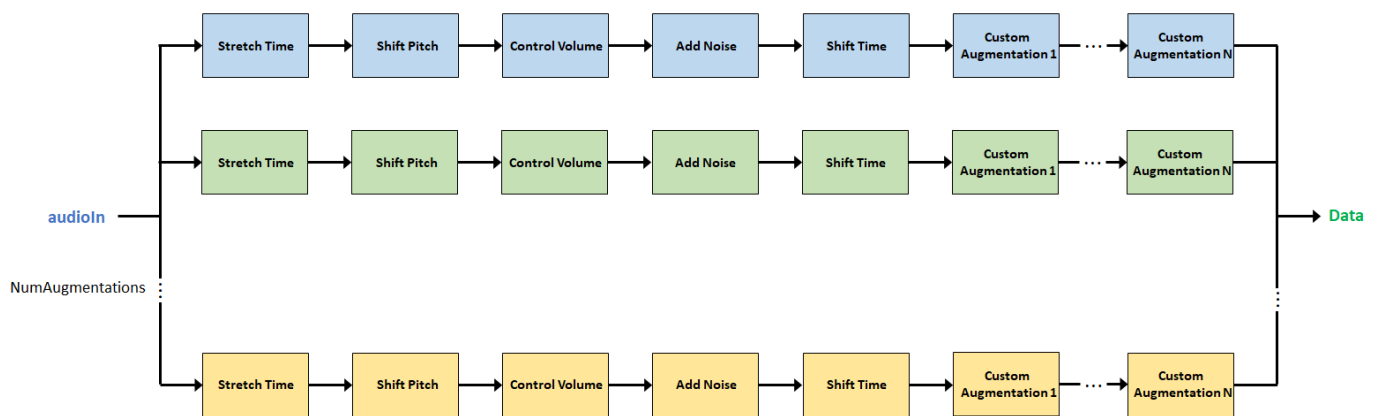
The order that augmentations are applied is always the same. If you specify custom algorithms, they are applied at the end of the sequence, in the order you specified them.



In this pipeline configuration, these parameters apply:

Augmentation Method	Parameters
Stretch Time	TimeStretchProbability SpeedupFactorRange
Shift Pitch	PitchShiftProbability SemitoneShiftRange
Control Volume	VolumeControlProbability VolumeGainRange
Add Noise	AddNoiseProbability SNRRange
Shift Time	TimeShiftProbability TimeShiftRange

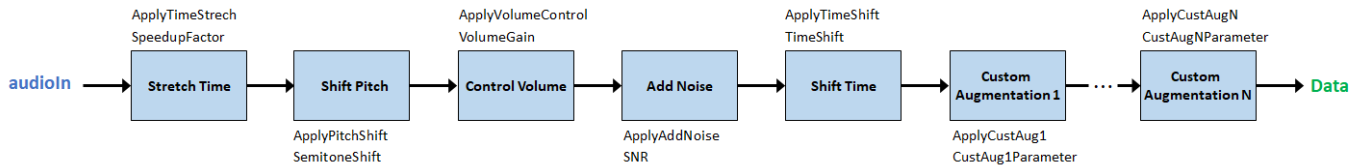
If you specify NumAugmentations as greater than 1, then the object applies NumAugmentations parallel random sequential augmentations. The probability of applying an augmentation, and the value of any parameters that are probabilistically determined, are independent.



Specified Sequential Augmentations

To define your augmentation as a sequence of deterministically applied augmentations, set `AugmentationParameterSource` to 'specify' and `AugmentationMode` to 'sequential'.

The order that augmentations are applied is always the same. If you specify custom algorithms, they are applied at the end of the sequence, in the order you specified them.



In this pipeline configuration, these parameters apply:

Augmentation Method	Parameters
Stretch Time	ApplyTimeStretch SpeedupFactor
Shift Pitch	ApplyPitchShift SemitoneShift
Control Volume	ApplyVolumeControl VolumeGain
Add Noise	ApplyAddNoise SNR
Shift Time	ApplyTimeShift TimeShift

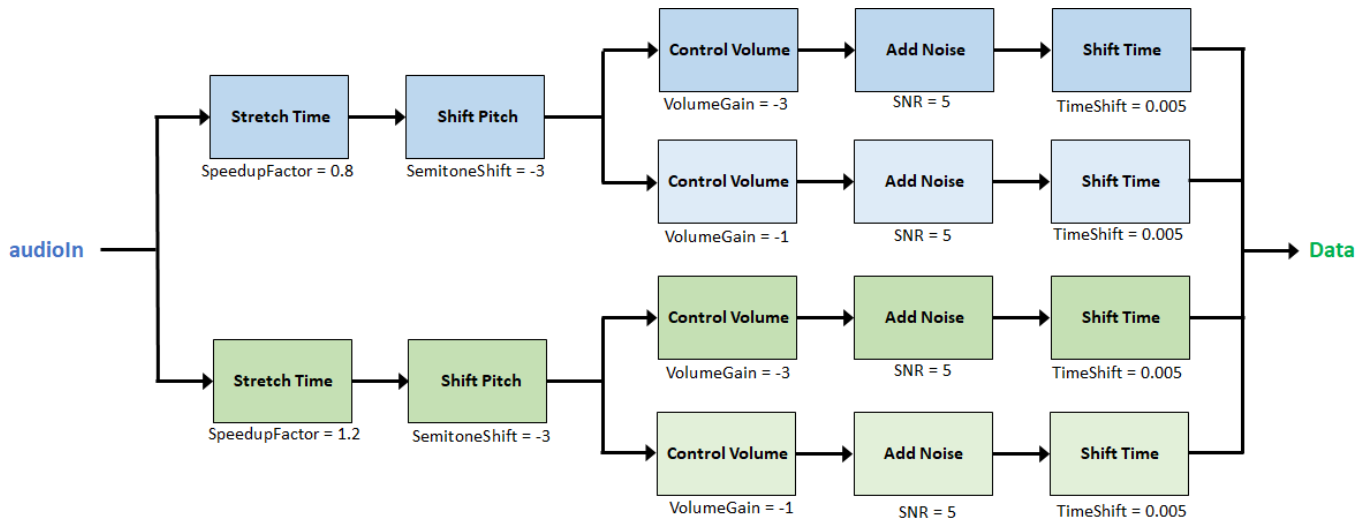
If you specify an augmentation method as a vector, then each element of the vector creates a separate branch in the augmentation pipeline. For example, the following object creates an augmentation pipeline that results in four separate augmentations:

```
aug = audioDataAugmenter("AugmentationMode", "sequential", ...
    "AugmentationParameterSource", "specify", ...
    "SpeedupFactor", [0.8, 1.2], ...
    "VolumeGain", [-3, -1])
```

aug =

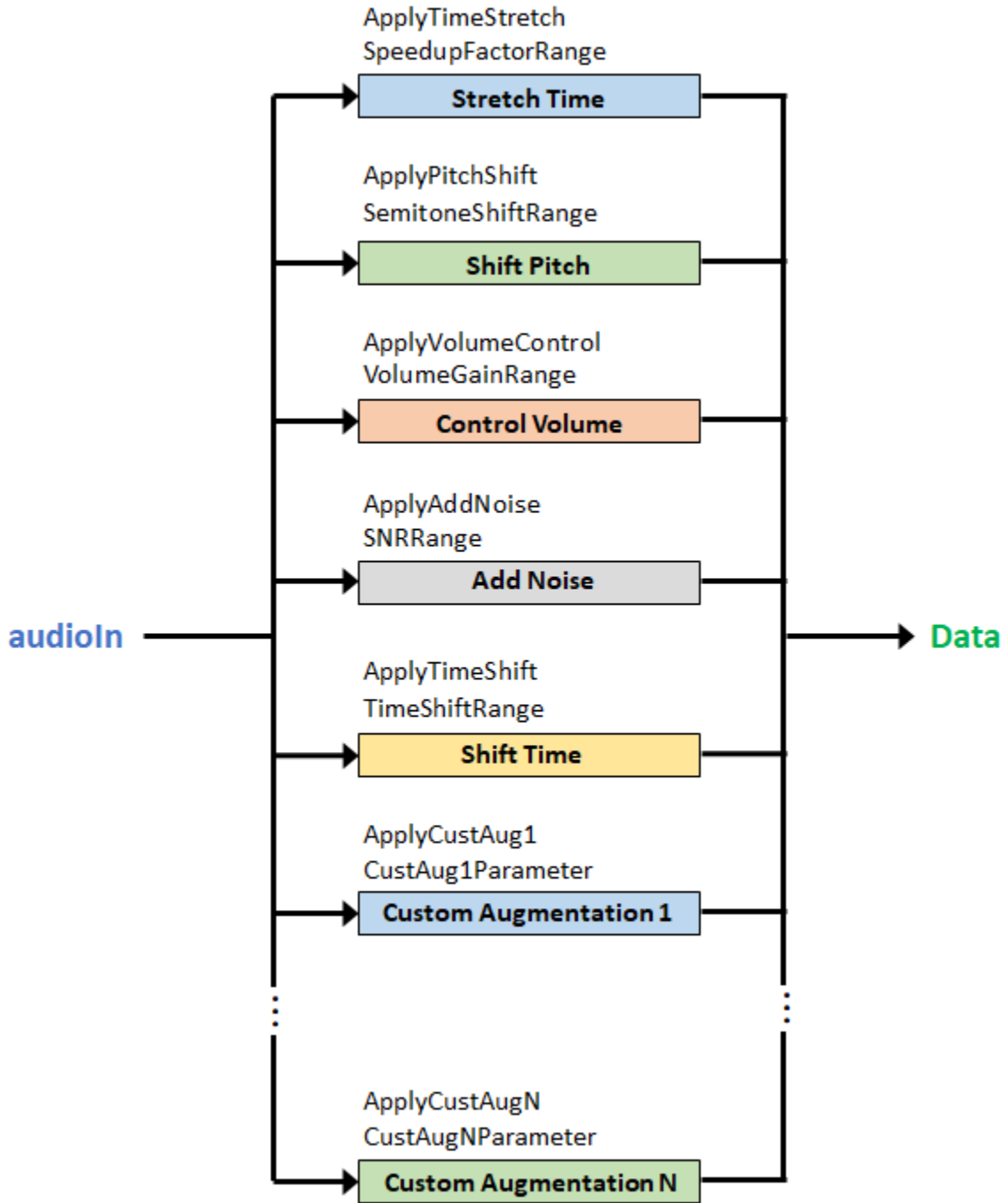
audioDataAugmenter with properties:

```
AugmentationMode: "sequential"
AugmentationParameterSource: "specify"
ApplyTimeStretch: 1
SpeedupFactor: [0.8000 1.2000]
ApplyPitchShift: 1
SemitoneShift: -3
ApplyVolumeControl: 1
VolumeGain: [-3 -1]
ApplyAddNoise: 1
SNR: 5
ApplyTimeShift: 1
TimeShift: 0.0050
```



Random Independent Augmentations

To define your augmentation as independently applied augmentations with randomly determined parameters, set `AugmentationParameterSource` to 'random' and `AugmentationMode` to 'independent'.

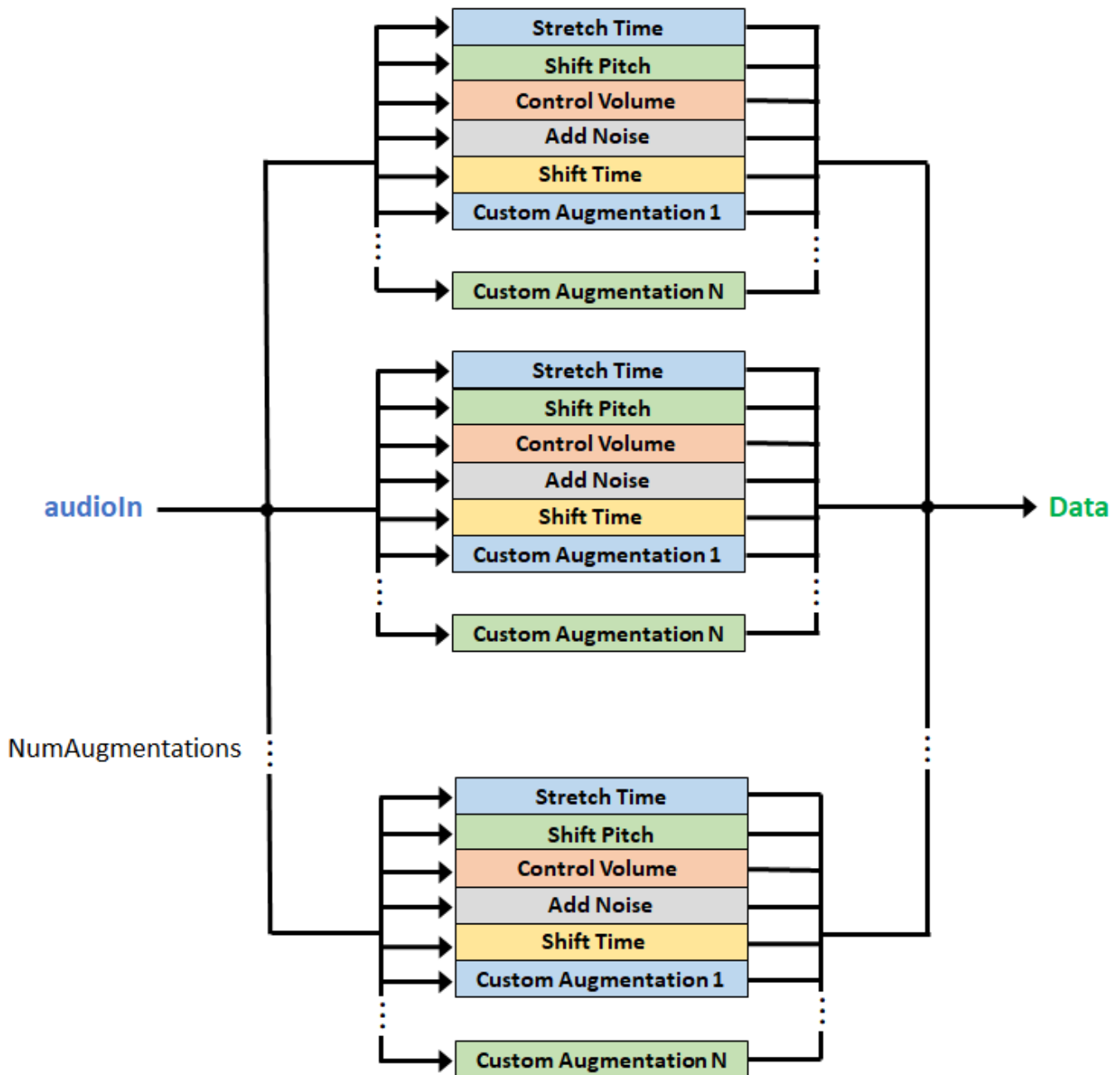


In this pipeline configuration, these parameters apply:

Augmentation Method	Parameters
Stretch Time	ApplyTimeStretch SpeedupFactorRange

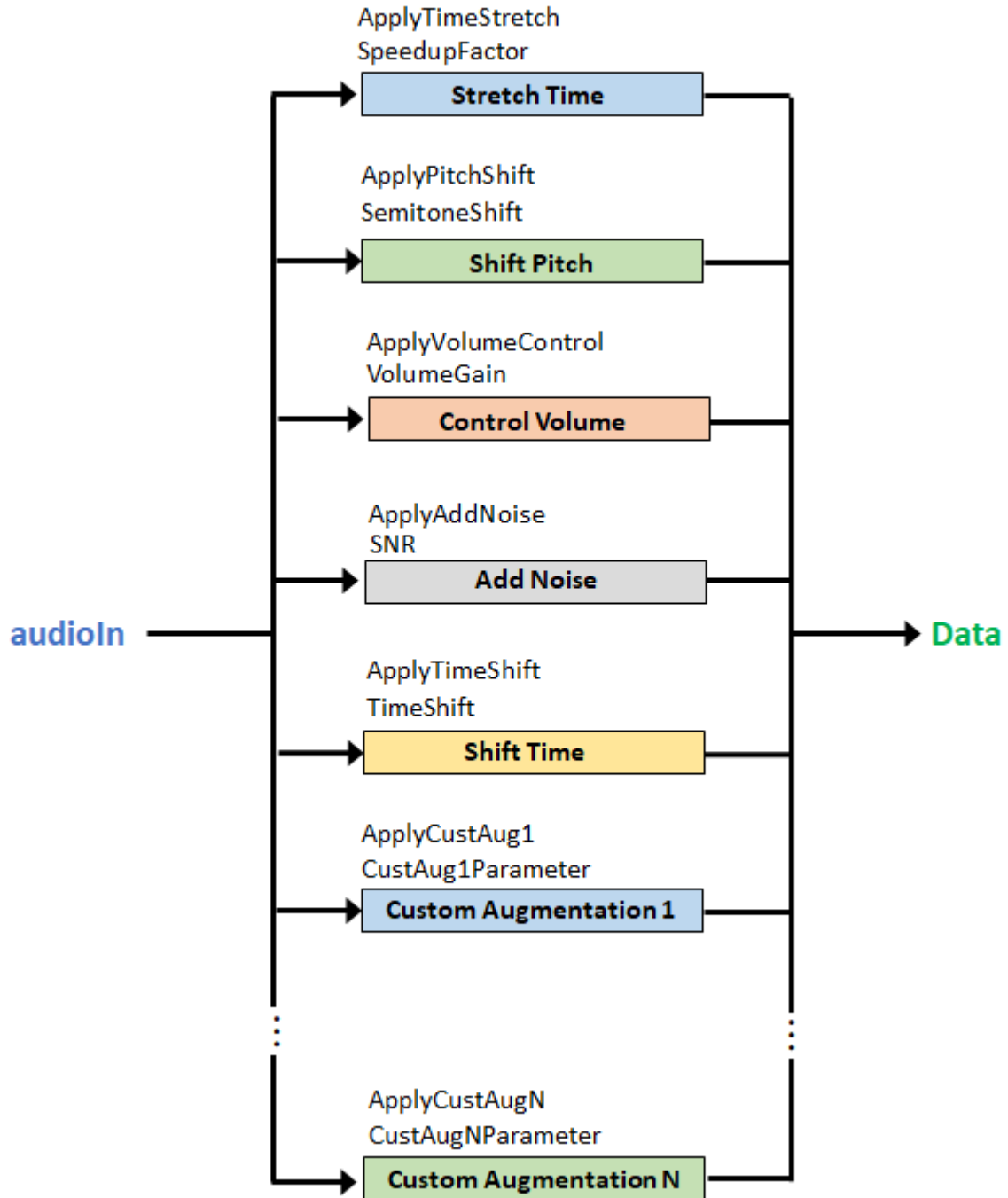
Augmentation Method	Parameters
Shift Pitch	ApplyPitchShift SemitoneShiftRange
Control Volume	ApplyVolumeControl VolumeGainRange
Add Noise	ApplyAddNoise SNRRange
Shift Time	ApplyTimeShift TimeShiftRange

If you specify NumAugmentations as greater than 1, then the object applies NumAugmentations parallel random independent augmentations. The value of any parameters that are probabilistically determined are independent.



Specified Independent Augmentations

To define your augmentation as deterministically applied independent augmentations with deterministic parameters, set `AugmentationParameterSource` to `'specify'` and `AugmentationMode` to `'independent'`.



In this pipeline configuration, these parameters apply:

Augmentation Method	Parameters
Stretch Time	ApplyTimeStretch SpeedupFactor

Augmentation Method	Parameters
Shift Pitch	ApplyPitchShift SemitoneShift
Control Volume	ApplyVolumeControl VolumeGain
Add Noise	ApplyAddNoise SNR
Shift Time	ApplyTimeShift TimeShift

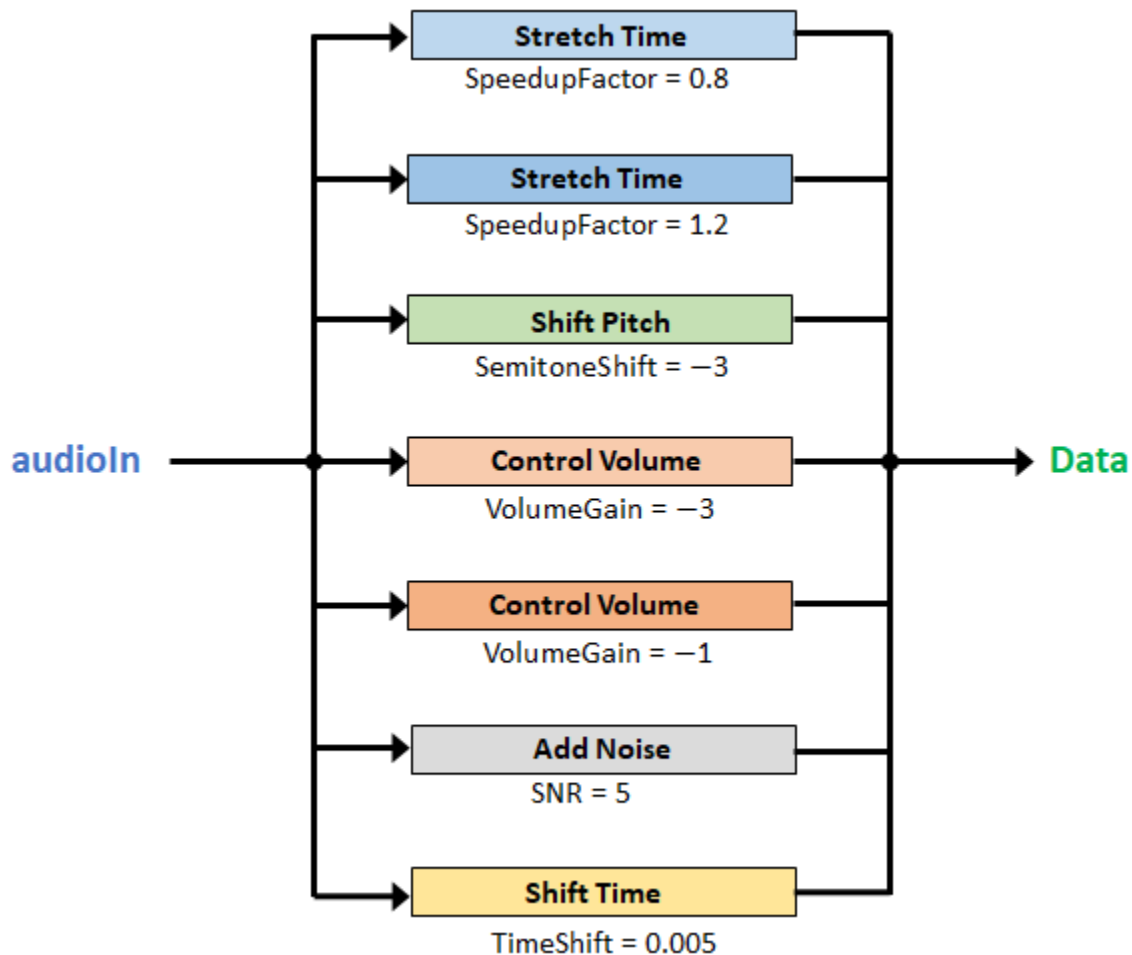
If you specify an augmentation method as a vector, then each element of the vector creates a separate branch in the augmentation pipeline. For example, the following object creates an augmentation pipeline that results in seven separate augmentations:

```
aug = audioDataAugmenter("AugmentationMode", "independent", ...
    "AugmentationParameterSource", "specify", ...
    "SpeedupFactor", [0.8, 1.2], ...
    "VolumeGain", [-3, -1])
```

aug =

audioDataAugmenter with properties:

```
    AugmentationMode: "independent"
AugmentationParameterSource: "specify"
    ApplyTimeStretch: 1
        SpeedupFactor: [0.8000 1.2000]
    ApplyPitchShift: 1
        SemitoneShift: -3
    ApplyVolumeControl: 1
        VolumeGain: [-3 -1]
    ApplyAddNoise: 1
        SNR: 5
    ApplyTimeShift: 1
        TimeShift: 0.0050
```



References

- [1] Salamon, Justin, and Juan Pablo Bello. "Deep Convolutional Neural Networks and Data Augmentation for Environmental Sound Classification." *IEEE Signal Processing Letters*. Vol. 24, Issue 3, 2017.

Extended Capabilities

GPU Arrays

Accelerate code by running on a graphics processing unit (GPU) using Parallel Computing Toolbox™.

Usage notes and limitations:

- `LockPhase` must be set to `false` for the time stretching and pitch shifting augmentations. For more information, see `setAugmenterParams`.
- Using `gpuArray` (Parallel Computing Toolbox) input with `audioDataAugmenter` is only recommended for a GPU with compute capability 7.0 ("Volta") or above. Other hardware might not offer any performance advantage. To check your GPU compute capability, see `ComputeCapability` in the output from the `gpuDevice` (Parallel Computing Toolbox) function. For more information, see "GPU Support by Release" (Parallel Computing Toolbox).

For an overview of GPU usage in MATLAB, see “Run MATLAB Functions on a GPU” (Parallel Computing Toolbox).

See Also

`shiftPitch` | `stretchAudio` | `audioTimeScaler` | `audioFeatureExtractor`

Introduced in R2019b

writeall

Write datastore to files

Syntax

```
writeall(ADS,outputLocation)
writeall(ADS,outputLocation,Name,Value)
```

Description

`writeall(ADS,outputLocation)` writes the data from the audio datastore ADS to files located at `outputLocation`.

`writeall(ADS,outputLocation,Name,Value)` writes the data with additional options specified by one or more name-value pair arguments.

Example: `writeall(ADS,outputLocation,'OutputFormat','flac')` writes the data to FLAC files.

Examples

Write Audio Data Set to New Location

Create an `audioDatastore` object that points to the WAV audio samples included with Audio Toolbox™. The `audioDatastore` object includes read-only properties indicating the supported file formats, and the default output format (WAV).

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ads = audioDatastore(folder,'FileExtensions','.wav')
```

`ads =`

`audioDatastore` with properties:

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5sec'
        ... and 17 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

Write the audio data set to your current folder. Save all files in the default (WAV) format.

```
outputLocation = pwd;
writeall(ads,outputLocation)
```

The folder, `samples`, and the audio files that the folder contains have been written to your current folder.

```
dir samples
.
..
Ambiance-16-44p1-mono-12secs.wav
AudioArray-16-16-4channels-20secs.wav
ChurchImpulseResponse-16-44p1-mono-5secs.wav
Click-16-44p1-mono-0.2secs.wav
Counting-16-44p1-mono-15secs.wav
Engine-16-44p1-stereo-20sec.wav
FemaleSpeech-16-8-mono-3secs.wav
Heli_16ch_ACN_SN3D.wav
JetAirplane-16-11p025-mono-16secs.wav
Laughter-16-8-mono-4secs.wav
MainStreetOne-16-16-mono-12secs.wav
NoisySpeech-16-22p5-mono-5secs.wav
Rainbow-16-8-mono-114secs.wav
RainbowNoisy-16-8-mono-114secs.wav
RockGuitar-16-44p1-stereo-72secs.wav
SpeechDFT-16-8-mono-5secs.wav
TrainWhistle-16-44p1-mono-9secs.wav
Turbine-16-44p1-mono-22secs.wav
WashingMachine-16-44p1-stereo-10secs.wav
multipleSounds-16-16-mono-18secs.wav
```

Pre-Extract Features from Audio Data Set

You can use pre-extracted features to reduce iteration time when developing a machine learning or deep learning system. It is also a common practice to use pre-extracted features for unsupervised learning tasks such as similarity clustering, and for content-based indexing tasks such as music information retrieval (MIR).

Create an `audioDatastore` object that points to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot,"toolbox","audio","samples");
ads = audioDatastore(folder)
```

```
ads =
  audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se'
        ... and 31 more
    }
  Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
```



```

AlternateFileSystemRoots: {}
      OutputDataType: 'double'
      Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Create a custom write function that extracts mel frequency cepstral coefficients (mfcc) from the audio and writes the them to a MAT file. The function definition is located at the end of this example.

```

function myWriter(audioIn,info,~)
    fs = info.ReadInfo.SampleRate;

    % Extract MFCC
    [coeffs,delta,deltaDelta] = mfcc(audioIn,fs);

    % Replace the file extension of the suggested output name with MAT.
    filename = strrep(info.SuggestedOutputName,".wav",".mat");

    % Save the MFCC coefficients to the MAT file.
    save(filename,"coeffs","delta","deltaDelta")
end

```

Define the output location for the extracted features.

```
outputLocation = pwd;
```

Call the `writeall` function with the `audioDatastore` object, output location, and custom write function. Also specify the suffix `_MFCC` to the file names.

```

tic
writeall(ads,outputLocation,"WriteFcn",@myWriter,"FilenameSuffix","_MFCC")
fprintf("Data set creation completed (%0.0f seconds)\n",toc)

```

```
Data set creation completed (13 seconds)
```

You have now created a data set consisting of MFCCs for each audio file.

```
fds = fileDatastore(pwd,"ReadFcn",@load,"FileExtensions",".mat","IncludeSubfolders",true)
```

```
fds =
```

```
FileDatastore with properties:
```

```

Files: {
    '...\audio-ex80013303\samples\Ambiance-16-44p1-mono-12secs_MFCC.m'
    '...\audio-ex80013303\samples\AudioArray-16-16-4channels-20secs_M'
    '...\samples\ChurchImpulseResponse-16-44p1-mono-5secs_MFCC.mat'
    ... and 31 more
}
Folders: {
    'C:\TEMP\Bdoc22a_1891349_13144\ibC86E06\2\tp5e2e159b\audio-ex800133'
}
UniformRead: 0
ReadMode: 'file'
BlockSize: Inf
PreviewFcn: @load
SupportedOutputFormats: ["txt"    "csv"    "xlsx"    "xls"    ...    ]
ReadFcn: @load

```

```
AlternateFileSystemRoots: {}
```

Helper Function

```
function myWriter(audioIn,info,~)
    fs = info.ReadInfo.SampleRate;
    [coeffs,delta,deltaDelta] = mfcc(audioIn,fs);
    filename = strrep(info.SuggestedOutputName, ".wav", ".mat");
    save(filename, "coeffs", "delta", "deltaDelta")
end
```

Augment Audio Data Set

Create an `audioDatastore` object that points to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, "toolbox", "audio", "samples");
ads = audioDatastore(folder);
```

Create an `audioDataAugmenter` object that outputs two augmentations for every input signal.

```
augmenter = audioDataAugmenter("NumAugmentations",2);
```

Define a custom write function that applies the `audioDataAugmenter` object to an audio file and writes the resulting new signals to separate files. The function definition is located at the end of this example.

```
function myWriter(audioIn,info,fileExtension,varargin)
    % create convenient variables for the augmenter and sample rate
    augmenter = varargin{1};
    fs = info.ReadInfo.SampleRate;

    % perform augmentation
    augmentations = augment(augmenter,audioIn,fs);

    for ii = 1:augmenter.NumAugmentations
        x = augmentations.Audio{ii};

        % protect against clipping
        if any(x<-1|x>1)
            [S,L] = bounds(x);
            x = x/max(abs([S,L]));
        end

        % update the audio file name to include the augmentation number
        filename = insertBefore(info.SuggestedOutputName, "."+fileExtension, string(ii));

        % write the audio file
        audiowrite(filename,x,fs)
    end
end
```

Call the `writeall` function to create a new augmented data set. To speed up processing, set `UseParallel` to `true`.

```
outputLocation = pwd;
writeall(ads,outputLocation,"FilenameSuffix", "_Aug", "UseParallel", true, "WriteFcn", @(x,y,z,a)myWr
```

Starting parallel pool (parpool) using the 'local' profile ...
 Connected to the parallel pool (number of workers: 6).

Create a new datastore that points to the augmented audio data set.

```
adsAug = audioDatastore(outputLocation,"IncludeSubfolders",true)
```

```
adsAug =
```

```
audioDatastore with properties:
```

```

    Files: {
        ' ...\audio-ex06587246\samples\Ambiance-16-44p1-mono-12secs_Aug1.wa
        ' ...\audio-ex06587246\samples\Ambiance-16-44p1-mono-12secs_Aug2.wa
        ' ...\audio-ex06587246\samples\AudioArray-16-16-4channels-20secs_A
        ... and 55 more
    }
    Folders: {
        ' ...\vmgr$\home07\bhemmat\Documents\MATLAB\Examples\audio-ex06587
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Helper Function

```

function myWriter(audioIn,info,fileExtension,varargin)
    augmenter = varargin{1};
    fs = info.ReadInfo.SampleRate;
    augmentations = augment(augmenter,audioIn,fs);
    for ii = 1:augmenter.NumAugmentations
        x = augmentations.Audio{ii};
        if any(x<-1|x>1)
            x = x./max(abs(x));
        end
        filename = insertBefore(info.SuggestedOutputName,("."+fileExtension),string(ii));
        audiowrite(filename,x,fs)
    end
end

```

Segment Audio Data

Use the `detectSpeech` and `writeall` functions to create a new audio data set that contains isolated speech segments.

Create an `audioDatastore` object that points to the audio samples included with this example.

```
ads = audioDatastore(pwd)
```

```
ads =
```

```
audioDatastore with properties:
```

```

    Files: {
        ' ...\4\tp2d1cfedd\audio-ex78151030\KeywordSpeech-16-16-mono-34secs
        ' ...\ibC86E06\4\tp2d1cfedd\audio-ex78151030\Plosives.wav';
    }

```

```

        ' ...\ibC86E06\4\tp2d1cfedd\audio-ex78151030\Sibilance.wav'
    }
    Folders: {
        'C:\TEMP\Bdoc22a_1891349_13144\ibC86E06\4\tp2d1cfedd\audio-ex78151030\Sibilance'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Define a custom write function that first determines the regions of speech in the audio signals read from the datastore, then writes the individual regions of speech to separate files. Append the region number to the file names. The function definition is located at the end of this example.

```

function myWriter(audioIn,info,fileExtension)
    fs = info.ReadInfo.SampleRate;

    % Get indices corresponding to regions of speech
    idx = detectSpeech(audioIn,fs);

    % For each region of speech
    for ii = 1:size(idx,1)
        x = audioIn(idx(ii,1):idx(ii,2),:);

        % Create a unique file name
        filename = insertBefore(info.SuggestedOutputName,("."+fileExtension),string(ii));

        % Write the detected region of speech
        audiowrite(filename,x,fs)
    end
end

```

Call the `writeall` function using the custom write function to create a new data set that consists of the isolated speech segments. Create a folder named `segmented` in your temporary directory and then write the data to that folder.

```

outputLocation = fullfile(tempdir,"segmented");
writeall(ads,outputLocation,'WriteFcn',@myWriter)

```

Create a new `audioDatastore` object that points to the segmented data set.

```

adsSegmented = audioDatastore(outputLocation,"IncludeSubfolders",true)

```

```

adsSegmented =
    audioDatastore with properties:

        Files: {
            ' ...\4\segmented\audio-ex78151030\KeywordSpeech-16-16-mono-34secs'
            ' ...\4\segmented\audio-ex78151030\KeywordSpeech-16-16-mono-34secs'
            ' ...\4\segmented\audio-ex78151030\KeywordSpeech-16-16-mono-34secs'
            ... and 24 more
        }
        Folders: {
            'C:\TEMP\Bdoc22a_1891349_13144\ibC86E06\4\segmented'
        }
    AlternateFileSystemRoots: {}

```

```

        OutputDataType: 'double'
        Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Read a sample from the datastore and listen to it.

```

[audioIn,adsInfo] = read(adsSegmented);
sound(audioIn,adsInfo.SampleRate)

```

Supporting Function

```

function myWriter(audioIn,info,fileExtension)
    fs = info.ReadInfo.SampleRate;
    idx = detectSpeech(audioIn,fs);
    for ii = 1:size(idx,1)
        x = audioIn(idx(ii,1):idx(ii,2),:);
        filename = insertBefore(info.SuggestedOutputName,("."+fileExtension),string(ii));
        audiowrite(filename,x,fs)
    end
end

```

Clean Audio Data Set

Audio data sets, especially open-source audio data sets, might have inconsistent sampling rates, numbers of channels, or durations. They might also contain garbage data, such as clips that are labeled as containing speech but contain silence.

It is often a first step in machine learning and deep learning workflows to clean the audio data set. This is particularly important for the validation and test data sets. Common types of cleaning include resampling, converting to mono or stereo, trimming or expanding the duration of clips to a consistent length, removing periods of silence, removing background noise, or gain normalization.

In this example, you clean an audio data set so that all the files have a sample rate of 16 kHz, are mono, are in the FLAC format, and are normalized such that the max absolute magnitude of a signal is 1.

Create an `audioDatastore` object that points to the audio samples included with Audio Toolbox™.

```

folder = fullfile(matlabroot,"toolbox","audio","samples");
ads = audioDatastore(folder);

```

Define a function to apply a sequence of operations on the audio data. The function definition is located at the end of this example.

```

function [audioOut,adsInfo] = myTransform(audioIn,adsInfo)
    fs = adsInfo.SampleRate;
    desiredFs = 16e3;

    % Convert to mono
    x = mean(audioIn,2);

    % Resample to 16 kHz
    y = resample(x,desiredFs,fs);
    adsInfo.SampleRate = desiredFs;

```

```

    % Normalize so that the max absolute value of a signal is 1
    audioOut = y/max(abs(y));
end

```

Create a transform datastore object that applies the cleaning operations.

```
adsTransform = transform(ads,@myTransform,"IncludeInfo",true);
```

Call `writeall` on the transform datastore object to create the clean data set. Specify the format as FLAC. Write the data set to your current folder.

```
outputLocation = pwd;
writeall(adsTransform,outputLocation,"OutputFormat","flac")
```

Create a new datastore object that points to the clean data set.

```
adsClean = audioDatastore(outputLocation,"IncludeSubfolders",true)
```

```
adsClean =
    audioDatastore with properties:
```

```

        Files: {
            ' ...\Examples\audio-ex59507606\samples\Ambiance-16-44p1-mono-12secs.flac'
            ' ...\audio-ex59507606\samples\AudioArray-16-16-4channels-20secs.flac'
            ' ...\samples\ChurchImpulseResponse-16-44p1-mono-5secs.flac'
            ... and 26 more
        }
        Folders: {
            ' ...\vmgr$\home07\bhemmat\Documents\MATLAB\Examples\audio-ex59507606'
        }
    AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Supporting Function

```

function [audioOut,adsInfo] = myTransform(audioIn,adsInfo)
    fs = adsInfo.SampleRate;
    desiredFs = 16e3;
    x = mean(audioIn,2);
    y = resample(x,desiredFs,fs);
    adsInfo.SampleRate = desiredFs;
    audioOut = y/max(abs(y));
end

```

Input Arguments

ADS — Audio datastore

audioDatastore object

Audio datastore, specified as an audioDatastore object.

outputLocation — Folder location to write data

character vector | string

Folder location to write data, specified as a character vector or string. You can specify a full or relative path in `outputLocation`.

Example: `outputLocation = '../..../dir/data'`

Example: `outputLocation = 'C:\Users\MyName\Desktop'`

Data Types: `char` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'FolderLayout', 'flatten'`

FolderLayout — Layout of files in output folder

`'duplicate'` (default) | `'flatten'`

Layout of files in output folder, specified as the comma-separated pair consisting of `'FolderLayout'` and `'duplicate'` or `'flatten'`.

- `'duplicate'` -- Replicate the folder structure of the data that the audio datastore points to. Specify the `FolderLayout` as `'duplicate'` to maintain correspondence between the input and output data sets.
- `'flatten'` -- Write all the files from the input to the specified output folder without any intermediate folders.

Data Types: `char` | `string`

OutputFormat — Output file format

`'wav'` (default) | `'flac'` | `'ogg'` | `'mp4'` | `'m4a'`

Output file format, specified as the comma-separated pair consisting of `'OutputFormat'` and `'wav'`, `'flac'`, `'ogg'`, `'mp4'`, or `'m4a'`.

Data Types: `char` | `string`

BitsPerSample — Number of output bits per sample

16 (default) | 8 | 24 | 32 | 64

Number of output bits per sample, specified as the comma-separated pair consisting of `'BitsPerSample'` and an integer.

Dependencies

To enable this name-value pair argument, set `OutputFormat` to `'wav'` or `'flac'`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

BitRate — Kilobits per second (kbit/s)

128 (default) | 64 | 96 | 160 | 192 | 256 | 320

Number of kilobits per second (kbit/s) used to compress audio files, specified as the comma-separated pair consisting of 'BitRate' and an integer. On Windows 7 or later, the only valid values are 96, 128, 160, and 192.

In general, a larger BitRate value results in higher compression quality.

Dependencies

To enable this name-value pair argument, set OutputFormat to 'm4a' or 'mp4'.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

FilenamePrefix — Prefix added to file name

character vector | string

Prefix added to file name, specified as the comma-separated pair consisting of 'FilenamePrefix' and a character vector or string.

The writeall function adds the specified prefix to the output file names. For example, the following code adds today's date as the prefix to all the output file names:

```
prefixText = string(datetime('today'));  
writeall(ADS, 'C:\myFolder', 'FilenamePrefix', prefixText);
```

Data Types: char | string

FilenameSuffix — Suffix added to file name

character vector | string

Suffix added to the file name, specified as the comma-separated pair consisting of 'FilenameSuffix' and a character vector or string. The file name suffix is applied before the file extension.

The writeall function adds the specified suffix to the output file names. For example, the following code adds the descriptive text 'clean' as the suffix to all the output file names:

```
writeall(ADS, 'C:\myFolder', 'FilenameSuffix', 'clean');
```

Data Types: char | string

UseParallel — Indicator to write in parallel

false (default) | true

Indicator to write in parallel, specified as the comma-separated pair consisting of 'UseParallel' and false or true.

By default, the writeall function writes in serial. If you set UseParallel to true, then the writeall function writes the output files in parallel.

Note Writing in parallel requires Parallel Computing Toolbox™.

Data Types: logical

WriteFcn — Custom write function

function handle

Custom write function, specified as the comma-separated pair consisting of 'WriteFcn' and a function handle. The specified function is responsible for creating the output files. You can use WriteFcn to write data in a variety of formats, even if writeall does not directly support the output format.

Function Signature

The custom write function requires three input arguments: `audioIn`, `info`, and `suggestedOutputType`. The function can also accept additional inputs, such as name-value pairs, after the first three required inputs.

```
function myWriter(audioIn,info,suggestedOutputType,varargin)
```

- `audioIn` contains data read from the input datastore ADS.
- `info` is an object of type `matlab.io.datastore.WriteInfo` with fields listed in the table.

Field	Description	Type
ReadInfo	The second output of the read method.	struct
SuggestedOutputName	A fully qualified, globally unique file name that meets the location and naming requirements.	string
Location	The specified outputLocation passed to writeall.	string

- `suggestedOutputType` -- Suggested output file type.

Example Function

A simple write function that resamples audio to 44.1 kHz before writing.

```
function myWriter(data,info,~)
    fs = info.ReadInfo.SampleRate;
    desiredFs = 44.1e3;
    data = resample(data,desiredFs,fs);
    audiowrite(writeInfo.SuggestedOutputName,data,desiredFs);
end
```

To use `myWriter` as in the `writeall` function, use these commands:

```
ads = audioDatastore(location);
outputLocation = 'C:/tmp/MyData';
writeall(ads,outputLocation,'WriteFcn',@myWriter)
```

Data Types: `function_handle`

See Also

`audioDatastore`

Introduced in R2020a

transform

Transform audio datastore

Syntax

```
transformDatastore = transform(ADS,@fcn)
transformDatastore = transform(ADS,@fcn,Name,Value)
```

Description

`transformDatastore = transform(ADS,@fcn)` creates a new datastore that transforms output from the read function.

`transformDatastore = transform(ADS,@fcn,Name,Value)` specifies options using one or more `Name,Value` pair arguments.

Examples

Output Mono Audio from Datastore

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);
```

Call `transform` to create a new datastore that mixes multichannel signals to mono.

```
ADSnew = transform(ADS,@(x)mean(x,2));
```

Read from the new datastore and confirm that it only outputs mono signals.

```
while hasdata(ADSnew)
    audio = read(ADSnew);
    fprintf('Number of channels = %d\n',size(audio,2))
end
```

```
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
```

```

Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1
Number of channels = 1

```

Clip Audio to Five Seconds

The audio samples included with Audio Toolbox™ have varying durations. Use the `transform` function to customize the `read` function so that it outputs a random five second segment of the audio samples.

Specify the file path to the audio samples included with Audio Toolbox. Create an audio datastore that points to the specified folder.

```

folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder);

```

Define a function to take as input the output of the `read` function. Make the function extract five seconds worth of data from the audio signal.

```

function [dataOut,info] = extractSegment(audioIn,info)
    [N,numChan] = size(audioIn);
    newN = round(info.SampleRate*5);
    if newN > N                                % signal length < 5 seconds
        numPad = newN - N + 1;
        dataOut = [audioIn;zeros(numPad,numChan,'like',audioIn)];
    elseif newN < N                            % signal length > 5 seconds
        start = randi(N - newN + 1);
        dataOut = audioIn(start:start+newN-1,:);
    else                                        % signal length == 5 seconds
        dataOut = audioIn;
    end
end

```

Call `transform` to create a `TransformedDatastore` with `Transforms` set to the function you defined.

```

ADSnew = transform(ADS,@extractSegment,'IncludeInfo',true)

```

```

ADSnew =
  TransformedDatastore with properties:

    UnderlyingDatastores: {audioDatastore}
    SupportedOutputFormats: ["txt" "csv" "xlsx" "xls" ... ]
    Transforms: {@extractSegment}
    IncludeInfo: 1

```

Read the first three audio files and verify that the outputs are five second segments.

```

for i = 1:3
    [audio,info] = read(ADSnew);
    fprintf('Duration = %d seconds\n',size(audio,1)/info.SampleRate)
end

Duration = 5 seconds
Duration = 5 seconds
Duration = 5 seconds

```

Output Mel Spectrogram

Use `transform` to create an audio datastore that returns a mel spectrogram representation from the `read` function.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```

folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);

```

Define a function that transforms audio data from a time-domain representation to a log mel spectrogram. The function adds the additional outputs from the `melSpectrogram` function to the `info` struct output from reading the audio datastore.

```

function [dataOut,infoOut] = extractMelSpectrogram(audioIn,info)

    [S,F,T] = melSpectrogram(audioIn,info.SampleRate);

    dataOut = 10*log10(S+eps);
    infoOut = info;
    infoOut.CenterFrequencies = F;
    infoOut.TimeInstants = T;
end

```

Call `transform` to create a `TransformedDatastore` with `Transforms` set to `extractMelSpectrogram`.

```

ADSnew = transform(ADS,@extractMelSpectrogram,'IncludeInfo',true)

```

```

ADSnew =
  TransformedDatastore with properties:

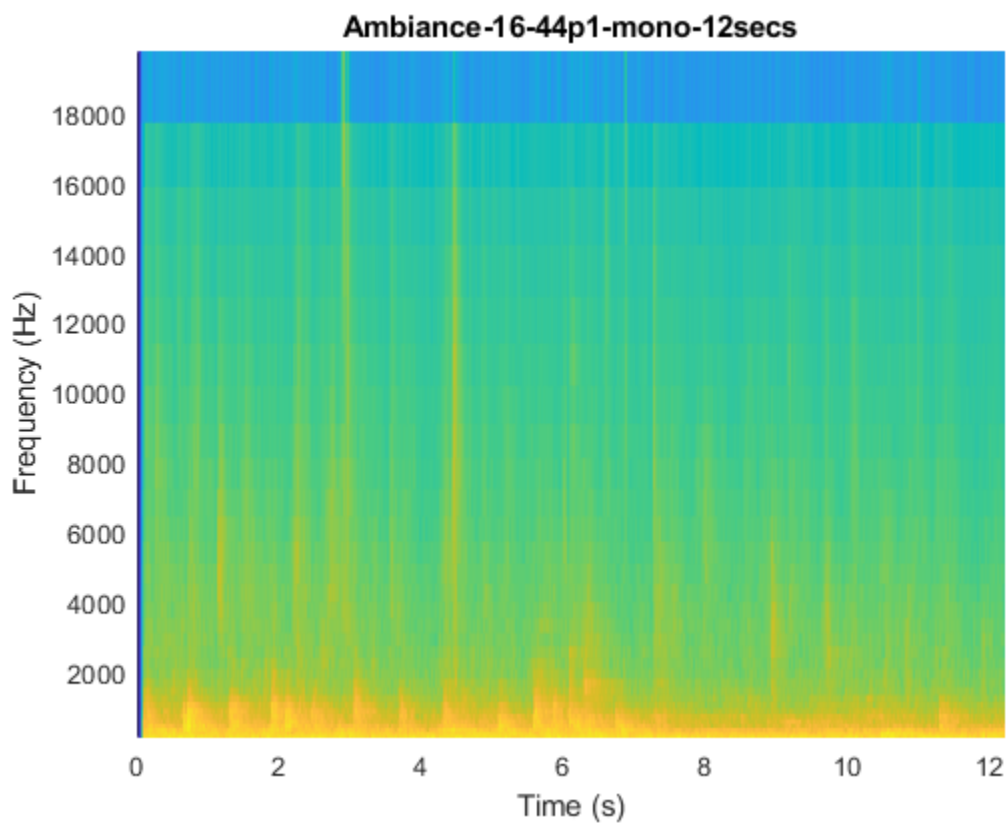
    UnderlyingDatastores: {audioDatastore}
    SupportedOutputFormats: ["txt" "csv" "xlsx" "xls" ... ]

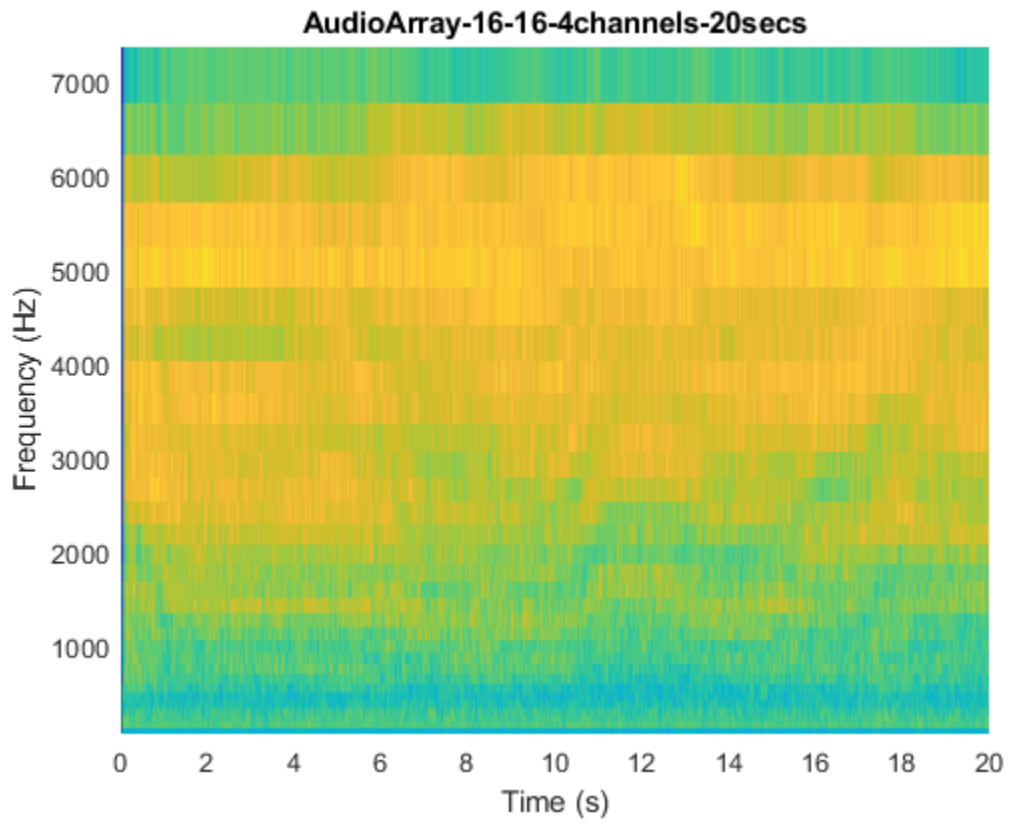
```

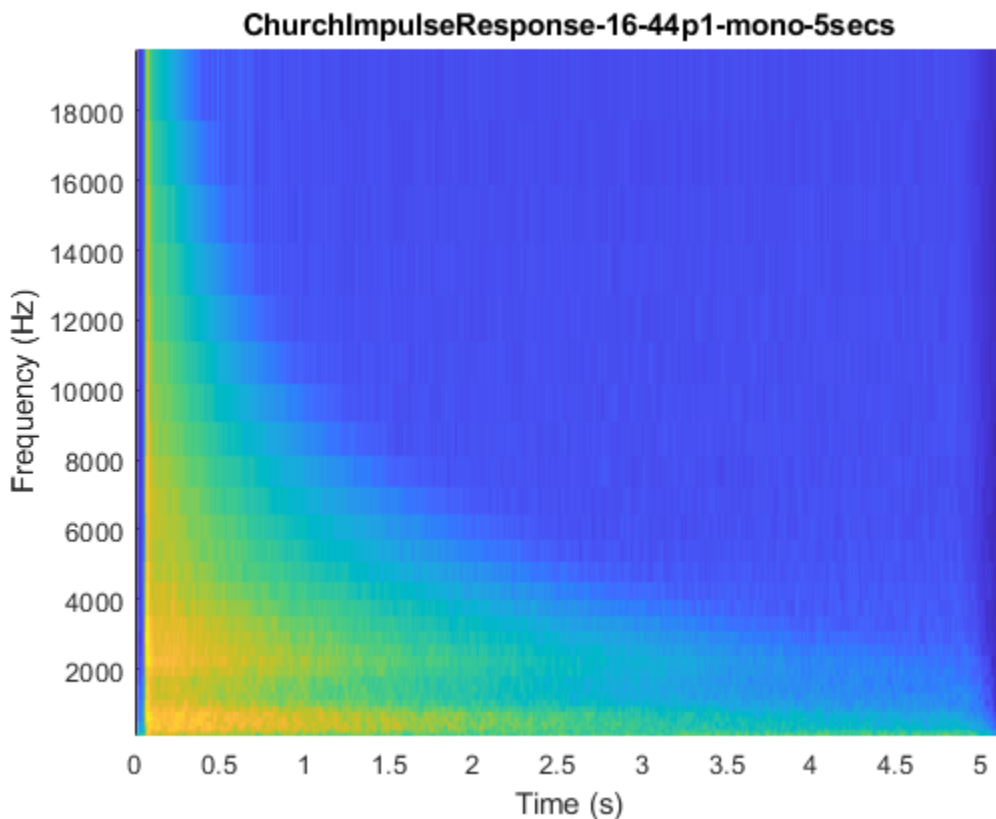
```
Transforms: {@extractMelSpectrogram}  
IncludeInfo: 1
```

Read the first three audio files and plot the log mel spectrograms. If there are multiple channels, plot only the first channel.

```
for i = 1:3  
    [melSpec,info] = read(ADSnew);  
  
    figure(i)  
    surf(info.TimeInstants,info.CenterFrequencies,melSpec(:,:,1), 'EdgeColor','none');  
    xlabel('Time (s)')  
    ylabel('Frequency (Hz)')  
    [~,name] = fileparts(info.FileName);  
    title(name)  
    axis([0 info.TimeInstants(end) info.CenterFrequencies(1) info.CenterFrequencies(end)])  
    view([0,90])  
end
```







Output Spectral Shape Features

Use `transform` to create an audio datastore that returns feature vectors.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);
```

Define a function, `extractFeatureVector`, that transforms the audio data from a time-domain representation to feature vectors.

```
function [dataOut,info] = extractFeatureVector(audioIn,info)

% Convert to frequency-domain representation
windowLength = 256;
overlapLength = 128;
[~,f,~,S] = spectrogram(mean(audioIn,2), ...
    hann(windowLength,"Periodic"), ...
    overlapLength, ...
    windowLength, ...
    info.SampleRate, ...
    "power", ...
```

```

        "onesided");

% Extract features
[kurtosis,spread,centroid] = spectralKurtosis(S,f);
skewness = spectralSkewness(S,f);
crest    = spectralCrest(S,f);
decrease = spectralDecrease(S,f);
entropy  = spectralEntropy(S,f);
flatness = spectralFlatness(S,f);
flux     = spectralFlux(S,f);
rolloff  = spectralRolloffPoint(S,f);
slope    = spectralSlope(S,f);

% Concatenate to create feature vectors
dataOut = [kurtosis,spread,centroid,skewness,crest,decrease,entropy,flatness,flux,rolloff,slope];
end

```

Call `transform` to create a `TransformedDatastore` with `Transforms` set to `extractFeatureVector`.

```
ADSnew = transform(ADS,@extractFeatureVector,'IncludeInfo',true)
```

```
ADSnew =
```

```
TransformedDatastore with properties:
```

```

    UnderlyingDatastores: {audioDatastore}
SupportedOutputFormats: ["txt" "csv" "xlsx" "xls" ... ]
      Transforms: {@extractFeatureVector}
      IncludeInfo: 1

```

Call `read` to return the feature vectors for the audio over time.

```
featureMatrix = read(ADSnew);
[numFeatureVectors,numFeatures] = size(featureMatrix)
```

```
numFeatureVectors =
```

```
4215
```

```
numFeatures =
```

```
11
```

Apply Bandpass Filtering

Use `transform` to create an audio datastore that applies bandpass filtering before returning audio from the `read` function.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder);
```

Define a function, `applyBandpassFilter`, that applies a bandpass filter with a passband between 1 and 15 kHz.

```
function [audioOut,info] = applyBandpassFilter(audioIn,info)
    audioOut = bandpass(audioIn,[1e3,15e3],info.SampleRate);
end
```

Call `transform` to create a `TransformedDatastore` with `Transforms` set to `applyBandpassFilter`.

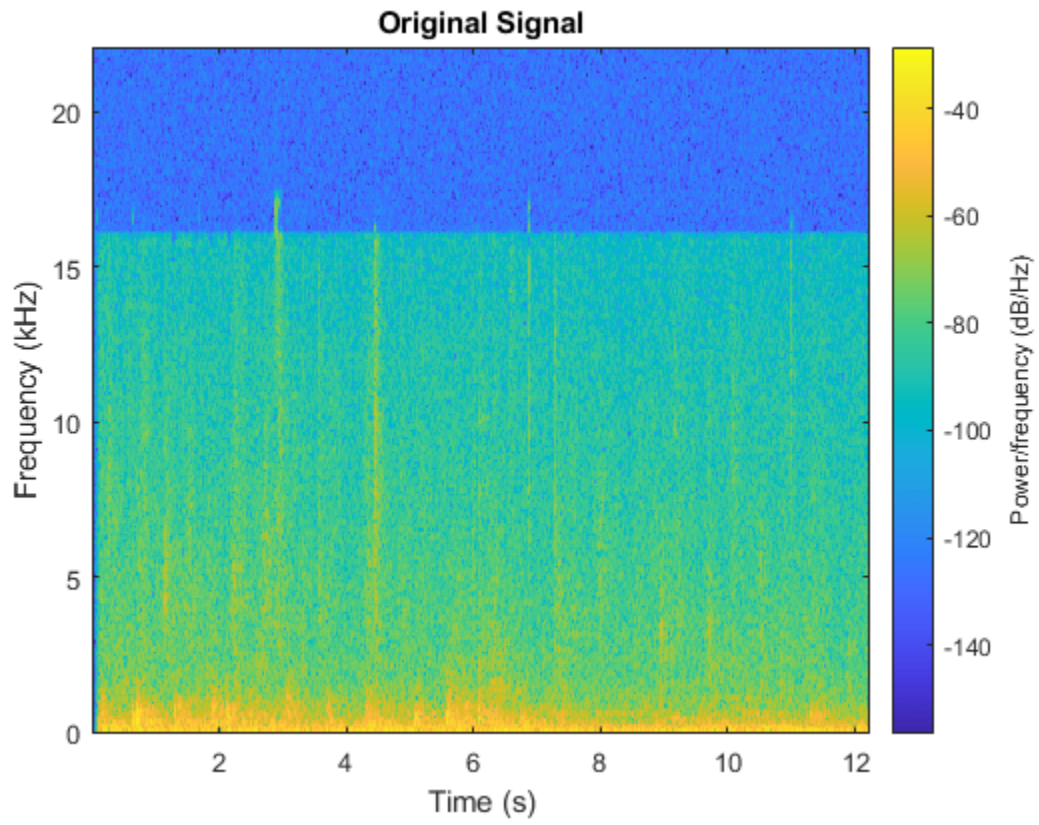
```
ADSnew = transform(ADS,@applyBandpassFilter,'IncludeInfo',true)
```

```
ADSnew =
    TransformedDatastore with properties:
        UnderlyingDatastores: {audioDatastore}
        SupportedOutputFormats: ["txt" "csv" "xlsx" "xls" ... ]
        Transforms: {@applyBandpassFilter}
        IncludeInfo: 1
```

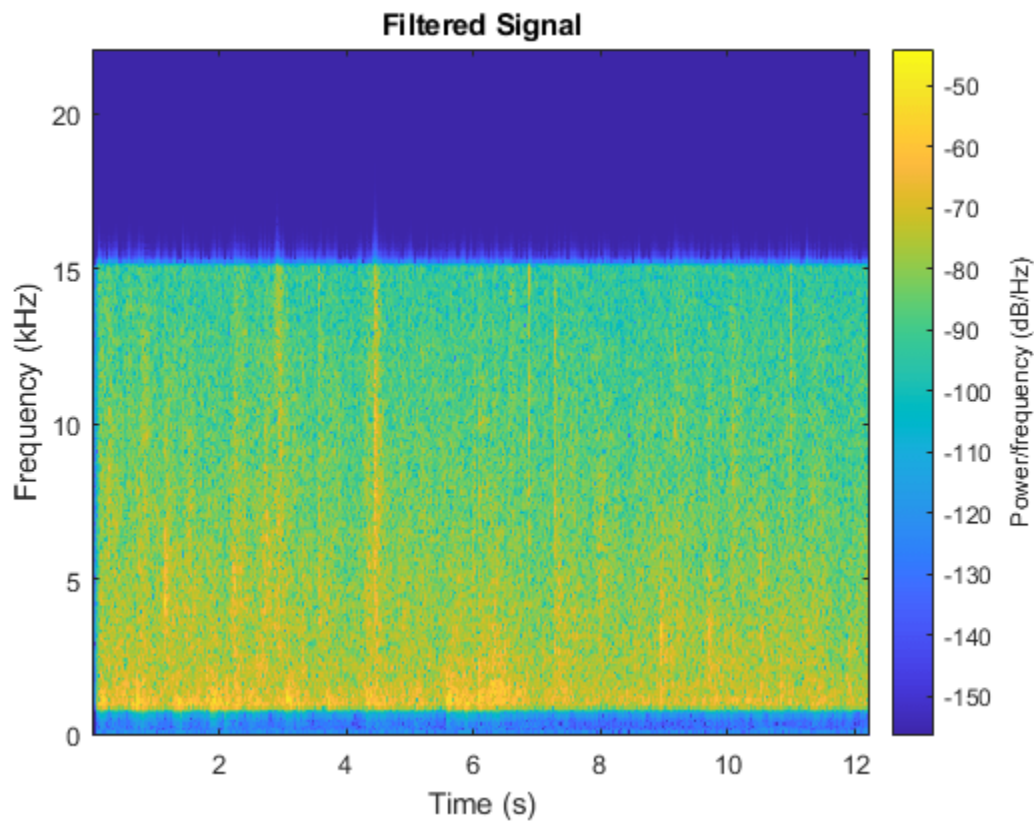
Call `read` to return the bandpass filtered audio from the transform datastore. Call `read` to return the bandpass filtered audio from the original datastore. Plot the spectrograms to visualize the difference.

```
[audio1,info1] = read(ADS);
[audio2,info2] = read(ADSnew);

spectrogram(audio1,hann(512),256,512,info1.SampleRate,'yaxis')
title('Original Signal')
```



```
spectrogram(audio2,hann(512),256,512,info2.SampleRate,'yaxis')  
title('Filtered Signal')
```



Input Arguments

ADS — Audio datastore

audioDatastore object

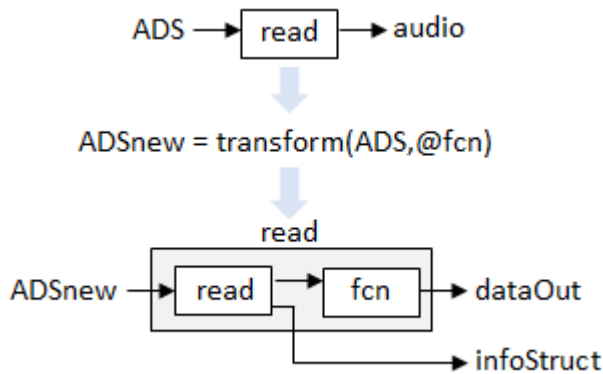
Audio datastore, specified as an audioDatastore object.

@fcn — Function that transforms data

function handle

Function that transforms data, specified as a function handle. The signature of the function depends on the IncludeInfo parameter.

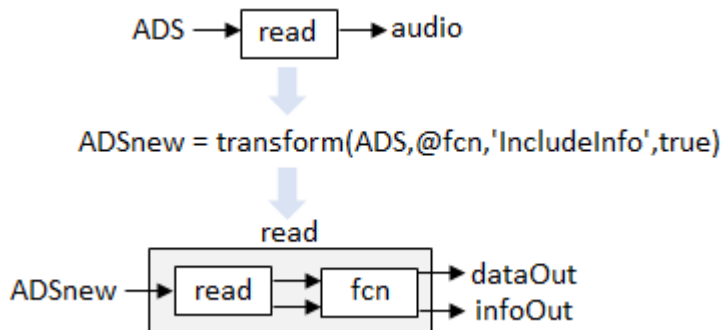
- If IncludeInfo is set to false (default), the function transforms the audio output from read. The info output from read is unaltered.



The transform function must have this signature:

```
function dataOut = fcn(audio)
...
end
```

- If `IncludeInfo` is set to `true`, the function transforms the audio output from `read`, and can use or modify the information returned from `read`.



The transform function must have this signature:

```
function [dataOut,infoOut] = fcn(audio,infoIn)
...
end
```

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `'IncludeInfo',tf`

IncludeInfo — Pass info through customized read function

false (default) | true

Pass info through the customized read function, specified as `true` or `false`. If `true`, the transform function can use or modify the information it gets from `read`. If unspecified, `IncludeInfo` defaults to `false`.

Data Types: `logical`

Output Arguments

transformDatastore — New datastore with customized read

`TransformedDatastore`

New datastore with customized read, returned as a `TransformedDatastore` with `UnderlyingDatastore` set to `ADS`, `Transforms` set to `fcn`, and `IncludeInfo` set to `true` or `false`.

See Also

`audioDatastore` | `combine` | `hasdata` | `preview` | `read` | `readall` | `reset`

Introduced in R2019a

combine

Combine data from multiple datastores

Syntax

```
ADSnew = combine(ADS1,ADS2,...,ADSN)
```

Description

`ADSnew = combine(ADS1,ADS2,...,ADSN)` combines two or more datastores by horizontally concatenating the data returned by `read` of the input datastores.

Examples

Combine Datastores

Create a datastore that maintains parity between the audio of the underlying datastores. Create two separate audio datastores, and then create a combined datastore representing the two underlying datastores.

Create a datastore `ads1` that points to the audio files included with Audio Toolbox.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');  
ads1 = audioDatastore(folder);
```

Create a second datastore `ads2` by adding noise to the audio in the `ads1`.

```
ads2 = transform(ads1,@(x) x + 0.01*randn(size(x)) );
```

Create a combined datastore from `ads1` and `ads2`.

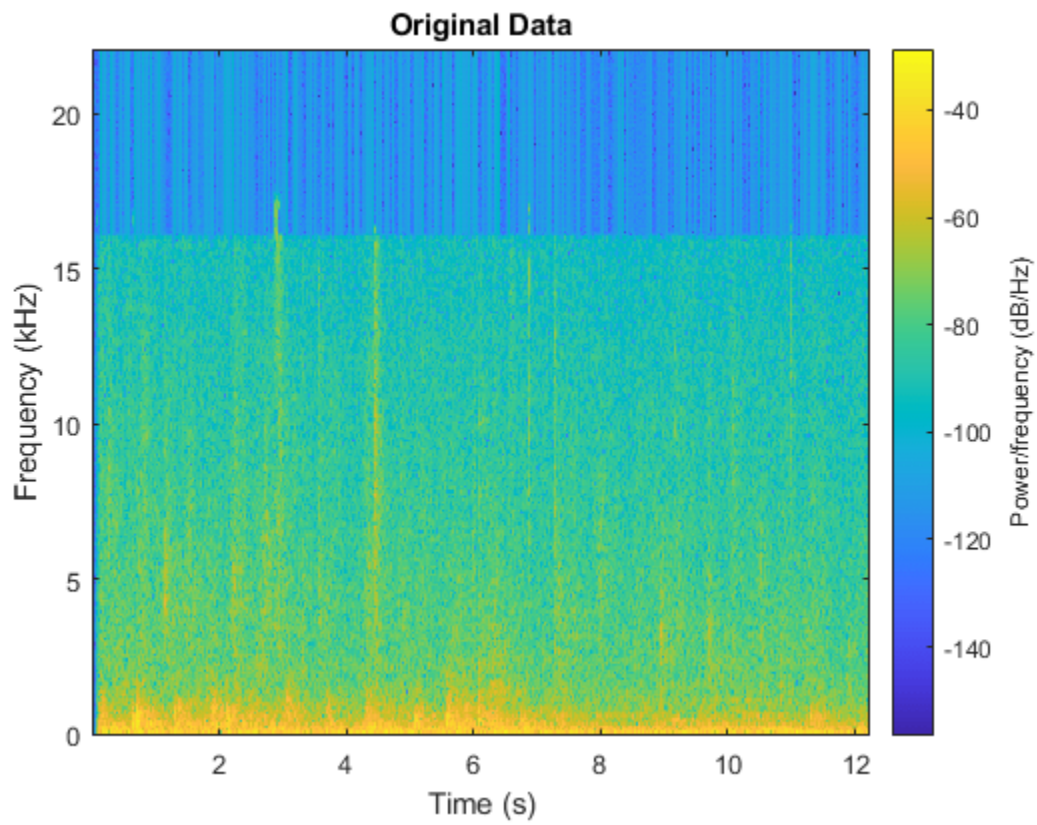
```
adsCombined = combine(ads1,ads2);
```

Read the first pair of audio files from the combined datastore. Each read operation on this combined datastore returns a pair of audio signals in a 1-by-2 cell array and a pair of info structs in a 1-by-2 cell array.

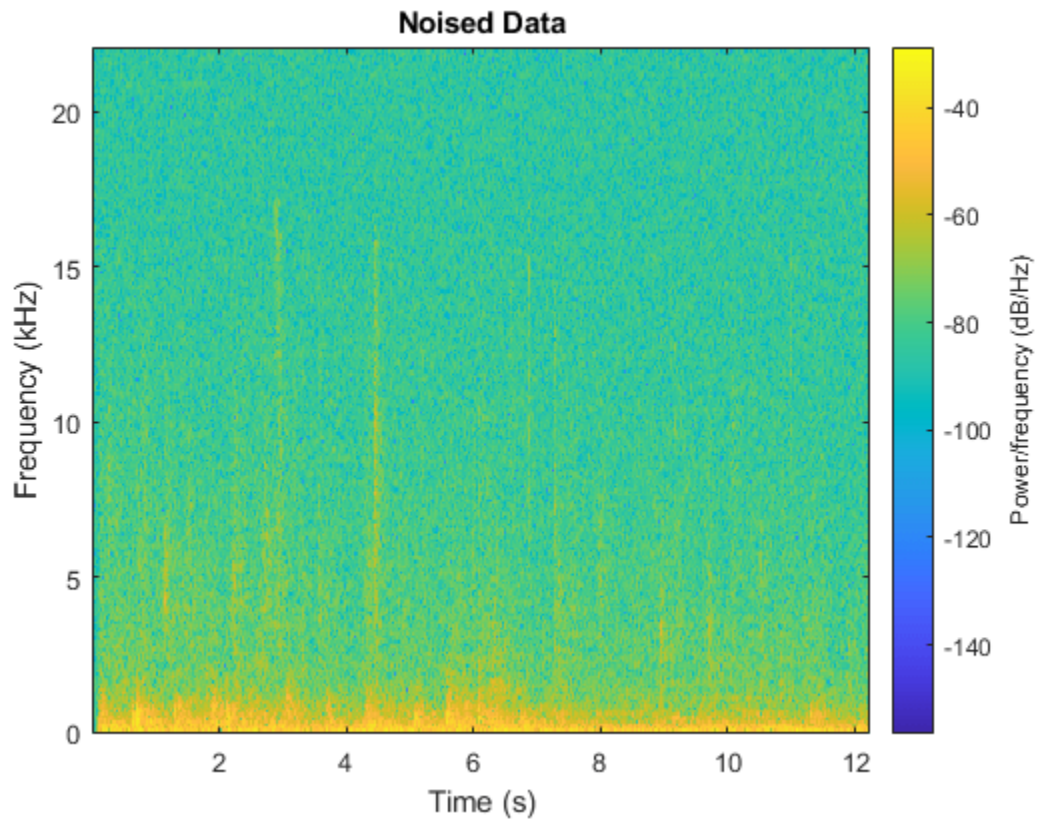
```
[dataOut,infoOut] = read(adsCombined)  
  
dataOut=1x2 cell array  
    {539648x1 double}    {539648x1 double}  
  
infoOut=1x2 cell array  
    {1x1 struct}    {1x1 struct}
```

Plot the spectrograms of the first channels from both audio signals.

```
figure(1)  
spectrogram(dataOut{1},hamming(512),256,512,infoOut{1}.SampleRate,'yaxis')  
title('Original Data')
```



```
figure(2)
idx = size(dataOut,2)/2+1;
spectrogram(dataOut{2},hamming(512),256,512,infoOut{2}.SampleRate,'yaxis')
title('Noised Data')
```



Input Arguments

ADS1, ADS2, ..., ADSN — Audio datastores to combine
audioDatastore objects

Audio datastores to combine, specified as two or more comma separated audioDatastore objects.

Output Arguments

ADSnew — New audio datastore with combined data
audioDatastore object

New audio datastore with combined data, returned as a matlab.io.datastore.CombinedDatastore object.

Calling read on the combined datastore returns a cell array containing the output of calling read on the individual datastores.

See Also

audioDatastore | transform | hasdata | preview | read | readall | reset

Introduced in R2019a

progress

Fraction of files read

Syntax

```
fractionRead = progress(ADS)
```

Description

`fractionRead = progress(ADS)` returns the fraction of files read in the datastore as a normalized value in the range [0,1].

Examples

Return Fraction of Files Read

Create an `audioDatastore` object `ADS`. Read a file from the datastore and then call `progress` to return the fraction of files read.

```
ADS = audioDatastore(fullfile(matlabroot, 'toolbox', 'audio', 'samples'))
```

```
ADS =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se'
        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

```
fractionOfFilesRead = progress(ADS)
```

```
fractionOfFilesRead = 0
```

```
data = read(ADS);
fractionOfFilesRead = progress(ADS)
```

```
fractionOfFilesRead = 0.0294
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

Output Arguments

fractionRead — Fraction of files read

normalized value in the range [0,1]

Fraction of files read, returned as a normalized value in the range [0,1].

Data Types: double

See Also

audioDatastore | hasdata

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

numpartitions

Return estimate for reasonable number of partitions for parallel processing

Syntax

```
n = numpartitions(ADS)
n = numpartitions(ADS,pool)
```

Description

`n = numpartitions(ADS)` returns the default number of partitions for the datastore, `ADS`. The default number of partitions is the total number of files.

`n = numpartitions(ADS,pool)` returns a reasonable number of partitions to parallelize `ADS` over the parallel pool, based on the total number of files and the number of workers in pool. To parallelize datastore access, you must have Parallel Computing Toolbox installed.

Examples

Estimate Reasonable Number of Partitions for Audio Datastore

`numpartitions` returns a reasonable number of partitions for an audio datastore. You can use `numpartitions` as input to the `partition` function.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);
```

Use `numpartitions` to estimate a reasonable number of partitions for the audio datastore, `ADS`. By default, `numpartitions` returns the number of files the audio datastore points to.

```
n = numpartitions(ADS)
n = 34
```

Number of Partitions for Parallel Datastore Access

Partition a datastore to facilitate parallel access over the available parallel pool of workers.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);
```

Return an estimate for a reasonable number of partitions for parallel processing, given the current parallel pool.

```
pool = gcp;  
n = numpartitions(ADS,pool);
```

Partition the audio datastore and read the data in each part.

```
parfor ii = 1:n  
    subds = partition(ADS,n,ii);  
    while hasdata(subds)  
        data = read(subds);  
    end  
end
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

pool — Parallel pool

parallel pool object

Parallel pool object.

Output Arguments

n — Number of partitions

positive integer

Number of partitions to parallelize datastore access over.

See Also

audioDatastore | partition

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

partition

Partition datastore and return on partitioned portion

Syntax

```
subADS = partition(ADS,numPartitions,index)
subADS = partition(ADS,'Files',index)
subADS = partition(ADS,'Files',filename)
```

Description

`subADS = partition(ADS,numPartitions,index)` partitions datastore `ADS` into the number of parts specified by `numPartitions` and returns the partition corresponding to the `index`.

`subADS = partition(ADS,'Files',index)` partitions the datastore by files and returns the partition corresponding to the file of index `index` in the `Files` property.

`subADS = partition(ADS,'Files',filename)` partitions the datastore by files and returns the partition corresponding to the file specified by `filename`.

Examples

Partition Datastore into Specific Number of Parts

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder)
```

ADS =

audioDatastore with properties:

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se'
        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

Partition the datastore into three parts.

```
subADS1 = partition(ADS,3,1)
```

```
subADS1 =
  audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5secs'
        ... and 9 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

```
subADS2 = partition(ADS,3,2)
```

```
subADS2 =
  audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\JetAirplane-16-11p025-mono-16secs'
        'B:\matlab\toolbox\audio\samples\Laughter-16-8-mono-4secs.wav';
        'B:\matlab\toolbox\audio\samples\MainStreetOne-16-16-mono-12secs.wav'
        ... and 8 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

```
subADS3 = partition(ADS,3,3)
```

```
subADS3 =
  audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\RockGuitar-16-96-stereo-72secs.flac'
        'B:\matlab\toolbox\audio\samples\SingingAMajor-16-mono-18secs.ogg'
        'B:\matlab\toolbox\audio\samples\SoftGuitar-44p1_mono-10mins.ogg'
        ... and 8 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
```

```
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"
```

Partition Datastore into Default Number of Parts

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder);
```

Get the default number of partitions for ADS.

```
n = numpartitions(ADS);
```

Partition the datastore into the default number of partitions and return the datastore corresponding to the first partition.

```
subADS = partition(ADS, n, 1);
```

Read the data in subADS.

```
while hasdata(subADS)
    data = read(subADS);
end
```

Partition Datastore by Files

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder);
```

Partition the datastore by files and return the part corresponding to the second file. subds contains one file.

```
subds = partition(ADS, 'Files', 2)
```

```
subds =
    audioDatastore with properties:
```

```
        Files: {
                'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
                }
        Folders: {
                'B:\matlab\toolbox\audio\samples'
                }
AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
```

```
DefaultOutputFormat: "wav"
```

Number of Partitions for Parallel Datastore Access

Partition a datastore to facilitate parallel access over the available parallel pool of workers.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');  
ADS = audioDatastore(folder);
```

Return an estimate for a reasonable number of partitions for parallel processing, given the current parallel pool.

```
pool = gcp;  
n = numpartitions(ADS, pool);
```

Partition the audio datastore and read the data in each part.

```
parfor ii = 1:n  
    subds = partition(ADS, n, ii);  
    while hasdata(subds)  
        data = read(subds);  
    end  
end
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Audio datastore, specified as an audioDatastore object.

numPartitions — Number of partitions

positive integer

Number of partitions, specified as a positive integer. Use numpartitions to estimate a reasonable value for numPartitions.

Data Types: double

index — Index of sub-datastore

positive integer

Index of sub-datastore, specified as a positive integer in the range [1, numPartitions].

Data Types: double

filename — File name

character vector

File name, specified as a character vector.

The value of `filename` must match exactly the file name contained in the `Files` property of the datastore.

Data Types: `char`

Output Arguments

subADS — Output audio datastore

`audioDatastore` object

Output audio datastore, returned as an `audioDatastore` object.

See Also

`audioDatastore` | `numpartitions`

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

countEachLabel

Count number of unique labels

Syntax

```
tbl = countEachLabel(ADS)
tbl = countEachLabel(ADS, 'TableVariable', VariableName)
```

Description

`tbl = countEachLabel(ADS)` counts the number of times each unique label occurs in the datastore. In other words, it counts the number of files with each unique label. The output `tbl` is a table with variable names `Label` and `Count`.

`tbl = countEachLabel(ADS, 'TableVariable', VariableName)` counts the number of times each unique label occurs in the datastore. When the datastore `Labels` property is specified by a table, you must specify `VariableName`. `VariableName` is the table variable (column) name you want to count.

Examples

Label Count

Specify the file path to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
```

Create an audio datastore that points to the specified folder. Specify the `LabelSource` property as `foldernames`, so that the label associated with each file is set to the folder name that contains the file.

```
ads = audioDatastore(folder, 'LabelSource', 'foldernames')
```

```
ads =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        ... and 31 more
    }
  Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: [samples; samples; samples ... and 31 more categorical]
AlternateFileSystemRoots: {}
      OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
  DefaultOutputFormat: "wav"
```

Call `countEachLabel` to count the number of times each unique label occurs.

```
tbl = countEachLabel(ads)
```

```
tbl=1x2 table
```

Label	Count
samples	34

Label Count when Labels Is Specified by Table

If the `Labels` property of an audio datastore is specified as a table, you must specify the table variable name when counting labels.

Specify the file path to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
```

Create an audio datastore that points to the specified folder.

```
ADS = audioDatastore(folder)
```

```
ADS =
```

```
audioDatastore with properties:
```

```

        Files: {
                'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
                'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
                ' ... \toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
                ... and 31 more
        }
        Folders: {
                'B:\matlab\toolbox\audio\samples'
        }
AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
SupportedOutputFormats: ["wav"      "flac"      "ogg"      "mp4"      "m4a"]
        DefaultOutputFormat: "wav"

```

The file names contain information about the files. Parse the file names to collect information about whether a file is mono or stereo and whether a file is longer than thirty seconds. Create a table containing the parsed information and then set the `Labels` property of the audio datastore to the label table.

```
numFiles = numel(ADS.Files);
```

```
numChannels = cell(numFiles,1);
```

```
isLong = cell(numFiles,1);
```

```
for i = 1:numFiles
    if ~isempty(strfind(ADS.Files{i}, 'mono'))
```

```

        numChannels{i} = 'mono';
elseif ~isempty(strfind(ADS.Files{i}, 'stereo'))
    numChannels{i} = 'stereo';
else
    numChannels{i} = 'unknown';
end

secs = str2double(regex(ADS.Files{i}, '-(\d+)secs', 'tokens', 'once'));
if secs > 30
    isLong{i} = true;
elseif secs <= 30
    isLong{i} = false;
else
    isLong{i} = 'unknown';
end
end
labelTable = table(numChannels,isLong, ...
    'VariableNames',{'NumberOfChannels','IsLongerThan30Seconds'});

ADS.Labels = labelTable;

```

Call `countEachLabel` on the audio datastore and specify the `TableVariable` as `NumberOfChannels`. Call `countEachLabel` and specify the `TableVariable` as `IsLongerThan30Seconds`.

```
countNumberOfChannelLabels = countEachLabel(ADS, 'TableVariable', 'NumberOfChannels')
```

```
countNumberOfChannelLabels=3x2 table
    NumberOfChannels    Count
    _____    _____
        mono            22
        stereo          10
        unknown         2
```

```
countDurationLabels = countEachLabel(ADS, 'TableVariable', 'IsLongerThan30Seconds')
```

```
countDurationLabels=3x2 table
    IsLongerThan30Seconds    Count
    _____    _____
        false                24
        true                  6
        unknown               4
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

VariableName — Label table variable name

character vector | string

Label table variable name, specified as a character vector or string that corresponds to a table variable of the `Label` property.

This syntax is required if the `Label` property of `audioDatastore` is specified by a table.

Data Types: `char` | `string`

Output Arguments

tbl — Table of label counts

two-column table

Table of label counts, returned as a two-column table containing the name of each label in ADS and the number of files associated with each label.

Data Types: `table`

See Also

`audioDatastore` | `splitEachLabel`

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

splitEachLabel

Splits datastore according to specified label proportions

Syntax

```
[ADS1,ADS2] = splitEachLabel(ADS,p)
[ADS1,...,ADSM] = splitEachLabel(ADS,p1,...,pN)
___ = splitEachLabel( ___, 'randomized')
___ = splitEachLabel( ___, Name, Value)
```

Description

`[ADS1,ADS2] = splitEachLabel(ADS,p)` splits the audio files in ADS into two new datastores, ADS1 and ADS2. The new datastore ADS1 contains the first `p` files from each label, and ADS2 contains the remaining files from each label. `p` can be either a number between 0 and 1, exclusive, indicating the percentage of the files from each label to assign to ADS1, or an integer indicating the absolute number of files from each label to assign to ADS1.

`[ADS1,...,ADSM] = splitEachLabel(ADS,p1,...,pN)` splits the datastore into `N+1` new datastores. The new datastore ADS1 contains the first `p1` files from each label, the next new datastore ADS2 contains the next `p2` files, and so on. If `p1,...,pN` represent numbers of files, then their sum must be no more than the number of files in the smallest label in the original datastore, ADS.

`___ = splitEachLabel(___, 'randomized')` randomly assigns the specified proportion of files from each label to the new datastores.

`___ = splitEachLabel(___, Name, Value)` specifies the properties of the new datastores using one or more name-value pair arguments. For example, you can specify which labels to split with `'Include', 'labelname'`.

Examples

Split by Fractions

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder, 'FileExtensions', '.wav');
```

Add the label A to the first half of the files, and the label B to the second half. If there are an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```
labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;
```

```
countEachLabel(ADS)
```

```
ans=2x2 table
  Label    Count
  _____
      A         10
      B         10
```

Split ADS into two datastores, ADS1 and ADS2, specifying that each new datastore contains fifty percent of each label and the corresponding files. Call `countEachLabel` to confirm that half of the files are labeled A and half of the files are labeled B for each of the new datastores.

```
[ADS1,ADS2] = splitEachLabel(ADS,0.5)
```

```
ADS1 =
  audioDatastore with properties:
      Files: {
          'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
          'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
          '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5secs'
          ... and 7 more
      }
      Folders: {
          'B:\matlab\toolbox\audio\samples'
      }
      Labels: {'A'; 'A'; 'A' ... and 7 more}
      AlternateFileSystemRoots: {}
      OutputDataType: 'double'
      SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
      DefaultOutputFormat: "wav"
```

```
ADS2 =
  audioDatastore with properties:
      Files: {
          'B:\matlab\toolbox\audio\samples\Engine-16-44p1-stereo-20sec.wav';
          'B:\matlab\toolbox\audio\samples\FemaleSpeech-16-8-mono-3secs.wav'
          'B:\matlab\toolbox\audio\samples\Heli_16ch_ACN_SN3D.wav'
          ... and 7 more
      }
      Folders: {
          'B:\matlab\toolbox\audio\samples'
      }
      Labels: {'A'; 'A'; 'A' ... and 7 more}
      AlternateFileSystemRoots: {}
      OutputDataType: 'double'
      SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
      DefaultOutputFormat: "wav"
```

```
ADS1count = countEachLabel(ADS1)
```

```
ADS1count=2x2 table
  Label    Count
  _____
```

```

A      5
B      5

```

```
ADS2count = countEachLabel(ADS2)
```

```

ADS2count=2x2 table
Label      Count
-----
A          5
B          5

```

Split by Number of Files

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```

folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder,'FileExtensions','.wav');

```

Add the label A to the first half of the files, and the label B to the second half. If there are an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```

labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;

```

```
countEachLabel(ADS)
```

```

ans=2x2 table
Label      Count
-----
A          10
B          10

```

Split ADS into two datastores, ADS1 and ADS2. Specify that ADS1 contains four of each label and its corresponding file. ADS2 contains the remaining labels and corresponding files. Call `countEachLabel` to confirm that ADS1 contains four files labeled A and four files labeled B, and that ADS2 contains the remaining labels.

```
[ADS1,ADS2] = splitEachLabel(ADS,4)
```

```
ADS1 =
audioDatastore with properties:
```

```

Files: {
    'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
    'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
    '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
    ... and 5 more
}

```



```

        Folders: {
            'B:\matlab\toolbox\audio\samples'
        }
        Labels: {'A'; 'A'; 'A' ... and 5 more}
    AlternateFileSystemRoots: {}
        OutputDataType: 'double'
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

```

ADS2 =
    audioDatastore with properties:

```

```

        Files: {
            'B:\matlab\toolbox\audio\samples\Counting-16-44p1-mono-15secs.wav'
            'B:\matlab\toolbox\audio\samples\Engine-16-44p1-stereo-20sec.wav';
            'B:\matlab\toolbox\audio\samples\FemaleSpeech-16-8-mono-3secs.wav'
            ... and 9 more
        }
        Folders: {
            'B:\matlab\toolbox\audio\samples'
        }
        Labels: {'A'; 'A'; 'A' ... and 9 more}
    AlternateFileSystemRoots: {}
        OutputDataType: 'double'
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

```

ADS1count = countEachLabel(ADS1)

```

```

ADS1count=2x2 table

```

Label	Count
A	4
B	4

```

ADS2count = countEachLabel(ADS2)

```

```

ADS2count=2x2 table

```

Label	Count
A	6
B	6

Split Several Ways by Fractions

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```

folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder, 'FileExtensions', '.wav');

```

Add the label A to the first half of the files, and the label B to the second half. If there is an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```
labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;
```

```
countEachLabel(ADS)
```

```
ans=2x2 table
    Label    Count
    -----
         A         10
         B         10
```

Split `ADS` into three new datastores, `ADS60`, `ADS10`, and `ADS30`. The first datastore, `ADS60`, contains the first 60% of files with the A label and the first 60% of files with the B label. `ADS10` contains the next 10% of files from each label. `ADS30` contains the remaining 30% of files from each label. If the percentage applied to a label does not result in a whole number of files, `splitEachLabel` rounds down to the nearest whole number.

```
[ADS60,ADS10,ADS30] = splitEachLabel(ADS,0.6,0.1)
```

```
ADS60 =
```

```
audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5secs'
        ... and 9 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'A'; 'A' ... and 9 more}
AlternateFileSystemRoots: {}
    OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"
```

```
ADS10 =
```

```
audioDatastore with properties:
```

```
    Files: {
        'B:\matlab\toolbox\audio\samples\FemaleSpeech-16-8-mono-3secs.wav'
        'B:\matlab\toolbox\audio\samples\TrainWhistle-16-44p1-mono-9secs.wav'
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'B'}
AlternateFileSystemRoots: {}
    OutputDataType: 'double'
```

```
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"
```

```
ADS30 =
```

```
audioDatastore with properties:
```

```
Files: {
    'B:\matlab\toolbox\audio\samples\Heli_16ch_ACN_SN3D.wav';
    'B:\matlab\toolbox\audio\samples\JetAirplane-16-11p025-mono-16secs';
    'B:\matlab\toolbox\audio\samples\Laughter-16-8-mono-4secs.wav'
    ... and 3 more
}
Folders: {
    'B:\matlab\toolbox\audio\samples'
}
Labels: {'A'; 'A'; 'A' ... and 3 more}
AlternateFileSystemRoots: {}
OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"
```

Call `countEachLabel` to confirm the correct distribution of labels for each datastore.

```
countEachLabel(ADS60)
```

```
ans=2x2 table
```

Label	Count
A	6
B	6

```
countEachLabel(ADS10)
```

```
ans=2x2 table
```

Label	Count
A	1
B	1

```
countEachLabel(ADS30)
```

```
ans=2x2 table
```

Label	Count
A	3
B	3

Split Labels Several Ways by Number of Files

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder:

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder, 'FileExtensions', '.wav');
```

Add the label A to the first half of the files, and the label B to the second half. If there is an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```
labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;
```

```
countEachLabel(ADS)
```

```
ans=2x2 table
    Label    Count
    ----    -
        A         10
        B         10
```

Split ADS into three new datastores, ADS1, ADS2, and ADS3. The first datastore, ADS1, contains the first file with the A label and the first file with the B label. ADS2 contains the next file from each label. ADS3 contains the remaining files from each label. If the percentage applied to a label does not result in a whole number of files, `splitEachLabel` rounds down to the nearest whole number.

```
[ADS1,ADS2,ADS3] = splitEachLabel(ADS,1,1)
```

```
ADS1 =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples>MainStreetOne-16-16-mono-12secs.wa
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'B'}
AlternateFileSystemRoots: {}
    OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

```
ADS2 =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
        'B:\matlab\toolbox\audio\samples\NoisySpeech-16-22p5-mono-5secs.wa
    }
    Folders: {
```

```

        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'B'}
AlternateFileSystemRoots: {}
    OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

ADS3 =

audioDatastore with properties:

```

    Files: {
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        'B:\matlab\toolbox\audio\samples\Click-16-44p1-mono-0.2secs.wav';
        'B:\matlab\toolbox\audio\samples\Counting-16-44p1-mono-15secs.wav'
        ... and 13 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'A'; 'A' ... and 13 more}
AlternateFileSystemRoots: {}
    OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Call `countEachLabel` to confirm the correct distribution of labels for each datastore.

`countEachLabel(ADS1)`

ans=2x2 table

Label	Count
A	1
B	1

`countEachLabel(ADS2)`

ans=2x2 table

Label	Count
A	1
B	1

`countEachLabel(ADS3)`

ans=2x2 table

Label	Count
A	8
B	8

Split Labels in Random Order

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder,'FileExtensions','.wav')
```

ADS =

audioDatastore with properties:

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        ... and 17 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

Add the label A to the first half of the files, and the label B to the second half. If there is an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```
labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;
```

`countEachLabel(ADS)`

ans=2x2 table

Label	Count
A	10
B	10

Create two new datastores from the files in ADS by randomly drawing from each label. The first datastore, ADS1, contains two random files with the A label and two random files with the B label. ADS2 contains the remaining files from each label.

```
[ADS1,ADS2] = splitEachLabel(ADS,2,'randomized')
```

ADS1 =

audioDatastore with properties:

```
Files: {
```

```

        ' ...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        'B:\matlab\toolbox\audio\samples\Engine-16-44p1-stereo-20sec.wav';
        'B:\matlab\toolbox\audio\samples\MainStreetOne-16-16-mono-12secs.w
        ... and 1 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'A'; 'B' ... and 1 more}
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

ADS2 =

audioDatastore with properties:

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
        'B:\matlab\toolbox\audio\samples\Click-16-44p1-mono-0.2secs.wav'
        ... and 13 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    Labels: {'A'; 'A'; 'A' ... and 13 more}
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Include and Exclude Specified Labels

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```

folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder, 'FileExtensions', '.wav')

```

ADS =

audioDatastore with properties:

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
        ' ...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        ... and 17 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }

```

```

AlternateFileSystemRoots: {}
      OutputDataType: 'double'
      Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Add the label A to the first half of the files, and the label B to the second half. If there is an odd number of files, assign the extra file the label B. Call `countEachLabel` to confirm that half of the files are labeled A and half the files are labeled B.

```

labels = [repmat({'A'},1,floor(numel(ADS.Files)/2)), ...
          repmat({'B'},1,ceil(numel(ADS.Files)/2))];
ADS.Labels = labels;

```

```
countEachLabel(ADS)
```

```
ans =
```

```
2x2 table
```

Label	Count
A	10
B	10

Create two new datastores from the files in ADS, including only the files with the A label. ADS1 contains the first 70% of files with the A label, and ADS2 contains the remaining 30% of labels with the A label.

```
[ADS1,ADS2] = splitEachLabel(ADS,0.7,'Include','A')
```

```
ADS1 =
```

```
audioDatastore with properties:
```

```

Files: {
    'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
    'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
    '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se'
    ... and 4 more
}
Folders: {
    'B:\matlab\toolbox\audio\samples'
}
Labels: {'A'; 'A'; 'A' ... and 4 more}
AlternateFileSystemRoots: {}
      OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

```
ADS2 =
```


audioDatastore with properties:

```

Files: {
    'B:\matlab\toolbox\audio\samples\Heli_16ch_ACN_SN3D.wav';
    'B:\matlab\toolbox\audio\samples\JetAirplane-16-11p025-mono-16secs';
    'B:\matlab\toolbox\audio\samples\Laughter-16-8-mono-4secs.wav'
}
Folders: {
    'B:\matlab\toolbox\audio\samples'
}
Labels: {'A'; 'A'; 'A'}
AlternateFileSystemRoots: {}
OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Equivalently, you can split only the A label by excluding the B label.

```
[ADS1,ADS2] = splitEachLabel(ADS,0.7,'Exclude','B')
```

ADS1 =

audioDatastore with properties:

```

Files: {
    'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav';
    'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs';
    '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5secs';
    ... and 4 more
}
Folders: {
    'B:\matlab\toolbox\audio\samples'
}
Labels: {'A'; 'A'; 'A' ... and 4 more}
AlternateFileSystemRoots: {}
OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

ADS2 =

audioDatastore with properties:

```

Files: {
    'B:\matlab\toolbox\audio\samples\Heli_16ch_ACN_SN3D.wav';
    'B:\matlab\toolbox\audio\samples\JetAirplane-16-11p025-mono-16secs';
    'B:\matlab\toolbox\audio\samples\Laughter-16-8-mono-4secs.wav'
}
Folders: {
    'B:\matlab\toolbox\audio\samples'
}
Labels: {'A'; 'A'; 'A'}
AlternateFileSystemRoots: {}
OutputDataType: 'double'
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]

```

```
DefaultOutputFormat: "wav"
```

Split Using Fraction and Label Table

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder)
```

```
ADS =
  audioDatastore with properties:
    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"
```

Create a label table with two variables:

- `containsMusic` -- Can be either true or false.
- `instrument` -- Can be Guitar, Drums, or Unknown.

```
containsGuitar = contains(ADS.Files, 'guitar', 'IgnoreCase', true);
containsDrums = contains(ADS.Files, 'drum', 'IgnoreCase', true);
containsMusic = or(containsGuitar, containsDrums);
```

```
instrument = strings(size(ADS.Files));
instrument(:) = "Unknown";
instrument(containsGuitar) = "Guitar";
instrument(containsDrums) = "Drums";
```

Assign the label table to the Labels property of audio datastore to associate the rows of the label table with the rows of the datastore. Call `countEachLabel` to determine the incidences of `containsMusic` and `instrument`.

```
labels = table(containsMusic, instrument);
ADS.Labels = labels;
```

```
containsMusicCount = countEachLabel(ADS, 'TableVariable', 'containsMusic')
```

```
containsMusicCount=2x2 table
    containsMusic    Count
    _____    _____
```

false	27
true	7

```
instrumentCount = countEachLabel(ADS, 'TableVariable', 'instrument')
```

```
instrumentCount=3x2 table
instrument      Count
-----
Drums          4
Guitar         3
Unknown       27
```

Split the datastore `ADS` into two, based on whether the audio file contains music. `ADS1` contains 70% of the audio files that contain music, and `ADS2` contains the rest. Call `countEachLabel` to verify that the ratio of `containsMusic == true` to `containsMusic == false` is preserved for the new datastores, within rounding.

```
[ADS1,ADS2] = splitEachLabel(ADS,0.7,'TableVariable','containsMusic');
ADS1_containsMusicCount = countEachLabel(ADS1,'TableVariable','containsMusic')
```

```
ADS1_containsMusicCount=2x2 table
containsMusic  Count
-----
false         19
true          5
```

```
ADS2_containsMusicCount = countEachLabel(ADS2,'TableVariable','containsMusic')
```

```
ADS2_containsMusicCount=2x2 table
containsMusic  Count
-----
false          8
true           2
```

Split the datastore `ADS` into two, based on the type of instrument present in the audio file. `ADS3` contains 25% of the audio files that have an instrument label, and `ADS4` contains the rest. Call `countEachLabel` to verify that the ratio of `instrument == "drums"` to `instrument == "guitar"` is preserved for the new datastores, within rounding.

```
[ADS3,ADS4] = splitEachLabel(ADS,0.25,'TableVariable','instrument');
ADS3_instrumentCount = countEachLabel(ADS3,'TableVariable','instrument')
```

```
ADS3_instrumentCount=3x2 table
instrument      Count
-----
Drums           1
Guitar          1
Unknown         7
```

```
ADS4_instrumentCount = countEachLabel(ADS4, 'TableVariable', 'instrument')
```

```
ADS4_instrumentCount=3×2 table
```

instrument	Count
Drums	3
Guitar	2
Unknown	20

Split by Number of Files and Label Table

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder);
```

Create a label table with two variables:

- `containsMusic` - Can be either true or false.
- `instrument` - Can be Guitar, Drums, or Unknown.

```
containsGuitar = contains(ADS.Files, 'guitar', 'IgnoreCase', true);
containsDrums = contains(ADS.Files, 'drum', 'IgnoreCase', true);
containsMusic = or(containsGuitar, containsDrums);
```

```
instrument = strings(size(ADS.Files));
instrument(:) = "Unknown";
instrument(containsGuitar) = "Guitar";
instrument(containsDrums) = "Drums";
```

Assign the label table to the `Labels` property of audio datastore to associate the rows of the label table with the rows of the datastore. Call `countEachLabel` to determine the incidences of `containsMusic` and `instrument`.

```
labels = table(containsMusic, instrument);
ADS.Labels = labels;
```

```
containsMusicCount = countEachLabel(ADS, 'TableVariable', 'containsMusic')
```

```
containsMusicCount=2×2 table
```

containsMusic	Count
false	27
true	7

```
instrumentCount = countEachLabel(ADS, 'TableVariable', 'instrument');
```

Split the datastore `ADS` into two, based on whether the audio file contains music. `ADS1` contains 5 of each label under the table variable `containsMusic`, and `ADS2` contains the rest. Call `countEachLabel` to verify.

```
[ADS1,ADS2] = splitEachLabel(ADS,5,'TableVariable','containsMusic');
ADS1_containsMusicCount = countEachLabel(ADS1,'TableVariable','containsMusic')
```

```
ADS1_containsMusicCount=2×2 table
containsMusic    Count
```

containsMusic	Count
false	5
true	5

```
ADS2_containsMusicCount = countEachLabel(ADS2,'TableVariable','containsMusic')
```

```
ADS2_containsMusicCount=2×2 table
containsMusic    Count
```

containsMusic	Count
false	22
true	2

Split the datastore ADS into two, based on the type of instrument present in the audio file. ADS3 contains 2 of each label under the table variable instrument, and ADS4 contains the rest. Call `countEachLabel` to verify.

```
[ADS3,ADS4] = splitEachLabel(ADS,2,'TableVariable','instrument');
ADS3_instrumentCount = countEachLabel(ADS3,'TableVariable','instrument')
```

```
ADS3_instrumentCount=3×2 table
instrument    Count
```

instrument	Count
Drums	2
Guitar	2
Unknown	2

```
ADS4_instrumentCount = countEachLabel(ADS4,'TableVariable','instrument')
```

```
ADS4_instrumentCount=3×2 table
instrument    Count
```

instrument	Count
Drums	2
Guitar	1
Unknown	25

Input Arguments

ADS — Input audio datastore

audioDatastore object

Input audio datastore, specified as an `audioDatastore` object.

p — Proportion of files to split

scalar in interval (0,1) | positive integer scalar

Proportion of files to split, specified as a scalar in the interval (0,1), or a positive integer scalar.

If p is in the interval (0,1), it represents the percentage of the files from each label to assign to ADS1. If p represents a percentage, and it does not result in a whole number, then `splitEachLabel` rounds down to the nearest whole number.

If p is an integer, it represents the absolute number of files from each label to assign to ADS1. When p represents a number of files, there must be at least p files associated with each label.

Data Types: double

p_1, \dots, p_N — List of proportions

scalars in interval (0,1) | positive integer scalars

List of proportions, specified as scalars in the interval (0,1) or positive integer scalars.

If the proportions are in the interval (0,1), they represent the percentage of the files from each label to assign to the output datastores. When the proportions represent percentages, their sum must be no more than 1.

If the proportions are integers, they indicate the absolute number of files from each label to assign to the output datastores. When the proportions represent numbers of files, there must be enough files associated with each label to satisfy each proportion.

Data Types: double

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `[ADS1,ADS2] = splitEachLabel(ADS,0.5,'Exclude','noisy')`

Include — Labels to include

categorical, logical, or numeric vector | cell array of character vectors | string array

Labels to include, specified as the comma-separated pair consisting of 'Include' and a vector, cell array, or string array of label names with the same type as the `Labels` property. Each name must match one of the labels in the `Labels` property of the datastore.

This option cannot be used with the 'Exclude' option.

Exclude — Labels to exclude

categorical, logical, or numeric vector | cell array of character vectors | string array

Labels to exclude, specified as the comma-separated pair consisting of 'Exclude' and a vector, cell array, or string array of label names with the same type as the `Labels` property. Each name must match one of the labels in the `Labels` property of the datastore.

This option cannot be used with the 'Include' option.

TableVariable — Label table variable name

char | string

Table variable name, specified as the comma-separated pair consisting of 'TableVariable' and a character vector or string. When the Labels property of the audio datastore ADS is a table, you must use 'TableVariable' to specify which label you are using to split.

Data Types: char | string

Output Arguments

[ADS1, ADS2] — Output audio datastores

audioDatastore objects

Output audio datastores, returned as audioDatastore objects. ADS1 contains the specified proportion of files from each label in ADS, and ADS2 contains the remaining files.

[ADS1, ..., ADSM] — List of output audio datastores

audioDatastore objects

List of output audio datastores, returned as audioDatastore objects. The number of elements in the list is one more than the number of listed proportions. Each of the new datastores contains the proportion of each label in ADS defined by p_1, \dots, p_N . Any files left over are assigned to the M th datastore.

See Also

audioDatastore | countEachLabel | subset

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

preview

Read first file from datastore for preview

Syntax

```
data = preview(ADS)
```

Description

`data = preview(ADS)` always reads the first file from ADS. `preview` does not affect the state of ADS.

Examples

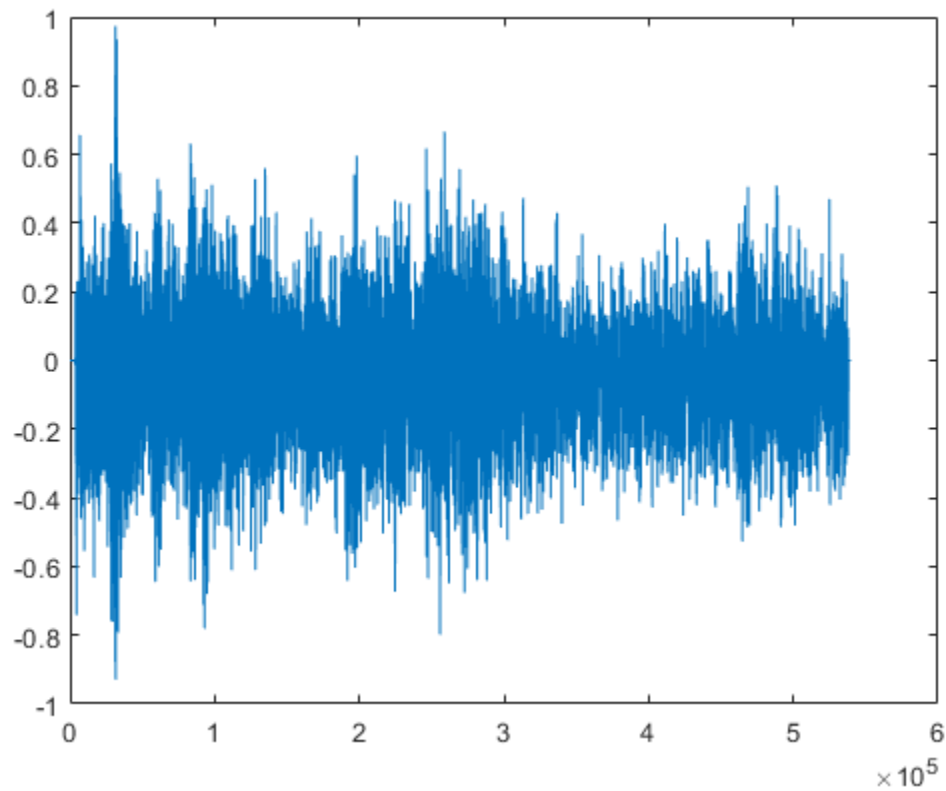
Preview Data in Audio Datastore

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');  
ADS = audioDatastore(folder);
```

Preview the data in the audio datastore.

```
data = preview(ADS);  
plot(data)
```

Input Arguments

ADS — Audio datastore
audioDatastore object

Specify ADS as an audioDatastore object.

Output Arguments

data — Subset of data
array of audio samples

Subset of data, returned as an array of audio samples.

See Also

audioDatastore | hasdata

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

subset

Create datastore with subset of files

Syntax

```
ADSsubset = subset(ADS,indices)
```

Description

`ADSsubset = subset(ADS,indices)` returns an audio datastore, `ADSsubset`, which contains a subset of the files in `ADS`.

Examples

Create Datastore with Subset Based on File Name

`subset` creates an audio datastore containing a subset of the files of the original datastore.

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
ADS = audioDatastore(folder)
```

```
ADS =
    audioDatastore with properties:
```

```

        Files: {
            'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
            'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs
            ' ..\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
            ... and 31 more
        }
        Folders: {
            'B:\matlab\toolbox\audio\samples'
        }
AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
SupportedOutputFormats: ["wav"      "flac"      "ogg"      "mp4"      "m4a"]
        DefaultOutputFormat: "wav"
```

Create a logical vector indicating whether the file names in the audio datastore contain 'Guitar'.

```
fileContainsGuitar = cellfun(@(c)contains(c, 'Guitar'), ADS.Files)
```

```
fileContainsGuitar = 34x1 logical array
```

```

0
0
```

```

0
0
0
0
0
0
0
0
0
:

```

Call `subset` with the audio datastore and the indices corresponding to the files you want create a new audio datastore from.

```
ADSsubset = subset(ADS,fileContainsGuitar)
```

```
ADSsubset =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\RockGuitar-16-44p1-stereo-72secs.wav'
        'B:\matlab\toolbox\audio\samples\RockGuitar-16-96-stereo-72secs.flac'
        'B:\matlab\toolbox\audio\samples\SoftGuitar-44p1_mono-10mins.ogg'
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Create Datastore with Every Other File

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
```

```
ADS = audioDatastore(folder)
```

```
ADS =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs.wav'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5secs.wav'
        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'

```

```

        Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Create an audio datastore containing every other file of the original datastore.

```

indices = 1:2:numel(ADS.Files);
ADSsubset = subset(ADS,indices)

```

```
ADSsubset =
```

```
  audioDatastore with properties:
```

```

        Files: {
            'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
            '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
            'B:\matlab\toolbox\audio\samples\Counting-16-44p1-mono-15secs.wav'
            ... and 14 more
        }
        Folders: {
            'B:\matlab\toolbox\audio\samples'
        }
AlternateFileSystemRoots: {}
        OutputDataType: 'double'
        Labels: {}
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
DefaultOutputFormat: "wav"

```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

indices — Indices of files for subset

vector of indices | logical vector

Specify indices as:

- A vector containing the indices of files to be included in ADSsubset.
- A logical vector the same length as the number of files in ADS. If specifying indices as a logical vector, true indicates that the corresponding files are included in ADSsubset.

Data Types: double | logical

Output Arguments

ADSsubset — Subset of audio datastore

audioDatastore object

Subset of audio datastore, returned as an audioDatastore object.

See Also

audioDatastore | splitEachLabel

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

shuffle

Shuffle files in datastore

Syntax

```
shuffledADS = shuffle(ADS)
```

Description

`shuffledADS = shuffle(ADS)` creates a deep copy of the input datastore, `ADS`, and shuffles the files using `randperm`.

Examples

Shuffle Files

Create an `audioDatastore` object `ADS`. Shuffle the files to create a new datastore containing the same files in random order.

```
ADS = audioDatastore(fullfile(matlabroot, 'toolbox', 'audio', 'samples'))
```

```
ADS =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'
        'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'
        '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

```
ADSshuffled = shuffle(ADS)
```

```
ADSshuffled =
```

```
audioDatastore with properties:
```

```

    Files: {
        'B:\matlab\toolbox\audio\samples\WashingMachine-16-8-mono-200secs.r
        'B:\matlab\toolbox\audio\samples\RockDrums-48-stereo-11secs.mp3';
        'B:\matlab\toolbox\audio\samples\multipleSounds-16-16-mono-18secs.r
        ... and 31 more
    }

```

```
        Folders: {  
            'B:\matlab\toolbox\audio\samples'  
        }  
AlternateFileSystemRoots: {}  
    OutputDataType: 'double'  
        Labels: {}  
SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]  
    DefaultOutputFormat: "wav"
```

Input Arguments

ADS — Input audio datastore

audioDatastore object

Input audio datastore, specified as an audioDatastore object.

Output Arguments

shuffledADS — Shuffled audio datastore

audioDatastore object

Shuffled audio datastore, returned as an audioDatastore object containing randomly ordered files from ADS.

See Also

audioDatastore

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

hasdata

Return true if there is more data in datastore

Syntax

```
tf = hasdata(ADS)
```

Description

`tf = hasdata(ADS)` returns logical 1 (`true`) if there is data available to read from the datastore specified by `ADS`. Otherwise, it returns logical 0 (`false`).

Examples

Keep Reading While Datastore Has Data

`hasdata` returns a logical scalar indicating whether or not there is unread data in the datastore. You can use `audioDatastore` to read files sequentially until all data is read.

Specify the file path to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
```

Create an audio datastore that points to the specified folder.

```
ADS = audioDatastore(folder);
```

While the datastore has unread data, read from the datastore.

```
while hasdata(ADS)
    data = read(ADS);
end
```

Input Arguments

ADS — Audio datastore

`audioDatastore` object

Specify `ADS` as an `audioDatastore` object.

Output Arguments

tf — Indication if data is available to read

`true` | `false`

Indication if data is available to read from the datastore, returned as `true` or `false`.

Data Types: `logical`

See Also

[audioDatastore](#) | [read](#) | [progress](#)

Topics

[“Speech Command Recognition Using Deep Learning”](#)

[“Speaker Identification Using Pitch and MFCC”](#)

[“Denoise Speech Using Deep Learning Networks”](#)

[“Music Genre Classification Using Wavelet Time Scattering”](#)

Introduced in R2018b

reset

Reset datastore read pointer to start of data

Syntax

```
reset(ADS)
```

Description

`reset(ADS)` resets the datastore read pointer to the start of the data. Resetting allows re-reading from the same datastore.

Examples

Reset Audio Datastore to Initial State

Create an `audioDatastore` object `ADS`.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');  
ADS = audioDatastore(folder);
```

While the datastore has unread files, call `read` in a loop to read files sequentially.

```
while hasdata(ADS)  
    data = read(ADS);  
end
```

Reset the datastore to the state where no data has been read from it. Read the first file from the datastore.

```
reset(ADS)  
data = read(ADS);
```

Input Arguments

ADS — Audio datastore

`audioDatastore` object

Specify `ADS` as an `audioDatastore` object.

See Also

`audioDatastore`

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

readall

Read all audio files from datastore

Syntax

```
data = readall(ADS)
```

Description

`data = readall(ADS)` reads all audio files from the datastore.

If all the data in the datastore does not fit in memory, then `readall` returns an error.

Examples

Read All Data in Audio Datastore

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');  
ADS = audioDatastore(folder);
```

Read all the data in the datastore.

```
readall(ADS)
```

```
ans=34x1 cell array  
    { 539648x1  double}  
    { 320512x4  double}  
    { 227497x1  double}  
    {   8000x1  double}  
    { 685056x1  double}  
    { 882688x2  double}  
    {  24000x1  double}  
    { 175104x1  double}  
    {1115760x2  double}  
    {1214832x2  double}  
    { 263304x16 double}  
    { 100868x1  double}  
    { 180224x1  double}  
    {  32768x1  double}  
    { 192150x1  double}  
    { 100352x1  double}  
    ⋮
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

Output Arguments

data — All audio files in audio datastore

cell array

All files in the audio datastore, returned as a cell array where each cell corresponds to a file.

See Also

audioDatastore | read

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

read

Read next consecutive audio file

Syntax

```
data = read(ADS)
[data,info] = read(ADS)
```

Description

`data = read(ADS)` returns audio extracted from the datastore. Each subsequent call to the `read` function continues reading from the endpoint of the previous call.

`[data,info] = read(ADS)` also returns information about the extracted audio data.

Examples

Read Data in Audio Datastore

Specify the file path to the audio samples included with Audio Toolbox™. Create an audio datastore that points to the specified folder.

```
folder = fullfile(matlabroot,'toolbox','audio','samples');
ADS = audioDatastore(folder);
```

While the audio datastore has unread files, read consecutive files from the datastore. Use `progress` to monitor the fraction of files read.

```
while hasdata(ADS)
    data = read(ADS);
    fprintf('Fraction of files read: %.2f\n',progress(ADS))
end
```

```
Fraction of files read: 0.03
Fraction of files read: 0.06
Fraction of files read: 0.09
Fraction of files read: 0.12
Fraction of files read: 0.15
Fraction of files read: 0.18
Fraction of files read: 0.21
Fraction of files read: 0.24
Fraction of files read: 0.26
Fraction of files read: 0.29
Fraction of files read: 0.32
Fraction of files read: 0.35
Fraction of files read: 0.38
Fraction of files read: 0.41
Fraction of files read: 0.44
Fraction of files read: 0.47
Fraction of files read: 0.50
Fraction of files read: 0.53
```

```
Fraction of files read: 0.56
Fraction of files read: 0.59
Fraction of files read: 0.62
Fraction of files read: 0.65
Fraction of files read: 0.68
Fraction of files read: 0.71
Fraction of files read: 0.74
Fraction of files read: 0.76
Fraction of files read: 0.79
Fraction of files read: 0.82
Fraction of files read: 0.85
Fraction of files read: 0.88
Fraction of files read: 0.91
Fraction of files read: 0.94
Fraction of files read: 0.97
Fraction of files read: 1.00
```

Return Information About Data

Specify the file path to the audio samples you want to include in the audio datastore. In this example, the samples are located on a local desktop. Create an audio datastore that points to the specified folder.

```
folder = 'C:\Users\bhemmat\Desktop';
ADS = audioDatastore(folder, 'LabelSource', 'foldernames');
```

When you read data from the datastore, you can additionally return information about the data as a struct. The information struct contains the file name, any labels associated with the file, and the sample rate of the file.

```
[data,info] = read(ADS);
info
```

```
info =
```

```
struct with fields:
```

```
SampleRate: 44100
FileName: 'C:\Users\bhemmat\Desktop\Turbine-16-44p1-mono-22secs.wav'
Label: Desktop
```

Input Arguments

ADS — Audio datastore

audioDatastore object

Specify ADS as an audioDatastore object.

Output Arguments

data — Audio data

M-by-*N* matrix

Audio data, returned as a M -by- N matrix, where:

- M -- Total samples per channel in file.
- N -- Number of channels in file.

info — Information about audio data

struct

Information about audio data, returned as a struct with the following fields:

- `FileName` -- Name of the current file.
- `Label` -- All labels of the file.
- `SampleRate` -- Sample rate of the file.

See Also

`audioDatastore` | `hasdata` | `readall`

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

Introduced in R2018b

audioDatastore

Datastore for collection of audio files

Description

Use an `audioDatastore` object to manage a collection of audio files, where each individual audio file fits in memory, but the entire collection of audio files does not necessarily fit.

Creation

Syntax

```
ADS = audioDatastore(location)
ADS = audioDatastore(location,Name,Value)
```

Description

`ADS = audioDatastore(location)` creates a datastore `ADS` based on an audio file or collection of audio files in `location`.

`ADS = audioDatastore(location,Name,Value)` specifies additional properties using one or more name-value pair arguments.

Input Arguments

location — Files or folders to include in datastore

`FileSet` object | path | `DsFileSet` object

Files or folders included in the datastore, specified as a `FileSet` object, as file paths, or as a `DsFileSet` object.

- `FileSet` object — You can specify `location` as a `FileSet` object. Specifying the location as a `FileSet` object leads to a faster construction time for datastores compared to specifying a path or `DsFileSet` object. For more information, see `matlab.io.datastore.FileSet`.
- File path — You can specify a single file path as a character vector or string scalar. You can specify multiple file paths as a cell array of character vectors or a string array.
- `DsFileSet` object — You can specify a `DsFileSet` object. For more information, see `matlab.io.datastore.DsFileSet`.

Files or folders may be local or remote:

- Local files or folders — Specify local paths to files or folders. If the files are not in the current folder, then specify full or relative paths. Files within subfolders of the specified folder are not automatically included in the datastore. You can use the wildcard character (*) when specifying the local path. This character specifies that the datastore include all matching files or all files in the matching folders.
- Remote files or folders — Specify full paths to remote files or folders as a uniform resource locator (URL) of the form `hdfs:///path_to_file`. For more information, see “Work with Remote Data”.

When you specify a folder, the datastore includes only files with supported file formats and ignores files with any other format. To specify a custom list of file extensions to include in your datastore, see the `FileExtensions` property.

Example: `'song.wav'`

Example: `'../dir/music/song.wav'`

Example: `{'C:\dir\music\song.wav','C:\dir\speech\english.mp3'}`

Example: `'C:\dir\music*.ogg'`

Data Types: `char` | `string` | `cell`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `ADS = audioDatastore('C:\dir\audiodata','FileExtensions','.ogg')`

IncludeSubfolders — Subfolder inclusion flag

`false` (default) | `true`

Subfolder inclusion flag, specified as the comma-separated pair consisting of `'IncludeSubfolders'` and `true` or `false`. Specify `true` to include all files and subfolders within each folder or `false` to include only the files within each folder.

If you do not specify `'IncludeSubfolders'`, then the default value is `false`.

Example: `'IncludeSubfolders',true`

Data Types: `logical` | `double`

LabelSource — Source providing label data

`'none'` (default) | `'foldernames'`

Source providing label data, specified as the comma-separated pair consisting of `'LabelSource'` and `'none'` or `'foldernames'`. If `'none'` is specified, then the `Labels` property is empty. If `'foldernames'` is specified, then labels are assigned according to the folder names and stored in the `Labels` property. You can later modify the labels by accessing the `Labels` property directly.

Data Types: `char` | `string`

FileExtensions — Audio file extensions

character vector | cell array of character vectors | string scalar | string array

Audio file extensions, specified as the comma-separated pair consisting of `'FileExtensions'` and a character vector, cell array of character vectors, string scalar, or string array. If you do not specify `'FileExtensions'`, then `audioDatastore` automatically includes all supported file types:

- `.wav`
- `.avi`
- `.aif`

- .aifc
- .aiff
- .mp3
- .au
- .snd
- .mp4
- .m4a
- .flac
- .ogg
- .mov

Example: 'FileExtensions', '.wav'

Example: 'FileExtensions', {' .mp3', '.mp4' }

Data Types: char | cell | string

In addition to these name-value pairs, you also can specify any of the properties on this page as name-value pairs, except for the `Files` property.

Properties

Files — Files included in datastore

character vector | cell array of character vectors | string scalar | string array

Files included in the datastore, specified as a character vector, cell array of character vectors, string scalar, or string array. Each character vector or string is a full path to a file. The `location` argument in the `audioDatastore` defines `Files` when the datastore is created.

Data Types: char | cell | string

Folders — Folders used to create audio datastore

N-by-1 cell array of character vectors

This property is read-only.

Folders used to create the audio datastore, returned as an *N*-by-1 cell array of character vectors. Each row specifies a unique folder containing audio files that the `audioDatastore` object points to.

Data Types: cell

Labels — File labels

categorical, logical, or numeric vector | cell array | string array | table

File labels for the files in the datastore, specified as a vector, a cell array, a string array, or a table. The order of the labels in the array or table corresponds to the order of the associated files in the datastore.

If you specify `LabelSource` as 'foldernames' when creating the `audioDatastore` object, then the label name for a file is the name of the folder containing it. If you do not specify `LabelSource` as 'foldernames', then `Labels` is an empty cell array or string array. If you change the `Files` property after the datastore is created, then the `Labels` property is not automatically updated to incorporate the added fields.

Data Types: `categorical` | `cell` | `logical` | `double` | `single` | `string` | `table`

OutputDataType — Data type of output read

'double' (default) | 'native'

Data type of the output, specified as 'double' or 'native'.

- 'double' -- Double-precision normalized samples.
- 'native' -- Native data type found in the file. Refer to `audioread` for more information about data types when `OutputDataType` is set to native.

The default value of this property is 'double'.

Data Types: `char` | `string`

AlternateFileSystemRoots — Alternate file system root paths

string row vector | cell array of string vectors | cell array of character vectors

Alternate file system root paths, specified as a string row vector, a cell array of string vectors, or a cell array of character vectors. Use `AlternateFileSystemRoots` when you create a datastore on a local machine but must access and process data on another machine (possibly of a different operating system). Also, when processing data using Parallel Computing Toolbox and MATLAB Parallel Server™, and the data is stored on your local machines with a copy of the data available on different platform cloud or cluster machines, you must use `AlternateFileSystemRoots` to associate the root paths.

- To associate a set of root paths that are equivalent to one another, specify `AlternateFileSystemRoots` as a string vector. For example:


```
["Z:\datasets", "/mynetwork/datasets"]
```
- To associate multiple sets of root paths that are equivalent for the datastore, specify `AlternateFileSystemRoots` as a cell array containing multiple rows, where each row represents a set of equivalent root paths. Specify each row in the cell array as either a string vector or a cell array of character vectors. For example:
 - Specify `AlternateFileSystemRoots` as a cell array of string vectors.


```
{["Z:\datasets", "/mynetwork/datasets"]; ...
  ["Y:\datasets", "/mynetwork2/datasets", "S:\datasets"]}
```
 - Alternatively, specify `AlternateFileSystemRoots` as a cell array of cell arrays of character vectors.


```
{{'Z:\datasets', '/mynetwork/datasets'}; ...
  {'Y:\datasets', '/mynetwork2/datasets', 'S:\datasets'}}
```

The value of `AlternateFileSystemRoots` must satisfy these conditions:

- Contains one or more rows, where each row specifies a set of equivalent root paths.
- Each row specifies multiple root paths, and each root path must contain at least two characters.
- Root paths are unique and are not subfolders of one another.
- Contains at least one root path entry that points to the location of the files.

Data Types: `char` | `cell` | `string`

SupportedOutputFormats — Formats supported for writing audio files

["wav", "flac", "ogg", "mp4", "m4a"]

This property is read-only.

Formats supported for writing audio files when using the `writeall` function, specified as `["wav", "flac", "ogg", "mp4", "m4a"]`.

Data Types: `string`

DefaultOutputFormat — Default output audio file format

"wav" (default)

This property is read-only.

Default output format for writing audio files when using the `writeall` function, specified as "wav".

Data Types: `string`

Object Functions

<code>read</code>	Read next consecutive audio file
<code>readall</code>	Read all audio files from datastore
<code>reset</code>	Reset datastore read pointer to start of data
<code>hasdata</code>	Return true if there is more data in datastore
<code>shuffle</code>	Shuffle files in datastore
<code>subset</code>	Create datastore with subset of files
<code>preview</code>	Read first file from datastore for preview
<code>progress</code>	Fraction of files read
<code>splitEachLabel</code>	Splits datastore according to specified label proportions
<code>countEachLabel</code>	Count number of unique labels
<code>partition</code>	Partition datastore and return on partitioned portion
<code>numpartitions</code>	Return estimate for reasonable number of partitions for parallel processing
<code>combine</code>	Combine data from multiple datastores
<code>transform</code>	Transform audio datastore
<code>writeall</code>	Write datastore to files
<code>isPartitionable</code>	Determine whether datastore is partitionable
<code>isShuffleable</code>	Determine whether datastore is shuffleable

Examples

Create Audio Datastore

Specify the file path to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
```

Create an audio datastore that points to the specified folder.

```
ADS = audioDatastore(folder)
```

```
ADS =  
  audioDatastore with properties:
```

```
    Files: {  
            'B:\matlab\toolbox\audio\samples\Ambiance-16-44p1-mono-12secs.wav'  
            'B:\matlab\toolbox\audio\samples\AudioArray-16-16-4channels-20secs'  
            '...\toolbox\audio\samples\ChurchImpulseResponse-16-44p1-mono-5se
```

```

        ... and 31 more
    }
    Folders: {
        'B:\matlab\toolbox\audio\samples'
    }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

Specify File Extensions to Include

Specify the file path to the audio samples included with Audio Toolbox™.

```
folder = fullfile(matlabroot, 'toolbox', 'audio', 'samples');
```

Create an audio datastore that points to the .ogg files in the specified folder.

```
ADS = audioDatastore(folder, 'FileExtension', '.ogg')
```

```
ADS =
    audioDatastore with properties:
```

```

        Files: {
            'B:\matlab\toolbox\audio\samples\FemaleVolumeUp-16-mono-11secs.ogg'
            'B:\matlab\toolbox\audio\samples\Hey-16-mono-6secs.ogg';
            'B:\matlab\toolbox\audio\samples\MaleVolumeUp-16-mono-6secs.ogg'
            ... and 2 more
        }
        Folders: {
            'B:\matlab\toolbox\audio\samples'
        }
    AlternateFileSystemRoots: {}
    OutputDataType: 'double'
    Labels: {}
    SupportedOutputFormats: ["wav"    "flac"    "ogg"    "mp4"    "m4a"]
    DefaultOutputFormat: "wav"

```

See Also

[datastore](#) | [mapreduce](#) | [tall](#)

Topics

“Speech Command Recognition Using Deep Learning”

“Speaker Identification Using Pitch and MFCC”

“Denoise Speech Using Deep Learning Networks”

“Music Genre Classification Using Wavelet Time Scattering”

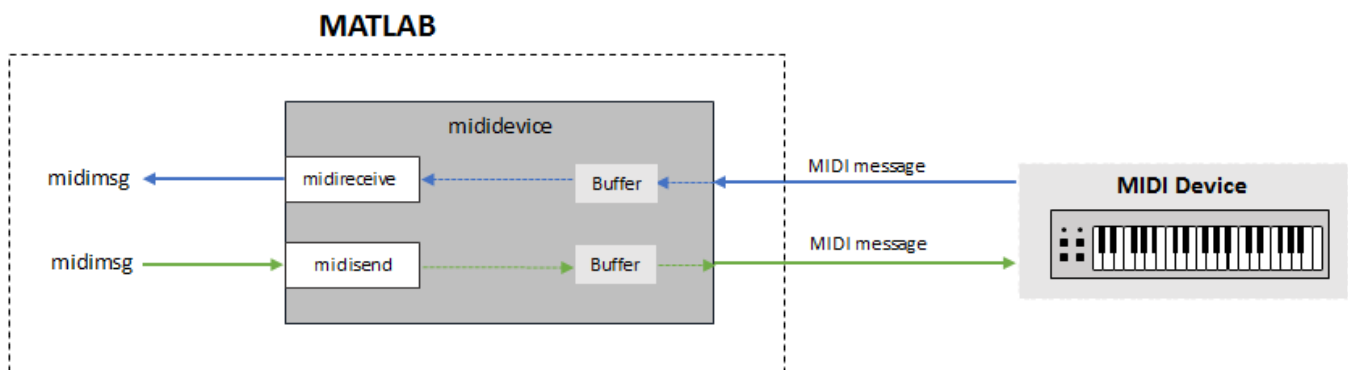
Introduced in R2018b

midimsg

Create MIDI message

Description

Create a MIDI message in MATLAB using `midimsg`. Create a MIDI device interface using `mididevice`. Send and receive messages using `midisend` and `midireceive`. When you create a MIDI message, you specify it as a MIDI message type.



For a tutorial on MIDI messages and interfacing with MIDI devices, see “MIDI Device Interface”.

Creation

Syntax

```
msg = midimsg('Note', channel, note, velocity, duration, timestamp)
msg = midimsg('NoteOn', channel, note, velocity, timestamp)
msg = midimsg('NoteOff', channel, note, velocity, timestamp)
msg = midimsg('ControlChange', channel, ccnumber, ccvalue, timestamp)
msg = midimsg('ProgramChange', channel, program, timestamp)
msg = midimsg('SystemExclusive', bytes, timestamp)
msg = midimsg('SystemExclusive', timestamp)
msg = midimsg('Data', bytes, timestamp)
msg = midimsg('EOX', timestamp)
msg = midimsg('TimingClock', timestamp)
msg = midimsg('Start', timestamp)
msg = midimsg('Continue', timestamp)
msg = midimsg('Stop', timestamp)
msg = midimsg('ActiveSensing', timestamp)
msg = midimsg('SystemReset', timestamp)
msg = midimsg('TuneRequest', timestamp)
msg = midimsg('MIDI TimeCodeQuarterFrame', seq, value, timestamp)
msg = midimsg('SongPositionPointer', position, timestamp)
msg = midimsg('SongSelect', song, timestamp)
```



```

msg = midimsg('AllSoundOff',channel,timestamp)
msg = midimsg('ResetAllControllers',channel,timestamp)
msg = midimsg('LocalControl',channel,localcontrol,timestamp)
msg = midimsg('PolyOn',channel,timestamp)
msg = midimsg('MonoOn',channel,monoChannels,timestamp)
msg = midimsg('OmniOn',channel,timestamp)
msg = midimsg('OmniOff',channel,timestamp)
msg = midimsg('AllNotesOff',channel,timestamp)
msg = midimsg('PolyKeyPressure',channel,note,pressure,timestamp)
msg = midimsg('ChannelPressure',channel,pressure,timestamp)
msg = midimsg('PitchBend',channel,change,timestamp)
msg = midimsg
msg = midimsg(size)
msg = midimsg(0)

```

Description

`msg = midimsg('Note',channel,note,velocity,duration,timestamp)` returns two MIDI messages: NoteOn and NoteOff, with specified Channel, Note, Velocity, and Timestamp properties. The Timestamp property of the NoteOff message is determined as the Timestamp property of the NoteOn message plus the duration.

`msg = midimsg('NoteOn',channel,note,velocity,timestamp)` returns a NoteOn midimsg, with specified Channel, Note, Velocity, and Timestamp properties.

`msg = midimsg('NoteOff',channel,note,velocity,timestamp)` returns a NoteOff midimsg, with specified Channel, Note, Velocity, and Timestamp properties.

`msg = midimsg('ControlChange',channel,ccnumber,ccvalue,timestamp)` returns a ControlChange midimsg, with specified Channel, CCNumber, CCValue, and Timestamp properties.

`msg = midimsg('ProgramChange',channel,program,timestamp)` returns a ProgramChange midimsg, with specified Channel, Program, and Timestamp properties.

`msg = midimsg('SystemExclusive',bytes,timestamp)` returns a complete SystemExclusive message sequence, with specified Timestamp property.

`msg = midimsg('SystemExclusive',timestamp)` returns a SystemExclusive midimsg, with specified Timestamp property.

`msg = midimsg('Data',bytes,timestamp)` returns a Data midimsg for use in a System Exclusive message, with specified MsgBytes and Timestamp properties. bytes is specified as a scalar, vector, or multi-dimensional array of elements. Each element of bytes must be in the range [0,127].

`msg = midimsg('EOX',timestamp)` returns an EOX midimsg, with specified Timestamp property.

`msg = midimsg('TimingClock',timestamp)` returns a TimingClock midimsg, with specified Timestamp property.

`msg = midimsg('Start',timestamp)` returns a Start midimsg, with specified Timestamp property.

`msg = midimsg('Continue', timestamp)` returns a `Continue` `midimsg`, with specified `Timestamp` property.

`msg = midimsg('Stop', timestamp)` returns a `Stop` `midimsg`, with specified `Timestamp` property.

`msg = midimsg('ActiveSensing', timestamp)` returns a `ActiveSensing` `midimsg`, with specified `Timestamp` property.

`msg = midimsg('SystemReset', timestamp)` returns a `SystemReset` `midimsg`, with specified `Timestamp` property.

`msg = midimsg('TuneRequest', timestamp)` returns a `TuneRequest` `midimsg`, with specified `Timestamp` property.

`msg = midimsg('MIDITimeCodeQuarterFrame', seq, value, timestamp)` returns a `MIDITimeCodeQuarterFrame` `midimsg`, with specified `TimeCodeSequence`, `TimeCodeValue`, and `Timestamp` properties.

`msg = midimsg('SongPositionPointer', position, timestamp)` returns a `SongPositionPointer` `midimsg`, with specified `SongPosition` and `Timestamp` properties.

`msg = midimsg('SongSelect', song, timestamp)` returns a `SongSelect` `midimsg`, with specified `Song` and `Timestamp` properties.

`msg = midimsg('AllSoundOff', channel, timestamp)` returns a `AllSoundOff` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('ResetAllControllers', channel, timestamp)` returns a `ResetAllControllers` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('LocalControl', channel, localcontrol, timestamp)` returns a `LocalControl` `midimsg`, with specified `Channel`, `LocalControl`, and `Timestamp` properties.

`msg = midimsg('PolyOn', channel, timestamp)` returns a `PolyOn` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('MonoOn', channel, monoChannels, timestamp)` returns a `MonoOn` `midimsg`, with specified `Channel`, `MonoChannels`, and `Timestamp` properties.

`msg = midimsg('OmniOn', channel, timestamp)` returns an `OmniOn` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('OmniOff', channel, timestamp)` returns an `OmniOff` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('AllNotesOff', channel, timestamp)` returns an `AllNotesOff` `midimsg`, with specified `Channel` and `Timestamp` properties.

`msg = midimsg('PolyKeyPressure', channel, note, pressure, timestamp)` returns a `PolyKeyPressure` `midimsg`, with specified `Channel`, `Note`, `Pressure`, and `Timestamp` properties.

`msg = midimsg('ChannelPressure', channel, pressure, timestamp)` returns a `ChannelPressure` `midimsg`, with specified `Channel`, `Pressure`, and `Timestamp` properties.

`msg = midimsg('PitchBend', channel, change, timestamp)` returns a PitchBend midimsg, with specified Channel, PitchChange, and Timestamp properties.

`msg = midimsg` returns a scalar midimsg with all zero bytes. All zero bytes indicates a MIDI message with Type set to Data.

`msg = midimsg(size)` returns a midimsg array of size with all zero bytes.

`msg = midimsg(0)` returns an empty midimsg.

Note If `timestamp` is listed as an argument, it is optional and defaults to zero. The exception is the 'SystemExclusive', bytes, timestamp syntax, in which case the timestamp argument is required.

Properties

Type – Type of MIDI message

NoteOn | NoteOff | ControlChange | ProgramChange | SystemExclusive | Data | EOX | ...

This property is read-only.

Type of MIDI message, returned as one of the following midimsgtype enumeration values:

NoteOn	Data	Stop	SongPosition Pointer	PolyOn	PolyKeyPressure
NoteOff	EOX	ActiveSensing	SongSelect	MonoOn	ChannelPressure
ControlChange	TimingClock	SystemReset	AllSoundOff	OmniOn	PitchBendChange
ProgramChange	Start	TuneRequest	ResetAllControllers	OmniOff	Undefined
SystemExclusive	Continue	MIDITimeCodeQuarterFrame	LocalControl	AllNotesOff	

You can specify the type of MIDI message during creation as a character vector, string, or member of the midimsgtype enumeration.

For example, the following create equivalent MIDI messages:

- `midimsg('SongPositionPointer', 1)`
- `midimsg("SongPositionPointer", 1)`
- `midimsg(midimsgtype.SongPositionPointer, 1)`

NumMsgBytes – Number of bytes in MIDI message

scalar | vector | array

This property is read-only.

Number of bytes in the MIDI message, returned as a scalar, vector, or array the same size as `msg`.

Data Types: double

MsgBytes — Actual bytes of constructed MIDI message (decimal)

scalar | vector | array

This property is read-only.

Actual bytes of the constructed MIDI message in decimal, returned as a scalar, vector, or array the same size as `msg`.

Data Types: `uint8`

Timestamp — Location in time for MIDI message

scalar | vector | array

Location in time for the MIDI message, specified as a scalar, vector, or array the same size as `msg`.

You can specify the timestamp as any numeric value. However, the timestamp is always stored and returned as type `double`.

For more on how MIDI timestamps are implemented in Audio Toolbox, see “MIDI Message Timing”.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Channel — MIDI channel to which message is addressed

integer in the range [1,16]

MIDI channel to which message is addressed, specified as an integer in the range [1,16].

Dependencies

This property is valid only for `NoteOn`, `NoteOff`, `PolyKeyPressure`, `AllSoundOff`, `ResetAllControllers`, `LocalControl`, `AllNotesOff`, `OmniOn`, `OmniOff`, `MonoOn`, `PolyOn`, `ControlChange`, `ProgramChange`, `ChannelPressure`, and `PitchBend` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Note — MIDI note number

integer in the range [0,127]

MIDI note number, specified as an integer in the range [0,127]. The MIDI specification defines note number 60 as Middle C, and all other notes are relative. MIDI devices and software define the mapping between a note and a MIDI note number. If Middle C is arbitrarily assumed to be C5 for the target MIDI hardware or software, the following table maps between MIDI note numbers and notes:

	Note Numbers											
Octave	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
0	0	1	2	3	4	5	6	7	8	9	10	11
1	12	13	14	15	16	17	18	19	20	21	22	23
2	24	25	26	27	28	29	30	31	32	33	34	35
3	36	37	38	39	40	41	42	43	44	45	46	47
4	48	49	50	51	52	53	54	55	56	57	58	59
5	60	61	62	63	64	65	66	67	68	69	70	71
6	72	73	74	75	76	77	78	79	80	81	82	83
7	84	85	86	87	88	89	90	91	92	93	94	95
8	96	97	98	99	100	101	102	103	104	105	106	107
9	108	109	110	111	112	113	114	115	116	117	118	119
10	120	121	122	123	124	125	126	127				

Dependencies

This property is valid only for `NoteOn`, `NoteOff`, and `PolyKeyPressure` midimsg objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Velocity – Velocity of MIDI message

integer in the range [0,127]

Velocity of MIDI message, specified as a scalar integer in the range [0,127]. Velocity describes how fast, or "hard," a note is played. A higher number corresponds to faster velocity.

Dependencies

This property is valid only for `NoteOn` and `NoteOff` midimsg objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

KeyPressure – Key pressure

integer in the range [0,127]

Key pressure, specified as a scalar integer in the range [0,127]. Key pressure applies *aftertouch* to an individual note. For example, on a keyboard, key pressure describes the pressure applied to a key after that key has been struck (after a `NoteOn` message is sent). You can use `KeyPressure` to add expression to held notes.

Dependencies

This property is valid only for `PolyKeyPressure` midimsg objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

LocalControl – Enable local control

`true` | `false`

Enable local control, specified as `true` or `false`. When local control is set to `false`, all devices on a given channel respond only to data received over MIDI.

Dependencies

This property is valid only for `LocalControl` `midimsg` objects.

Data Types: `logical`

MonoChannels — Channels for MonoOn messages

integer in the range [0,16]

Channels for `MonoOn` messages, specified as a scalar integer in the range [0,16].

Dependencies

This property is valid only for `MonoOn` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

CCNumber — Control change number

integer in the range [0,119]

Control change number, specified as an integer in the range [0,119].

Dependencies

This property is valid only for `ControlChange` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

CCValue — Control change value

integer in the range [0,127]

Control change value, specified as an integer in the range [0,127].

Dependencies

This property is valid only for `ControlChange` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Program — Program number to switch to

integer in the range [0,127]

Program number to switch to, specified as an integer in the range [0,127].

Dependencies

This property is valid only for `ProgramChange` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

ChannelPressure — Channel pressure

integer in the range [0,127]

Channel pressure, specified as an integer in the range [0,127]. Key pressure applies *aftertouch* to all notes in a channel.

Dependencies

This property is valid only for `ChannelPressure` `midimsg` objects.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

PitchChange — Amount of pitch change to apply

integer in the range [0,16383]

Amount of pitch change to apply, specified as an integer in the range [0,16383]. The center position (no effect) is 8192. Sensitivity is a function of the receiver.

Dependencies

This property is valid only for PitchBend midimsg objects.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

TimeCodeSequence — Sequence number

integer in the range [0,7]

Sequence number, specified as an integer in the range [0,7].

Dependencies

This property is valid only for MIDITimeCodeQuarterFrame midimsg objects.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

TimeCodeValue — Time code value

integer in the range [0,15]

Time code value, specified as an integer in the range [0,15].

Dependencies

This property is valid only for MIDITimeCodeQuarterFrame midimsg objects.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

SongPosition — Position in song to go to

integer in the range [0,16383]

Position in song to go to, specified as an integer in the range [0,16383].

Dependencies

This property is valid only for SongPositionPointer midimsg objects.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Song — Song number to switch to

integer in the range [0,127]

Song number to switch to, specified as an integer in the range [0,127].

Dependencies

This property is valid only for SongSelect midimsg objects.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Examples

Create Note Messages

You can create MIDI note messages using the `NoteOn` and `NoteOff` `midimsg` objects. A `NoteOn` message indicates that a note should begin playing. A `NoteOff` message indicates that a note should stop playing. Alternatively, you can send a second `NoteOn` message with velocity set to zero to indicate that the note should stop playing. The Audio Toolbox® provides a convenience syntax to create pairs of note on and note off messages.

Create a pair of MIDI messages to indicate a Note On and Note Off sequence using the `Note` convenience syntax. Specify that the note starts after one second, and has a duration of two seconds.

```
channel = 1;
note = 60;
velocity = 64;
duration = 2;
timestamp = 1;
msg = midimsg('Note',channel,note,velocity,duration,timestamp)

msgs =
MIDI message:
NoteOn          Channel: 1 Note: 60 Velocity: 64 Timestamp: 1 [ 90 3C 40 ]
NoteOn          Channel: 1 Note: 60 Velocity: 0  Timestamp: 3 [ 90 3C 00 ]
```

Two `midimsg` objects are created and returned as an array. The `Note` syntax returns the note off message as a `NoteOn` `midimsg` object with `Velocity` set to zero.

To create Note On and Note Off messages separately, create two `NoteOn` messages and concatenate them.

```
msgs = [midimsg('NoteOn',channel,note,velocity,timestamp), ...
        midimsg('NoteOn',channel,note,0,3)]

msgs =
MIDI message:
NoteOn          Channel: 1 Note: 60 Velocity: 64 Timestamp: 1 [ 90 3C 40 ]
NoteOn          Channel: 1 Note: 60 Velocity: 0  Timestamp: 3 [ 90 3C 00 ]
```

You can also specify the Note Off using a `NoteOff` `midimsg` object. Using the `NoteOff` syntax enables you to specify a release velocity.

```
msgs = [midimsg('NoteOn',channel,note,velocity,timestamp), ...
        midimsg('NoteOff',channel,note,velocity,3)]

msgs =
MIDI message:
NoteOn          Channel: 1 Note: 60 Velocity: 64 Timestamp: 1 [ 90 3C 40 ]
NoteOff         Channel: 1 Note: 60 Velocity: 64 Timestamp: 3 [ 80 3C 40 ]
```

Control Change Messages for Control Surfaces

To create a control change message, specify the `midimsg` Type as `ControlChange` and set the required parameters: `Channel`, `CCNumber`, and `CCValue`. To determine the channel and control number assigned to your MIDI control surface, use `midid`. Enter `midid` at the Command Prompt and then move the control you want to identify.


```
[ccInfo,deviceName] = midiid;
```

Move the control you wish to identify; type ^C to abort.
Waiting for control message... done

`midiid` returns the control change number and channel as a single number according to the following formula: `ccInfo = (Channel*1000 + CCNumber)`. Define a MIDI Control Change message to move the identified controller. Your MIDI Control Surface must be bidirectional to receive Control Change messages.

```
channel = floor(ccInfo/1000);
ccnumber = ccInfo - channel*1000;
ccvalue = 1;
msg = midimsg('ControlChange',channel,ccnumber,ccvalue)

msg =
  MIDI message:
    ControlChange Channel: 1 CCNumber: 16 CCValue: 1 Timestamp: 0 [ B0 10 01 ]
```

Create a `mididevice` object using the `deviceName` identified using `midiid`. Send the MIDI message to your device.

```
device = mididevice(deviceName);
midisend(device,msg);
```

Create a Program Change Message

Program Change messages, sometimes called "patch change" messages, specify how notes are interpreted. For example, a Program Change message can specify the instrument being played. To create a `ProgramChange` `midimsg` object, specify the `midimsg` type as `ProgramChange`, and the required property values: `Channel` and `Program`.

```
channel = 4;
program = 7;
msg = midimsg('ProgramChange',channel,program)

msg =
  MIDI message:
    ProgramChange Channel: 4 Program: 7 Timestamp: 0 [ C3 07 ]
```

Create a System Exclusive Message

System Exclusive messages are defined by a sequence of `midimsg` objects: `SystemExclusive`, `Data`, and `E0X`. To create a System Exclusive sequence, specify the `SystemExclusive` `midimsg` type during creation and then specify the bytes of the message. This syntax requires a timestamp.

```
bytes = [0 1 2];
timestamp = 0;
msg = midimsg('SystemExclusive',bytes,timestamp)

msg =
  MIDI message:
    SystemExclusive Timestamp: 0 [ F0 ]
```

```
Data          Timestamp: 0 [ 00 01 02 ]
EOX           Timestamp: 0 [ F7 ]
```

You can also create the `SystemExclusive`, `Data`, and `EOX` `midimsg` objects individually. For example, the following `midimsg` array is the same as the preceding.

```
msg = [midimsg('SystemExclusive',timestamp), ...
       midimsg('Data',bytes,timestamp), ...
       midimsg('EOX',timestamp)]
```

```
msg =
MIDI message:
SystemExclusive Timestamp: 0 [ F0 ]
Data            Timestamp: 0 [ 00 01 02 ]
EOX            Timestamp: 0 [ F7 ]
```

Create a Scalar Default MIDI Message

The default MIDI message is a scalar with all zero bytes, and `Type` is `Data`.

```
msg = midimsg
msg =
MIDI message:
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
```

Preallocate Array of MIDI Messages

You can create a MIDI message array by specifying the size by a scalar or row vector.

If you specify the size as a scalar M , `midimsg` returns an M -by- M array with all zero bytes.

```
msg = midimsg(2)
msg =
MIDI message:
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
```

An array of MIDI messages is always displayed vertically in order of their linear indexing. You can refer to individual elements of the array by specifying its position in each dimension, or by its linear index. For example, change the `Timestamp` of the third element from 0 to 2 using `linear indexing`, and then from 2 to 3 using `first dimensional indexing`.

```
msg(3).Timestamp = 2
msg =
MIDI message:
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 2 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
```

```
msg(1,2).Timestamp = 3
```

```
msg =
MIDI message:
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 3 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
```

You can also specify nonsymmetric arrays. If you specify the size as a row vector of two or more elements, `midimsg` returns an M -by- N -by-...- X multidimensional array. For example, to specify a three dimensional array with each dimension having a different number of elements, specify the size as a row vector of three elements.

```
msg = midimsg([2,1,3])
```

```
msg =
MIDI message:
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
Data          Timestamp: 0 [ 00 00 00 00 00 00 00 00 ]
```

```
size(msg)
```

```
ans = 1×3
```

```
    2    1    3
```

Create Empty MIDI Message

```
msg = midimsg(0)
```

```
msg =
```

```
empty MIDI message array
```

Manipulate Array of MIDI Messages

In this example, you create an array of MIDI messages, and then index into the array in a loop to define a melody.

Create a 22-by-1 array of MIDI messages with all zero data.

```
msgArray = midimsg([22,1]);
```

To create a melody, create MIDI `NoteOn` and `NoteOff` messages by indexing in a loop. Display the result.

```
melody = [60,65,60,57,55,53,60,65,60,67,60];
for i = 1:numel(melody)
```

```

        idx = (2*i-1):(2*i);
        msgArray(idx) = midimsg('Note',1,melody(i),50,0.5,i);
    end
    msgArray

msgArray =
    MIDI message:
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 1  [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 1.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 50  Timestamp: 2   [ 90 41 32 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 0   Timestamp: 2.5 [ 90 41 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 3   [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 3.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 57  Velocity: 50  Timestamp: 4   [ 90 39 32 ]
    NoteOn      Channel: 1  Note: 57  Velocity: 0   Timestamp: 4.5 [ 90 39 00 ]
    NoteOn      Channel: 1  Note: 55  Velocity: 50  Timestamp: 5   [ 90 37 32 ]
    NoteOn      Channel: 1  Note: 55  Velocity: 0   Timestamp: 5.5 [ 90 37 00 ]
    NoteOn      Channel: 1  Note: 53  Velocity: 50  Timestamp: 6   [ 90 35 32 ]
    NoteOn      Channel: 1  Note: 53  Velocity: 0   Timestamp: 6.5 [ 90 35 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 7   [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 7.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 50  Timestamp: 8   [ 90 41 32 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 0   Timestamp: 8.5 [ 90 41 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 9   [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 9.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 67  Velocity: 50  Timestamp: 10  [ 90 43 32 ]
    NoteOn      Channel: 1  Note: 67  Velocity: 0   Timestamp: 10.5 [ 90 43 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 11  [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 11.5 [ 90 3C 00 ]

```

The order of the MIDI messages in the array is only important for readability. When you send MIDI messages using a `mididevice` object, the `mididevice` object reorders your MIDI messages according to their timestamps and sends them in chronological order. Create a `PitchBend` MIDI message to bend the fourth note downward and add it to the MIDI message array. For readability, sort the MIDI message array by `Timestamp`.

```

msg = midimsg('PitchBend',1,7192,4.01);
msgArray = [msgArray;msg]

msgArray =
    MIDI message:
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 1  [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 1.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 50  Timestamp: 2   [ 90 41 32 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 0   Timestamp: 2.5 [ 90 41 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 3   [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 3.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 57  Velocity: 50  Timestamp: 4   [ 90 39 32 ]
    NoteOn      Channel: 1  Note: 57  Velocity: 0   Timestamp: 4.5 [ 90 39 00 ]
    NoteOn      Channel: 1  Note: 55  Velocity: 50  Timestamp: 5   [ 90 37 32 ]
    NoteOn      Channel: 1  Note: 55  Velocity: 0   Timestamp: 5.5 [ 90 37 00 ]
    NoteOn      Channel: 1  Note: 53  Velocity: 50  Timestamp: 6   [ 90 35 32 ]
    NoteOn      Channel: 1  Note: 53  Velocity: 0   Timestamp: 6.5 [ 90 35 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 7   [ 90 3C 32 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 0   Timestamp: 7.5 [ 90 3C 00 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 50  Timestamp: 8   [ 90 41 32 ]
    NoteOn      Channel: 1  Note: 65  Velocity: 0   Timestamp: 8.5 [ 90 41 00 ]
    NoteOn      Channel: 1  Note: 60  Velocity: 50  Timestamp: 9   [ 90 3C 32 ]

```

```

NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 9.5 [ 90 3C 00 ]
NoteOn      Channel: 1 Note: 67 Velocity: 50 Timestamp: 10 [ 90 43 32 ]
NoteOn      Channel: 1 Note: 67 Velocity: 0 Timestamp: 10.5 [ 90 43 00 ]
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 11 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 11.5 [ 90 3C 00 ]
PitchBend   Channel: 1 PitchChange: 7192 Timestamp: 4.01 [ E0 18 38 ]

```

```

timeStamps = [msgArray.Timestamp];
[~,idx] = sort(timeStamps);

```

```

msgArray = msgArray(idx)

```

```

msgArray =
MIDI message:
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 1 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 1.5 [ 90 3C 00 ]
NoteOn      Channel: 1 Note: 65 Velocity: 50 Timestamp: 2 [ 90 41 32 ]
NoteOn      Channel: 1 Note: 65 Velocity: 0 Timestamp: 2.5 [ 90 41 00 ]
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 3 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 3.5 [ 90 3C 00 ]
NoteOn      Channel: 1 Note: 57 Velocity: 50 Timestamp: 4 [ 90 39 32 ]
PitchBend   Channel: 1 PitchChange: 7192 Timestamp: 4.01 [ E0 18 38 ]
NoteOn      Channel: 1 Note: 57 Velocity: 0 Timestamp: 4.5 [ 90 39 00 ]
NoteOn      Channel: 1 Note: 55 Velocity: 50 Timestamp: 5 [ 90 37 32 ]
NoteOn      Channel: 1 Note: 55 Velocity: 0 Timestamp: 5.5 [ 90 37 00 ]
NoteOn      Channel: 1 Note: 53 Velocity: 50 Timestamp: 6 [ 90 35 32 ]
NoteOn      Channel: 1 Note: 53 Velocity: 0 Timestamp: 6.5 [ 90 35 00 ]
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 7 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 7.5 [ 90 3C 00 ]
NoteOn      Channel: 1 Note: 65 Velocity: 50 Timestamp: 8 [ 90 41 32 ]
NoteOn      Channel: 1 Note: 65 Velocity: 0 Timestamp: 8.5 [ 90 41 00 ]
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 9 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 9.5 [ 90 3C 00 ]
NoteOn      Channel: 1 Note: 67 Velocity: 50 Timestamp: 10 [ 90 43 32 ]
NoteOn      Channel: 1 Note: 67 Velocity: 0 Timestamp: 10.5 [ 90 43 00 ]
NoteOn      Channel: 1 Note: 60 Velocity: 50 Timestamp: 11 [ 90 3C 32 ]
NoteOn      Channel: 1 Note: 60 Velocity: 0 Timestamp: 11.5 [ 90 3C 00 ]

```

See Also

parameterTuner | **Audio Test Bench** | midisend | midireceive | mididevice

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

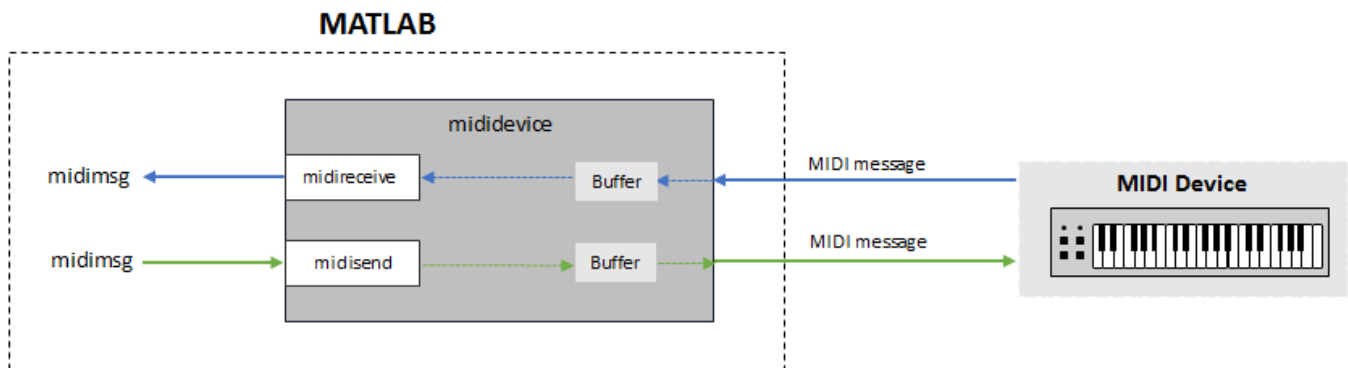
Introduced in R2018a

mididevice

Send and receive MIDI messages

Description

Interface to a MIDI device in MATLAB using `mididevice`. Package MIDI messages using `midimsg`. Send and receive messages using `midisend` and `midireceive`. Use `mididevinfo` to query your system for available MIDI devices.



For a tutorial on interfacing with MIDI devices, see “MIDI Device Interface”.

Creation

Syntax

```
device = mididevice(deviceNameOrID)
device = mididevice('Input',inDeviceNameOrID)
device = mididevice('Output',outDeviceNameOrID)
device = mididevice('Input',inDeviceNameOrID,'Output',outDeviceNameOrID)
```

Description

`device = mididevice(deviceNameOrID)` returns an interface to the MIDI device specified by `deviceNameOrID`. If the MIDI device supports MIDI in and MIDI out, then `device` also supports MIDI in and MIDI out.

`device = mididevice('Input',inDeviceNameOrID)` returns an input interface to the MIDI input device, `inDeviceNameOrID`.

`device = mididevice('Output',outDeviceNameOrID)` returns an output interface to the MIDI output device, `outDeviceNameOrID`.

`device = mididevice('Input',inDeviceNameOrID,'Output',outDeviceNameOrID)` returns a MIDI I/O interface, where input is received from `inDeviceNameOrID` and output is sent to `outDeviceNameOrID`.

Properties

Input — Input device name associated with mididevice

empty char array (default)

This property is read-only.

Input device name attached to your mididevice object, returned as a character array.

Input is set during the creation of the mididevice object and cannot be modified later.

Data Types: char

Output — Output device name associated with mididevice

empty char array (default)

This property is read-only.

Output device name attached to your mididevice object, returned as a character array

Output is set during the creation of the mididevice object and cannot be modified later.

Data Types: char

InputID — Input device ID associated with mididevice

- 1 (default)

This property is read-only.

Unique MIDI input device ID attached to your mididevice object, returned as a scalar double. If your system includes different MIDI devices with the same name, using the device ID removes ambiguity.

InputID is set during the creation of the mididevice object and cannot be modified later.

Data Types: double

OutputID — Output device name associated with mididevice

- 1 (default)

This property is read-only.

Unique MIDI output device ID attached to your mididevice object, returned as a scalar double. If your system includes different MIDI devices with the same name, using the device ID removes ambiguity.

OutputID is set during the creation of the mididevice object and cannot be modified later.

Data Types: double

Object Functions

midisend	Send MIDI message to MIDI device
midireceive	Receive MIDI message from MIDI device
hasdata	Determine if data is available to read from MIDI device

Examples

Connect Input and Output to Single MIDI Device

Query your system for available MIDI devices.

```
mididevinfo
```

```
MIDI devices available:
ID Direction Interface Name
0 output MMSystem 'Microsoft MIDI Mapper'
1 input MMSystem 'USB MIDI Interface '
2 output MMSystem 'Microsoft GS Wavetable Synth'
3 output MMSystem 'USB MIDI Interface '
```

Create a MIDI device object to interface with your selected device. If you specify a single MIDI device object, and it is capable of both input and output, `mididevice` connects to both the input and output.

```
device = mididevice('USB MIDI Interface ')
```

```
device =
mididevice connected to
  Input: 'USB MIDI Interface ' (1)
  Output: 'USB MIDI Interface ' (3)
```

Connect Input to MIDI Device

Query your system for MIDI devices.

```
mididevinfo
```

```
MIDI devices available:
ID Direction Interface Name
0 output MMSystem 'Microsoft MIDI Mapper'
1 input MMSystem 'USB MIDI Interface '
2 output MMSystem 'Microsoft GS Wavetable Synth'
3 output MMSystem 'USB MIDI Interface '
```

Create a MIDI device object to interface with your selected input device. As soon as you create the MIDI device object, it begins listening for MIDI messages and storing them in a buffer.

```
device = mididevice('Input', 'USB MIDI Interface ');
```

Connect Output to MIDI Device

Query your system for available MIDI devices.

```
mididevinfo
```

```
MIDI devices available:
ID Direction Interface Name
0 output MMSystem 'Microsoft MIDI Mapper'
```



```

1  input  MMSystem  'USB MIDI Interface '
2  output MMSystem  'Microsoft GS Wavetable Synth'
3  output MMSystem  'USB MIDI Interface '

```

Create a MIDI device object to interface with your selected output device.

```

device = mididevice('Output', 'USB MIDI Interface ')

device =
  mididevice connected to
    Output: 'USB MIDI Interface ' (3)

```

Connect Input and Output to Different MIDI Devices

Query your system for available MIDI devices.

```

mididevinfo

MIDI devices available:
ID Direction Interface Name
0  output  MMSystem  'Microsoft MIDI Mapper'
1  input   MMSystem  'USB MIDI Interface '
2  output  MMSystem  'Microsoft GS Wavetable Synth'
3  output  MMSystem  'USB MIDI Interface '

```

Create a MIDI device object that receives data from one device and sends data to another device. In this example, the MIDI device object receives MIDI messages from the 'USB MIDI Interface ' device and sends data to the 'Microsoft GS Wavetable Synth' virtual output device. To avoid ambiguity, the MIDI devices are specified by the device IDs.

```

device = mididevice('Input', 1, 'Output', 2)

device =
  mididevice connected to
    Input: 'USB MIDI Interface ' (1)
    Output: 'Microsoft GS Wavetable Synth' (2)

```

See Also

parameterTuner | **Audio Test Bench** | midisend | midireceive | mididevinfo | midimsg

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

Introduced in R2018a

hasdata

Determine if data is available to read from MIDI device

Syntax

```
tf = hasdata(device)
```

Description

`tf = hasdata(device)` returns logical 1 (true) if there is data available to read from the `mididevice` specified by `device`. Otherwise, it returns logical 0 (false).

Examples

Determine if Data Is Available to Receive

Create a `mididevice` object to interface with your MIDI device. Query your system for available MIDI devices.

```
mididevinfo
```

```
MIDI devices available:
ID  Direction  Interface  Name
0   output    MMSystem  'Microsoft MIDI Mapper'
1   input     MMSystem  'nanoKONTROL2'
2   input     MMSystem  'USB Uno MIDI Interface'
3   output    MMSystem  'Microsoft GS Wavetable Synth'
4   output    MMSystem  'nanoKONTROL2'
5   output    MMSystem  'USB Uno MIDI Interface'
```

```
device = mididevice('USB Uno MIDI Interface')
```

```
device =
mididevice connected to
  Input: 'USB Uno MIDI Interface' (2)
  Output: 'USB Uno MIDI Interface' (5)
```

As soon as your `mididevice` object is created, it begins listening for MIDI messages and storing them in a buffer. When you call `midireceive`, MIDI messages are retrieved from the buffer and returned. You can use `hasdata` to query whether your `mididevice` object buffer contains unread MIDI messages.

```
hasdata(device)
```

```
ans = logical
     0
```

Input Arguments

device — mididevice object

mididevice object

Specify device as an object created by mididevice.

See Also

midisend | mididevice | mididevinfo | midimsg

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

Introduced in R2018a

midireceive

Receive MIDI message from MIDI device

Syntax

```
msgs = midireceive(device)
msgs = midireceive(device,maxmsgs)
```

Description

`msgs = midireceive(device)` returns the MIDI messages, `msgs`, received from a MIDI device using the MIDI device interface, `device`.

`msgs = midireceive(device,maxmsgs)` specifies the maximum number of MIDI messages to return as `maxmsgs`.

Examples

Receive MIDI Messages

To determine what MIDI devices are attached to your MIDI input ports, call `mididevinfo`. Use the `availableDevices` struct to specify a valid MIDI device to create a `mididevice` object.

```
availableDevices = mididevinfo;
device = mididevice(availableDevices.input(1).ID);
```

Once your MIDI device object is created, it begins listening to MIDI messages from your specified device and storing them in a buffer. To get all MIDI messages in the buffer, call `midireceive`. In this example, several keys on a MIDI keyboard are played.

```
msgs = midireceive(device)
```

```
msgs =
```

```
MIDI message:
NoteOn      Channel: 1 Note: 52 Velocity: 64 Timestamp: 3.94 [ 90 34 40 ]
NoteOn      Channel: 1 Note: 52 Velocity: 0  Timestamp: 4.179 [ 90 34 00 ]
NoteOn      Channel: 1 Note: 48 Velocity: 64 Timestamp: 4.19  [ 90 30 40 ]
NoteOn      Channel: 1 Note: 47 Velocity: 64 Timestamp: 4.382 [ 90 2F 40 ]
NoteOn      Channel: 1 Note: 48 Velocity: 0  Timestamp: 4.459 [ 90 30 00 ]
NoteOn      Channel: 1 Note: 48 Velocity: 64 Timestamp: 4.59  [ 90 30 40 ]
NoteOn      Channel: 1 Note: 47 Velocity: 0  Timestamp: 4.776 [ 90 2F 00 ]
NoteOn      Channel: 1 Note: 50 Velocity: 64 Timestamp: 4.788 [ 90 32 40 ]
NoteOn      Channel: 1 Note: 47 Velocity: 64 Timestamp: 4.802 [ 90 2F 40 ]
NoteOn      Channel: 1 Note: 52 Velocity: 64 Timestamp: 4.831 [ 90 30 40 ]
NoteOn      Channel: 1 Note: 47 Velocity: 0  Timestamp: 4.84  [ 90 2F 00 ]
NoteOn      Channel: 1 Note: 48 Velocity: 0  Timestamp: 4.912 [ 90 30 00 ]
NoteOn      Channel: 1 Note: 52 Velocity: 0  Timestamp: 4.953 [ 90 34 00 ]
NoteOn      Channel: 1 Note: 50 Velocity: 0  Timestamp: 5.079 [ 90 32 00 ]
```

Reading from the buffer clears the data. For example, if no more MIDI messages are sent, and the buffer is reread, `midireceive` returns an empty MIDI message.

```
msgs = midireceive(device)
```

```
msgs =
    empty MIDI message array
```

Receive Limited Number of MIDI Messages

Query your system for available output from MIDI devices. Specify that the output of a MIDI device is connected to the input of your `mididevice` object.

```
mididevinfo
```

```
MIDI devices available:
ID Direction Interface Name
0 output MMSystem 'Microsoft MIDI Mapper'
1 input MMSystem 'USB MIDI Interface '
2 output MMSystem 'Microsoft GS Wavetable Synth'
3 output MMSystem 'USB MIDI Interface '
```

```
device = mididevice('Input', 'USB MIDI Interface ');
```

Once your MIDI device object is created, it begins listening to MIDI messages from your specified device and storing them in a buffer. To get a limited number of MIDI messages from the buffer, call `midireceive` and specify the maximum number of messages to return. In this example, five keys are played on a MIDI device. A maximum of four MIDI messages are received at each call to `midireceive`.

```
midireceive(device,4)
```

```
ans =
```

```
MIDI message:
NoteOn Channel: 1 Note: 36 Velocity: 64 Timestamp: 2929.71 [ 90 24 40 ]
NoteOn Channel: 1 Note: 36 Velocity: 0 Timestamp: 2929.91 [ 90 24 00 ]
NoteOn Channel: 1 Note: 37 Velocity: 64 Timestamp: 2930.43 [ 90 25 40 ]
NoteOn Channel: 1 Note: 37 Velocity: 0 Timestamp: 2930.59 [ 90 25 00 ]
```

```
midireceive(device,4)
```

```
ans =
```

```
MIDI message:
NoteOn Channel: 1 Note: 38 Velocity: 64 Timestamp: 2931.16 [ 90 26 40 ]
NoteOn Channel: 1 Note: 38 Velocity: 0 Timestamp: 2931.32 [ 90 26 00 ]
NoteOn Channel: 1 Note: 39 Velocity: 64 Timestamp: 2931.87 [ 90 27 40 ]
NoteOn Channel: 1 Note: 39 Velocity: 0 Timestamp: 2932.01 [ 90 27 00 ]
```

```
midireceive(device,4)
```

```
ans =
```

```
MIDI message:
NoteOn Channel: 1 Note: 40 Velocity: 64 Timestamp: 2932.52 [ 90 28 40 ]
NoteOn Channel: 1 Note: 40 Velocity: 0 Timestamp: 2932.66 [ 90 28 00 ]
```

Input Arguments

device — Object of `mididevice`

object of `mididevice`

Specify `device` as an object created by `mididevice`.

maxmsgs — Maximum number of messages to return

positive integer scalar

Maximum number of messages to return, specified as a positive integer scalar.

Data Types: single | double

Output Arguments

msgs — Object of midimsg

scalar | column vector

Object of midimsg, returned as a scalar or column vector. The number of MIDI messages in the mididevice buffer and maxmsgs determine the size of msgs.

See Also

midisend | mididevice | mididevinfo | midimsg

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

Introduced in R2018a

midisend

Send MIDI message to MIDI device

Syntax

```
midisend(device,msg)
midisend(device,varargin)
```

Description

`midisend(device,msg)` sends the MIDI message, `msg`, to a MIDI device using the MIDI device interface, `device`.

`midisend(device,varargin)` creates MIDI messages using `varargin` and then sends the MIDI messages. The `varargin` syntax is for convenience and includes a call to `midimsg` with the call to `midisend`.

Examples

Send MIDI Messages to Device

Query your system for available MIDI device output ports. Use the `availableDevices` struct to specify a valid MIDI device and create a `mididevice` object.

```
availableDevices = mididevinfo;
device = mididevice(availableDevices.output(2).ID);
```

Create a pair of `NoteOn` messages (to indicate Note On and Note Off) and send them to your selected MIDI device.

```
msgs = midimsg('Note',1,48,64,0.25);
midisend(device,msgs)
```

Define and Send MIDI Messages to Device

`midisend` enables you to combine the definition and sending of a `midimsg` into a single function call. Send middle C on channel 3 with velocity 64.

```
mididevinfo
```

```
MIDI devices available:
ID Direction Interface Name
0 output MMSystem 'Microsoft MIDI Mapper'
1 input MMSystem 'nanoKONTROL2'
2 input MMSystem 'USB Uno MIDI Interface'
3 output MMSystem 'Microsoft GS Wavetable Synth'
4 output MMSystem 'nanoKONTROL2'
5 output MMSystem 'USB Uno MIDI Interface'
```

```
device = mididevice('USB Uno MIDI Interface')

device =
  mididevice connected to
    Input: 'USB Uno MIDI Interface' (2)
    Output: 'USB Uno MIDI Interface' (5)

midisend(device, 'NoteOn', 3, 60, 64)
```

Compile and Play MIDI Messages

Get the name of an available output MIDI device on your system.

```
mInfo = mididevinfo;
```

```
Disregard cmd.exe warnings about UNC directory pathnames.
Disregard cmd.exe warnings about UNC directory pathnames.
```

```
midiDeviceName = mInfo.output(1).Name;
```

Create a mididevice object.

```
device = mididevice(midiDeviceName);
```

Create a MIDI message array.

```
msgs = [];
for ii = 1:8
    msgs = [msgs; midimsg('Note', 1, 20+8*ii, 64, 1, ii)];
end
```

To listen to the MIDI messages, send the MIDI messages to your device.

```
midisend(device, msgs)
```

To compile the previous steps, encapsulate the code in a function and then call `mcc`.

```
function playMusic1()
    mInfo = mididevinfo;
    midiDeviceName = mInfo.output(1).Name;
    device = mididevice(midiDeviceName);

    msgs = [];
    for ii = 1:8
        msgs = [msgs; midimsg('Note', 1, 20+8*ii, 64, 1, ii)];
    end

    midisend(device, msgs)
end

mcc playMusic1 -m -w disable
```

Execute the compiled code. You will not hear any sound. This is because the executable opened, sent the MIDI messages to the queue, and then closed, aborting its commands before the MIDI messages had a chance to play.

```
!playMusic1.exe
```


To keep the executable open long enough for the MIDI messages to play, add a pause to the executable. Set the duration of the pause to equal the duration of the MIDI messages.

```
function playMusic2()
    mInfo = mididevinfo;
    midiDeviceName = mInfo.output(1).Name;
    device = mididevice(midiDeviceName);

    msgs = [];
    for ii = 1:8
        msgs = [msgs;midimsg('Note',1,20+8*ii,64,1,ii)];
    end

    midisend(device,msgs)
    pause(msgs(end).Timestamp)
end

mcc playMusic2 -m -w disable
```

Play the compiled executable. The sound that plays through your MIDI device is the same as the uncompiled version.

```
!playMusic2.exe
```

Input Arguments

device — Object of mididevice

scalar

Specify device as an object created by mididevice.

msg — Object of midimsg

scalar | vector | array

Specify msg as an object created by midimsg.

varargin — Variable number of arguments describing MIDI message

midimsg input arguments

Specify varargin as a valid combination of arguments that can construct a MIDI message. See midimsg for a description of valid arguments.

See Also

midireceive | mididevice | mididevinfo | midimsg

Topics

“MIDI Device Interface”

External Websites

MIDI Manufacturers Association

Introduced in R2018a

audioPlugin class

Base class for audio plugins

Description

`audioPlugin` is the base class for audio plugins. In your class definition file, you must subclass your object from this base class or from the `audioPluginSource` class, which inherits from `audioPlugin`. Subclassing enables you to inherit the attributes necessary to generate plugins and access Audio Toolbox functionality.

To inherit from the `audioPlugin` base class directly, type this syntax as the first line of your class definition file:

```
classdef myAudioPlugin < audioPlugin
```

`myAudioPlugin` is the name of your object.

For a tutorial on designing audio plugins, see “Audio Plugins in MATLAB”.

Methods

<code>setLatencyInSamples</code>	Set latency in samples reported to DAW
<code>getSampleRate</code>	Get sample rate at which the plugin is run
<code>setSampleRate</code>	Set sample rate at which the plugin is run

Copy Semantics

Handle. To learn how handle classes affect copy operations, see “Copying Objects”.

Examples

Design Valid Audio Plugin

Design a valid basic audio plugin class.

Terminology:

- A valid audio plugin is one that can be deployed in a digital audio workstation (DAW) environment. To validate it, use the `validateAudioPlugin` function. To generate it, use the `generateAudioPlugin` function.
- A basic audio plugin inherits from the `audioPlugin` class but not the `matlab.System` class.

Define a basic audio plugin class that inherits from `audioPlugin`.

```
classdef myAudioPlugin < audioPlugin  
end
```

Add a processing function to your plugin class. All valid audio plugins include a processing function. For basic audio plugins, the processing function is named `process`. The processing function is where audio processing occurs. It always has an output.

```
classdef myAudioPlugin < audioPlugin
    methods
        function out = process(~,in)
            out = in;
        end
    end
end
```

Design Valid Audio Plugin That Uses `getSampleRate`

Design an `audioPlugin` class that uses the `getSampleRate` method to get the sample rate at which the plugin is run. The plugin in this example, `simpleStrobe`, uses the sample rate to determine a constant 50 ms strobe period.

```
classdef simpleStrobe < audioPlugin
    % simpleStrobe Add audio strobe effect
    % Add a strobe effect by gain switching between 0 and 1 in
    % 50 ms increments. Although the input sample rate can change,
    % the strobe period remains constant.
    %
    % simpleStrobe properties:
    % period - Number of samples between gain switches
    % gain - Gain multiplier, one or zero
    % count - Number of samples since last gain switch
    %
    %
    % simpleStrobe methods:
    % process - Multiply input frame by gain, element by element
    % reset - Reset count and gain to initial conditions
    % and get sample rate

    properties
        Period = 44100*0.05;
        Gain = 1;
    end
    properties (Access = private)
        Count = 1;
    end
    methods
        function out = process(plugin,in)
            for i = 1:size(in,1)
                if plugin.Count == plugin.Period
                    plugin.Gain = 1 - plugin.Gain;
                    plugin.Count = 1;
                end
                in(i,:) = in(i,)*plugin.Gain;
                plugin.Count = plugin.Count + 1;
            end
            out = in;
        end
        function reset(plugin)
```

```

        plugin.Period = floor( getSampleRate(plugin)*0.05 );
        plugin.Count = 1;
        plugin.Gain = 1;
    end
end
end

```

Design Valid Audio Plugin That Uses setLatencyInSamples

Design an `audioPlugin` class that uses the `setLatencyInSamples` method to report the latency of the plugin. The plugin in this example, `simpleDelay`, delays the audio signal by a fixed integer and reports the delay to the host application.

```

classdef simpleDelay < audioPlugin
    % simpleDelay Add delay to audio signal
    % This plugin adds a 100 sample delay to the audio input and reports
    % the latency to the host application.
    properties (Access = private)
        Delay
    end
    methods
        function plugin = simpleDelay
            plugin.Delay = dsp.Delay(100);
        end
        function out = process(plugin,in)
            out = plugin.Delay(in);
        end
        function reset(plugin)
            setLatencyInSamples(plugin,100)
        end
    end
end
end

```

This example is intended to show the pattern for using `setLatencyInSamples`. For a detailed use-case, see `audiopluginexample.FastConvolver` in the “Audio Plugin Example Gallery”.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

[audioPluginParameter](#) | [generateAudioPlugin](#) | [validateAudioPlugin](#) | [audioPluginInterface](#) | [audioPluginSource](#) | [audioPluginConfig](#) | [parameterTuner](#) |

Audio Test Bench

Topics

“Design an Audio Plugin”
 “Audio Plugins in MATLAB”
 “Audio Plugin Example Gallery”

Introduced in R2016a

setLatencyInSamples

Class: audioPlugin

Set latency in samples reported to DAW

Syntax

```
setLatencyInSamples(myAudioPlugin, latency)
```

Description

`setLatencyInSamples(myAudioPlugin, latency)` sets the latency, in samples, that `myAudioPlugin` reports to a digital audio workstation (DAW) or other host application. Specify latency as a positive integer.

Note Latency is reported to a host application when the `reset` method is called. As a best practice, call `setLatencyInSamples` in the `reset` method of your `audioPlugin` class.

See Also

`audioPlugin`

Introduced in R2020b

getSampleRate

Class: audioPlugin

Get sample rate at which the plugin is run

Syntax

```
sampleRate = getSampleRate(myAudioPlugin)
```

Description

`sampleRate = getSampleRate(myAudioPlugin)` returns the sample rate in Hz at which the plugin is being run.

- In a digital audio workstation (DAW) environment, the DAW user sets the sample rate. `getSampleRate` interacts with the DAW to determine the sample rate.
- In the MATLAB environment, `getSampleRate` returns the value set by a previous call to `setSampleRate`. If `setSampleRate` has not been called, `getSampleRate` returns the default value, 44100.

Introduced in R2016a

setSampleRate

Class: audioPlugin

Set sample rate at which the plugin is run

Syntax

```
setSampleRate(myAudioPlugin, sampleRate)
```

Description

`setSampleRate(myAudioPlugin, sampleRate)` sets the sample rate of the plugin, `myAudioPlugin`, to the value specified by `sampleRate`. Specify `sampleRate` as a positive real integer. `setSampleRate` enables the MATLAB environment to mimic behavior in a digital audio workstation (DAW) environment.

Note A plugin must not call `setSampleRate` on itself. If the plugin attempts to call `setSampleRate` on itself, `generateAudioPlugin` throws an error.

Introduced in R2016a

audioPluginConfig

Specify coder configuration of audio plugin

Description

The `audioPluginConfig` object enables you to validate and generate audio plugins that use deep learning pretrained networks. This object also allows you to pass code replacement libraries to the `generateAudioPlugin` function.

Creation

Syntax

```
obj = audioPluginConfig(Name,Value)
```

Description

`obj = audioPluginConfig(Name,Value)` creates an object that describes the coder configuration for your audio plugin. Use name-value arguments to specify the properties of the object.

This object generates a constant property called `PluginConfig` for audio plugin classes. Use the `audioPluginConfig` object if your plugin uses deep learning networks or a code replacement library.

Properties

DeepLearningConfig — Deep learning library configuration

```
[] (default) | coder.DeepLearningConfig('none') |  
coder.DeepLearningConfig('mklDnn')
```

Deep learning library configuration, specified as an empty array (`[]`), `coder.DeepLearningConfig('none')`, or `coder.DeepLearningConfig('mklDnn')`.

- `[]` — Do not use a deep learning library.
- `coder.DeepLearningConfig('none')` — Generate code that does not use any third-party library.
- `coder.DeepLearningConfig('mklDnn')` — Generate code that uses the Intel Math Kernel Library for Deep Neural Networks (Intel MKL-DNN). This option does not work on ARM®-based Macintosh platforms. This option is not supported with the `-win32` option of the `generateAudioPlugin` function.
 - On Intel Macintosh platforms, `generateAudioPlugin` packages the required libraries (`libdnnl.1.4.dylib`, `libdnnl.1.dylib`, `libdnnl.dylib`, and `libomp.dylib`) within the generated plugin bundle. The path to required the libraries is set to the `INTEL_MKLDNN` environment variable. You must install the libraries. To distribute the generated plugin, you must have licenses to distribute the Intel MKL-DNN and OpenMP libraries.

- On Microsoft® Windows platforms, `generateAudioPlugin` creates upon compilation a folder named `pluginName_juceproject_NetworkWeights` in the build directory. The folder contains the network weight files that are read by the generated plugin. When you add the generated plugin to a third-party DAW, you must copy the generated folder along with the plugin binary to your DAW's plugin location. The generated plugin will work in a DAW only if the required library MKL-DNN is visible to the DAW. To make the MKL-DNN library visible to a DAW, you must add the path to the MKL-DNN library to the Windows environment variable `PATH`.
- On Linux platforms, `generateAudioPlugin` creates upon compilation a folder named `.MWPluginData/pluginName_juceproject_NetworkWeights` in your home directory. The folder contains the network weight files that are read by the generated plugin. The generated plugin will work in a DAW only if the required library MKL-DNN is visible to the DAW. To make the MKL-DNN library visible to a DAW, you must keep the MKL-DNN library in the `/usr/lib` directory or in the `/usr/local/lib` directory.

You must have MATLAB Coder Interface for Deep Learning Libraries installed to use this property unless you choose the `[]` option. For more information, see `coder.DeepLearningConfig`. For more information about installing the MKL-DNN library and setting the related environment variables, see “Prerequisites for Deep Learning with MATLAB Coder” (MATLAB Coder).

CodeReplacementLibrary — Code replacement library configuration

```
'' (default) | 'none' | 'Intel AVX (Windows)' | 'DSP Intel AVX2-FMA (Windows)' | 'DSP Intel AVX2-FMA (Linux)' | 'DSP Intel AVX2-FMA (Mac)'
```

Code replacement library configuration, specified as an empty character vector (''), 'none', 'Intel AVX (Windows)', 'DSP Intel AVX2-FMA (Windows)', 'DSP Intel AVX2-FMA (Linux)', or 'DSP Intel AVX2-FMA (Mac)'.

- '' — Do not use a code replacement library. 'none' is equivalent to ''.
- 'Intel AVX (Windows)' — Generate code that uses the Intel AVX code replacement library. This option works only on Windows platforms. This option is not supported with the `-win32` option of the `generateAudioPlugin` function.
- 'DSP Intel AVX2-FMA (Windows)' — Generate code that uses the Intel DSP AVX2-FMA code replacement library. This option works only on Windows platforms. This option is not supported with the `-win32` option of the `generateAudioPlugin` function.
- 'DSP Intel AVX2-FMA (Linux)' — Generate a JUCE project that uses the Intel DSP AVX2-FMA code replacement library for Linux platforms. This option works only with the `-juceproject` option of the `generateAudioPlugin` function.
- 'DSP Intel AVX2-FMA (Mac)' — Generate code that uses the Intel DSP AVX2-FMA code replacement library. This option works only on Intel Macintosh platforms.

You must have Embedded Coder® installed to use this property.

Examples

Audio Configuration Information for Plugin Class Definition

Create the source file for a plugin class, `MyAudioPlugin`, that uses the Intel AVX code replacement library for Windows. Add a processing function to the class.

```
classdef MyAudioPlugin < audioPlugin
    properties (Constant)
```

```

        PluginConfig = audioPluginConfig( ...
            'DeepLearningConfig', coder.DeepLearningConfig('none'), ...
            'CodeReplacementLibrary', 'Intel AVX (Windows)');
    end
    methods
        function out = process(~, in)
            out = in;
        end
    end
end
end

```

To validate the plugin, use the `validateAudioPlugin` function. To generate the plugin, use the `generateAudioPlugin` function.

Audio Configuration Information on the Command Line

Create a `DeepLearningConfigBase` configuration object that generates code that does not use any third-party library. Use the `audioPluginConfig` object to specify a plugin that incorporates the previous property and uses the Intel AVX code replacement library for Windows. Generate the audio plugin.

```

dlcfg = coder.DeepLearningConfig('none');
cfg = audioPluginConfig( ...
    'DeepLearningConfig', dlcfg, ...
    'CodeReplacementLibrary', 'Intel AVX (Windows)');
generateAudioPlugin -audioconfig cfg MyAudioPlugin

```

See Also

Functions

`generateAudioPlugin` | `validateAudioPlugin`

Objects

`audioPlugin` | `audioPluginInterface` | `audioPluginParameter` | `audioPluginSource` | `coder.DeepLearningConfig`

Apps

Audio Test Bench

Topics

“Design an Audio Plugin”
 “Audio Plugins in MATLAB”
 “Audio Plugin Example Gallery”

Introduced in R2021b

audioPluginSource class

Base class for audio source plugins

Description

`audioPluginSource` is the base class for audio source plugins. Use audio source plugins to produce audio signals.

To create a valid audio source plugin, in your class definition file, subclass your object from the `audioPluginSource` class. Subclassing enables you to inherit the attributes necessary to generate audio source plugins and access Audio Toolbox functionality. To inherit from the `audioPluginSource` base class directly, type this syntax as the first line of your class definition file:

```
classdef myAudioSourcePlugin < audioPluginSource
```

`myAudioSourcePlugin` is the name of your object.

Methods

<code>getSamplesPerFrame</code>	Get frame size returned by the plugin
<code>setSamplesPerFrame</code>	Set frame size returned by the plugin (MATLAB environment only)

Inherited Methods

<code>setLatencyInSamples</code>	Set latency in samples reported to DAW
<code>getSampleRate</code>	Get sample rate at which the plugin is run
<code>setSampleRate</code>	Set sample rate at which the plugin is run

Copy Semantics

Handle. To learn how handle classes affect copy operations, see “Copying Objects”.

Examples

Design Valid Audio Plugin

Design a valid basic audio source plugin class

Terminology:

- A valid audio source plugin is one that can be deployed in a digital audio workstation (DAW) environment. To validate it, use the `validateAudioPlugin` function. To generate it, use the `generateAudioPlugin` function.
- A basic audio source plugin inherits from the `audioPluginSource` class but not the `matlab.System` class.

Define a basic audio source plugin class that inherits from `audioPluginSource`.

```
classdef myAudioSourcePlugin < audioPluginSource
end
```

Add a processing function to your audio source plugin class.

All valid audio source plugins include a processing function. For basic audio source plugins, the processing function is named `process`. The processing function defines the audio signal that your plugin outputs. Audio source plugins do not accept audio signals as input to the processing function.

The default audio plugin interface assumes a stereo output. Specify the processing output as a matrix with two columns. These columns correspond to the left and right channels of a stereo signal. The number of rows in the output matrix correspond to the frame size.

The output frame size must match the frame size of the environment in which the plugin is run. A DAW environment has variable frame size. To determine the current environment frame size, call `getSamplesPerFrame` in the `process` function.

```
classdef myAudioSourcePlugin < audioPluginSource
    methods
        function out = process(plugin)
            out = 0.5*randn(getSamplesPerFrame(plugin),2);
        end
    end
end
```

`myAudioSourcePlugin` generates a Gaussian white noise audio signal with 0.5 standard deviation.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using MATLAB® Coder™.

See Also

[validateAudioPlugin](#) | [generateAudioPlugin](#) | [audioPluginParameter](#) | [audioPluginInterface](#) | [audioPlugin](#) | [audioPluginConfig](#) | [parameterTuner](#) | **Audio Test Bench**

Topics

“Audio Plugins in MATLAB”
 “Audio Plugin Example Gallery”
 “Hierarchies of Classes — Concepts”

Introduced in R2016a

getSamplesPerFrame

Class: audioPluginSource

Get frame size returned by the plugin

Syntax

```
frameSize = getSamplesPerFrame(myAudioSourcePlugin)
```

Description

`frameSize = getSamplesPerFrame(myAudioSourcePlugin)` returns the frame size at which the plugin is run. `frameSize` is the number of output samples (rows) that the current call to the processing function of `myAudioSourcePlugin` must return.

- In a digital audio workstation (DAW) environment, `getSamplesPerFrame` interacts with the DAW to determine the frame size. Frame size can vary from call to call, as determined by the DAW environment.
- In the MATLAB environment, `getSamplesPerFrame` returns the value set by a previous call to the `setSamplesPerFrame` method. If `setSamplesPerFrame` has not been called, then `getSamplesPerFrame` returns the default value, 256.

Note When authoring source plugins in MATLAB, `getSamplesPerFrame` is valid only when called in the processing function.

Introduced in R2016a

setSamplesPerFrame

Class: audioPluginSource

Set frame size returned by the plugin (MATLAB environment only)

Syntax

```
setSamplesPerFrame(myAudioSourcePlugin, frameSize)
```

Description

`setSamplesPerFrame(myAudioSourcePlugin, frameSize)` sets the frame size (rows) that the source plugin, `myAudioSourcePlugin`, must return in subsequent calls to its processing function. Specify `frameSize` as a real integer greater than or equal to 0. `setSamplesPerFrame` enables the MATLAB environment to mimic behavior in a digital audio workstation (DAW) environment.

Note Do not use `setSamplesPerFrame` in a generated plugin. If you call `setSamplesPerFrame` in your authored plugin, `generateAudioPlugin` throws an error.

Introduced in R2016a

externalAudioPlugin class

Base class for external audio plugins

Description

`externalAudioPlugin` is the base class for hosted audio plugins. When you load an external plugin using `loadAudioPlugin`, an object of that plugin is created having `externalAudioPlugin` or `externalAudioPluginSource` as a base class. The `externalAudioPluginSource` class is used when the external audio plugin is a source plugin.

For a tutorial on hosting audio plugins, see “Host External Audio Plugins”.

Methods

<code>dispParameter</code>	Display information of single or multiple parameters
<code>getParameter</code>	Get normalized value and information about parameter
<code>info</code>	Get information about hosted plugin
<code>process</code>	Process audio stream
<code>setParameter</code>	Set normalized parameter value of hosted plugin

Inherited Methods

<code>setLatencyInSamples</code>	Set latency in samples reported to DAW
<code>getSampleRate</code>	Get sample rate at which the plugin is run
<code>setSampleRate</code>	Set sample rate at which the plugin is run

Copy Semantics

Handle. To learn how handle classes affect copy operations, see “Copying Objects”.

Examples

Specify Hosted Plugin Parameter Values

Load a VST audio plugin into MATLAB® by specifying its full path. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
pluginPath = fullfile(matlabroot, 'toolbox/audio/samples/ParametricEqualizer.dll');
hostedPlugin = loadAudioPlugin(pluginPath)
```

Use `info` to return information about the hosted plugin.

```
info(hostedPlugin)
```

Use `setParameter` to change the normalized value of the Medium Center Frequency parameter to 0.75. Specify the parameter by its index.


```
setParameter(hostedPlugin,5,0.75)
```

When you set the normalized parameter value, the parameter display value is automatically updated. The normalized parameter value generally corresponds to the position of a UI widget or MIDI controller. The parameter display value typically reflects the value used internally for processing.

Use `dispParameter` to display the updated table of parameters.

```
dispParameter(hostedPlugin)
```

Alternatively, you can use `getParameter` to return the normalized value of a single parameter.

```
parameterIndex = 5;
parameterValue = getParameter(hostedPlugin,parameterIndex)
```

Run External Plugin in MATLAB

Load a VST audio plugin into MATLAB™ by specifying its full path. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
pluginPath = fullfile(matlabroot,'toolbox','audio','samples','ParametricEqualizer.dll');
hostedPlugin = loadAudioPlugin(pluginPath);
```

Create input and output objects for an audio stream loop that reads from a file and writes to your audio device. Set the sample rate of the hosted plugin to the sample rate of the input to the plugin.

```
fileReader = dsp.AudioFileReader('FunkyDrums-44p1-stereo-25secs.mp3');
deviceWriter = audioDeviceWriter('SampleRate',fileReader.SampleRate);
setSampleRate(hostedPlugin,fileReader.SampleRate);
```

Set the `MediumPeakGain` property to -20 dB.

```
hostedPlugin.MediumPeakGain = -20;
```

Use the hosted plugin to process the audio file in an audio stream loop. Sweep the medium peak gain upward in the loop to hear the effect.

```
while hostedPlugin.MediumPeakGain < 19
    hostedPlugin.MediumPeakGain = hostedPlugin.MediumPeakGain + 0.04;
    x = fileReader();
    y = process(hostedPlugin,x);
    deviceWriter(y);
end
```

```
release(fileReader)
release(deviceWriter)
```

Limitations

- Saving an external plugin as a MAT-file and then loading it preserves the external settings and parameters of the plugin but does not preserve its internal state or memory. Do not save and load your plugins when you are processing audio.

See Also

[externalAudioPluginSource](#) | [audioPluginSource](#) | [audioPlugin](#) | [loadAudioPlugin](#) | [parameterTuner](#) | **Audio Test Bench**

Topics

[“Host External Audio Plugins”](#)

[“Hierarchies of Classes — Concepts”](#)

Introduced in R2016b

dispParameter

Class: externalAudioPlugin

Display information of single or multiple parameters

Syntax

```
dispParameter(hostedPlugin)
dispParameter(hostedPlugin,parameter)
```

Description

`dispParameter(hostedPlugin)` displays all parameters and associated indices, values, displayed values, and display labels. For example:

```
dispParameter(hostedPlugin)
```

	Parameter	Value	Display
1	Wet:	1.0000	+0.0 dB
2	Dry:	1.0000	+0.0 dB
3	1: Enabled:	1.0000	ON
4	1: Length:	0.0000	0.0 ms
5	1: Length:	0.0156	4.00 8N
6	1: Feedback:	0.0000	-inf dB
7	1: Lowpass:	1.0000	20000 Hz
8	1: Hipass:	0.0000	0 Hz
9	1: Resolution:	1.0000	24 bits
10	1: Stereo width:	1.0000	1.00
11	1: Volume:	1.0000	+0.0 dB
12	1: Pan:	0.5000	0.0 %

The **Value** column corresponds to the normalized parameter value. Generally, the normalized parameter value represents the position of a UI widget or MIDI controller. The **Display** column corresponds to an internal parameter value used for processing. The **Value** and **Display** are related by an unknown mapping that is internal to the hosted plugin.

`dispParameter(hostedPlugin,parameter)` displays a subset of parameters. You can specify a parameter by its name as a character vector, string, or as a vector of one or more parameter indices. For example:

- `dispParameter(hostedPlugin, 'Gain')` displays information about the 'Gain' parameter of `hostedPlugin`.
- `dispParameter(hostedPlugin, [1,3])` displays information about parameters specified by indices 1 and 3.

Introduced in R2016b

getParameter

Class: externalAudioPlugin

Get normalized value and information about parameter

Syntax

```
value = getParameter(hostedPlugin,parameter)
[value, parameterInformation] = getParameter(hostedPlugin,parameter)
```

Description

`value = getParameter(hostedPlugin,parameter)` returns the normalized value of the parameter of `hostedPlugin`. You can specify a parameter by its name as a character vector, string, or by its index. For example:

- `getParameter(hostedPlugin, 'Gain')` returns the normalized value of the hosted plugin parameter named 'Gain'. If the parameter name is not unique, `getParameter` returns an error.
- `getParameter(hostedPlugin, 2)` returns information about the parameter specified by index 2.

`[value, parameterInformation] = getParameter(hostedPlugin,parameter)` returns a structure containing additional information about the specified parameter of the hosted plugin.

Field	Description
DisplayName	Display name or prompt of the plugin parameter, returned as a character vector. The display name is intended for display on the plugin user interface (UI).
DisplayValue	Display value of the plugin parameter, returned as a character vector. The parameter <code>DisplayValue</code> corresponds to the normalized parameter <code>value</code> by an unknown mapping internal to the hosted plugin. Generally, the display value reflects the value used internally by the plugin for processing, while the normalized parameter value corresponds to the position of a MIDI control or widget on a UI.
Label	Label intended for display with <code>DisplayValue</code> on the plugin UI, returned as a character vector. Typical labels include dB and Hz.

Introduced in R2016b

info

Class: externalAudioPlugin

Get information about hosted plugin

Syntax

```
pluginInfo = info(hostedPlugin)
```

Description

`pluginInfo = info(hostedPlugin)` returns a structure containing information about the hosted plugin.

Field	Description
PluginName	Display name of plugin.
Format	Software interface. Supported formats include VST, VST 3, and AU.
InputChannels	Number of channels passed to the processing function of the plugin.
OutputChannels	Number of channels returned from the processing function of the plugin.
NumParams	Total number of plugin parameters.
PluginPath	Path specified when plugin is loaded using <code>loadAudioPlugin</code> .
VendorName	Name of the plugin creator.
VendorVersion	Version number. Typically used to track plugin releases.
UniqueID	Unique identifier of plugin used for recognition in certain digital audio workstation (DAW) environments.

Introduced in R2016b

process

Class: externalAudioPlugin

Process audio stream

Syntax

```
audioOut = process(hostedPlugin, audioIn)
```

Description

`audioOut = process(hostedPlugin, audioIn)` returns an audio signal processed according to the algorithm and parameters of `hostedPlugin`. For source plugins, call `process` without an audio input. Use `info(hostedPlugin)` to determine the number of channels (columns) of the input and output audio signal.

Use `setSamplesPerFrame(hostedPlugin)` to specify the frame size returned by hosted source plugins.

Introduced in R2016b

setParameter

Class: externalAudioPlugin

Set normalized parameter value of hosted plugin

Syntax

```
setParameter(hostedPlugin,parameter,newValue)
```

Description

`setParameter(hostedPlugin,parameter,newValue)` sets the normalized value corresponding to the parameter of `hostedPlugin` to `newValue`. Specify the parameter by its unique display name or its index. Specify the new normalized parameter value as a scalar in the range 0-1.

For example, assume `hostedPlugin` has a parameter with index 3 and a unique display name, 'Gain'. These commands are identical:

- `setParameter(hostedPlugin,'Gain',0.2)`
- `setParameter(hostedPlugin,3,0.2)`

Note A hosted plugin might quantize its parameters. The result of `setParameter` for quantized parameters depends on the type of quantization.

Introduced in R2016b

externalAudioPluginSource class

Base class for external audio source plugins

Description

`externalAudioPluginSource` is the base class for hosted audio source plugins. When you load an external plugin using `loadAudioPlugin`, an object of that plugin is created having `externalAudioPlugin` or `externalAudioPluginSource` as a base class. The `externalAudioPluginSource` class is used when the external audio plugin is a source plugin.

For a tutorial on hosting audio plugins, see “Host External Audio Plugins”.

Methods

Inherited Methods

<code>dispParameter</code>	Display information of single or multiple parameters
<code>getParameter</code>	Get normalized value and information about parameter
<code>info</code>	Get information about hosted plugin
<code>process</code>	Process audio stream
<code>setParameter</code>	Set normalized parameter value of hosted plugin
<code>setLatencyInSamples</code>	Set latency in samples reported to DAW
<code>getSampleRate</code>	Get sample rate at which the plugin is run
<code>setSampleRate</code>	Set sample rate at which the plugin is run
<code>getSamplesPerFrame</code>	Get frame size returned by the plugin
<code>setSamplesPerFrame</code>	Set frame size returned by the plugin (MATLAB environment only)

Copy Semantics

Handle. To learn how handle classes affect copy operations, see “Copying Objects”.

Examples

Specify Hosted Source Plugin Parameter Values

Load a VST audio source plugin into MATLAB® by specifying its full path. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
pluginPath = fullfile(matlabroot, 'toolbox/audio/samples/oscillator.dll');  
hostedSourcePlugin = loadAudioPlugin(pluginPath)
```

Use `info` to return information about the hosted plugin.


```
info(hostedSourcePlugin)
```

Use `setParameter` to change the normalized value of the Frequency parameter to 0.8. Specify the parameter by its index.

```
setParameter(hostedSourcePlugin,1,0.8)
```

When you set the normalized parameter value, the parameter display value is automatically updated. Generally, the normalized parameter value corresponds to the position of a UI widget or MIDI controller. The parameter display value typically reflects the value used internally by the plugin for processing.

Use `dispParameter` to display the updated table of parameters.

```
dispParameter(hostedSourcePlugin)
```

Alternatively, you can use `getParameter` to return the normalized value of a single parameter.

```
getParameter(hostedSourcePlugin,1)
```

Run External Source Plugin in MATLAB

Load a VST audio source plugin into MATLAB™ by specifying its full path. If you are using a Mac, replace the `.dll` file extension with `.vst`.

```
pluginPath = fullfile(matlabroot,'toolbox','audio','samples','oscillator.dll');
hostedSourcePlugin = loadAudioPlugin(pluginPath);
```

Set the Amplitude property to 0.5. Set the Frequency property to 16 kHz.

```
hostedSourcePlugin.Amplitude = 0.5;
hostedSourcePlugin.Frequency = 16000;
```

Set the sample rate at which to run the plugin. Create an output object to write to your audio device.

```
setSampleRate(hostedSourcePlugin,44100);
deviceWriter = audioDeviceWriter('SampleRate',44100);
```

Use the hosted source plugin to output an audio stream. The processing in the audio stream loop ramps the frequency parameter down and then up.

```
k = 1;
for i = 1:1000
    hostedSourcePlugin.Frequency = hostedSourcePlugin.Frequency - 30*k;
    y = process(hostedSourcePlugin);
    deviceWriter(y);
    if (hostedSourcePlugin.Frequency - 30 <= 0.1) || (hostedSourcePlugin.Frequency + 30 >= 20e3)
        k = -1*k;
    end
end
release(deviceWriter)
```

Limitations

- Saving an external plugin as a MAT-file and then loading it preserves the external settings and parameters of the plugin but does not preserve its internal state or memory. Do not save and load your plugins when you are processing audio.

See Also

`parameterTuner` | **Audio Test Bench** | `loadAudioPlugin` | `audioPlugin` | `audioPluginSource` | `externalAudioPlugin`

Topics

“Host External Audio Plugins”

“Hierarchies of Classes — Concepts”

Introduced in R2016b

ivectorSystem

Create i-vector system

Description

i-vectors are compact statistical representations of identity extracted from audio signals. `ivectorSystem` creates a trainable i-vector system to extract i-vectors and perform classification tasks such as speaker recognition, speaker diarization, and sound classification. You can also determine thresholds for open set tasks and enroll labels into the system for both open and closed set classification.

Creation

Syntax

```
ivs = ivectorSystem
ivs = ivectorSystem(Name=Value)
```

Description

`ivs = ivectorSystem` creates a default i-vector system. You can train the i-vector system to extract i-vectors and perform classification tasks.

`ivs = ivectorSystem(Name=Value)` specifies nondefault properties for `ivs` using one or more name-value arguments.

Properties

InputType — Type of input

"audio" (default) | "features"

Input type, specified as "audio" or "features".

- "audio" -- The i-vector system accepts mono audio signals as input. The audio data is processed to extract 20 mel frequency cepstral coefficients (MFCCs), delta MFCCs, and delta-delta MFCCs for 60 coefficients per frame.

If `InputType` is set to "audio" when the i-vector system is created, the training data can be:

- A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
- An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.
- A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to read from the transform datastore must be mono audio signals with underlying data type `single` or `double`.

- "features" -- The i-vector accepts pre-extracted audio features as input.

If `InputType` is set to "features" when the i-vector system is created, the training data can be:

- A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
- A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
- A `signalDatastore` object whose `read` function has output as described in the first bullet.

Example: `ivs = ivectorSystem(InputType="audio")`

Data Types: `char` | `string`

SampleRate — Sample rate of audio input in Hz

16000 (default) | positive scalar

Sample rate of the audio input in Hz, specified as a positive scalar.

Note The "SampleRate" property applies only when `InputType` is set to "audio".

Example: `ivs = ivectorSystem(InputType="audio",SampleRate=48000)`

Data Types: `single` | `double`

DetectSpeech — Apply speech detection

`true` (default) | `false`

Apply speech detection, specified as `true` or `false`. With `DetectSpeech` set to `true`, the i-vector system extracts features only from regions where speech is detected.

Note The `DetectSpeech` property applies only when `InputType` is set to "audio".

`ivectorSystem` uses the `detectSpeech` function to detect regions of speech.

Example: `ivs = ivectorSystem(InputType="audio",DetectSpeech=true)`

Data Types: `logical` | `single` | `double`

Verbose — Display training progress

`true` (default) | `false`

Display training progress, specified as `true` or `false`. With `Verbose` set to `true`, the i-vector system displays the training progress in the command window or the Live Editor.

Tip To toggle between verbose and non-verbose behavior, use dot notation to set the `Verbose` property between object function calls.

Example: `ivs = ivectorSystem(InputType="audio",Verbose=false)`

Data Types: `logical | single | double`

EnrolledLabels — Table containing enrolled labels

0-by-2 table (default)

This property is read-only.

Table containing enrolled labels, specified as a table. Table row names correspond to labels and column names correspond to the template i-vector and the number of individual i-vectors used to generate the template i-vector. The number of i-vectors used to generate the template i-vector may be viewed as a measure of confidence in the template.

- Use `enroll` to enroll new labels or update existing labels.
- Use `unenroll` to remove labels from the system.

Data Types: `table`

Object Functions

<code>trainExtractor</code>	Train i-vector extractor
<code>trainClassifier</code>	Train i-vector classifier
<code>calibrate</code>	Train i-vector system calibrator
<code>enroll</code>	Enroll labels
<code>unenroll</code>	Unenroll labels
<code>detectionErrorTradeoff</code>	Evaluate binary classification system
<code>verify</code>	Verify label
<code>identify</code>	Identify label
<code>ivector</code>	Extract i-vector
<code>info</code>	Return training configuration and data info
<code>addInfoHeader</code>	Add custom information about i-vector system
<code>release</code>	Allow property values and input characteristics to change

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder, "SPEECH DATA", "FEMALE", "MIC"), fullfile(datasetFolder, "SPEECH DATA", "MALE", "MIC")], fullfile(datasetFolder, "SPEECH DATA", "MIC"),
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

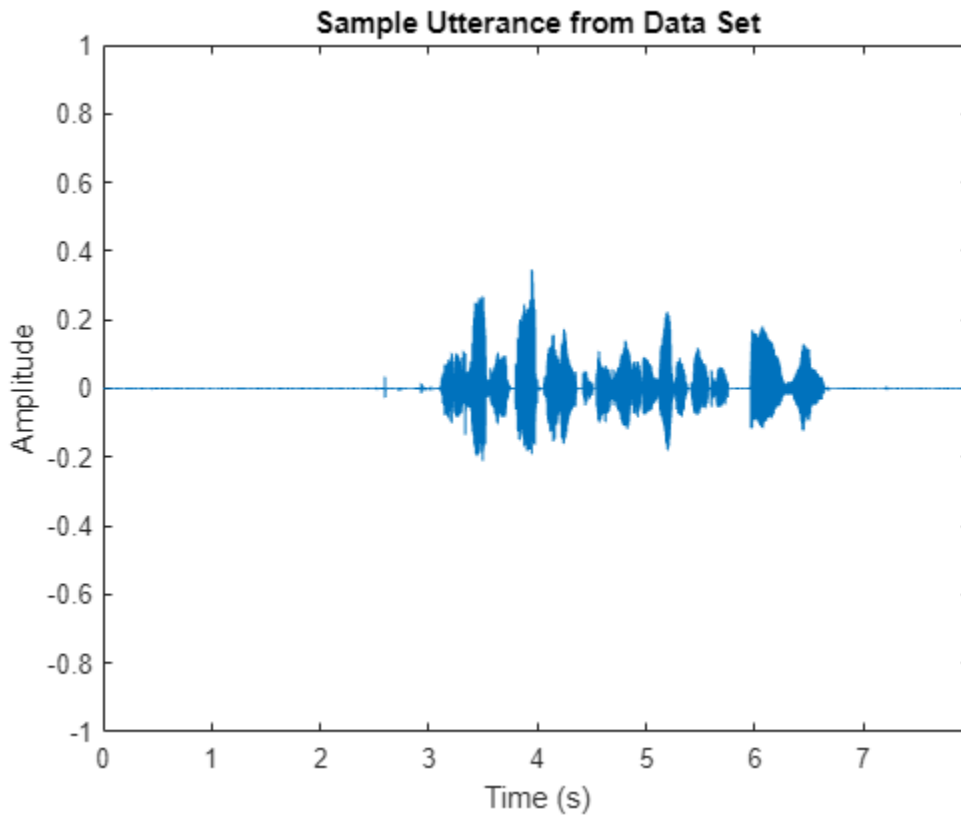
```
ads.Labels = extractBetween(ads.Files, "mic_", "_");
countEachLabel(ads)
```

```
ans=20x2 table
  Label    Count
  _____  _____
  F01      236
  F02      236
  F03      236
  F04      236
  F05      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M01      236
  M02      236
  M03      236
  M04      236
  M05      236
  M06      236
  :
```

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);
fs = audioInfo.SampleRate;

t = (0:size(audioIn,1)-1)/fs;
sound(audioIn, fs)
plot(t, audioIn)
xlabel("Time (s)")
ylabel("Amplitude")
axis([0 t(end) -1 1])
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  -----
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```
M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236
```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 48000  
    DetectSpeech: 1  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```


To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
Input feature vector length: 60
Input data type: double
```

```
trainExtractor
Train signals: 3774
UBMNumComponents: 128
UBMNumIterations: 5
TVSRank: 64
TVSNumIterations: 3
```

```
trainClassifier
Train signals: 3774
Train labels: F02 (236), F03 (236) ... and 14 more
NumEigenvectors: 16
PLDANumDimensions: 16
PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
F01      {16x1 double}      1
F05      {16x1 double}      1
M01      {16x1 double}      1
M05      {16x1 double}      1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
F01      {16x1 double}      3
F05      {16x1 double}      3
M01      {16x1 double}      3
M05      {16x1 double}      3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

results

```

results = struct with fields:
    PLDA: [1000x3 table]
    CSS: [1000x3 table]

```

results.CSS

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  1.7736e-09         1         0
  1.8233e-09    0.99964         0
  1.8745e-09    0.99964         0
  1.927e-09     0.99964         0
  1.9811e-09    0.99964         0
  2.0366e-09    0.99964         0
  2.0937e-09    0.99964         0
  2.1524e-09    0.99964         0
  2.2128e-09    0.99964         0
  2.2748e-09    0.99964         0
  2.3386e-09    0.99964         0
  2.4042e-09    0.99964         0
  2.4716e-09    0.99964         0
  2.5409e-09    0.99964         0
  2.6122e-09    0.99964         0
  2.6854e-09    0.99964         0
  :

```

results.P LDA

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  4.7045e-34         1         0
  5.143e-34    0.99964         0
  5.6225e-34    0.99964         0
  6.1466e-34    0.99964         0
  6.7197e-34    0.99964         0
  7.3461e-34    0.99964         0
  8.0309e-34    0.99964         0
  8.7796e-34    0.99964         0
  9.5981e-34    0.99964         0
  1.0493e-33    0.99964         0
  1.1471e-33    0.99964         0

```

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

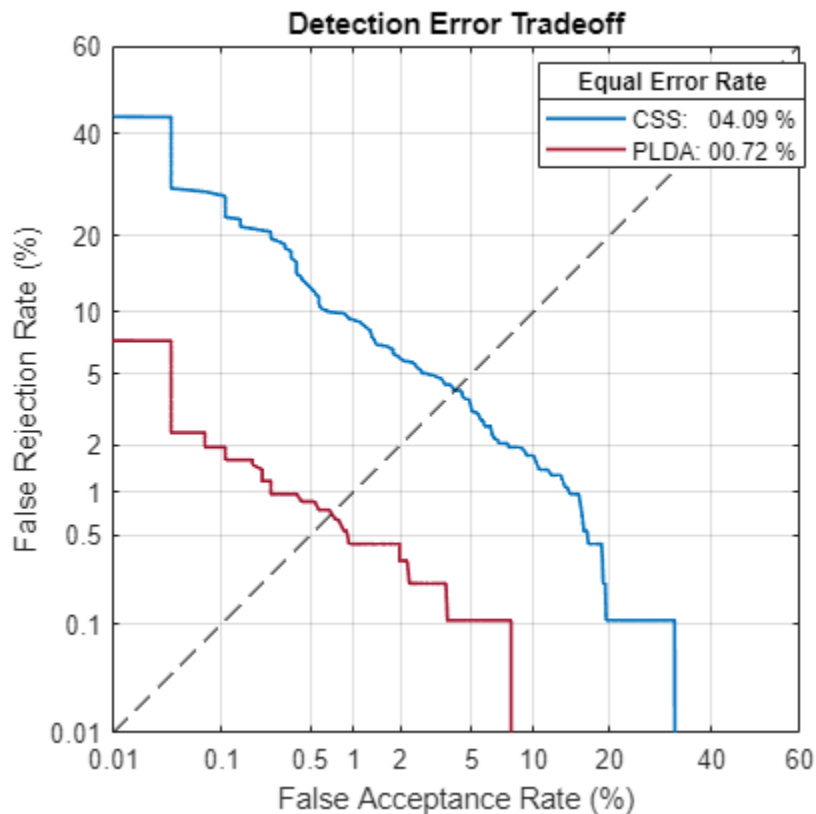
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

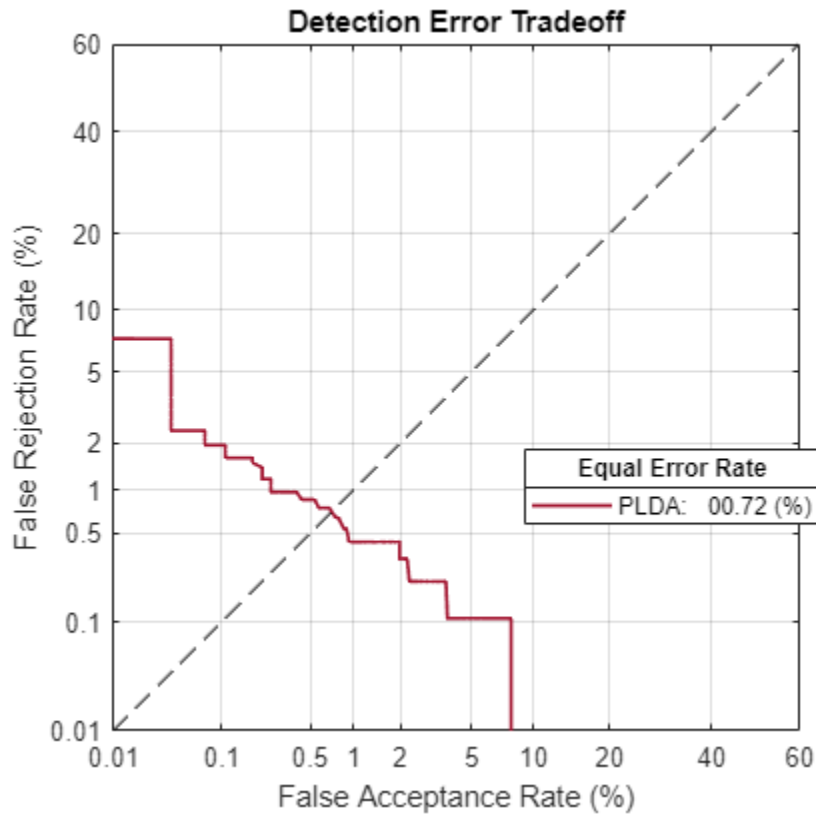
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

```
detectionErrorTradeoff(speakerVerification)
```



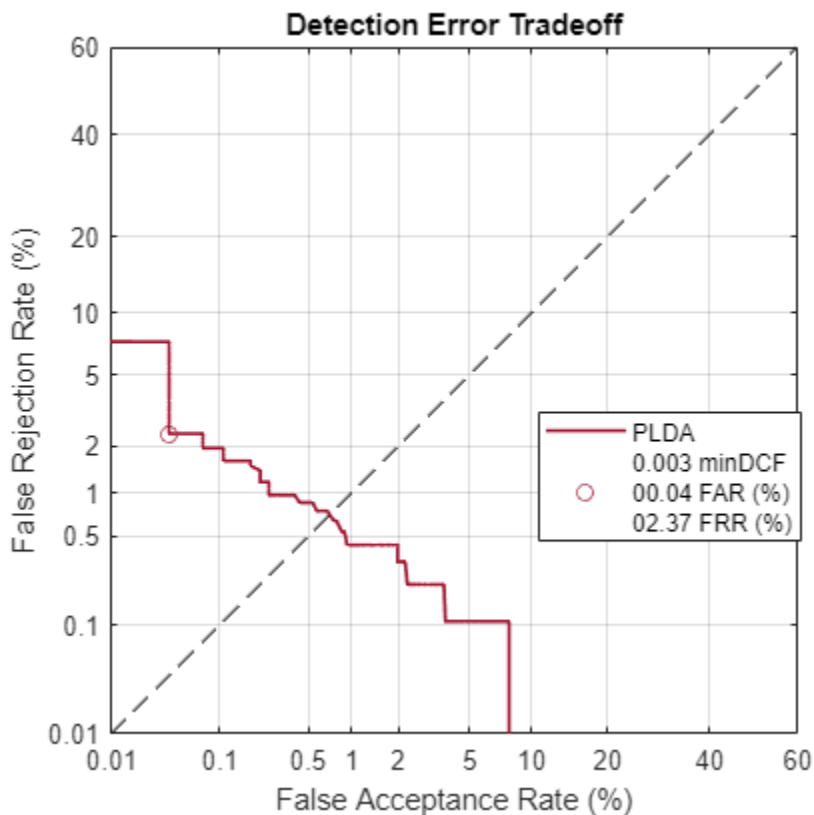
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label

knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.P LDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```
    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker accepted.
Similarity score = 1.00
```

Call speaker verification again. This time, specify an incorrect speaker ID.

```
possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))
```

```
imposter = 1x1 cell array
    {'F01'}
```

```
[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker rejected.
Similarity score = 0.00
```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Train Speaker Identification System

Use the Census Database (also known as AN4 Database) from the CMU Robust Speech Recognition Group [1] on page 4-0 . The data set contains recordings of male and female subjects speaking words and numbers. The helper function in this example downloads the data set for you and converts the raw files to FLAC, and returns two `audioDatastore` objects containing the training set and test set. By default, the data set is reduced so that the example runs quickly. You can use the full data set by setting `ReduceDataset` to false.

```
[adsTrain,adsTest] = HelperAN4Download(ReduceDataset=true);
```

Split the test data set into enroll and test sets. Use two utterances for enrollment and the remaining for the test set. Generally, the more utterances you use for enrollment, the better the performance of the system. However, most practical applications are limited to a small set of enrollment utterances.

```
[adsEnroll,adsTest] = splitEachLabel(adsTest,2);
```

Inspect the distribution of speakers in the training, test, and enroll sets. The speakers in the training set do not overlap with the speakers in the test and enroll sets.

```
summary(adsTrain.Labels)
```

```

fejs      13
fmjd      13
fsrb      13
ftmj      13
fwxs      12
mcen      13
mrcb      13
msjm      13
msjr      13
msmn      9

```

```
summary(adsEnroll.Labels)
```

```

fvap      2
marh      2

```

```
summary(adsTest.Labels)
```

```

fvap      11
marh      11

```

Create an i-vector system that accepts feature input.

```

fs = 16e3;
iv = ivectorSystem(SampleRate=fs, InputType="features");

```

Create an `audioFeatureExtractor` object to extract the gammatone cepstral coefficients (GTCC), the delta GTCC, the delta-delta GTCC, and the pitch from 50 ms periodic Hann windows with 45 ms overlap.

```

afe = audioFeatureExtractor(gtcc=true, gtccDelta=true, gtccDeltaDelta=true, pitch=true, SampleRate=fs);
afe.Window = hann(round(0.05*fs), "periodic");
afe.OverlapLength = round(0.045*fs);
afe

```

```

afe =
audioFeatureExtractor with properties:

```

```
Properties
```

```

          Window: [800x1 double]
      OverlapLength: 720
          SampleRate: 16000
              FFTLength: []
SpectralDescriptorInput: 'linearSpectrum'
      FeatureVectorLength: 40

```

```
Enabled Features
```

```
gtcc, gtccDelta, gtccDeltaDelta, pitch
```

```
Disabled Features
```

```

linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
mfccDeltaDelta, spectralCentroid, spectralCrest, spectralDecrease, spectralEntropy, spectralFlux,
spectralKurtosis, spectralRolloffPoint, spectralSkewness, spectralSlope, spectralHarmonicRatio,
zeroCrossRate, shortTimeEnergy

```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds mfcc to the list of enabled features.

Create transformed datastores by adding feature extraction to the read function of adsTrain and adsEnroll.

```
trainLabels = adsTrain.Labels;
adsTrain = transform(adsTrain,@(x)extract(afe,x));
enrollLabels = adsEnroll.Labels;
adsEnroll = transform(adsEnroll,@(x)extract(afe,x));
```

Train both the extractor and classifier using the training set.

```
trainExtractor(iv,adsTrain, ...
    UBMNumComponents=64, ...
    UBMNumIterations=5, ...
    TVSRank=32, ...
    TVSNumIterations=3);
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

```
trainClassifier(iv,adsTrain,trainLabels, ...
    NumEigenvectors=16, ...
    ...
    PLDANumDimensions=16, ...
    PLDANumIterations=5);
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(iv,adsTrain,trainLabels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

Enroll the speakers from the enrollment set.

```
enroll(iv,adsEnroll,enrollLabels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

Evaluate the file-level prediction accuracy on the test set.

```
numCorrect = 0;
reset(adsTest)
for index = 1:numel(adsTest.Files)
    features = extract(afe,read(adsTest));

    results = identify(iv,features);
```

```

    trueLabel = adsTest.Labels(index);
    predictedLabel = results.Label(1);
    isPredictionCorrect = trueLabel==predictedLabel;

    numCorrect = numCorrect + isPredictionCorrect;
end
display("File Accuracy: " + round(100*numCorrect/numel(adsTest.Files),2) + " (%)")

    "File Accuracy: 100 (%)"

```

References

[1] "CMU Sphinx Group - Audio Databases." <http://www.speech.cs.cmu.edu/databases/an4/>. Accessed 19 Dec. 2019.

Train Environmental Sound Classification System

Download and unzip the environment sound classification data set. This data set consists of recordings labeled as one of 10 different audio sound classes (ESC-10).

```
loc = matlab.internal.examples.downloadSupportFile("audio","ESC-10.zip");
unzip(loc,pwd)
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets. Call `countEachLabel` to display the distribution of sound classes and the number of unique labels.

```
ads = audioDatastore(pwd,IncludeSubfolders=true,LabelSource="foldernames");
countEachLabel(ads)
```

```
ans=10x2 table
      Label      Count
-----
chainsaw      40
clock_tick    40
crackling_fire 40
crying_baby   40
dog           40
helicopter    40
rain          40
rooster       38
sea_waves     40
sneezing      40
```

Listen to one of the files.

```
[audioIn,audioInfo] = read(ads);
fs = audioInfo.SampleRate;
sound(audioIn,fs)
audioInfo.Label
```

```
ans = categorical
      chainsaw
```

Split the datastore into training and test sets.

```
[adsTrain,adsTest] = splitEachLabel(ads,0.8);
```

Create an `audioFeatureExtractor` to extract all possible features from the audio.

```
afe = audioFeatureExtractor(SampleRate=fs, ...
    Window=hamming(round(0.03*fs), "periodic"), ...
    OverlapLength=round(0.02*fs));
params = info(afe, "all");
params = structfun(@(x) true, params, UniformOutput=false);
set(afe, params);
afe
```

```
afe =
    audioFeatureExtractor with properties:
```

```
    Properties
```

```
        Window: [1323x1 double]
    OverlapLength: 882
        SampleRate: 44100
            FFTLength: []
    SpectralDescriptorInput: 'linearSpectrum'
        FeatureVectorLength: 862
```

```
    Enabled Features
```

```
    linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
    mfccDeltaDelta, gtcc, gtccDelta, gtccDeltaDelta, spectralCentroid, spectralCrest
    spectralDecrease, spectralEntropy, spectralFlatness, spectralFlux, spectralKurtosis, spectralSkewness, spectralSlope, spectralSpread, pitch, harmonicRatio, zerocrossrate
    shortTimeEnergy
```

```
    Disabled Features
```

```
    none
```

To extract a feature, set the corresponding property to true.
For example, `obj.mfcc = true`, adds mfcc to the list of enabled features.

Create two directories in your current folder: `train` and `test`. Extract features from the training and the test data sets and write the features as MAT files to the respective directories. Pre-extracting features can save time when you want to evaluate different feature combinations or training configurations.

```
if ~isdir("train")
    mkdir("train")
    mkdir("test")

    outputType = ".mat";
    writeall(adsTrain, "train", WriteFcn=@(x,y,z) writeFeatures(x,y,z,afe))
    writeall(adsTest, "test", WriteFcn=@(x,y,z) writeFeatures(x,y,z,afe))
end
```

Create signal datastores to point to the audio features.

```
sdsTrain = signalDatastore("train", IncludeSubfolders=true);
sdsTest = signalDatastore("test", IncludeSubfolders=true);
```

Create label arrays that are in the same order as the `signalDatastore` files.

```
labelsTrain = categorical(extractBetween(sdsTrain.Files,"ESC-10"+filesep,filesep));
labelsTest = categorical(extractBetween(sdsTest.Files,"ESC-10"+filesep,filesep));
```

Create a transform datastore from the signal datastores to isolate and use only the desired features. You can use the output from `info` on the `audioFeatureExtractor` to map your chosen features to the index in the features matrix. You can experiment with the example by choosing different features.

```
featureIndices = info(afe)
```

```
featureIndices = struct with fields:
    linearSpectrum: [1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100]
    melSpectrum: [663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    barkSpectrum: [695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    erbSpectrum: [727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    mfcc: [770 771 772 773 774 775 776 777 778 779 780 781 782]
    mfccDelta: [783 784 785 786 787 788 789 790 791 792 793 794 795]
    mfccDeltaDelta: [796 797 798 799 800 801 802 803 804 805 806 807 808]
    gtcc: [809 810 811 812 813 814 815 816 817 818 819 820 821]
    gtccDelta: [822 823 824 825 826 827 828 829 830 831 832 833 834]
    gtccDeltaDelta: [835 836 837 838 839 840 841 842 843 844 845 846 847]
    spectralCentroid: 848
    spectralCrest: 849
    spectralDecrease: 850
    spectralEntropy: 851
    spectralFlatness: 852
    spectralFlux: 853
    spectralKurtosis: 854
    spectralRolloffPoint: 855
    spectralSkewness: 856
    spectralSlope: 857
    spectralSpread: 858
    pitch: 859
    harmonicRatio: 860
    zerocrossrate: 861
    shortTimeEnergy: 862
```

```
idxToUse = [...
    featureIndices.harmonicRatio ...
    ,featureIndices.spectralRolloffPoint ...
    ,featureIndices.spectralFlux ...
    ,featureIndices.spectralSlope ...
];
tdsTrain = transform(sdsTrain,@(x)x(:,idxToUse));
tdsTest = transform(sdsTest,@(x)x(:,idxToUse));
```

Create an i-vector system that accepts feature input.

```
soundClassifier = ivectorSystem(InputType="features");
```

Train the extractor and classifier using the training set.

```
trainExtractor(soundClassifier,tdsTrain,UBMNumComponents=128,TVSRank=64);
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

```
trainClassifier(soundClassifier,tdsTrain,labelsTrain,NumEigenvectors=32,PLDANumIterations=0)
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
i-vector classifier training complete.
```

Enroll the labels from the training set to create i-vector templates for each of the environmental sounds.

```
enroll(soundClassifier,tdsTrain,labelsTrain)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

Calibrate the i-vector system.

```
calibrate(soundClassifier,tdsTrain,labelsTrain)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibration complete.
```

Use the `identify` function on the test set to return the system's inferred label.

```
inferredLabels = labelsTest;
inferredLabels(:) = inferredLabels(1);
for ii = 1:numel(labelsTest)
    features = read(tdsTest);
    tableOut = identify(soundClassifier,features,"css",NumCandidates=1);
    inferredLabels(ii) = tableOut.Label(1);
end
```

Create a confusion matrix to visualize performance on the test set.

```
uniqueLabels = unique(labelsTest);
cm = zeros(numel(uniqueLabels),numel(uniqueLabels));
for ii = 1:numel(uniqueLabels)
    for jj = 1:numel(uniqueLabels)
        cm(ii,jj) = sum((labelsTest==uniqueLabels(ii)) & (inferredLabels==uniqueLabels(jj)));
    end
end
labelStrings = replace(string(uniqueLabels),"_"," ");
heatmap(labelStrings,labelStrings,cm)
colorbar off
ylabel("True Labels")
xlabel("Predicted Labels")
accuracy = mean(inferredLabels==labelsTest);
title(sprintf("Accuracy = %0.2f %%",accuracy*100))
```

Accuracy = 73.75 %

True Labels	chainsaw	7	0	0	0	0	1	0	0	0	0
	clock tick	0	7	1	0	0	0	0	0	0	0
	crackling fire	0	1	4	0	0	1	1	0	1	0
	crying baby	0	0	0	8	0	0	0	0	0	0
	dog	0	0	0	0	7	0	0	1	0	0
	helicopter	1	1	0	0	0	6	0	0	0	0
	rain	0	1	0	0	0	0	7	0	0	0
	rooster	0	0	0	1	4	0	0	3	0	0
	sea waves	0	0	0	0	0	1	1	0	6	0
	sneezing	0	0	0	1	1	0	0	2	0	4
		chainsaw	clock tick	crackling fire	crying baby	dog	helicopter	rain	rooster	sea waves	sneezing
		Predicted Labels									

Release the i-vector system.

```
release(soundClassifier)
```

Supporting Functions

```
function writeFeatures(audioIn,info,~,afe)
    % Convert to single-precision
    audioIn = single(audioIn);

    % Extract features
    features = extract(afe,audioIn);

    % Replace the file extension of the suggested output name with MAT.
    filename = strrep(info.SuggestedOutputName, ".wav", ".mat");

    % Save the MFCC coefficients to the MAT file.
    save(filename, "features")
end
```

Train Acoustic Fault Recognition System

Download and unzip the air compressor data set [1] on page 4-0 . This data set consists of recordings from air compressors in a healthy state or one of seven faulty states.

```
loc = matlab.internal.examples.downloadSupportFile("audio", ...
    "AirCompressorDataset/AirCompressorDataset.zip");
unzip(loc,pwd)
```

Create an audioDatastore object to manage the data and split it into training and validation sets.

```
ads = audioDatastore(pwd,IncludeSubfolders=true,LabelSource="foldernames");

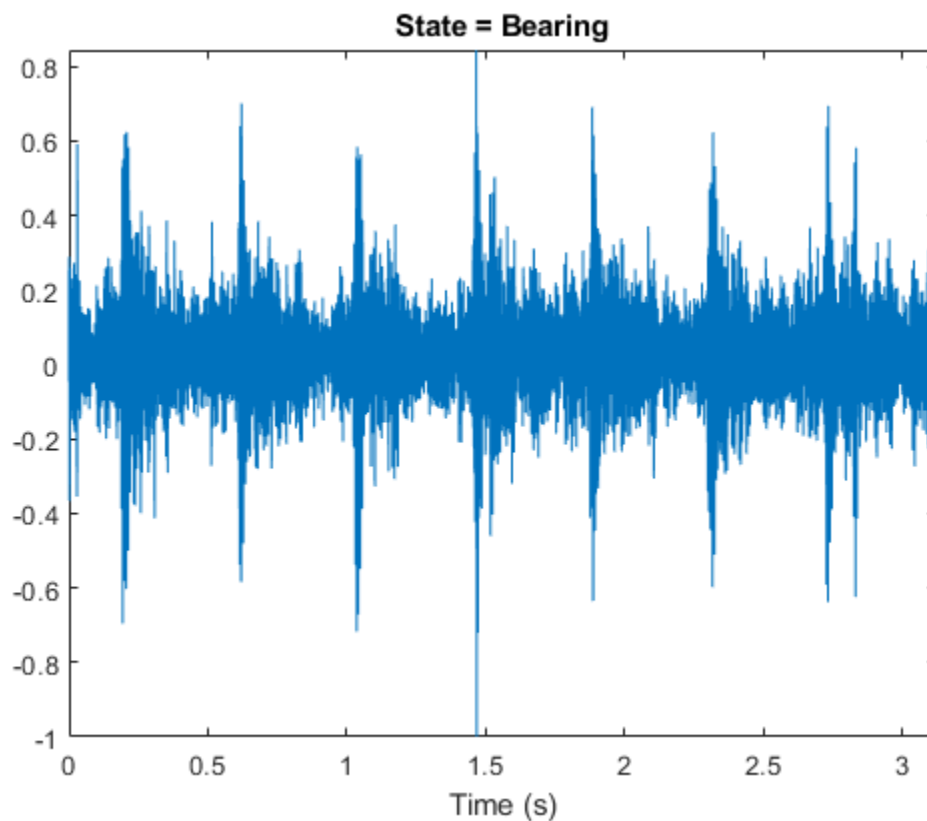
[adsTrain,adsTest] = splitEachLabel(ads,0.8,0.2);
```

Read an audio file from the datastore and save the sample rate. Listen to the audio signal and plot the signal in the time domain.

```
[x,fileInfo] = read(adsTrain);
fs = fileInfo.SampleRate;

sound(x,fs)

t = (0:size(x,1)-1)/fs;
plot(t,x)
xlabel("Time (s)")
title("State = " + string(fileInfo.Label))
axis tight
```



Create an i-vector system with DetectSpeech set to false. Turn off the verbose behavior.

```
faultRecognizer = ivectorSystem(SampleRate=fs,DetectSpeech=false, ...
    Verbose=false)
```

```

faultRecognizer =
  ivectorSystem with properties:

    InputType: 'audio'
    SampleRate: 16000
    DetectSpeech: 0
    Verbose: 0
    EnrolledLabels: [0x2 table]

```

Train the i-vector extractor and the i-vector classifier using the training datastore.

```

trainExtractor(faultRecognizer,adsTrain, ...
  UBMNumComponents=80, ...
  UBMNumIterations=3, ...
  ...
  TVSRank=40, ...
  TVSNumIterations=3)

trainClassifier(faultRecognizer,adsTrain,adsTrain.Labels, ...
  NumEigenvectors=7, ...
  ...
  PLDANumDimensions=32, ...
  PLDANumIterations=5)

```

Calibrate the scores output by `faultRecognizer` so they can be interpreted as a measure of confidence in a positive decision. Turn the verbose behavior back on. Enroll all of the labels from the training set.

```
calibrate(faultRecognizer,adsTrain,adsTrain.Labels)
```

```
faultRecognizer.Verbose = true;
```

```
enroll(faultRecognizer,adsTrain,adsTrain.Labels)
```

```

Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.

```

Use the read-only property `EnrolledLabels` to view the enrolled labels and the corresponding i-vector templates.

```
faultRecognizer.EnrolledLabels
```

```
ans=8x2 table
```

	ivector	NumSamples
	-----	-----
Bearing	{7x1 double}	180
Flywheel	{7x1 double}	180
Healthy	{7x1 double}	180
LIV	{7x1 double}	180
LOV	{7x1 double}	180
NRV	{7x1 double}	180
Piston	{7x1 double}	180
Riderbelt	{7x1 double}	180

Use the `identify` function with the PLDA scorer to predict the condition of machines in the test set. The `identify` function returns a table of possible labels sorted in descending order of confidence.

```
[audioIn, audioInfo] = read(adsTest);
trueLabel = audioInfo.Label

trueLabel = categorical
    Bearing

predictedLabels = identify(faultRecognizer, audioIn, "plda")
```

```
predictedLabels=8x2 table
    Label      Score
-----
Bearing      0.99997
Flywheel     2.265e-05
Piston       8.6076e-08
LIV          1.4237e-15
NRV          4.5529e-16
Riderbelt    3.7359e-16
LOV          6.3025e-19
Healthy      4.2094e-30
```

By default, the `identify` function returns all possible candidate labels and their corresponding scores. Use `NumCandidates` to reduce the number of candidates returned.

```
results = identify(faultRecognizer, audioIn, "plda", NumCandidates=3)

results=3x2 table
    Label      Score
-----
Bearing      0.99997
Flywheel     2.265e-05
Piston       8.6076e-08
```

References

[1] Verma, Nishchal K., et al. "Intelligent Condition Based Monitoring Using Acoustic Signals for Air Compressors." *IEEE Transactions on Reliability*, vol. 65, no. 1, Mar. 2016, pp. 291-309. *DOI.org (Crossref)*, doi:10.1109/TR.2015.2459684.

Train Speech Emotion Recognition System

Download the Berlin Database of Emotional Speech [1] on page 4-0 . The database contains 535 utterances spoken by 10 actors intended to convey one of the following emotions: anger, boredom, disgust, anxiety/fear, happiness, sadness, or neutral. The emotions are text independent.

```
url = "http://emodb.bilderbar.info/download/download.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder, "Emo-DB");
```

```

if ~exist(datasetFolder, "dir")
    disp("Downloading Emo-DB (40.5 MB) ...")
    unzip(url, datasetFolder)
end

```

Create an `audioDatastore` that points to the audio files.

```
ads = audioDatastore(fullfile(datasetFolder, "wav"));
```

The file names are codes indicating the speaker id, text spoken, emotion, and version. The website contains a key for interpreting the code and additional information about the speakers such as gender and age. Create a table with the variables `Speaker` and `Emotion`. Decode the file names into the table.

```

filepaths = ads.Files;
emotionCodes = cellfun(@(x)x(end-5), filepaths, "UniformOutput", false);
emotions = replace(emotionCodes, {'W', 'L', 'E', 'A', 'F', 'T', 'N'}, ...
    {'Anger', 'Boredom', 'Disgust', 'Anxiety', 'Happiness', 'Sadness', 'Neutral'});

speakerCodes = cellfun(@(x)x(end-10:end-9), filepaths, "UniformOutput", false);
labelTable = table(categorical(speakerCodes), categorical(emotions), VariableNames=["Speaker", "Emotion"], ...
    'Summary', summary(labelTable))

```

Variables:

```
Speaker: 535x1 categorical
```

Values:

03	49
08	58
09	43
10	38
11	55
12	35
13	61
14	69
15	56
16	71

```
Emotion: 535x1 categorical
```

Values:

Anger	127
Anxiety	69
Boredom	81
Disgust	46
Happiness	71
Neutral	79
Sadness	62

`labelTable` is in the same order as the files in `audioDatastore`. Set the `Labels` property of the `audioDatastore` to `labelTable`.

```
ads.Labels = labelTable;
```

Read a signal from the datastore and listen to it. Display the speaker ID and emotion of the audio signal.

```
[audioIn, audioInfo] = read(ads);
fs = audioInfo.SampleRate;
sound(audioIn, fs)
audioInfo.Label
```

```
ans=1x2 table
   Speaker   Emotion
   _____  _____
       03      Happiness
```

Split the datastore into a training set and a test set. Assign two speakers to the test set and the remaining to the training set.

```
testSpeakerIdx = ads.Labels.Speaker=="12" | ads.Labels.Speaker=="13";
adsTrain = subset(ads, ~testSpeakerIdx);
adsTest = subset(ads, testSpeakerIdx);
```

Read all the training and testing audio data into cell arrays. If your data can fit in memory, training is usually faster to input cell arrays to an i-vector system rather than datastores.

```
trainSet = readall(adsTrain);
trainLabels = adsTrain.Labels.Emotion;
testSet = readall(adsTest);
testLabels = adsTest.Labels.Emotion;
```





Create an i-vector system that does not apply speech detection. When `DetectSpeech` is set to `true` (the default), only regions of detected speech are used to train the i-vector system. When `DetectSpeech` is set to `false`, the entire input audio is used to train the i-vector system. The usefulness of applying speech detection depends on the data input to the system.

```
emotionRecognizer = ivectorSystem(SampleRate=fs, DetectSpeech=)
```

```
emotionRecognizer =
  ivectorSystem with properties:
```

```
    InputType: 'audio'
    SampleRate: 16000
    DetectSpeech: 0
    Verbose: 1
    EnrolledLabels: [0x2 table]
```

Call `trainExtractor` using the training set.




```
rng default
trainExtractor(emotionRecognizer, trainSet, ...
    UBMNumComponents = 256 , ...
    UBMNumIterations = 5 , ...
    ...
    TVSRank = 128 , ...
    TVSNumIterations = 5 );
```

```
Calculating standardization factors .....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

Copy the emotion recognition system for use later in the example.

```
sentimentRecognizer = copy(emotionRecognizer);
```

Call `trainClassifier` using the training set.

```
rng default
trainClassifier(emotionRecognizer,trainSet,trainLabels, ...
    NumEigenvectors = 32  , ...
    ...
    PLDANumDimensions = 16  , ...
    PLDANumIterations = 10  );
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

Call `calibrate` using the training set. In practice, the calibration set should be different than the training set.

```
calibrate(emotionRecognizer,trainSet,trainLabels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

Enroll the training labels into the i-vector system.

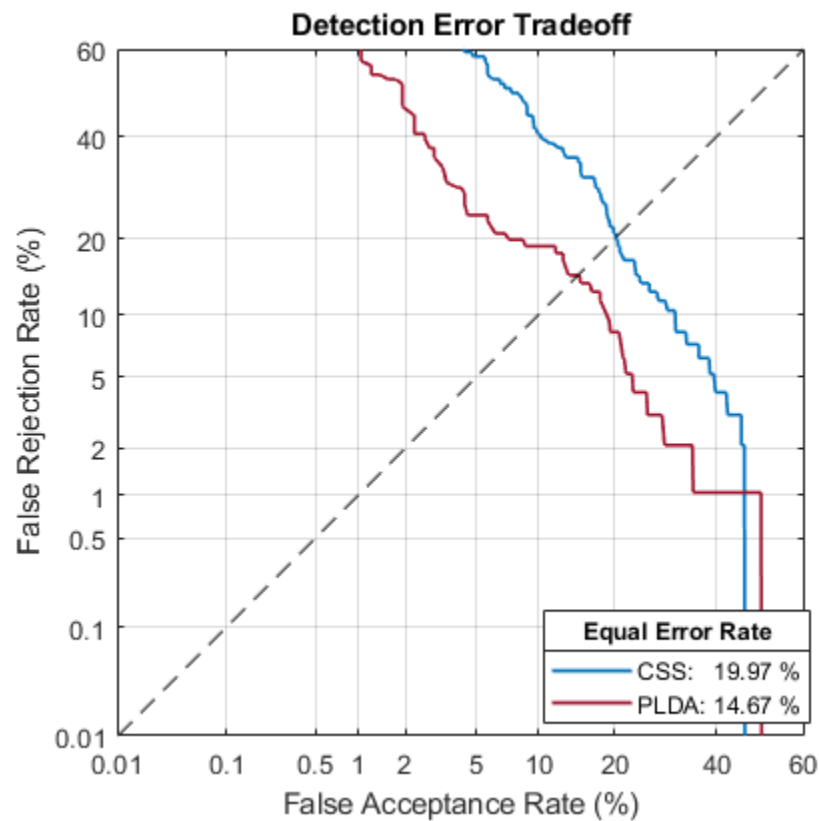
```
enroll(emotionRecognizer,trainSet,trainLabels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

You can use `detectionErrorTradeoff` as a quick sanity check on the performance of a multilabel closed-set classification system. However, `detectionErrorTradeoff` provides information more suitable to open-set binary classification problems, for example, speaker verification tasks.

```
detectionErrorTradeoff(emotionRecognizer,testSet,testLabels)
```

```
Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.
```



For a more detailed view of the i-vector system's performance in a multilabel closed set application, you can use the `identify` function and create a confusion matrix. The confusion matrix enables you to identify which emotions are misidentified and what they are misidentified as. Use the supporting function `plotConfusion` to display the results.

```

trueLabels = testLabels;
predictedLabels = trueLabels;
scorer = ;
for ii = 1:numel(testSet)
    tableOut = identify(emotionRecognizer, testSet{ii}, scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels, predictedLabels)

```

Accuracy = 73.96 %

True Labels \ Predicted Labels	Anger	Anxiety	Boredom	Disgust	Happiness	Neutral	Sadness
Anger	18	2	0	0	4	0	0
Anxiety	0	11	0	0	0	0	2
Boredom	0	2	8	0	0	5	0
Disgust	0	1	0	8	0	1	0
Happiness	0	0	0	0	12	0	0
Neutral	0	3	4	0	0	6	0
Sadness	0	0	1	0	0	0	8

Call `info` to inspect how `emotionRecognizer` was trained and evaluated.

```
info(emotionRecognizer)
```

```
i-vector system input
  Input feature vector length: 60
  Input data type: double
```

```
trainExtractor
  Train signals: 439
  UBMNumComponents: 256
  UBMNumIterations: 5
  TVSRank: 128
  TVSNumIterations: 5
```

```
trainClassifier
  Train signals: 439
  Train labels: Anger (103), Anxiety (56) ... and 5 more
  NumEigenvectors: 32
  PLDANumDimensions: 16
  PLDANumIterations: 10
```

```
calibrate
  Calibration signals: 439
  Calibration labels: Anger (103), Anxiety (56) ... and 5 more
```

```
detectionErrorTradeoff
```




```
Evaluation signals: 96
Evaluation labels: Anger (24), Anxiety (13) ... and 5 more
```

Next, modify the i-vector system to recognize emotions as positive, neutral, or negative. Update the labels to only include the categories negative, positive, and categorical.

```
trainLabelsSentiment = trainLabels;
trainLabelsSentiment(ismember(trainLabels,categorical(["Anger","Anxiety","Boredom","Sadness","Disgust","Fear","Guilt","Happiness","Love","Pain","Shame","Surprise","Tenderness","Worry","Zest"])) = categorical("Positive");
trainLabelsSentiment = removecats(trainLabelsSentiment);

testLabelsSentiment = testLabels;
testLabelsSentiment(ismember(testLabels,categorical(["Anger","Anxiety","Boredom","Sadness","Disgust","Fear","Guilt","Happiness","Love","Pain","Shame","Surprise","Tenderness","Worry","Zest"])) = categorical("Positive");
testLabelsSentiment = removecats(testLabelsSentiment);
```

Train the i-vector system classifier using the updated labels. You do not need to retrain the extractor. Recalibrate the system.

```
rng default
trainClassifier(sentimentRecognizer,trainSet,trainLabelsSentiment, ...
    NumEigenvectors = 64  , ...
    ...
    PLDANumDimensions = 32  , ...
    PLDANumIterations = 10  );
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

```
calibrate(sentimentRecognizer,trainSet,trainLabels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

Enroll the training labels into the system and then plot the confusion matrix for the test set.

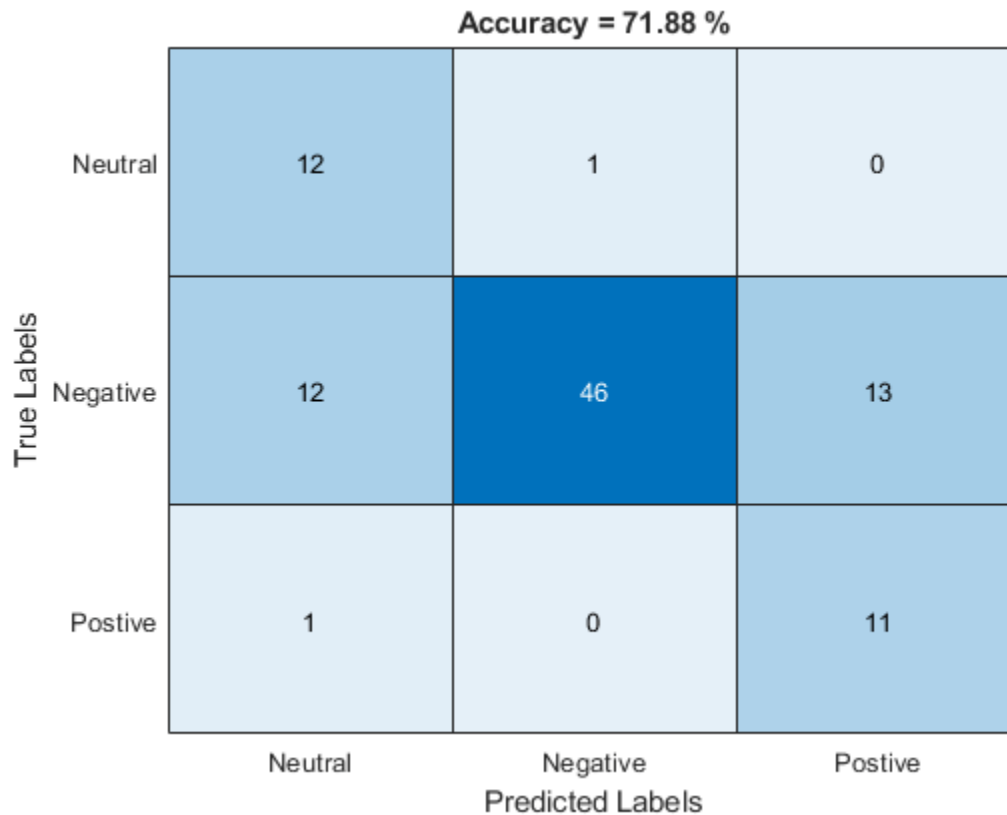
```
enroll(sentimentRecognizer,trainSet,trainLabelsSentiment)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
trueLabels = testLabelsSentiment;
predictedLabels = trueLabels;

scorer =  ;
for ii = 1:numel(testSet)
    tableOut = identify(sentimentRecognizer,testSet{ii},scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels,predictedLabels)
```



An i-vector system does not require the labels used to train the classifier to be equal to the enrolled labels.

Unenroll the sentiment labels from the system and then enroll the original emotion categories in the system. Analyze the system's classification performance.

```
unenroll(sentimentRecognizer)
enroll(sentimentRecognizer,trainSet,trainLabels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
trueLabels = testLabels;
predictedLabels = trueLabels;
scorer = ;
for ii = 1:numel(testSet)
    tableOut = identify(sentimentRecognizer,testSet{ii},scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels,predictedLabels)
```


Accuracy = 43.75 %

True Labels	Anger	17	1	0	3	1	0	2
	Anxiety	2	2	0	2	0	0	7
	Boredom	0	0	11	0	0	0	4
	Disgust	1	2	1	4	0	0	2
	Happiness	6	0	1	0	4	0	1
	Neutral	0	0	12	0	0	0	1
	Sadness	0	0	5	0	0	0	4
		Anger	Anxiety	Boredom	Disgust	Happiness	Neutral	Sadness
		Predicted Labels						

Supporting Functions

```
function plotConfusion(trueLabels,predictedLabels)
uniqueLabels = unique(trueLabels);
cm = zeros(numel(uniqueLabels),numel(uniqueLabels));
for ii = 1:numel(uniqueLabels)
    for jj = 1:numel(uniqueLabels)
        cm(ii,jj) = sum((trueLabels==uniqueLabels(ii)) & (predictedLabels==uniqueLabels(jj)));
    end
end

heatmap(uniqueLabels,uniqueLabels,cm)
colorbar off
ylabel('True Labels')
xlabel('Predicted Labels')
accuracy = mean(trueLabels==predictedLabels);
title(sprintf("Accuracy = %0.2f %%",accuracy*100))
end
```

References

[1] Burkhardt, F., A. Paeschke, M. Rolfes, W.F. Sendlmeier, and B. Weiss, "A Database of German Emotional Speech." In Proceedings Interspeech 2005. Lisbon, Portugal: International Speech Communication Association, 2005.

Train Word Recognition System

An i-vector system consists of a trainable front end that learns how to extract i-vectors based on unlabeled data, and a trainable backend that learns how to classify i-vectors based on labeled data. In this example, you apply an i-vector system to the task of word recognition. First, evaluate the accuracy of the i-vector system using the classifiers included in a traditional i-vector system: probabilistic linear discriminant analysis (PLDA) and cosine similarity scoring (CSS). Next, evaluate the accuracy of the system if you replace the classifier with bidirectional long short-term memory (BiLSTM) network or a K-nearest neighbors classifier.

Create Training and Validation Sets

Download the Free Spoken Digit Dataset (FSDD) [1] on page 4-0 . FSDD consists of short audio files with spoken digits (0-9).

```
loc = matlab.internal.examples.downloadSupportFile("audio","FSDD.zip");
unzip(loc,pwd)
```

Create an `audioDatastore` to point to the recordings. Get the sample rate of the data set.

```
ads = audioDatastore(pwd,IncludeSubfolders=true);
[~,adsInfo] = read(ads);
fs = adsInfo.SampleRate;
```

The first element of the file names is the digit spoken in the file. Get the first element of the file names, convert them to categorical, and then set the `Labels` property of the `audioDatastore`.

```
[~,filenames] = cellfun(@(x)fileparts(x),ads.Files,UniformOutput=false);
ads.Labels = categorical(string(cellfun(@(x)x(1),filenames)));
```

To split the datastore into a development set and a validation set, use `splitEachLabel`. Allocate 80% of the data for development and the remaining 20% for validation.

```
[adsTrain,adsValidation] = splitEachLabel(ads,0.8);
```

Evaluate Traditional i-vector Backend Performance

Create an i-vector system that expects audio input at a sample rate of 8 kHz and does not perform speech detection.

```
wordRecognizer = ivectorSystem(DetectSpeech=false,SampleRate=fs)
```

```
wordRecognizer =
  ivectorSystem with properties:
```

```
    InputType: 'audio'
    SampleRate: 8000
    DetectSpeech: 0
    Verbose: 1
    EnrolledLabels: [0x2 table]
```

Train the i-vector extractor using the data in the training set.

```
trainExtractor(wordRecognizer,adsTrain, ...
    UBMNumComponents=64, ...
    UBMNumIterations=5, ...
    ...)
```

```
TVSRank=32, ...
TVSNumIterations=5);
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

Train the i-vector classifier using the data in the training data set and the corresponding labels.

```
trainClassifier(wordRecognizer,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=10, ...
    ...
    PLDANumDimensions=10, ...
    PLDANumIterations=5);
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

Calibrate the scores output by `wordRecognizer` so they can be interpreted as a measure of confidence in a positive decision. Enroll labels into the system using the entire training set.

```
calibrate(wordRecognizer,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

```
enroll(wordRecognizer,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

In a loop, read audio from the validation datastore, identify the most-likely word present according to the specified scorer, and save the prediction for analysis.

```
trueLabels = adsValidation.Labels;
predictedLabels = trueLabels;
```

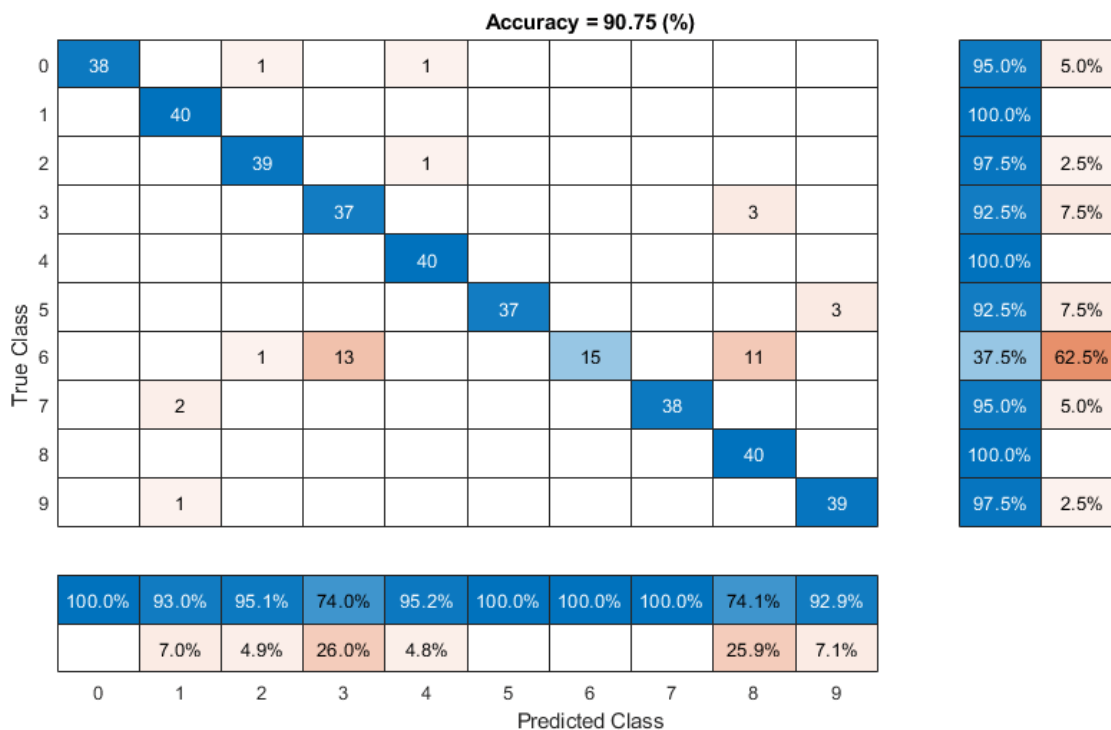
```
reset(adsValidation)
```

```
scorer = ;
for ii = 1:numel(trueLabels)
    audioIn = read(adsValidation);
    to = identify(wordRecognizer,audioIn,scorer);
    predictedLabels(ii) = to.Label(1);
```

```
end
```

Display a confusion chart of the i-vector system's performance on the validation set.

```
figure(Units="normalized",Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels,predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%%)',100*mean(predictedLabels==trueLabels)))
```



Evaluate Deep Learning Backend Performance

Next, train a fully-connected network using i-vectors as input.

```
ivectorsTrain = (ivector(wordRecognizer,adsTrain))';
ivectorsValidation = (ivector(wordRecognizer,adsValidation))';
```

Define a fully connected network.

```
layers = [ ...
    featureInputLayer(size(ivectorsTrain,2),Normalization="none")
    fullyConnectedLayer(128)
    dropoutLayer(0.4)
    fullyConnectedLayer(256)
    dropoutLayer(0.4)
    fullyConnectedLayer(256)
    dropoutLayer(0.4)
    fullyConnectedLayer(128)
    dropoutLayer(0.4)
    fullyConnectedLayer(numel(unique(adsTrain.Labels)))
    softmaxLayer
    classificationLayer];
```

Define training parameters.

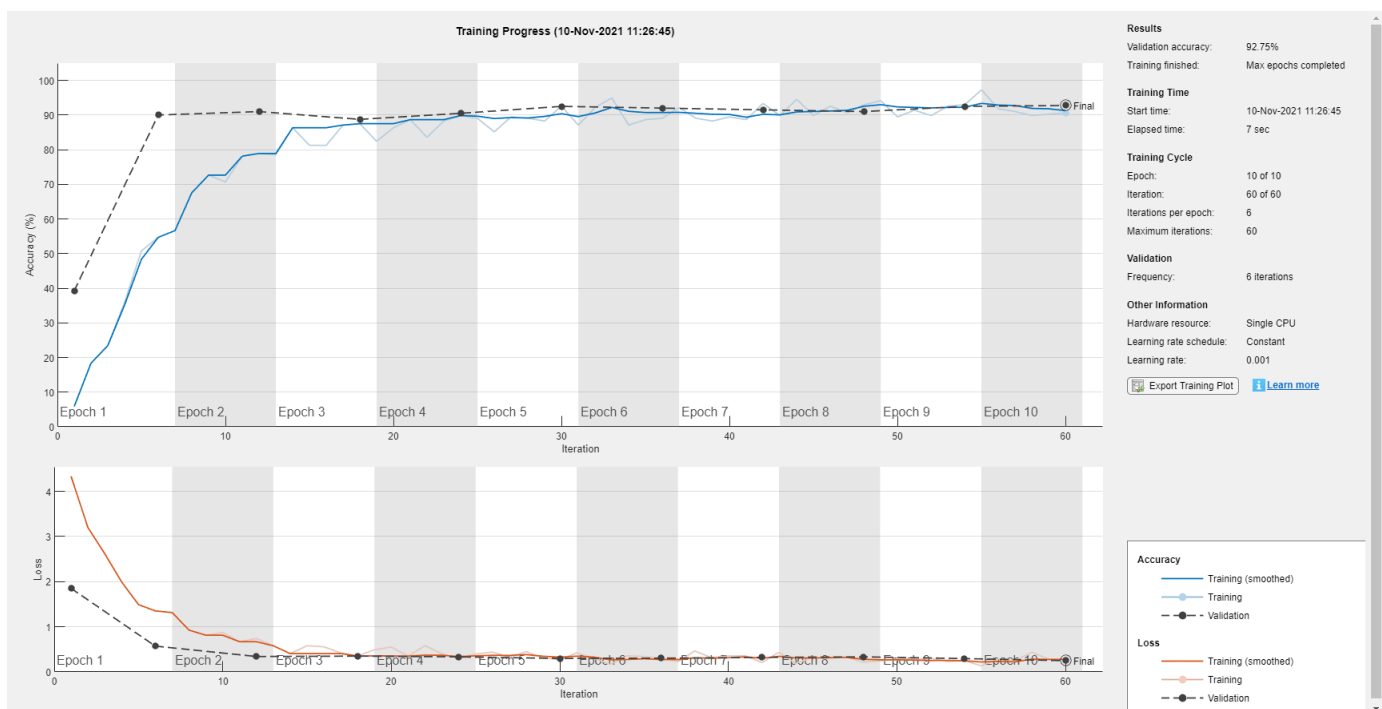
```

miniBatchSize = 256;
validationFrequency = floor(numel(adsTrain.Labels)/miniBatchSize);
options = trainingOptions("adam", ...
    MaxEpochs=10, ...
    MiniBatchSize=miniBatchSize, ...
    Plots="training-progress", ...
    Verbose=false, ...
    Shuffle="every-epoch", ...
    ValidationData={ivectorsValidation,adsValidation.Labels}, ...
    ValidationFrequency=validationFrequency);

```

Train the network.

```
net = trainNetwork(ivectorsTrain,adsTrain.Labels,layers,options);
```



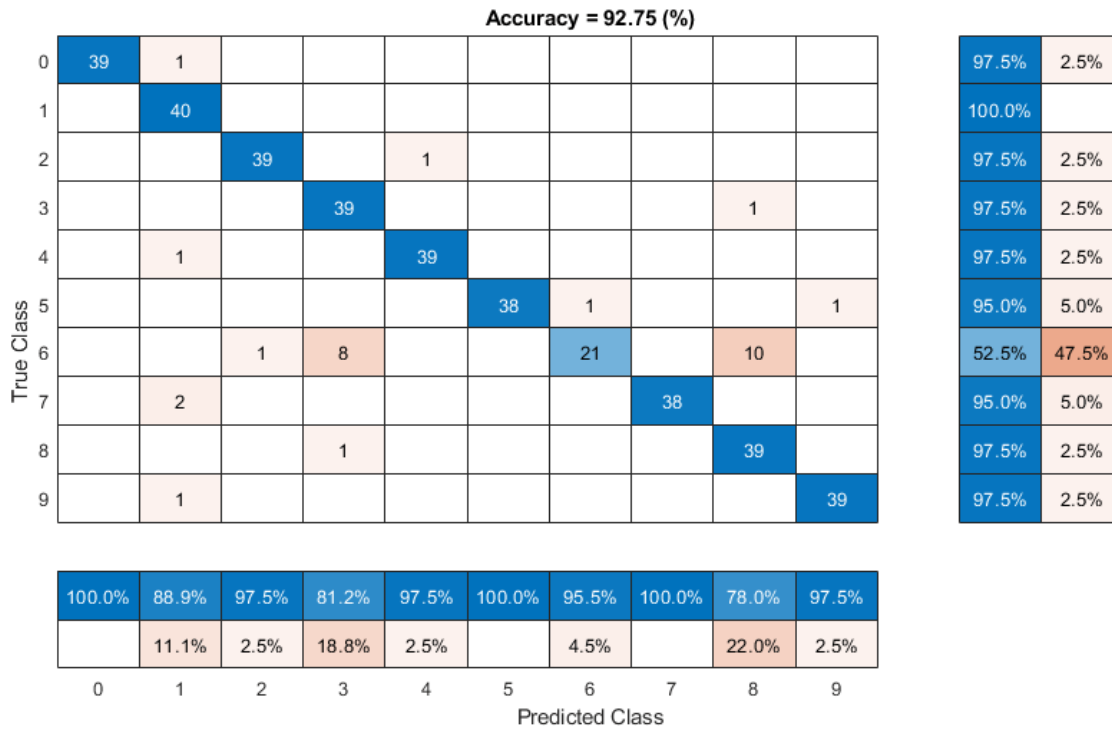
Evaluate the performance of the deep learning backend using a confusion chart.

```

predictedLabels = classify(net,ivectorsValidation);
trueLabels = adsValidation.Labels;

figure(Units="normalized",Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels,predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%)',100*mean(predictedLabels==trueLabels)))

```



Evaluate KNN Backend Performance

Train and evaluate i-vectors with a k -nearest neighbor (KNN) backend.

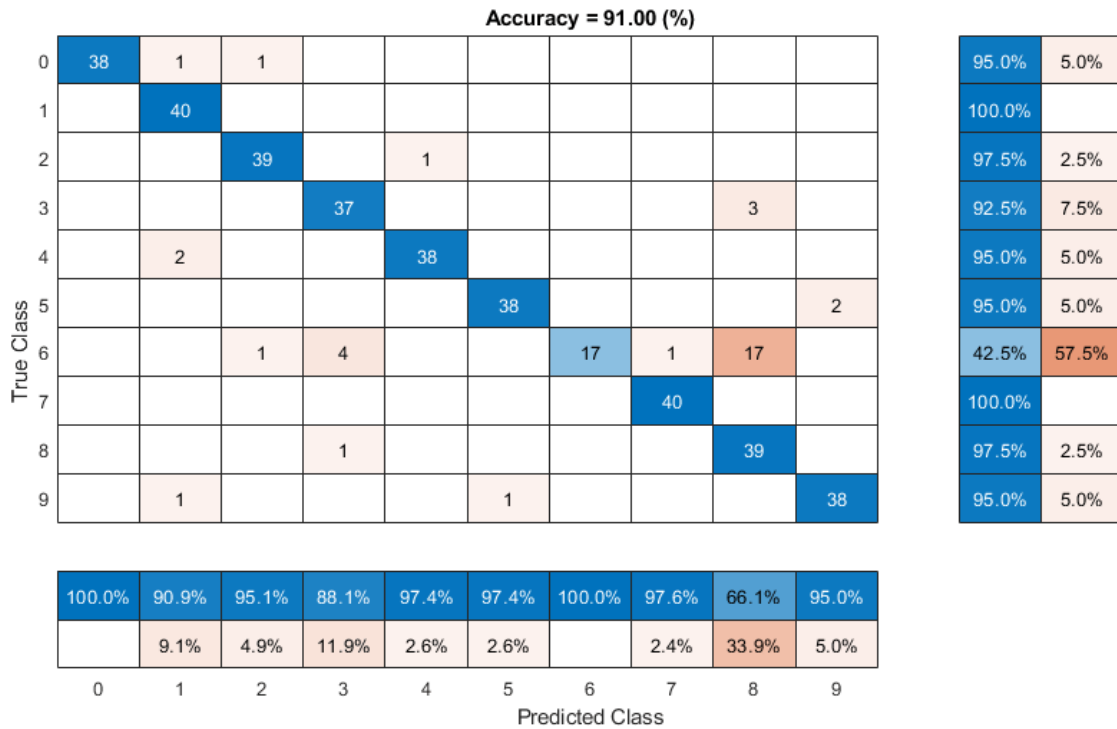
Use `fitcknn` to train a KNN model.

```
classificationKNN = fitcknn(...
    ivectorsTrain, ...
    adsTrain.Labels, ...
    Distance="Euclidean", ...
    Exponent=[], ...
    NumNeighbors=10, ...
    DistanceWeight="SquaredInverse", ...
    Standardize=true, ...
    ClassNames=unique(adsTrain.Labels));
```

Evaluate the KNN backend.

```
predictedLabels = predict(classificationKNN,ivectorsValidation);
trueLabels = adsValidation.Labels;

figure(Units="normalized",Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels,predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%)',100*mean(predictedLabels==trueLabels)))
```



References

[1] Jakobovski. "Jakobovski/Free-Spoken-Digit-Dataset." GitHub, May 30, 2019. <https://github.com/Jakobovski/free-spoken-digit-dataset>.

References

- [1] Reynolds, Douglas A., et al. "Speaker Verification Using Adapted Gaussian Mixture Models." *Digital Signal Processing*, vol. 10, no. 1-3, Jan. 2000, pp. 19-41. DOI.org (Crossref), doi:10.1006/dspr.1999.0361.
- [2] Kenny, Patrick, et al. "Joint Factor Analysis Versus Eigenchannels in Speaker Recognition." *IEEE Transactions on Audio, Speech and Language Processing*, vol. 15, no. 4, May 2007, pp. 1435-47. DOI.org (Crossref), doi:10.1109/TASL.2006.881693.
- [3] Kenny, P., et al. "A Study of Interspeaker Variability in Speaker Verification." *IEEE Transactions on Audio, Speech, and Language Processing*, vol. 16, no. 5, July 2008, pp. 980-88. DOI.org (Crossref), doi:10.1109/TASL.2008.925147.
- [4] Dehak, Najim, et al. "Front-End Factor Analysis for Speaker Verification." *IEEE Transactions on Audio, Speech, and Language Processing*, vol. 19, no. 4, May 2011, pp. 788-98. DOI.org (Crossref), doi:10.1109/TASL.2010.2064307.
- [5] Matejka, Pavel, Ondrej Glembek, Fabio Castaldo, M. J. Alam, Oldrich Plchot, Patrick Kenny, Lukas Burget, and Jan Cernocky. "Full-Covariance UBM and Heavy-Tailed PLDA in i-Vector Speaker Verification." *2011 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2011. <https://doi.org/10.1109/icassp.2011.5947436>.

- [6] Snyder, David, et al. "X-Vectors: Robust DNN Embeddings for Speaker Recognition." *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2018, pp. 5329–33. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2018.8461375.
- [7] Signal Processing and Speech Communication Laboratory. Accessed December 12, 2019. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>.
- [8] Variani, Ehsan, et al. "Deep Neural Networks for Small Footprint Text-Dependent Speaker Verification." *2014 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2014, pp. 4052–56. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2014.6854363.
- [9] Dehak, Najim, Réda Dehak, James R. Glass, Douglas A. Reynolds and Patrick Kenny. "Cosine Similarity Scoring without Score Normalization Techniques." *Odyssey* (2010).
- [10] Verma, Pulkit, and Pradip K. Das. "I-Vectors in Speech Processing Applications: A Survey." *International Journal of Speech Technology*, vol. 18, no. 4, Dec. 2015, pp. 529–46. *DOI.org (Crossref)*, doi:10.1007/s10772-015-9295-3.
- [11] D. García-Romero and C. Espy-Wilson, "Analysis of I-vector Length Normalization in Speaker Recognition Systems." *Interspeech*, 2011, pp. 249–252.
- [12] Kenny, Patrick. "Bayesian Speaker Verification with Heavy-Tailed Priors". *Odyssey 2010 - The Speaker and Language Recognition Workshop*, Brno, Czech Republic, 2010.
- [13] Sizov, Aleksandr, Kong Aik Lee, and Tomi Kinnunen. "Unifying Probabilistic Linear Discriminant Analysis Variants in Biometric Authentication." *Lecture Notes in Computer Science Structural, Syntactic, and Statistical Pattern Recognition*, 2014, 464–75. https://doi.org/10.1007/978-3-662-44415-3_47.
- [14] Rajan, Padmanabhan, Anton Afanasyev, Ville Hautamäki, and Tomi Kinnunen. "From Single to Multiple Enrollment I-Vectors: Practical PLDA Scoring Variants for Speaker Verification." *Digital Signal Processing* 31 (August), 2014, pp. 93–101. <https://doi.org/10.1016/j.dsp.2014.05.001>.

See Also

`audioDatastore` | `audioFeatureExtractor` | `audioDataAugmenter` | `speakerRecognition`

Topics

"i-vector Score Normalization"

"i-vector Score Calibration"

Introduced in R2021a

trainExtractor

Train i-vector extractor

Syntax

```
trainExtractor(ivs,data)
trainExtractor(ivs,data,Name=Value)
```

Description

`trainExtractor(ivs,data)` trains the `ivectorSystem` object `ivs` to extract i-vectors using training data.

`trainExtractor(ivs,data,Name=Value)` specifies options using one or more name-value arguments. For example, `trainExtractor(ivs,data,UBMNumComponents=A)` specifies the maximum number of Gaussian components used to train the universal background model (UBM).

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder,"SPEECH DATA","FEMALE","MIC"),fullfile(datasetFolder,
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

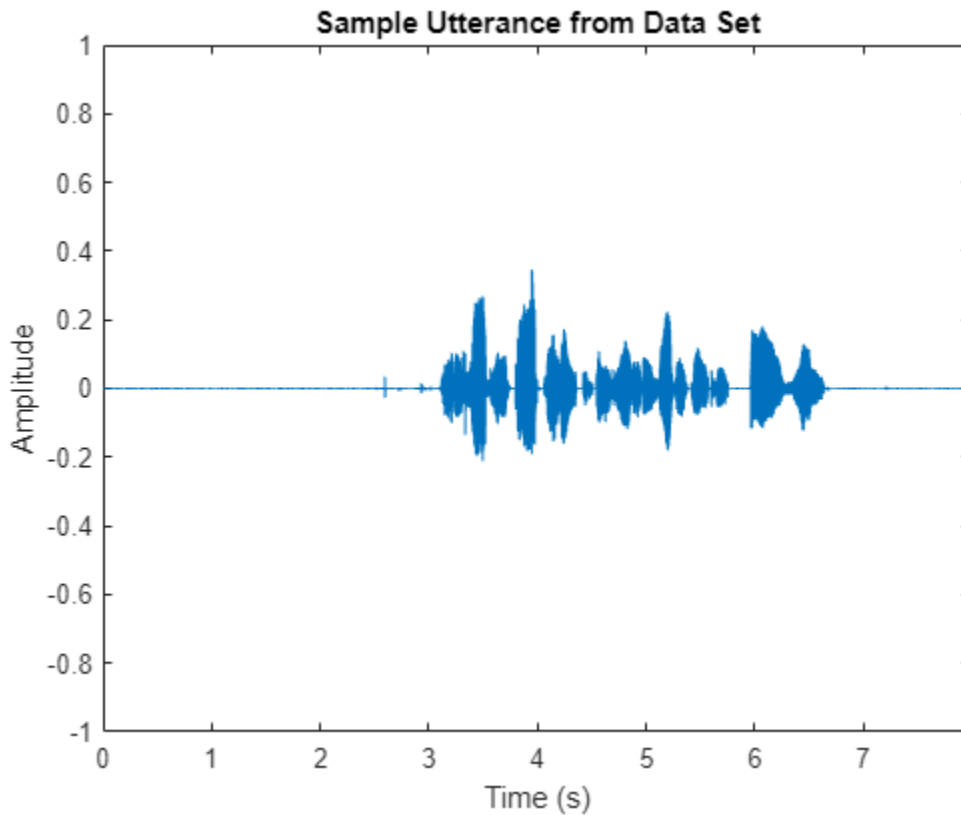
```
ads.Labels = extractBetween(ads.Files,"mic_","_");
countEachLabel(ads)
```

```
ans=20x2 table
    Label    Count
```

F01	236
F02	236
F03	236
F04	236
F05	236
F06	236
F07	236
F08	234
F09	236
F10	236
M01	236
M02	236
M03	236
M04	236
M05	236
M06	236
:	

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);  
fs = audioInfo.SampleRate;  
  
t = (0:size(audioIn,1)-1)/fs;  
sound(audioIn, fs)  
plot(t, audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis([0 t(end) -1 1])  
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  _____  _____
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```
M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236
```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 48000  
    DetectSpeech: 1  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```

To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
  Input feature vector length: 60
  Input data type: double
```

```
trainExtractor
  Train signals: 3774
  UBMNumComponents: 128
  UBMNumIterations: 5
  TVSRank: 64
  TVSNumIterations: 3
```

```
trainClassifier
  Train signals: 3774
  Train labels: F02 (236), F03 (236) ... and 14 more
  NumEigenvectors: 16
  PLDANumDimensions: 16
  PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          1
  F05      {16x1 double}          1
  M01      {16x1 double}          1
  M05      {16x1 double}          1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          3
  F05      {16x1 double}          3
  M01      {16x1 double}          3
  M05      {16x1 double}          3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

results

```

results = struct with fields:
    PLDA: [1000x3 table]
    CSS: [1000x3 table]

```

results.CSS

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  1.7736e-09         1         0
  1.8233e-09    0.99964         0
  1.8745e-09    0.99964         0
  1.927e-09     0.99964         0
  1.9811e-09    0.99964         0
  2.0366e-09    0.99964         0
  2.0937e-09    0.99964         0
  2.1524e-09    0.99964         0
  2.2128e-09    0.99964         0
  2.2748e-09    0.99964         0
  2.3386e-09    0.99964         0
  2.4042e-09    0.99964         0
  2.4716e-09    0.99964         0
  2.5409e-09    0.99964         0
  2.6122e-09    0.99964         0
  2.6854e-09    0.99964         0
  :

```

results.PLDA

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  4.7045e-34         1         0
  5.143e-34    0.99964         0
  5.6225e-34    0.99964         0
  6.1466e-34    0.99964         0
  6.7197e-34    0.99964         0
  7.3461e-34    0.99964         0
  8.0309e-34    0.99964         0
  8.7796e-34    0.99964         0
  9.5981e-34    0.99964         0
  1.0493e-33    0.99964         0
  1.1471e-33    0.99964         0

```

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

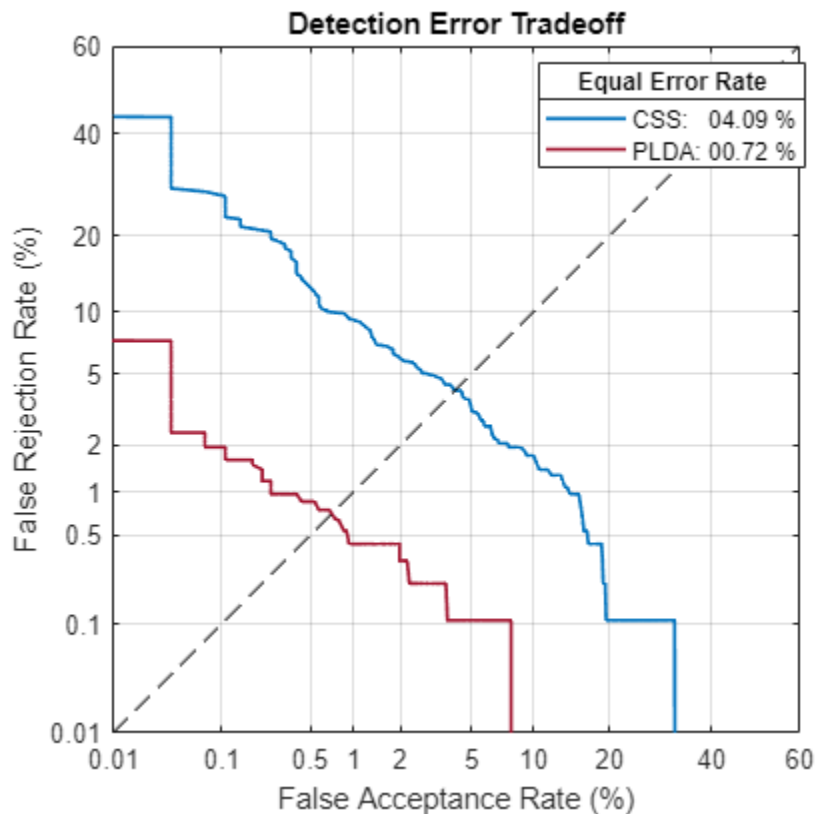
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

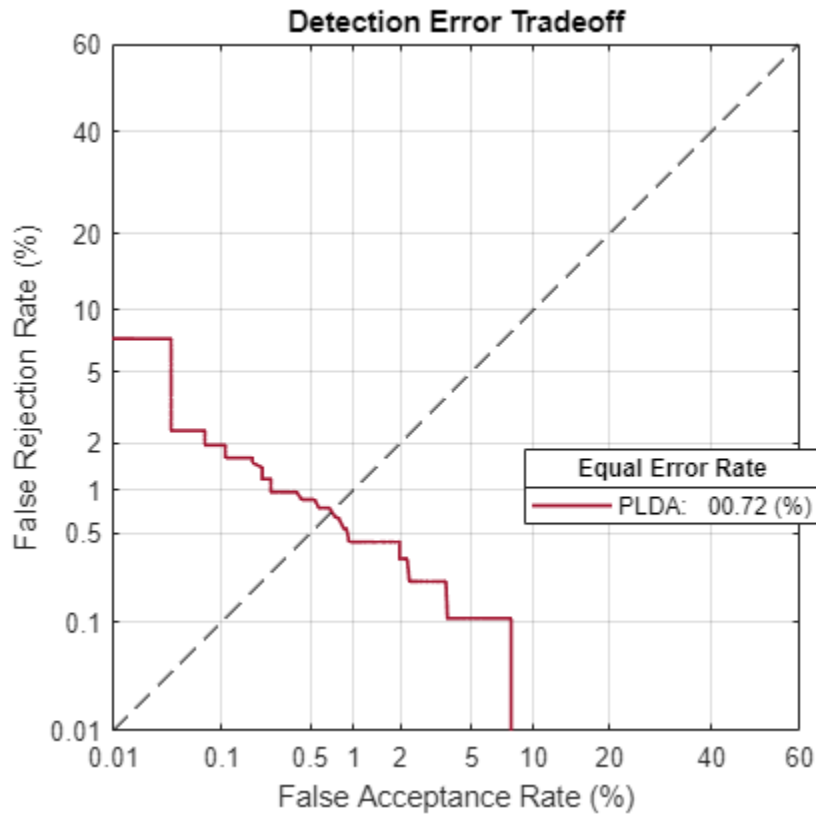
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

```
detectionErrorTradeoff(speakerVerification)
```



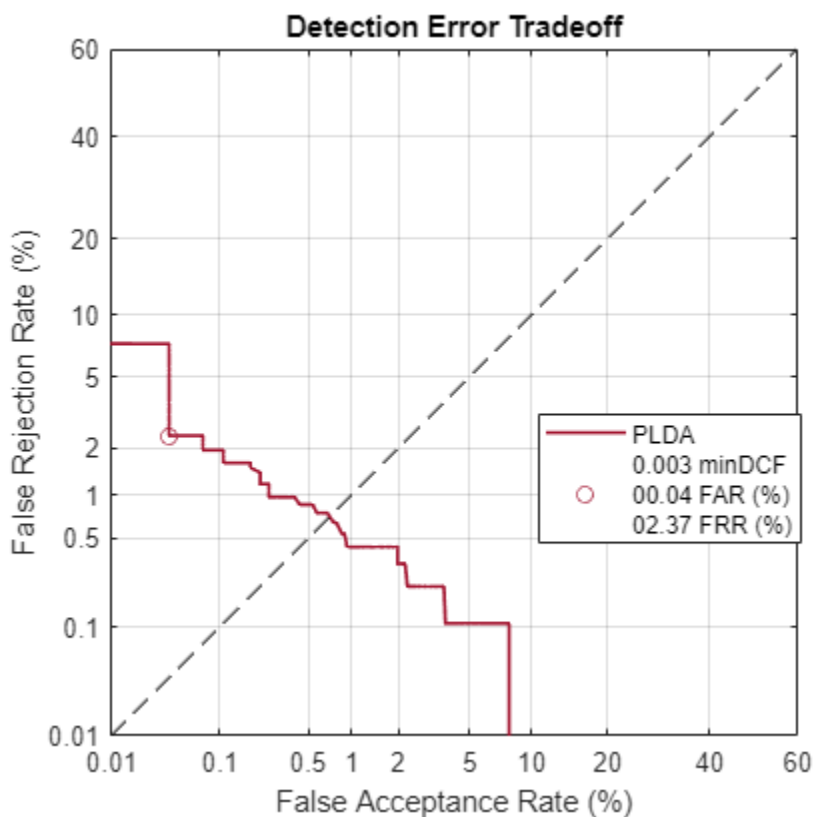
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```

    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker accepted.
Similarity score = 1.00

Call speaker verification again. This time, specify an incorrect speaker ID.

possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))

imposter = 1x1 cell array
    {'F01'}

[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker rejected.
Similarity score = 0.00

```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Training data for i-vector system

cell array | `audioDatastore` | `signalDatastore` | `TransformedDatastore`

Training data for an i-vector system, specified as a cell array or as an `audioDatastore`, `signalDatastore`, or `TransformedDatastore` object.

- If `InputType` is set to "audio" when the i-vector system is created, specify `data` as one of these:
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
 - An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.
 - A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to read from the transform datastore must be mono audio signals with underlying data type `single` or `double`.

- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
 - A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `trainExtractor(ivs,data,UBMNumIterations=B)`

UBMNumComponents — Maximum number of Gaussian components

32 (default) | positive integer

Maximum number of Gaussian components used to train the UBM, specified as a positive integer. The algorithm trims unused components determined during training to avoid numerical issues.

Example: `trainExtractor(ivs,data,UBMNumComponents=40)`

Data Types: `single` | `double`

UBMNumIterations — Number of expectation-maximization iterations

2 (default) | positive integer

Number of expectation-maximization iterations used to train the UBM, specified as a positive integer.

Example: `trainExtractor(ivs,data,UBMNumIterations=5)`

Data Types: `single` | `double`

TVSRank — Maximum rank of total variability space

16 (default) | positive integer

Maximum rank of the total variability space (TVS) trained to extract i-vectors, specified as a positive integer.

Example: `trainExtractor(ivs,data,TVSRank=24)`

Data Types: `single` | `double`

TVSNumIterations — Number of expectation-maximization iterations

3 (default) | positive integer

Number of expectation-maximization iterations used to train the TVS, specified as a positive integer.

Example: `trainExtractor(ivs,data,TVSNumIterations=5)`

Data Types: `single` | `double`

ExecutionEnvironment — Hardware resource for execution

`"auto"` (default) | `"cpu"` | `"gpu"` | `"multi-gpu"` | `"parallel"`

Hardware resource for execution, specified as one of these:

- `"auto"` — Use the GPU if it is available. Otherwise, use the CPU.
- `"cpu"` — Use the CPU.
- `"gpu"` — Use the GPU. This option requires Parallel Computing Toolbox.
- `"multi-gpu"` — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- `"parallel"` — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: `char` | `string`

DispatchInBackground — Option to use prefetch queuing

`false` (default) | `true`

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: `logical`

See Also

`trainClassifier` | `calibrate` | `enroll` | `unenroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

trainClassifier

Train i-vector classifier

Syntax

```
trainClassifier(ivs,data,labels)
trainClassifier(ivs,data,labels,Name=Value)
```

Description

`trainClassifier(ivs,data,labels)` trains the `ivectorSystem` object `ivs` to classify i-vectors as `labels`.

`trainClassifier(ivs,data,labels,Name=Value)` specifies options using one or more name-value arguments. For example, `trainClassifier(ivs,data,labels,NumEigenvectors=A)` specifies the number of eigenvectors used to perform dimensionality reduction.

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder,"SPEECH DATA","FEMALE","MIC"),fullfile(datasetFolder,
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

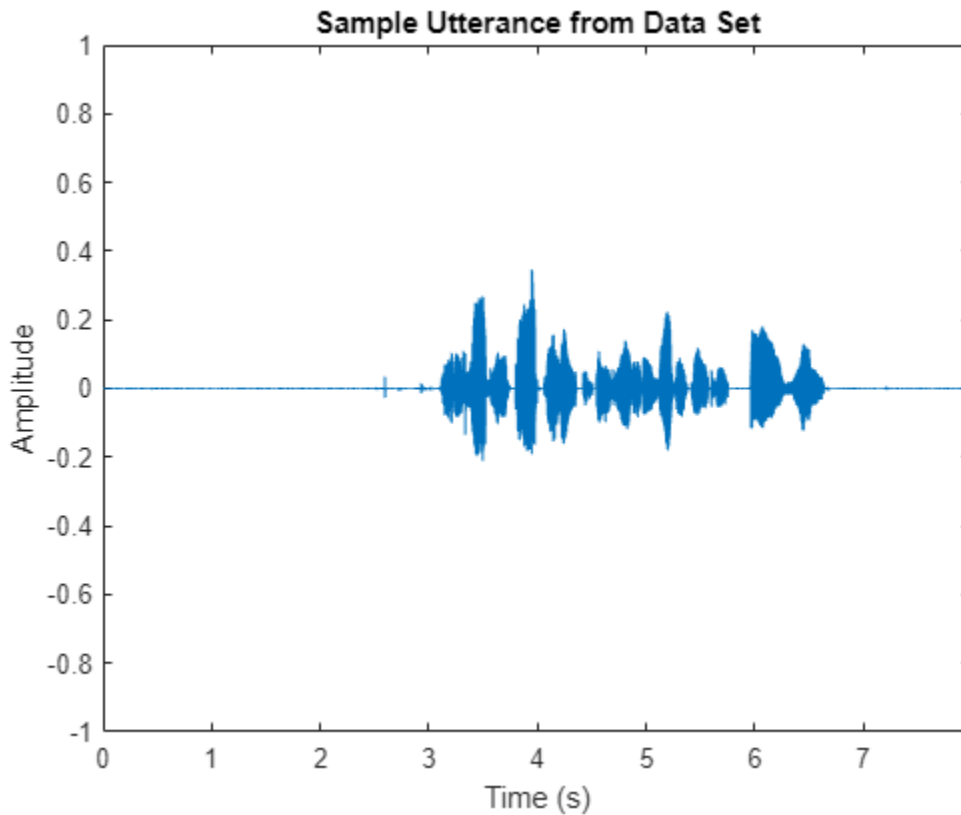
```
ads.Labels = extractBetween(ads.Files,"mic_","_");
countEachLabel(ads)
```

```
ans=20x2 table
    Label    Count
```

F01	236
F02	236
F03	236
F04	236
F05	236
F06	236
F07	236
F08	234
F09	236
F10	236
M01	236
M02	236
M03	236
M04	236
M05	236
M06	236
:	

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);  
fs = audioInfo.SampleRate;  
  
t = (0:size(audioIn,1)-1)/fs;  
sound(audioIn, fs)  
plot(t, audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis([0 t(end) -1 1])  
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  _____  _____
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```



```

M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236

```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =
  ivectorSystem with properties:
```

```

    InputType: 'audio'
    SampleRate: 48000
    DetectSpeech: 1
    Verbose: 1
    EnrolledLabels: [0x2 table]

```

To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
Input feature vector length: 60
Input data type: double
```

```
trainExtractor
Train signals: 3774
UBMNumComponents: 128
UBMNumIterations: 5
TVSRank: 64
TVSNumIterations: 3
```

```
trainClassifier
Train signals: 3774
Train labels: F02 (236), F03 (236) ... and 14 more
NumEigenvectors: 16
PLDANumDimensions: 16
PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
F01      {16x1 double}      1
F05      {16x1 double}      1
M01      {16x1 double}      1
M05      {16x1 double}      1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
F01      {16x1 double}      3
F05      {16x1 double}      3
M01      {16x1 double}      3
M05      {16x1 double}      3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

```
results
```

```

results = struct with fields:
  PLDA: [1000x3 table]
  CSS: [1000x3 table]

```

```
results.CSS
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
1.7736e-09	1	0
1.8233e-09	0.99964	0
1.8745e-09	0.99964	0
1.927e-09	0.99964	0
1.9811e-09	0.99964	0
2.0366e-09	0.99964	0
2.0937e-09	0.99964	0
2.1524e-09	0.99964	0
2.2128e-09	0.99964	0
2.2748e-09	0.99964	0
2.3386e-09	0.99964	0
2.4042e-09	0.99964	0
2.4716e-09	0.99964	0
2.5409e-09	0.99964	0
2.6122e-09	0.99964	0
2.6854e-09	0.99964	0
⋮		

```
results.PLDA
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
4.7045e-34	1	0
5.143e-34	0.99964	0
5.6225e-34	0.99964	0
6.1466e-34	0.99964	0
6.7197e-34	0.99964	0
7.3461e-34	0.99964	0
8.0309e-34	0.99964	0
8.7796e-34	0.99964	0
9.5981e-34	0.99964	0
1.0493e-33	0.99964	0
1.1471e-33	0.99964	0

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

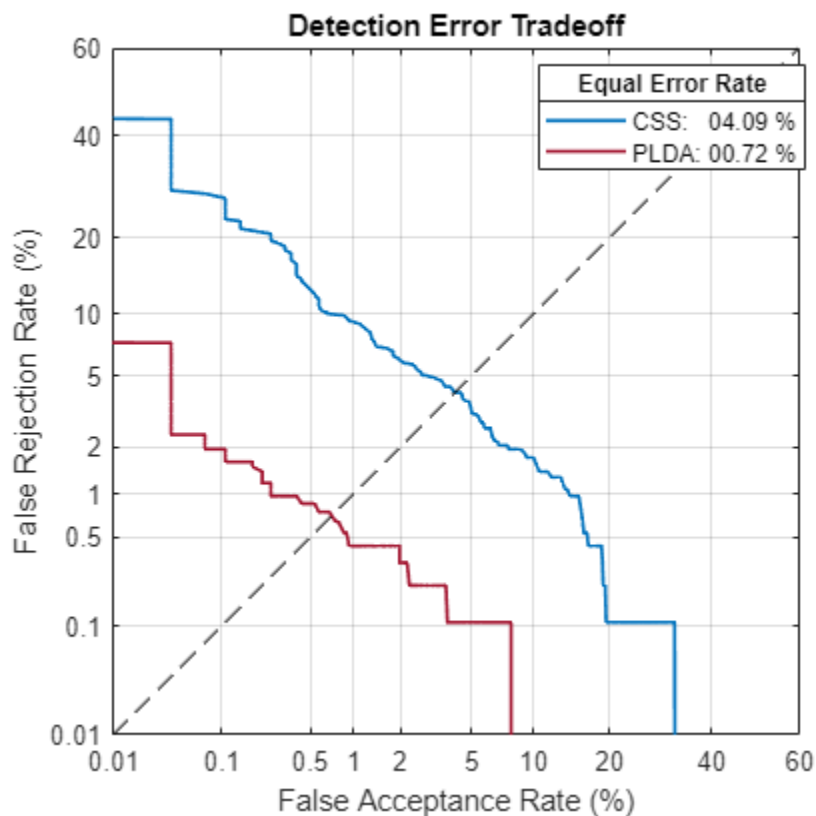
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

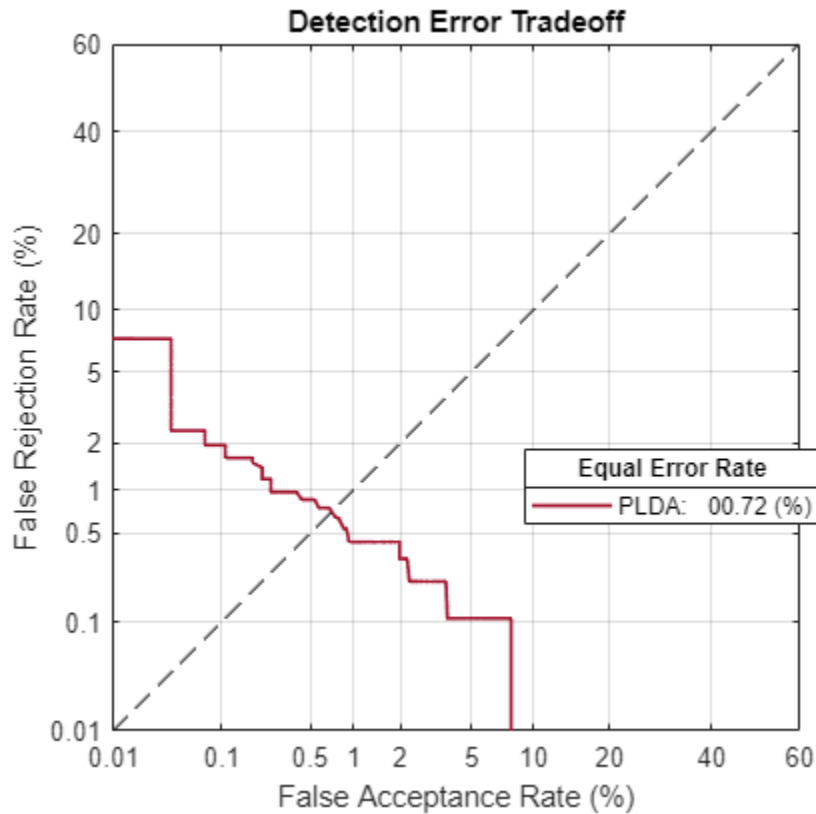
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

`detectionErrorTradeoff(speakerVerification)`



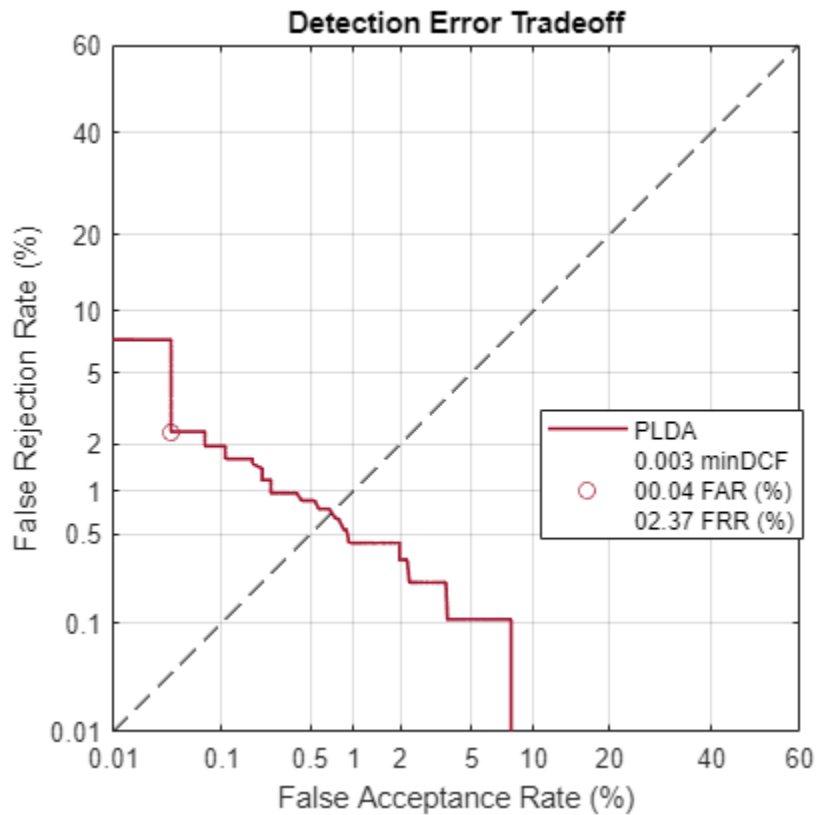
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```
    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker accepted.
Similarity score = 1.00
```

Call speaker verification again. This time, specify an incorrect speaker ID.

```
possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))
```

```
imposter = 1x1 cell array
    {'F01'}
```

```
[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker rejected.
Similarity score = 0.00
```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Training data for i-vector system

cell array | `audioDatastore` | `signalDatastore` | `TransformedDatastore`

Training data for an i-vector system, specified as a cell array or as an `audioDatastore`, `signalDatastore`, or `TransformedDatastore` object.

- If `InputType` is set to "audio" when the i-vector system is created, specify `data` as one of these:
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
 - An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.
 - A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to read from the transform datastore must be mono audio signals with underlying data type `single` or `double`.

- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
 - A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Labels — Classification labels

categorical array | cell array | string array

Classification labels used by the i-vector system, specified as one of the following:

- A categorical array
- A cell array of character vectors
- A string array

Note The number of audio signals in `data` must match the number of `labels`.

Data Types: `categorical` | `cell` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `trainClassifier(ivs,data,labels,PLDANumIterations=D)`

NumEigenvectors — Number of eigenvectors

16 (default) | positive integer

The number of eigenvectors used to perform dimensionality reduction, specified as a positive integer.

Example: `trainClassifier(ivs,data,labels,NumEigenvectors=18)`

Data Types: `single` | `double`

PLDANumIterations — Number of expectation-maximization iterations

5 (default) | positive integer

The number of expectation-maximization iterations used to train the probabilistic linear discriminant analysis (PLDA) model, specified as a positive integer.

Example: `trainClassifier(ivs,data,labels,PLDANumIterations=3)`

Data Types: `single` | `double`

PLDANumDimensions — Maximum number of PLDA dimensions

16 (default) | positive integer

The maximum number of dimensions for the PLDA model, specified as a positive integer.

Example: `trainClassifier(ivs,data,labels,PLDANumDimensions=10)`

Note `PLDANumDimensions` must be less than or equal to the rank of the total variability matrix.

Data Types: `single` | `double`

ExecutionEnvironment — Hardware resource for execution

"auto" (default) | "cpu" | "gpu" | "multi-gpu" | "parallel"

Hardware resource for execution, specified as one of these:

- "auto" — Use the GPU if it is available. Otherwise, use the CPU.
- "cpu" — Use the CPU.
- "gpu" — Use the GPU. This option requires Parallel Computing Toolbox.
- "multi-gpu" — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- "parallel" — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: `char` | `string`

DispatchInBackground — Option to use prefetch queuing

false (default) | true

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: `logical`

See Also

`trainExtractor` | `calibrate` | `enroll` | `unenroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

calibrate

Train i-vector system calibrator

Syntax

```
calibrate(ivs,data,labels)
calibrate(ivs,data,labels,Name=Value)
```

Description

`calibrate(ivs,data,labels)` calibrates scores output from by i-vector system `ivs`. The calibration scheme is determined using the calibration data and associated labels. A properly calibrated system outputs scores that can be interpreted as confidence in a positive decision.

`calibrate(ivs,data,labels,Name=Value)` specifies additional options using name-value arguments. You can choose the hardware resource to extract i-vectors and whether to use prefetch queuing when reading from a datastore.

Examples

Train Acoustic Fault Recognition System

Download and unzip the air compressor data set [1] on page 4-0 . This data set consists of recordings from air compressors in a healthy state or one of seven faulty states.

```
loc = matlab.internal.examples.downloadSupportFile("audio", ...
    "AirCompressorDataset/AirCompressorDataset.zip");
unzip(loc,pwd)
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets.

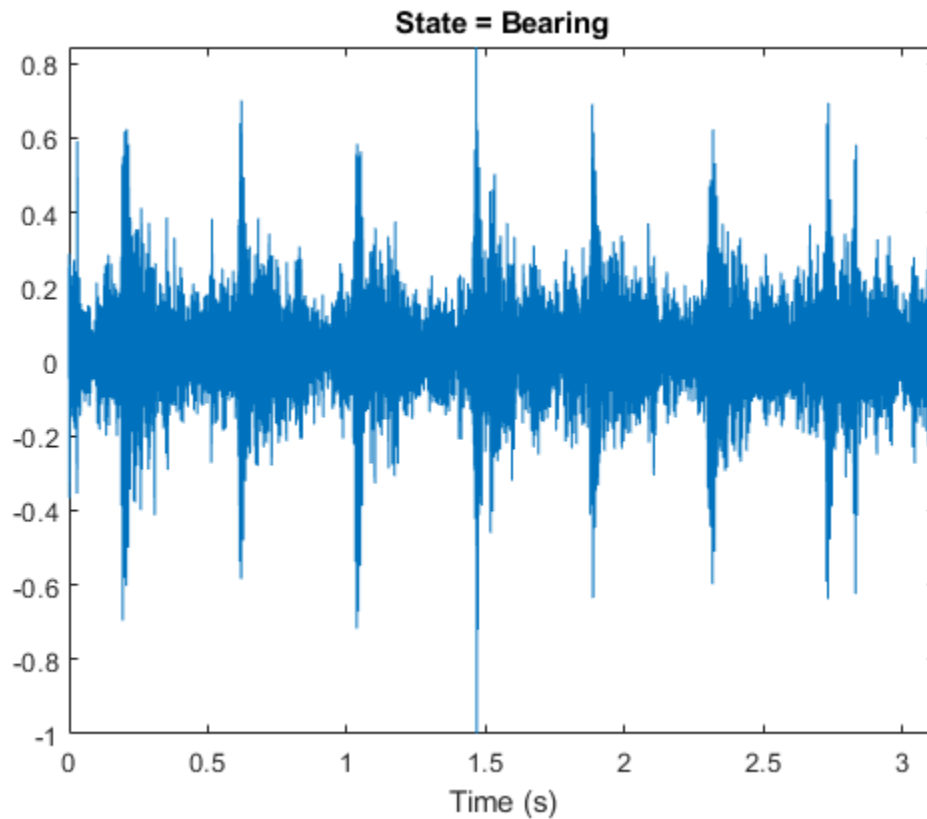
```
ads = audioDatastore(pwd,IncludeSubfolders=true,LabelSource="foldernames");
[adsTrain,adsTest] = splitEachLabel(ads,0.8,0.2);
```

Read an audio file from the datastore and save the sample rate. Listen to the audio signal and plot the signal in the time domain.

```
[x,fileInfo] = read(adsTrain);
fs = fileInfo.SampleRate;

sound(x,fs)

t = (0:size(x,1)-1)/fs;
plot(t,x)
xlabel("Time (s)")
title("State = " + string(fileInfo.Label))
axis tight
```



Create an i-vector system with DetectSpeech set to false. Turn off the verbose behavior.

```
faultRecognizer = ivectorSystem(SampleRate=fs, DetectSpeech=false, ...
    Verbose=false)
```

```
faultRecognizer =
  ivectorSystem with properties:
    InputType: 'audio'
    SampleRate: 16000
    DetectSpeech: 0
    Verbose: 0
    EnrolledLabels: [0x2 table]
```

Train the i-vector extractor and the i-vector classifier using the training datastore.

```
trainExtractor(faultRecognizer, adsTrain, ...
    UBMNumComponents=80, ...
    UBMNumIterations=3, ...
    ...
    TVSRank=40, ...
    TVSNumIterations=3)

trainClassifier(faultRecognizer, adsTrain, adsTrain.Labels, ...
    NumEigenvectors=7, ...
    ...)
```

```

PLDANumDimensions=32, ...
PLDANumIterations=5)

```

Calibrate the scores output by `faultRecognizer` so they can be interpreted as a measure of confidence in a positive decision. Turn the verbose behavior back on. Enroll all of the labels from the training set.

```
calibrate(faultRecognizer,adsTrain,adsTrain.Labels)
```

```
faultRecognizer.Verbose = true;
```

```
enroll(faultRecognizer,adsTrain,adsTrain.Labels)
```

```

Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.

```

Use the read-only property `EnrolledLabels` to view the enrolled labels and the corresponding i-vector templates.

```
faultRecognizer.EnrolledLabels
```

```
ans=8x2 table
```

	ivector	NumSamples
Bearing	{7x1 double}	180
Flywheel	{7x1 double}	180
Healthy	{7x1 double}	180
LIV	{7x1 double}	180
LOV	{7x1 double}	180
NRV	{7x1 double}	180
Piston	{7x1 double}	180
Riderbelt	{7x1 double}	180

Use the `identify` function with the PLDA scorer to predict the condition of machines in the test set. The `identify` function returns a table of possible labels sorted in descending order of confidence.

```
[audioIn,audioInfo] = read(adsTest);
trueLabel = audioInfo.Label
```

```

trueLabel = categorical
    Bearing

```

```
predictedLabels = identify(faultRecognizer,audioIn,"plda")
```

```
predictedLabels=8x2 table
```

Label	Score
Bearing	0.99997
Flywheel	2.265e-05
Piston	8.6076e-08
LIV	1.4237e-15
NRV	4.5529e-16
Riderbelt	3.7359e-16
LOV	6.3025e-19

```
Healthy      4.2094e-30
```

By default, the `identify` function returns all possible candidate labels and their corresponding scores. Use `NumCandidates` to reduce the number of candidates returned.

```
results = identify(faultRecognizer, audioIn, "plda", NumCandidates=3)
```

```
results=3x2 table
      Label      Score
-----
Bearing      0.99997
Flywheel     2.265e-05
Piston       8.6076e-08
```

References

[1] Verma, Nishchal K., et al. "Intelligent Condition Based Monitoring Using Acoustic Signals for Air Compressors." *IEEE Transactions on Reliability*, vol. 65, no. 1, Mar. 2016, pp. 291-309. DOI.org (Crossref), doi:10.1109/TR.2015.2459684.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Training data for i-vector system

cell array | `audioDatastore` | `signalDatastore` | `TransformedDatastore`

Training data for an i-vector system, specified as a cell array or as an `audioDatastore`, `signalDatastore`, or `TransformedDatastore` object.

- If `InputType` is set to "audio" when the i-vector system is created, specify `data` as one of these:
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
 - An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.
 - A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to `read` from the transform datastore must be mono audio signals with underlying data type `single` or `double`.
- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.

- A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
- A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Labels — Classification labels

`character vector` | `string` | `cell array` | `string array` | `categorical array`

Classification labels used by an i-vector system, specified as one of these:

- A categorical array
- A cell array of character vectors
- A string array

Data Types: `categorical` | `cell` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, . . . , NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `calibrate(ivs,data,labels,DispatchInBackground=true)`

ExecutionEnvironment — Hardware resource for execution

`"auto"` (default) | `"cpu"` | `"gpu"` | `"multi-gpu"` | `"parallel"`

Hardware resource for execution, specified as one of these:

- `"auto"` — Use the GPU if it is available. Otherwise, use the CPU.
- `"cpu"` — Use the CPU.
- `"gpu"` — Use the GPU. This option requires Parallel Computing Toolbox.
- `"multi-gpu"` — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- `"parallel"` — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: `char` | `string`

DispatchInBackground — Option to use prefetch queuing

`false` (default) | `true`

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: `logical`

See Also

`trainExtractor` | `trainClassifier` | `enroll` | `unenroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2022a

enroll

Enroll labels

Syntax

```
enroll(ivs,data,labels)
enroll(ivs,data,labels,Name,Value)
```

Description

`enroll(ivs,data,labels)` enrolls the data and corresponding labels into the i-vector system `ivs`.

`enroll(ivs,data,labels,Name,Value)` specifies additional options using name-value arguments. You can choose the hardware resource to extract i-vectors and whether to use prefetch queuing when reading from a datastore.

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder,"SPEECH DATA","FEMALE","MIC"),fullfile(datasetFolder,
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

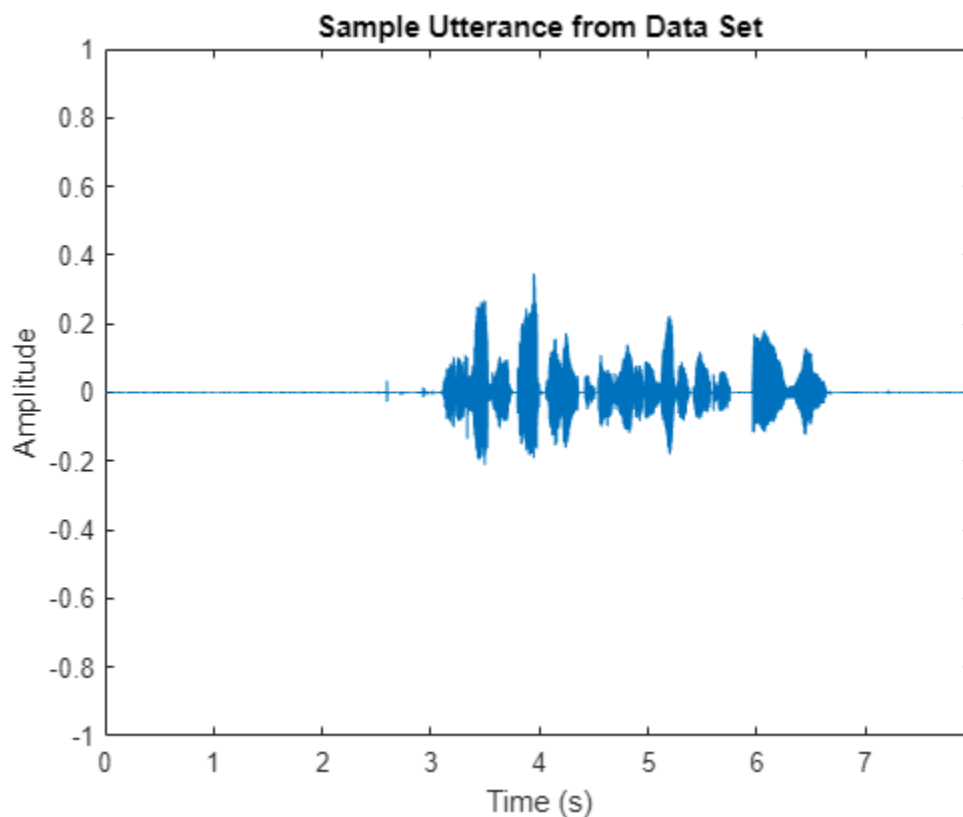
```
ads.Labels = extractBetween(ads.Files,"mic_","_");
countEachLabel(ads)
```

```
ans=20x2 table
    Label    Count
```

F01	236
F02	236
F03	236
F04	236
F05	236
F06	236
F07	236
F08	234
F09	236
F10	236
M01	236
M02	236
M03	236
M04	236
M05	236
M06	236
:	

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);  
fs = audioInfo.SampleRate;  
  
t = (0:size(audioIn,1)-1)/fs;  
sound(audioIn, fs)  
plot(t, audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis([0 t(end) -1 1])  
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  -----
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```
M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236
```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 48000  
    DetectSpeech: 1  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```

To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
  Input feature vector length: 60
  Input data type: double
```

```
trainExtractor
  Train signals: 3774
  UBMNumComponents: 128
  UBMNumIterations: 5
  TVSRank: 64
  TVSNumIterations: 3
```

```
trainClassifier
  Train signals: 3774
  Train labels: F02 (236), F03 (236) ... and 14 more
  NumEigenvectors: 16
  PLDANumDimensions: 16
  PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          1
  F05      {16x1 double}          1
  M01      {16x1 double}          1
  M05      {16x1 double}          1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          3
  F05      {16x1 double}          3
  M01      {16x1 double}          3
  M05      {16x1 double}          3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

results

```

results = struct with fields:
    PLDA: [1000x3 table]
    CSS: [1000x3 table]

```

results.CSS

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  1.7736e-09         1         0
  1.8233e-09    0.99964         0
  1.8745e-09    0.99964         0
  1.927e-09     0.99964         0
  1.9811e-09    0.99964         0
  2.0366e-09    0.99964         0
  2.0937e-09    0.99964         0
  2.1524e-09    0.99964         0
  2.2128e-09    0.99964         0
  2.2748e-09    0.99964         0
  2.3386e-09    0.99964         0
  2.4042e-09    0.99964         0
  2.4716e-09    0.99964         0
  2.5409e-09    0.99964         0
  2.6122e-09    0.99964         0
  2.6854e-09    0.99964         0
  :

```

results.PLDA

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  4.7045e-34         1         0
  5.143e-34    0.99964         0
  5.6225e-34    0.99964         0
  6.1466e-34    0.99964         0
  6.7197e-34    0.99964         0
  7.3461e-34    0.99964         0
  8.0309e-34    0.99964         0
  8.7796e-34    0.99964         0
  9.5981e-34    0.99964         0
  1.0493e-33    0.99964         0
  1.1471e-33    0.99964         0

```

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

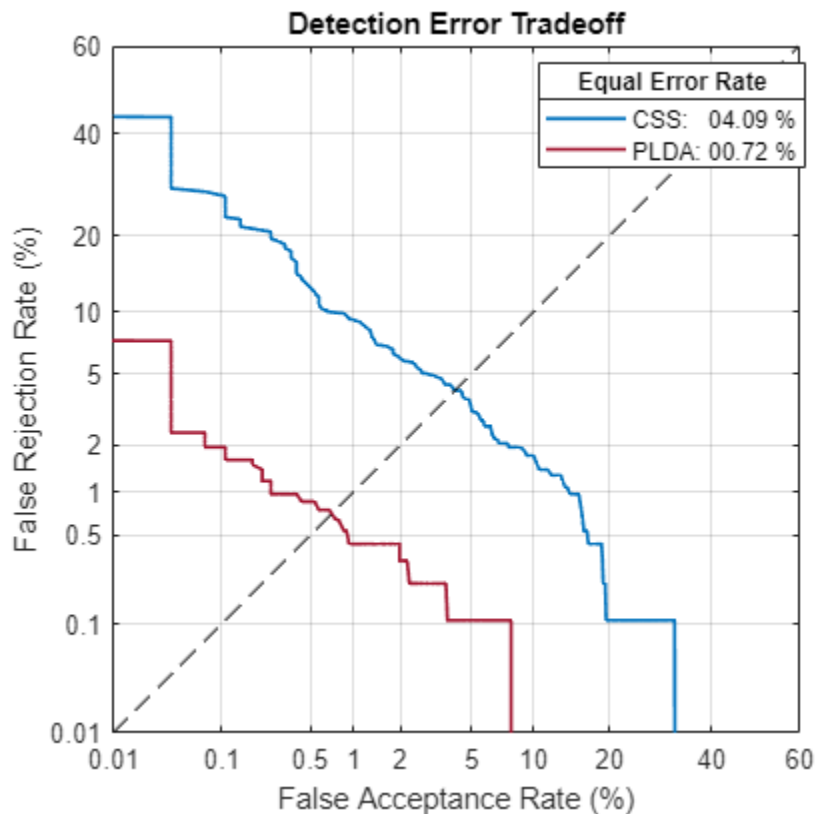
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

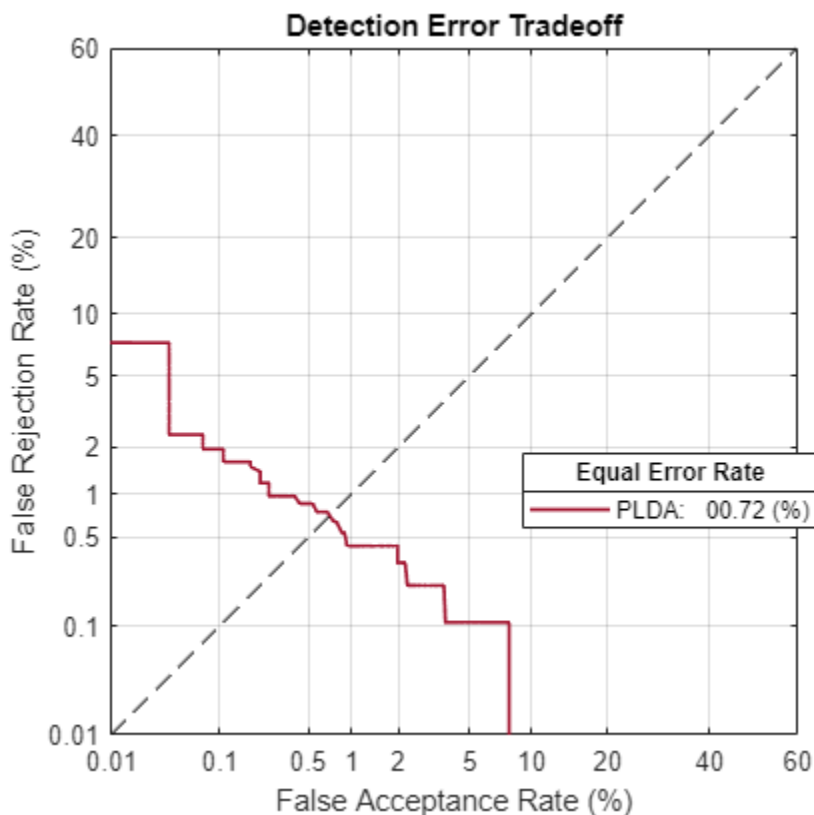
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

```
detectionErrorTradeoff(speakerVerification)
```



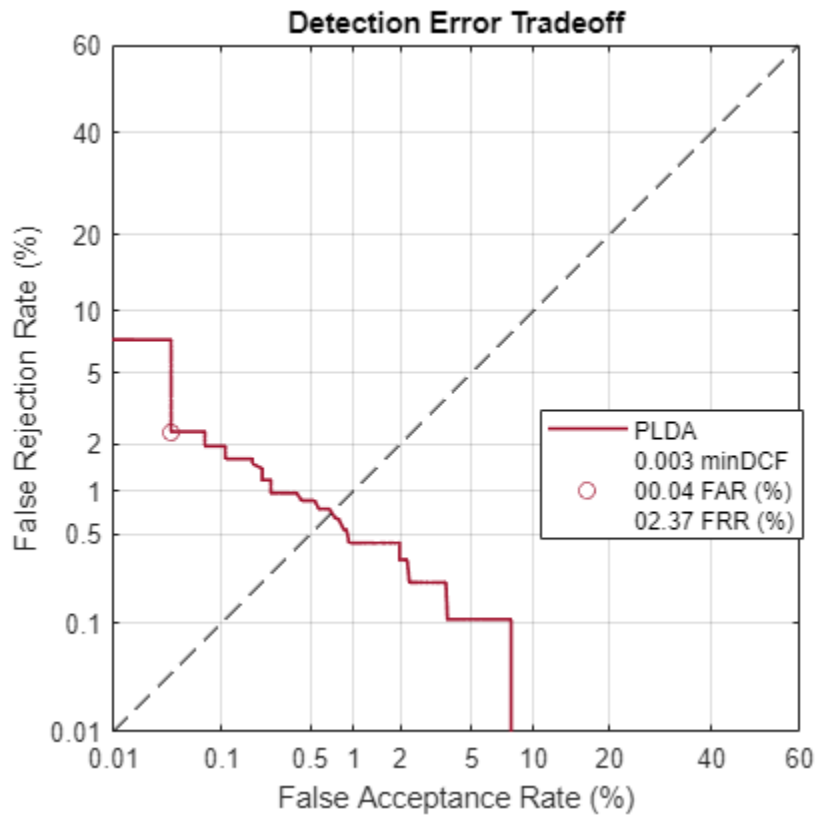
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```

    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

```

```

Success!
Speaker accepted.
Similarity score = 1.00

```

Call speaker verification again. This time, specify an incorrect speaker ID.

```

possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))

imposter = 1x1 cell array
    {'F01'}

[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

```

```

Success!
Speaker rejected.
Similarity score = 0.00

```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Labeled enrollment data

column vector | cell array | `audioDatastore` | `signalDatastore` | `TransformedDatastore`

Labeled enrollment data, specified as a cell array or as an `audioDatastore`, `signalDatastore`, or `TransformedDatastore` object.

- If `InputType` is set to "audio" when the i-vector system is created, specify `data` as one of these:
 - A column vector with underlying type `single` or `double`.
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
 - An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.

- A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to `read` from the transform datastore must be mono audio signals with underlying data type `single` or `double`.
- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
 - A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Labels — Classification labels

character vector | string | cell array | string array | categorical array

Classification labels used by an i-vector system, specified as one of these:

- A categorical array
- A cell array of character vectors
- A string array

Data Types: `categorical` | `cell` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose Name in quotes.

Example: `enroll(ivs,data,labels,DispatchInBackground=true)`

ExecutionEnvironment — Hardware resource for execution

"auto" (default) | "cpu" | "gpu" | "multi-gpu" | "parallel"

Hardware resource for execution, specified as one of these:

- "auto" — Use the GPU if it is available. Otherwise, use the CPU.
- "cpu" — Use the CPU.
- "gpu" — Use the GPU. This option requires Parallel Computing Toolbox.
- "multi-gpu" — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- "parallel" — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool

does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: `char` | `string`

DispatchInBackground — Option to use prefetch queuing

`false` (default) | `true`

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: `logical`

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `unenroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

unenroll

Unenroll labels

Syntax

```
unenroll(ivs)
unenroll(ivs,labels)
```

Description

`unenroll(ivs)` unenrolls all labels and corresponding i-vectors from the i-vector system `ivs`.

`unenroll(ivs,labels)` unenrolls the specified labels and corresponding i-vectors from the i-vector system `ivs`.

Examples

Train Speech Emotion Recognition System

Download the Berlin Database of Emotional Speech [1] on page 4-0 . The database contains 535 utterances spoken by 10 actors intended to convey one of the following emotions: anger, boredom, disgust, anxiety/fear, happiness, sadness, or neutral. The emotions are text independent.

```
url = "http://emodb.bilderbar.info/download/download.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"Emo-DB");

if ~exist(datasetFolder,"dir")
    disp("Downloading Emo-DB (40.5 MB) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` that points to the audio files.

```
ads = audioDatastore(fullfile(datasetFolder,"wav"));
```

The file names are codes indicating the speaker id, text spoken, emotion, and version. The website contains a key for interpreting the code and additional information about the speakers such as gender and age. Create a table with the variables `Speaker` and `Emotion`. Decode the file names into the table.

```
filepaths = ads.Files;
emotionCodes = cellfun(@(x)x(end-5),filepaths,"UniformOutput",false);
emotions = replace(emotionCodes,{'W','L','E','A','F','T','N'}, ...
    {'Anger','Boredom','Disgust','Anxiety','Happiness','Sadness','Neutral'});

speakerCodes = cellfun(@(x)x(end-10:end-9),filepaths,"UniformOutput",false);
labelTable = table(categorical(speakerCodes),categorical(emotions),VariableNames=["Speaker","Emotion"]);
summary(labelTable)
```

Variables:

Speaker: 535×1 categorical

Values:

03	49
08	58
09	43
10	38
11	55
12	35
13	61
14	69
15	56
16	71

Emotion: 535×1 categorical

Values:

Anger	127
Anxiety	69
Boredom	81
Disgust	46
Happiness	71
Neutral	79
Sadness	62

labelTable is in the same order as the files in audioDatastore. Set the Labels property of the audioDatastore to labelTable.

```
ads.Labels = labelTable;
```

Read a signal from the datastore and listen to it. Display the speaker ID and emotion of the audio signal.

```
[audioIn, audioInfo] = read(ads);
fs = audioInfo.SampleRate;
sound(audioIn, fs)
audioInfo.Label
```

```
ans=1×2 table
  Speaker      Emotion
  _____  _____
      03      Happiness
```

Split the datastore into a training set and a test set. Assign two speakers to the test set and the remaining to the training set.

```
testSpeakerIdx = ads.Labels.Speaker=="12" | ads.Labels.Speaker=="13";
adsTrain = subset(ads, ~testSpeakerIdx);
adsTest = subset(ads, testSpeakerIdx);
```

Read all the training and testing audio data into cell arrays. If your data can fit in memory, training is usually faster to input cell arrays to an i-vector system rather than datastores.





```
trainSet = readall(adsTrain);
trainLabels = adsTrain.Labels.Emotion;
```

```
testSet = readall(adsTest);
testLabels = adsTest.Labels.Emotion;
```

Create an i-vector system that does not apply speech detection. When `DetectSpeech` is set to `true` (the default), only regions of detected speech are used to train the i-vector system. When `DetectSpeech` is set to `false`, the entire input audio is used to train the i-vector system. The usefulness of applying speech detection depends on the data input to the system.

```
emotionRecognizer = ivectorSystem(SampleRate=fs,DetectSpeech=)
emotionRecognizer =
  ivectorSystem with properties:
      InputType: 'audio'
      SampleRate: 16000
      DetectSpeech: 0
      Verbose: 1
      EnrolledLabels: [0x2 table]
```

Call `trainExtractor` using the training set.




```
rng default
trainExtractor(emotionRecognizer,trainSet, ...
  UBMNumComponents = 256 , ...
  UBMNumIterations = 5 , ...
  ...
  TVSRank = 128 , ...
  TVSNumIterations = 5  );
```

```
Calculating standardization factors .....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

Copy the emotion recognition system for use later in the example.

```
sentimentRecognizer = copy(emotionRecognizer);
```

Call `trainClassifier` using the training set.

```
rng default
trainClassifier(emotionRecognizer,trainSet,trainLabels, ...
  NumEigenvectors = 32 , ...
  ...
  PLDANumDimensions = 16 , ...
  PLDANumIterations = 10  );
```

```
Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.
```


Call `calibrate` using the training set. In practice, the calibration set should be different than the training set.

```
calibrate(emotionRecognizer, trainSet, trainLabels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

Enroll the training labels into the i-vector system.

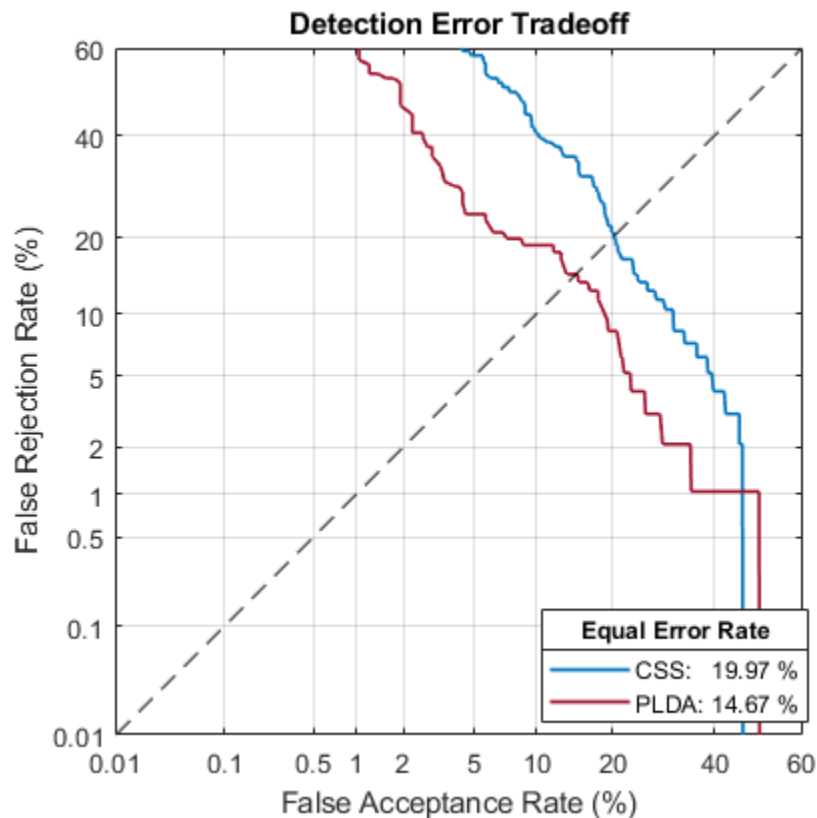
```
enroll(emotionRecognizer, trainSet, trainLabels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

You can use `detectionErrorTradeoff` as a quick sanity check on the performance of a multilabel closed-set classification system. However, `detectionErrorTradeoff` provides information more suitable to open-set binary classification problems, for example, speaker verification tasks.

```
detectionErrorTradeoff(emotionRecognizer, testSet, testLabels)
```

```
Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.
```



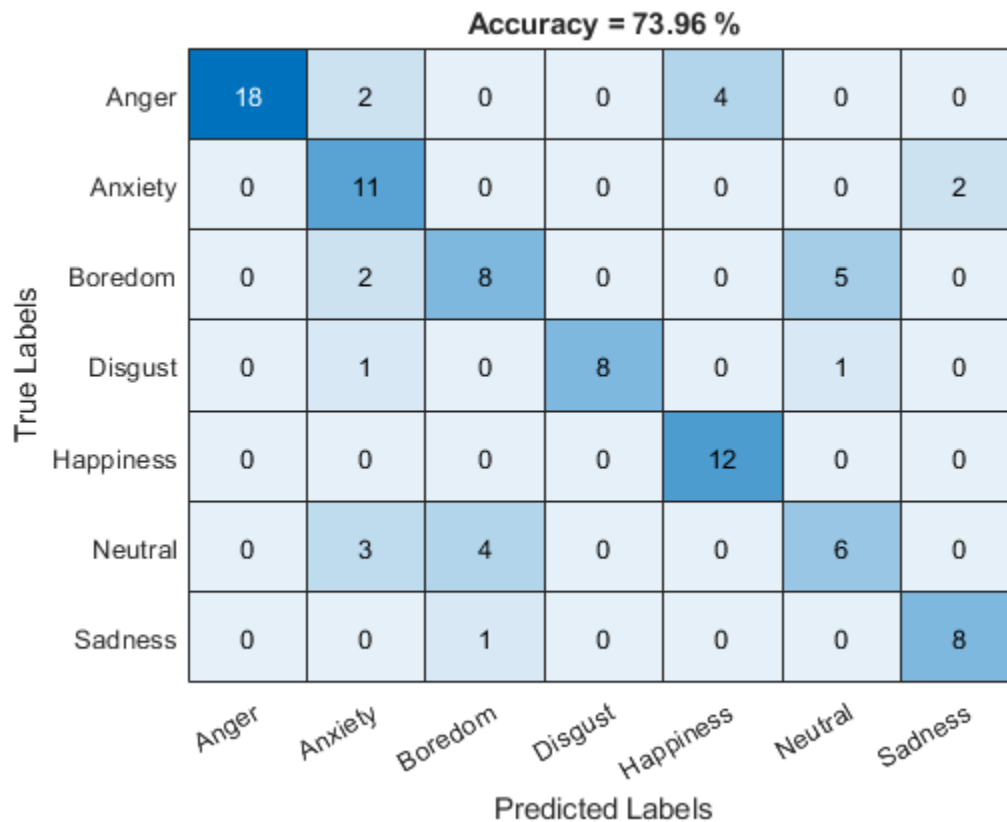
For a more detailed view of the i-vector system's performance in a multilabel closed set application, you can use the `identify` function and create a confusion matrix. The confusion matrix enables you to identify which emotions are misidentified and what they are misidentified as. Use the supporting function `plotConfusion` to display the results.

```

trueLabels = testLabels;
predictedLabels = trueLabels;
scorer = plda;
for ii = 1:numel(testSet)
    tableOut = identify(emotionRecognizer, testSet{ii}, scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels, predictedLabels)

```



Call `info` to inspect how `emotionRecognizer` was trained and evaluated.

```

info(emotionRecognizer)

i-vector system input
  Input feature vector length: 60
  Input data type: double

trainExtractor
  Train signals: 439
  UBMNumComponents: 256
  UBMNumIterations: 5

```

```

TVSRank: 128
TVSNumIterations: 5

trainClassifier
  Train signals: 439
  Train labels: Anger (103), Anxiety (56) ... and 5 more
  NumEigenvectors: 32
  PLDANumDimensions: 16
  PLDANumIterations: 10

calibrate
  Calibration signals: 439
  Calibration labels: Anger (103), Anxiety (56) ... and 5 more

detectionErrorTradeoff
  Evaluation signals: 96
  Evaluation labels: Anger (24), Anxiety (13) ... and 5 more

```

Next, modify the i-vector system to recognize emotions as positive, neutral, or negative. Update the labels to only include the categories negative, positive, and categorical.

```




trainLabelsSentiment = trainLabels;
trainLabelsSentiment(ismember(trainLabels,categorical(["Anger","Anxiety","Boredom","Sadness","Disgust"]))) = categorical("Negative");
trainLabelsSentiment(ismember(trainLabels,categorical("Happiness"))) = categorical("Positive");
trainLabelsSentiment = removecats(trainLabelsSentiment);

testLabelsSentiment = testLabels;
testLabelsSentiment(ismember(testLabels,categorical(["Anger","Anxiety","Boredom","Sadness","Disgust"]))) = categorical("Negative");
testLabelsSentiment(ismember(testLabels,categorical("Happiness"))) = categorical("Positive");
testLabelsSentiment = removecats(testLabelsSentiment);

```

Train the i-vector system classifier using the updated labels. You do not need to retrain the extractor. Recalibrate the system.

```

rng default
trainClassifier(sentimentRecognizer,trainSet,trainLabelsSentiment, ...
  NumEigenvectors = 64  , ...
  ...
  PLDANumDimensions = 32  , ...
  PLDANumIterations = 10  );

```

```

Extracting i-vectors ...done.
Training projection matrix .....done.
Training PLDA model .....done.
i-vector classifier training complete.

```

```
calibrate(sentimentRecognizer,trainSet,trainLabels)
```

```

Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.

```

Enroll the training labels into the system and then plot the confusion matrix for the test set.

```
enroll(sentimentRecognizer,trainSet,trainLabelsSentiment)
```

```

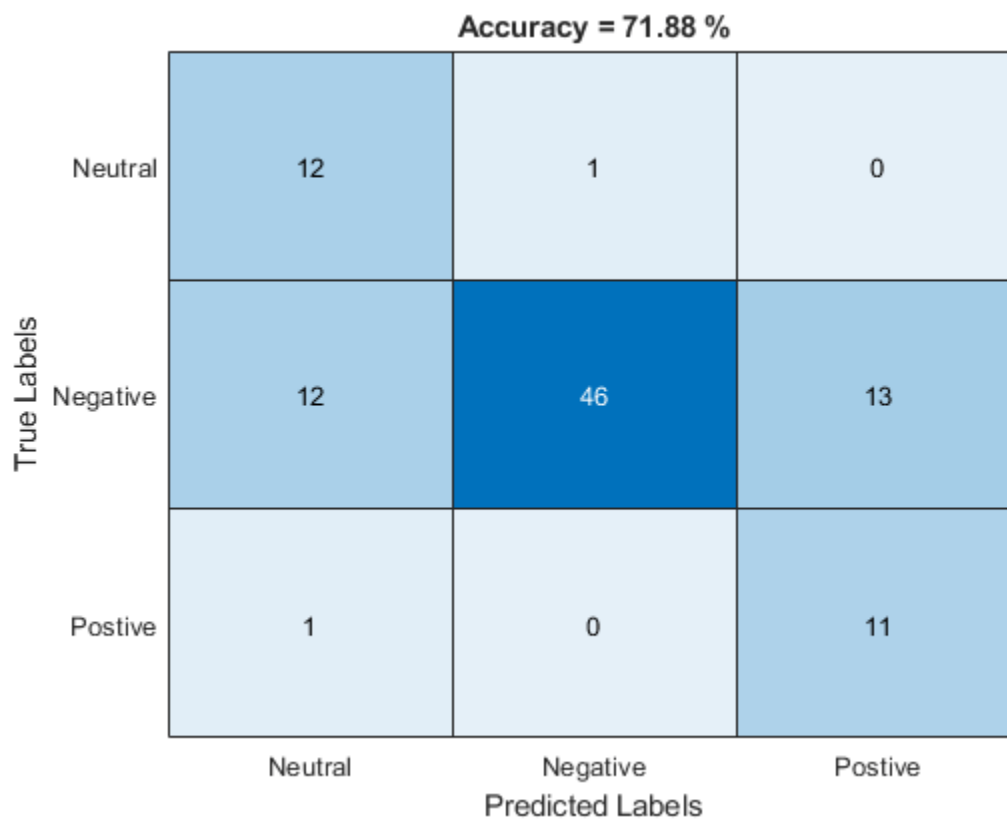
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.

trueLabels = testLabelsSentiment;
predictedLabels = trueLabels;

scorer = ;
for ii = 1:numel(testSet)
    tableOut = identify(sentimentRecognizer,testSet{ii},scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels,predictedLabels)

```



An i-vector system does not require the labels used to train the classifier to be equal to the enrolled labels.

Unenroll the sentiment labels from the system and then enroll the original emotion categories in the system. Analyze the system's classification performance.

```

unenroll(sentimentRecognizer)
enroll(sentimentRecognizer,trainSet,trainLabels)

```

```

Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.

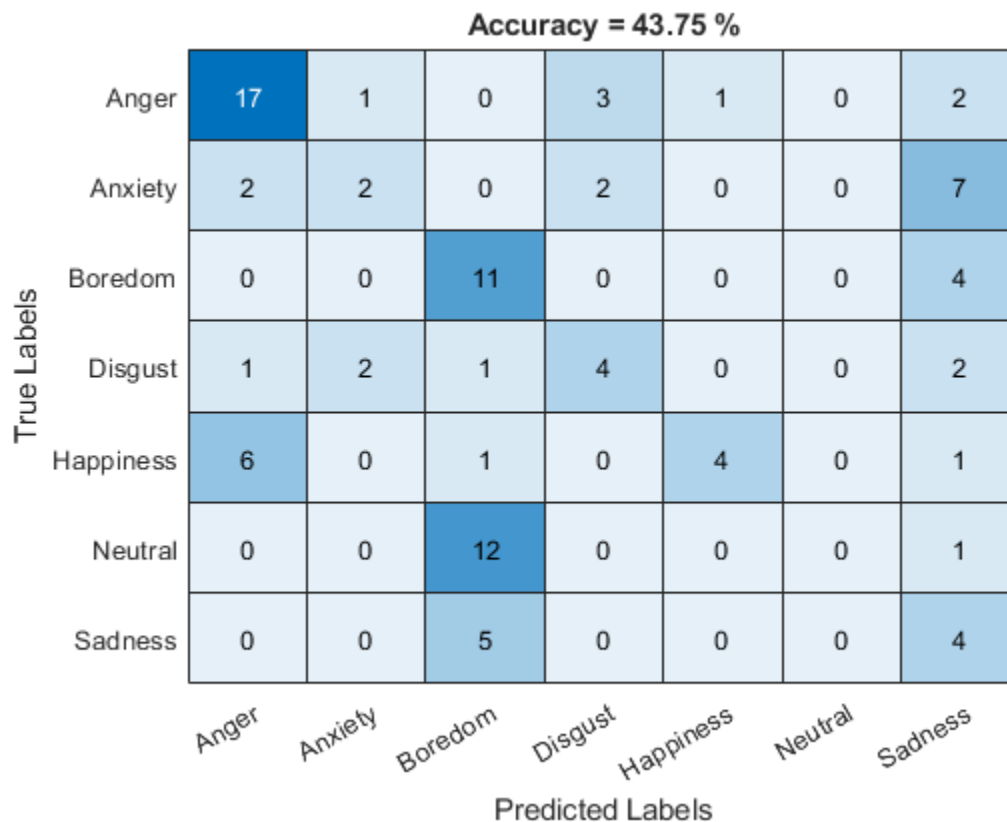
```

```

trueLabels = testLabels;
predictedLabels = trueLabels;
scorer = plda;
for ii = 1:numel(testSet)
    tableOut = identify(sentimentRecognizer, testSet{ii}, scorer);
    predictedLabels(ii) = tableOut.Label(1);
end

plotConfusion(trueLabels, predictedLabels)

```



Supporting Functions

```

function plotConfusion(trueLabels, predictedLabels)
    uniqueLabels = unique(trueLabels);
    cm = zeros(numel(uniqueLabels), numel(uniqueLabels));
    for ii = 1:numel(uniqueLabels)
        for jj = 1:numel(uniqueLabels)
            cm(ii, jj) = sum((trueLabels==uniqueLabels(ii)) & (predictedLabels==uniqueLabels(jj)));
        end
    end

    heatmap(uniqueLabels, uniqueLabels, cm)
    colorbar off
    ylabel('True Labels')
    xlabel('Predicted Labels')
    accuracy = mean(trueLabels==predictedLabels);

```

```
title(sprintf("Accuracy = %0.2f %%",accuracy*100))  
end
```

References

[1] Burkhardt, F, A. Paeschke, M. Rolfes, W.F. Sendlmeier, and B. Weiss, "A Database of German Emotional Speech." In Proceedings Interspeech 2005. Lisbon, Portugal: International Speech Communication Association, 2005.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

labels — Classification labels

character vector | string | cell array | string array | categorical array

Classification labels used by an i-vector system, specified as one of these:

- A categorical array
- A cell array of character vectors
- A string array

Data Types: `categorical` | `cell` | `string`

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `enroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

detectionErrorTradeoff

Evaluate binary classification system

Syntax

```
results = detectionErrorTradeoff(ivs,data,labels)
results = detectionErrorTradeoff(ivs)

[results,threshold] = detectionErrorTradeoff( ___ )

[ ___ ] = detectionErrorTradeoff( ___ ,Name,Value)

detectionErrorTradeoff( ___ )
```

Description

`results = detectionErrorTradeoff(ivs,data,labels)` computes detection error tradeoff of the i-vector system `ivs` for the enrolled labels and the specified data.

`results = detectionErrorTradeoff(ivs)` returns a structure containing previously calculated results of threshold sweeping for probabilistic linear discriminant analysis (PLDA) and cosine similarity scoring (CSS).

`[results,threshold] = detectionErrorTradeoff(___)` also returns the threshold corresponding to the equal error rate.

`[___] = detectionErrorTradeoff(___ ,Name,Value)` specifies additional options using name-value arguments. For example, you can choose the scorer results and the hardware resource for extracting i-vectors.

`detectionErrorTradeoff(___)` with no output arguments plots the equal error rate and the detection error tradeoff.

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder, "SPEECH DATA", "FEMALE", "MIC"), fullfile(datasetFolder, "SPEECH DATA", "FEMALE", "MIC")], fullfile(datasetFolder, "SPEECH DATA", "FEMALE", "MIC"),
                    IncludeSubfolders=true, ...
                    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

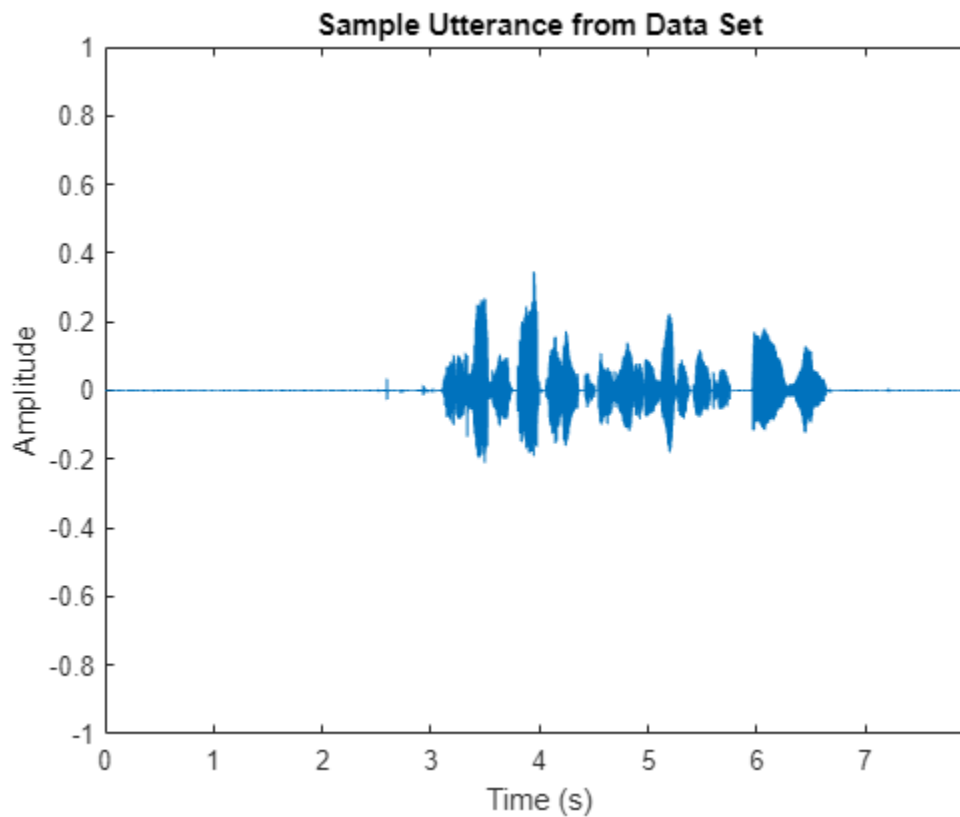
```
ads.Labels = extractBetween(ads.Files, "mic_", "_");
countEachLabel(ads)
```

```
ans=20x2 table
   Label   Count
   _____
   F01     236
   F02     236
   F03     236
   F04     236
   F05     236
   F06     236
   F07     236
   F08     234
   F09     236
   F10     236
   M01     236
   M02     236
   M03     236
   M04     236
   M05     236
   M06     236
   :
```

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);
fs = audioInfo.SampleRate;

t = (0:size(audioIn,1)-1)/fs;
sound(audioIn, fs)
plot(t, audioIn)
xlabel("Time (s)")
ylabel("Amplitude")
axis([0 t(end) -1 1])
title("Sample Utterance from Data Set")
```

Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  _____  _____
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```
M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236
```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 48000  
    DetectSpeech: 1  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```

To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
Input feature vector length: 60
Input data type: double
```

```
trainExtractor
Train signals: 3774
UBMNumComponents: 128
UBMNumIterations: 5
TVSRank: 64
TVSNumIterations: 3
```

```
trainClassifier
Train signals: 3774
Train labels: F02 (236), F03 (236) ... and 14 more
NumEigenvectors: 16
PLDANumDimensions: 16
PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          1
  F05      {16x1 double}          1
  M01      {16x1 double}          1
  M05      {16x1 double}          1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          3
  F05      {16x1 double}          3
  M01      {16x1 double}          3
  M05      {16x1 double}          3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

```
results
```

```

results = struct with fields:
  PLDA: [1000x3 table]
  CSS: [1000x3 table]

```

```
results.CSS
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
1.7736e-09	1	0
1.8233e-09	0.99964	0
1.8745e-09	0.99964	0
1.927e-09	0.99964	0
1.9811e-09	0.99964	0
2.0366e-09	0.99964	0
2.0937e-09	0.99964	0
2.1524e-09	0.99964	0
2.2128e-09	0.99964	0
2.2748e-09	0.99964	0
2.3386e-09	0.99964	0
2.4042e-09	0.99964	0
2.4716e-09	0.99964	0
2.5409e-09	0.99964	0
2.6122e-09	0.99964	0
2.6854e-09	0.99964	0
:		

```
results.PLDA
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
4.7045e-34	1	0
5.143e-34	0.99964	0
5.6225e-34	0.99964	0
6.1466e-34	0.99964	0
6.7197e-34	0.99964	0
7.3461e-34	0.99964	0
8.0309e-34	0.99964	0
8.7796e-34	0.99964	0
9.5981e-34	0.99964	0
1.0493e-33	0.99964	0
1.1471e-33	0.99964	0

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

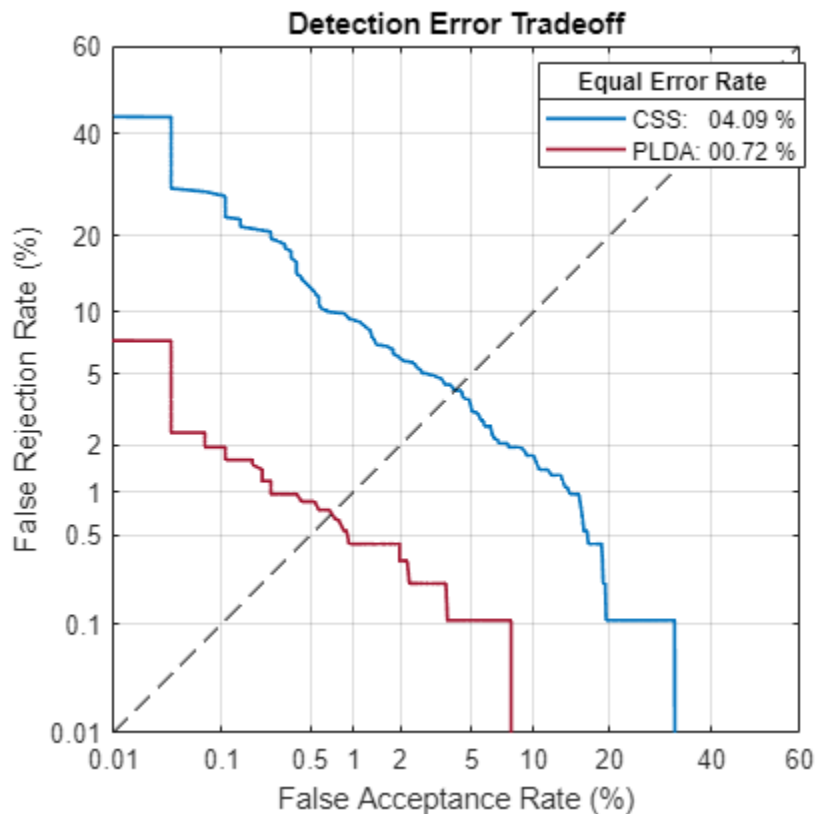
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

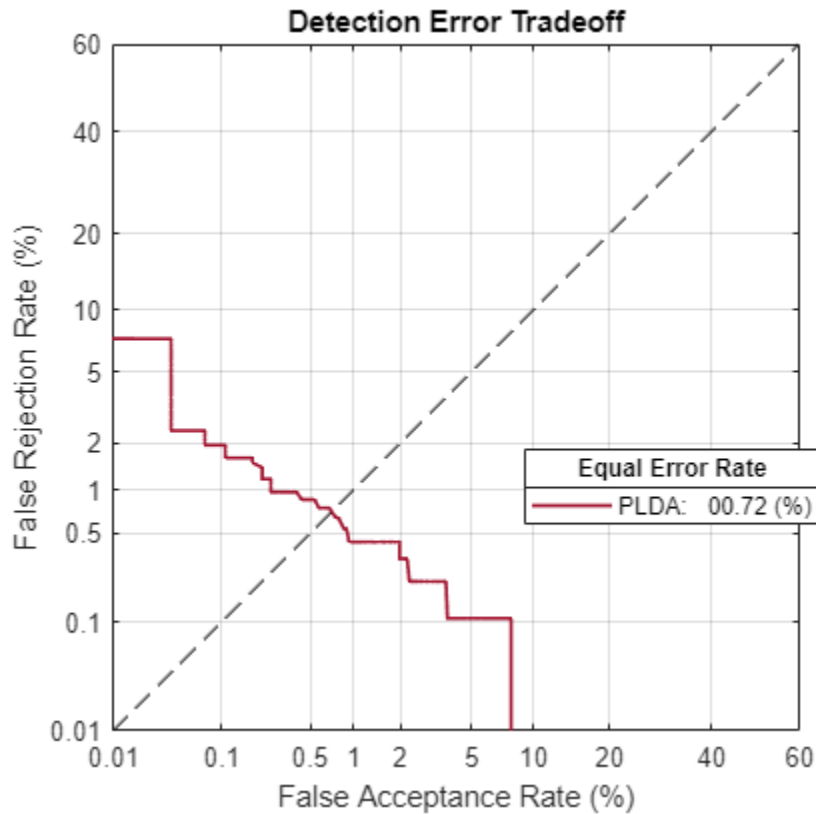
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

```
detectionErrorTradeoff(speakerVerification)
```



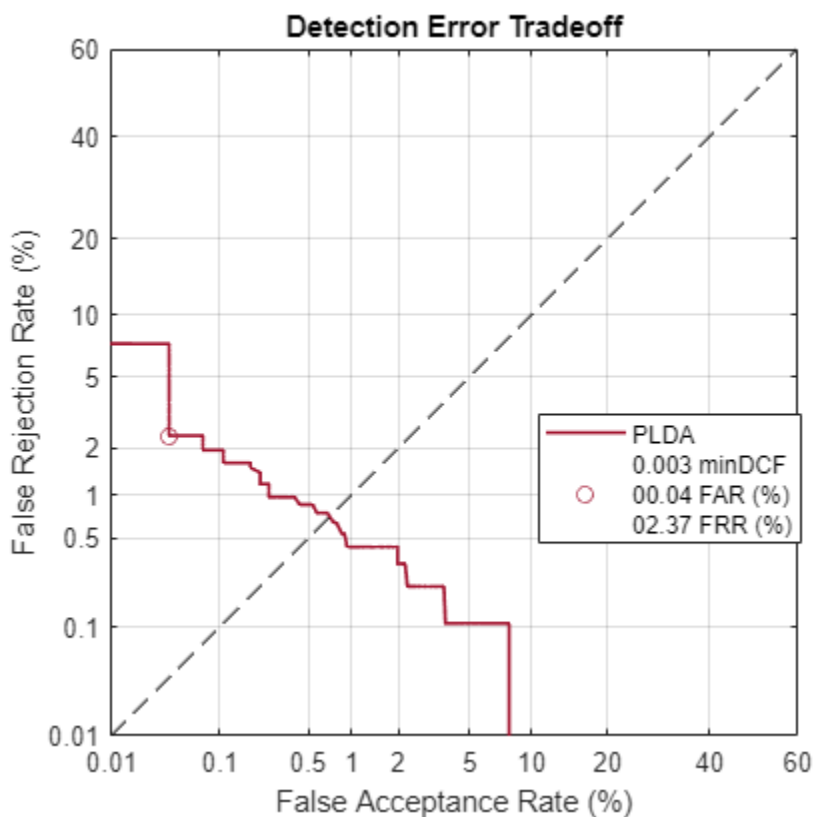
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```



```

    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker accepted.
Similarity score = 1.00

Call speaker verification again. This time, specify an incorrect speaker ID.

possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))

imposter = 1x1 cell array
    {'F01'}

[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker rejected.
Similarity score = 0.00

```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Labeled evaluation data

cell array | `audioDatastore` | `signalDatastore` | `TransformedDatastore`

Labeled evaluation data, specified as a cell array or as an `audioDatastore`, `signalDatastore`, or `TransformedDatastore` object.

- If `InputType` is set to "audio" when the i-vector system is created, specify `data` as one of these:
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type `single` or `double`.
 - An `audioDatastore` object or a `signalDatastore` object that points to a data set of mono audio signals.
 - A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to `read` from the transform datastore must be mono audio signals with underlying data type `single` or `double`.

- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
 - A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Labels — Classification labels

categorical array | cell array | string array

Classification labels used by an i-vector system, specified as one of the following:

- A categorical array
- A cell array of character vectors
- A string array

Note The number of audio signals in `data` must match the number of `labels`.

Data Types: `categorical` | `cell` | `string`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example: `detectionErrorTradeoff(ivs, Scorer="css")`

Scorer — Scorer results

"all" (default) | "plda" | "css"

Scorer results returned from an i-vector system, specified as "plda", which corresponds to probabilistic linear discriminant analysis (PLDA), "css", which corresponds to cosine similarity score (CSS), or "all".

Data Types: `char` | `string`

minDCF — Parameters of detection cost function

three-element vector

Parameters of the detection cost function, specified as a three-element vector consisting of the cost of a false rejection, the cost of a false acceptance, and the prior probability of an enrolled label being present, in that order.

When you specify parameters of a detection cost function, `detectionErrorTradeoff` returns the threshold corresponding to the minimum of the detection cost function [1]. The detection cost function is defined as

$$C_{\text{det}}(P_{\text{FR}}, P_{\text{FA}}) = C_{\text{FR}} \times P_{\text{FR}} \times P_{\text{present}} + C_{\text{FA}} \times P_{\text{FA}} \times (1 - P_{\text{present}}),$$

where

- C_{det} — Detection cost function
- C_{FR} — Cost of a false rejection
- C_{FA} — Cost of a false acceptance
- P_{present} — Prior probability of an enrolled label being present
- P_{FR} — Observed probability of a false rejection given the data input to `detectionErrorTradeoff`
- P_{FA} — Observed probability of a false acceptance given the data input to `detectionErrorTradeoff`

Data Types: `single` | `double`

ExecutionEnvironment — Hardware resource for execution

`"auto"` (default) | `"cpu"` | `"gpu"` | `"multi-gpu"` | `"parallel"`

Hardware resource for execution, specified as one of these:

- `"auto"` — Use the GPU if it is available. Otherwise, use the CPU.
- `"cpu"` — Use the CPU.
- `"gpu"` — Use the GPU. This option requires Parallel Computing Toolbox.
- `"multi-gpu"` — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- `"parallel"` — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: `char` | `string`

DispatchInBackground — Option to use prefetch queuing

`false` (default) | `true`

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: `logical`

Output Arguments

results — FAR and FRR per threshold tested

`structure` | `table`

FAR and FRR per threshold tested, returned as a structure or a table.

- If `Scorer` is specified as "all", then `results` is returned as a structure with fields `PLDA` and `CSS` and values containing tables. Each table has three variables: `Threshold`, `FAR`, and `FRR`.
- If `Scorer` is specified as "plda" or "css", then `results` is returned as a table corresponding to the specified scorer.

Data Types: `struct` | `table`

threshold — Threshold corresponding to equal error rate

`scalar` | `structure`

Threshold corresponding to the equal error rate (EER) or minimum of the detection cost function (minDCF), returned as a scalar or a structure. If the `minDCF` is specified, then `threshold` corresponds to `minDCF`. Otherwise, `threshold` corresponds to the EER.

- If `Scorer` is specified as "all", then `threshold` is returned as a structure with fields `PLDA` and `CSS` and values equal to the respective thresholds.
- If `Scorer` is specified as "plda" or "css", then `threshold` is returned as a scalar corresponding to the specified scorer.

Data Types: `single` | `double` | `struct`

References

- [1] Leeuwen, David A. van, and Niko Brümmer. "An Introduction to Application-Independent Evaluation of Speaker Recognition Systems." In *Speaker Classification I*, edited by Christian Müller, 4343:330-53. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007. https://doi.org/10.1007/978-3-540-74200-5_19.

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `unenroll` | `enroll` | `verify` | `identify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

verify

Verify label

Syntax

```
tf = verify(ivs,data,label)
tf = verify(ivs,data,label,scorer)
tf = verify(ivs,data,label,scorer,threshold)
```

```
[tf,score] = verify( __ )
```

Description

`tf = verify(ivs,data,label)` returns true if i-vector system `ivs` finds that `data` corresponds to `label` and false otherwise.

`tf = verify(ivs,data,label,scorer)` specifies the `scorer` used for verification.

`tf = verify(ivs,data,label,scorer,threshold)` specifies the decision threshold used for the score.

`[tf,score] = verify(__)` also returns a `score` indicating the similarity between the i-vector derived from the `data` and the i-vector template corresponding to the `label`.

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder,"SPEECH DATA","FEMALE","MIC"),fullfile(datasetFolder,
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

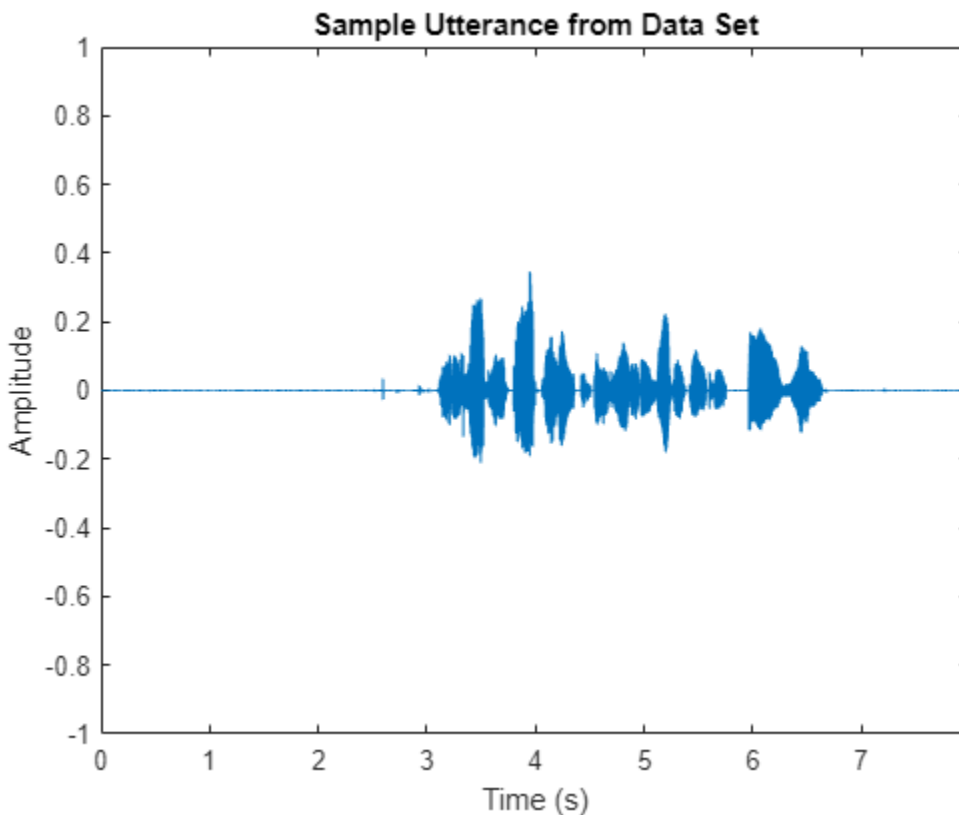
The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

```
ads.Labels = extractBetween(ads.Files,"mic_","_");  
countEachLabel(ads)
```

```
ans=20×2 table  
  Label    Count  
  _____  _____  
  F01      236  
  F02      236  
  F03      236  
  F04      236  
  F05      236  
  F06      236  
  F07      236  
  F08      234  
  F09      236  
  F10      236  
  M01      236  
  M02      236  
  M03      236  
  M04      236  
  M05      236  
  M06      236  
  ⋮
```

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);  
fs = audioInfo.SampleRate;  
  
t = (0:size(audioIn,1)-1)/fs;  
sound(audioIn, fs)  
plot(t, audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis([0 t(end) -1 1])  
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  _____  _____
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```
M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236
```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 48000  
    DetectSpeech: 1  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```


To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
  Input feature vector length: 60
  Input data type: double
```

```
trainExtractor
  Train signals: 3774
  UBMNumComponents: 128
  UBMNumIterations: 5
  TVSRank: 64
  TVSNumIterations: 3
```

```
trainClassifier
  Train signals: 3774
  Train labels: F02 (236), F03 (236) ... and 14 more
  NumEigenvectors: 16
  PLDANumDimensions: 16
  PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
    F01    {16x1 double}          1
    F05    {16x1 double}          1
    M01    {16x1 double}          1
    M05    {16x1 double}          1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
    F01    {16x1 double}          3
    F05    {16x1 double}          3
    M01    {16x1 double}          3
    M05    {16x1 double}          3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

results

```

results = struct with fields:
    PLDA: [1000x3 table]
    CSS: [1000x3 table]

```

results.CSS

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  1.7736e-09         1         0
  1.8233e-09    0.99964         0
  1.8745e-09    0.99964         0
  1.927e-09     0.99964         0
  1.9811e-09    0.99964         0
  2.0366e-09    0.99964         0
  2.0937e-09    0.99964         0
  2.1524e-09    0.99964         0
  2.2128e-09    0.99964         0
  2.2748e-09    0.99964         0
  2.3386e-09    0.99964         0
  2.4042e-09    0.99964         0
  2.4716e-09    0.99964         0
  2.5409e-09    0.99964         0
  2.6122e-09    0.99964         0
  2.6854e-09    0.99964         0
  :

```

results.P LDA

```

ans=1000x3 table
  Threshold    FAR    FRR
  _____  _____  _____
  4.7045e-34         1         0
  5.143e-34    0.99964         0
  5.6225e-34    0.99964         0
  6.1466e-34    0.99964         0
  6.7197e-34    0.99964         0
  7.3461e-34    0.99964         0
  8.0309e-34    0.99964         0
  8.7796e-34    0.99964         0
  9.5981e-34    0.99964         0
  1.0493e-33    0.99964         0
  1.1471e-33    0.99964         0

```

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

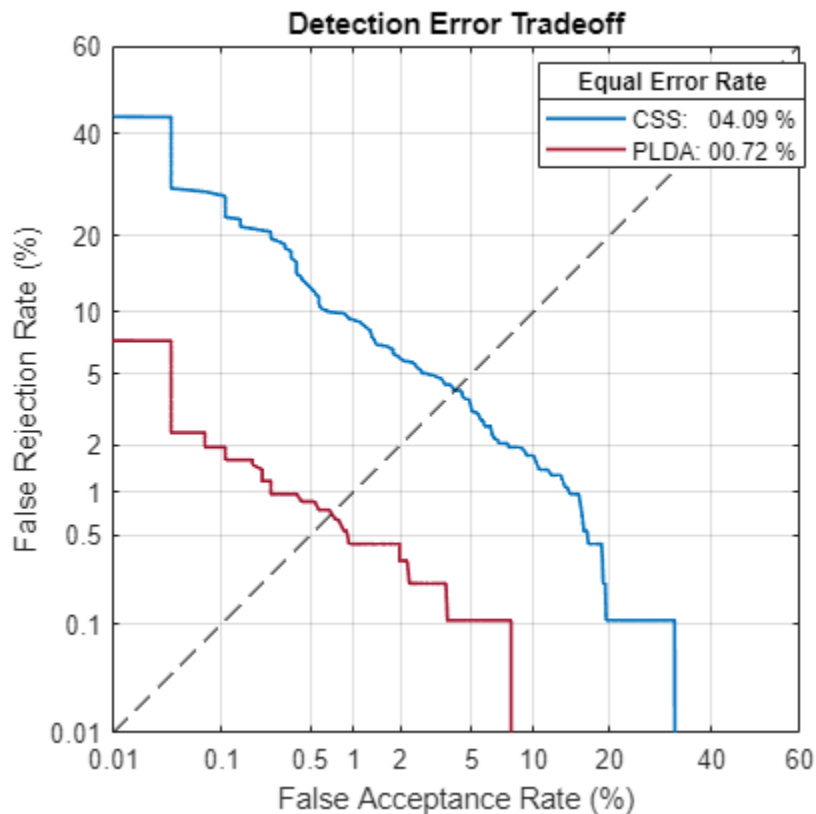
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

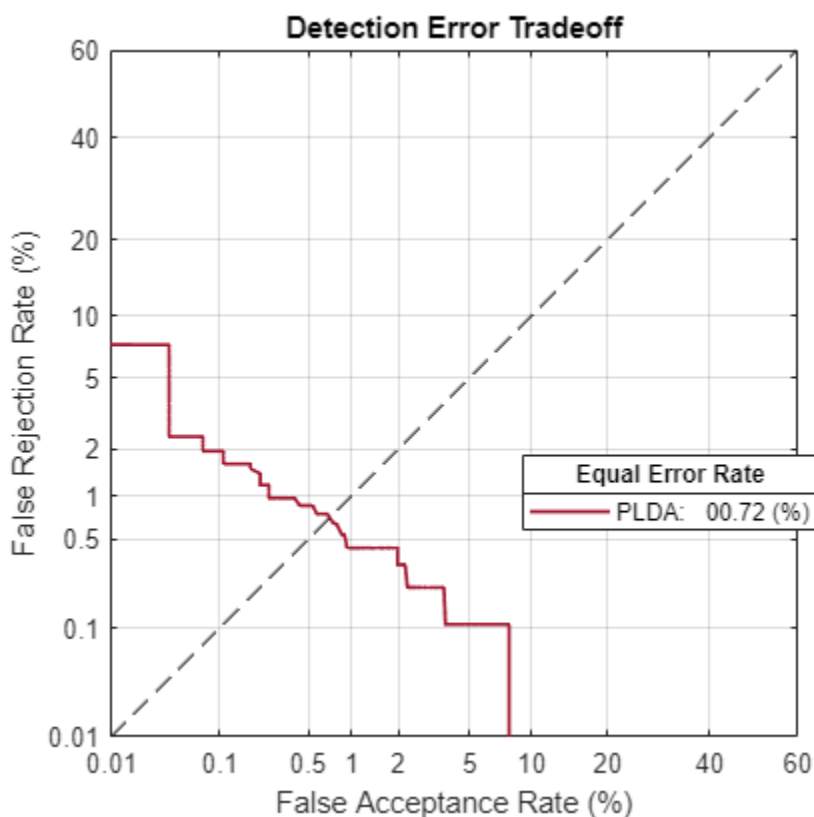
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

```
detectionErrorTradeoff(speakerVerification)
```



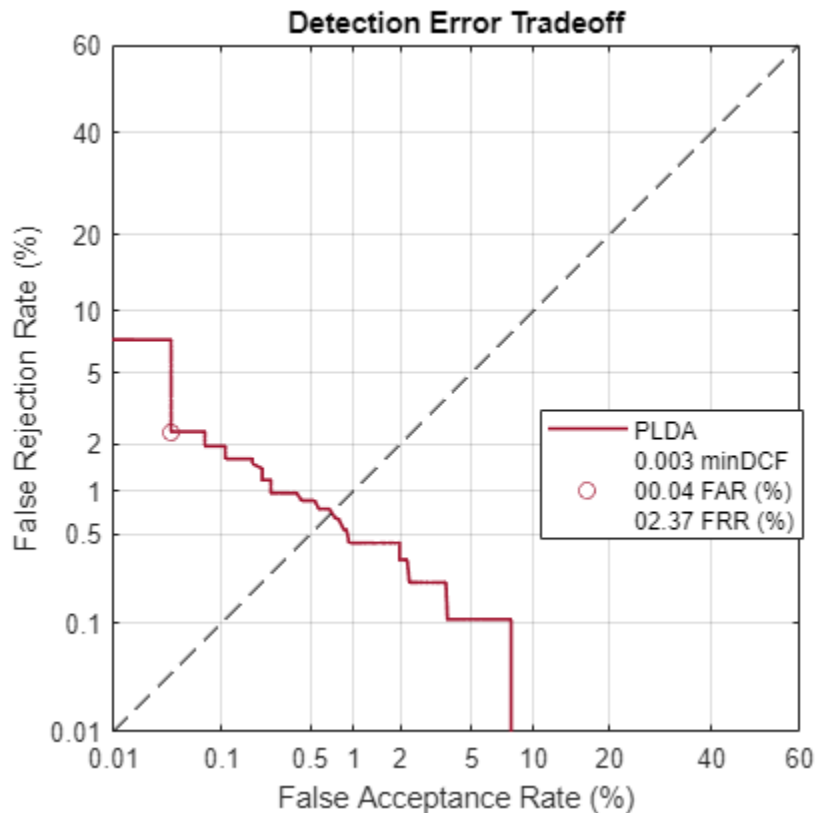
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```



Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```
    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker accepted.
Similarity score = 1.00
```

Call speaker verification again. This time, specify an incorrect speaker ID.

```
possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))
```

```
imposter = 1x1 cell array
    {'F01'}
```

```
[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end
```

```
Success!
Speaker rejected.
Similarity score = 0.00
```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Data to verify

column vector | matrix

Data to verify, specified as a column vector representing a single-channel (mono) audio signal or a matrix of audio features.

- If `InputType` is set to "audio" when the i-vector system is created, `data` must be a column vector with underlying type `single` or `double`.
- If `InputType` is set to "features" when the i-vector system is created, `data` must be a matrix with underlying type `single` or `double`. The matrix must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized.

Data Types: `single` | `double`

label — Label to verify

categorical scalar | character vector | string

Label to verify, specified as a categorical scalar, a character vector, or a string.

Data Types: `categorical` | `char` | `string`

scorer — Scoring algorithm`"plda" | "css"`

Scoring algorithm used by the i-vector system, specified as `"plda"`, which corresponds to probabilistic linear discriminant analysis (PLDA), or `"css"`, which corresponds to cosine similarity score (CSS). If the PLDA model was trained by `trainClassifier`, the default scorer is `"plda"`. Otherwise, the default scorer is `"css"`.

Data Types: `char` | `string`

threshold — Decision threshold

scalar

Decision threshold applied to the similarity score, specified as a scalar. The default decision threshold is the equal error rate of the scorer determined by calling `detectionErrorTradeoff`. If `detectionErrorTradeoff` is not called, then you must define the threshold.

Data Types: `single` | `double`

Output Arguments

tf — Correspondence indicator`true | false`

Correspondence indicator, returned as a logical.

- If the i-vector system finds that `data` corresponds to `label`, `tf` is returned as `true`.
- If the i-vector system finds that `data` does not correspond to `label`, `tf` is returned as `false`.

Data Types: `logical`

score — Similarity score

scalar

Score indicating the similarity between the i-vector derived from `data` and the i-vector corresponding to `label`, returned as a scalar.

Data Types: `double`

Compatibility Considerations

verify throws warning if scores are not calibrated*Behavior changed in R2022a*

Starting in R2022a, the `verify` function throws a warning if it is called with two output arguments and the scores from the i-vector system are not calibrated. Use `calibrate` to calibrate the scores.

See Also

trainExtractor | trainClassifier | calibrate | unenroll | enroll |
detectionErrorTradeoff | identify | ivector | info | addInfoHeader | release |
ivectorSystem | speakerRecognition

Introduced in R2021a

identify

Identify label

Syntax

```
tableOut = identify(ivs,data)
tableOut = identify(ivs,data,scorer)

tableOut = identify( ____,NumCandidates=N)
```

Description

`tableOut = identify(ivs,data)` identifies the label corresponding to the data.

`tableOut = identify(ivs,data,scorer)` specifies the scorer used to perform identification.

`tableOut = identify(____,NumCandidates=N)` specifies the number of candidates to return in `tableOut`.

Examples

Train Speaker Identification System

Use the Census Database (also known as AN4 Database) from the CMU Robust Speech Recognition Group [1] on page 4-0 . The data set contains recordings of male and female subjects speaking words and numbers. The helper function in this example downloads the data set for you and converts the raw files to FLAC, and returns two `audioDatastore` objects containing the training set and test set. By default, the data set is reduced so that the example runs quickly. You can use the full data set by setting `ReduceDataset` to false.

```
[adsTrain,adsTest] = HelperAN4Download(ReduceDataset=true);
```

Split the test data set into enroll and test sets. Use two utterances for enrollment and the remaining for the test set. Generally, the more utterances you use for enrollment, the better the performance of the system. However, most practical applications are limited to a small set of enrollment utterances.

```
[adsEnroll,adsTest] = splitEachLabel(adsTest,2);
```

Inspect the distribution of speakers in the training, test, and enroll sets. The speakers in the training set do not overlap with the speakers in the test and enroll sets.

```
summary(adsTrain.Labels)
```

```
fejs      13
fmjd      13
fsrb      13
ftmj      13
fwxs      12
mcen      13
mrcb      13
```

```

msjm      13
msjr      13
msmn      9

```

```
summary(adsEnroll.Labels)
```

```

fvap      2
marh      2

```

```
summary(adsTest.Labels)
```

```

fvap      11
marh      11

```

Create an i-vector system that accepts feature input.

```

fs = 16e3;
iv = ivectorSystem(SampleRate=fs, InputType="features");

```

Create an `audioFeatureExtractor` object to extract the gammatone cepstral coefficients (GTCC), the delta GTCC, the delta-delta GTCC, and the pitch from 50 ms periodic Hann windows with 45 ms overlap.

```

afe = audioFeatureExtractor(gtcc=true,gtccDelta=true,gtccDeltaDelta=true,pitch=true,SampleRate=fs);
afe.Window = hann(round(0.05*fs),"periodic");
afe.OverlapLength = round(0.045*fs);
afe

```

```

afe =
  audioFeatureExtractor with properties:

```

Properties

```

          Window: [800x1 double]
    OverlapLength: 720
      SampleRate: 16000
         FFTLength: []
SpectralDescriptorInput: 'linearSpectrum'
   FeatureVectorLength: 40

```

Enabled Features

```
gtcc, gtccDelta, gtccDeltaDelta, pitch
```

Disabled Features

```

linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
mfccDeltaDelta, spectralCentroid, spectralCrest, spectralDecrease, spectralEntropy, spectralFlux,
spectralKurtosis, spectralRolloffPoint, spectralSkewness, spectralSlope, spectralHarmonicRatio,
zeroCrossRate, shortTimeEnergy

```

To extract a feature, set the corresponding property to true.

For example, `obj.mfcc = true`, adds mfcc to the list of enabled features.

Create transformed datastores by adding feature extraction to the read function of `adsTrain` and `adsEnroll`.

```

trainLabels = adsTrain.Labels;
adsTrain = transform(adsTrain,@(x)extract(afe,x));

```

```
enrollLabels = adsEnroll.Labels;  
adsEnroll = transform(adsEnroll,@(x)extract(afe,x));
```

Train both the extractor and classifier using the training set.

```
trainExtractor(iv,adsTrain, ...  
    UBMNumComponents=64, ...  
    UBMNumIterations=5, ...  
    TVSRank=32, ...  
    TVSNumIterations=3);
```

```
Calculating standardization factors ....done.  
Training universal background model .....done.  
Training total variability space .....done.  
i-vector extractor training complete.
```

```
trainClassifier(iv,adsTrain,trainLabels, ...  
    NumEigenvectors=16, ...  
    ...  
    PLDANumDimensions=16, ...  
    PLDANumIterations=5);
```

```
Extracting i-vectors ...done.  
Training projection matrix .....done.  
Training PLDA model .....done.  
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(iv,adsTrain,trainLabels)
```

```
Extracting i-vectors ...done.  
Calibrating CSS scorer ...done.  
Calibrating PLDA scorer ...done.  
Calibration complete.
```

Enroll the speakers from the enrollment set.

```
enroll(iv,adsEnroll,enrollLabels)
```

```
Extracting i-vectors ...done.  
Enrolling i-vectors .....done.  
Enrollment complete.
```

Evaluate the file-level prediction accuracy on the test set.

```
numCorrect = 0;  
reset(adsTest)  
for index = 1:numel(adsTest.Files)  
    features = extract(afe,read(adsTest));  
  
    results = identify(iv,features);  
  
    trueLabel = adsTest.Labels(index);  
    predictedLabel = results.Label(1);  
    isPredictionCorrect = trueLabel==predictedLabel;  
  
    numCorrect = numCorrect + isPredictionCorrect;
```

```
end
display("File Accuracy: " + round(100*numCorrect/numel(adsTest.Files),2) + " (%)")
    "File Accuracy: 100 (%)"
```

References

[1] "CMU Sphinx Group - Audio Databases." <http://www.speech.cs.cmu.edu/databases/an4/>. Accessed 19 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

data — Data to identify

column vector | matrix

Data to identify, specified as a column vector representing a single-channel (mono) audio signal or a matrix of audio features.

- If `InputType` is set to "audio" when the i-vector system is created, `data` must be a column vector with underlying type `single` or `double`.
- If `InputType` is set to "features" when the i-vector system is created, `data` must be a matrix with underlying type `single` or `double`. The matrix must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized.

Data Types: `single` | `double`

scorer — Scoring algorithm

"plda" | "css"

Scoring algorithm used by the i-vector system, specified as "plda", which corresponds to probabilistic linear discriminant analysis (PLDA), or "css", which corresponds to cosine similarity score (CSS).

To use "plda", you must train the PLDA model using `trainClassifier`. If the PLDA model has been trained, then `scorer` defaults to "plda". Otherwise, the `scorer` defaults to "css".

Data Types: `char` | `string`

N — Number of candidates

positive scalar

Number of candidates to return in `tableOut`, specified as a positive scalar.

Note If you request a number of candidates greater than the number of `labels` enrolled in the i-vector system, then all candidates are returned. If unspecified, the number of candidates defaults to the number of enrolled `labels`.

Data Types: `single` | `double`

Output Arguments

tableOut — Score table

table

Candidate labels and corresponding scores, returned as a table. The number of rows of `tableOut` is equal to `N`, the number of candidates. The candidates are sorted in order of confidence.

Data Types: `table`

Compatibility Considerations

identify throws warning if scores are not calibrated

Behavior changed in R2022a

Starting in R2022a, the `identify` function throws a warning if the scores from the i-vector system are not calibrated. Use `calibrate` to calibrate the scores.

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `unenroll` | `enroll` | `detectionErrorTradeoff` | `verify` | `ivector` | `info` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

ivector

Extract i-vector

Syntax

```
w = ivector(ivs,data)
```

```
w = ivector(ivs,data,Name,Value)
```

Description

`w = ivector(ivs,data)` extracts i-vectors from the input `data`.

`w = ivector(ivs,data,Name,Value)` specifies additional options using name-value arguments. You can choose the hardware resource for extracting i-vectors and whether to apply the projection matrix from `trainClassifier`.

Examples

Train Word Recognition System

An i-vector system consists of a trainable front end that learns how to extract i-vectors based on unlabeled data, and a trainable backend that learns how to classify i-vectors based on labeled data. In this example, you apply an i-vector system to the task of word recognition. First, evaluate the accuracy of the i-vector system using the classifiers included in a traditional i-vector system: probabilistic linear discriminant analysis (PLDA) and cosine similarity scoring (CSS). Next, evaluate the accuracy of the system if you replace the classifier with bidirectional long short-term memory (BiLSTM) network or a K-nearest neighbors classifier.

Create Training and Validation Sets

Download the Free Spoken Digit Dataset (FSDD) [1] on page 4-0 . FSDD consists of short audio files with spoken digits (0-9).

```
loc = matlab.internal.examples.downloadSupportFile("audio","FSDD.zip");
unzip(loc,pwd)
```

Create an `audioDatastore` to point to the recordings. Get the sample rate of the data set.

```
ads = audioDatastore(pwd,IncludeSubfolders=true);
[~,adsInfo] = read(ads);
fs = adsInfo.SampleRate;
```

The first element of the file names is the digit spoken in the file. Get the first element of the file names, convert them to categorical, and then set the `Labels` property of the `audioDatastore`.

```
[~,filenames] = cellfun(@(x)fileparts(x),ads.Files,UniformOutput=false);
ads.Labels = categorical(string(cellfun(@(x)x(1),filenames)));
```

To split the datastore into a development set and a validation set, use `splitEachLabel`. Allocate 80% of the data for development and the remaining 20% for validation.

```
[adsTrain,adsValidation] = splitEachLabel(ads,0.8);
```

Evaluate Traditional i-vector Backend Performance

Create an i-vector system that expects audio input at a sample rate of 8 kHz and does not perform speech detection.

```
wordRecognizer = ivectorSystem(DetectSpeech=false,SampleRate=fs)
```

```
wordRecognizer =  
  ivectorSystem with properties:
```

```
    InputType: 'audio'  
    SampleRate: 8000  
    DetectSpeech: 0  
    Verbose: 1  
    EnrolledLabels: [0x2 table]
```

Train the i-vector extractor using the data in the training set.

```
trainExtractor(wordRecognizer,adsTrain, ...  
  UBMNumComponents=64, ...  
  UBMNumIterations=5, ...  
  ...  
  TVSRank=32, ...  
  TVSNumIterations=5);
```

```
Calculating standardization factors ....done.  
Training universal background model .....done.  
Training total variability space .....done.  
i-vector extractor training complete.
```

Train the i-vector classifier using the data in the training data set and the corresponding labels.

```
trainClassifier(wordRecognizer,adsTrain,adsTrain.Labels, ...  
  NumEigenvectors=10, ...  
  ...  
  PLDANumDimensions=10, ...  
  PLDANumIterations=5);
```

```
Extracting i-vectors ...done.  
Training projection matrix ....done.  
Training PLDA model .....done.  
i-vector classifier training complete.
```

Calibrate the scores output by `wordRecognizer` so they can be interpreted as a measure of confidence in a positive decision. Enroll labels into the system using the entire training set.

```
calibrate(wordRecognizer,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.  
Calibrating CSS scorer ...done.  
Calibrating PLDA scorer ...done.  
Calibration complete.
```

```
enroll(wordRecognizer,adsTrain,adsTrain.Labels)
```



```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

In a loop, read audio from the validation datastore, identify the most-likely word present according to the specified scorer, and save the prediction for analysis.

```
trueLabels = adsValidation.Labels;
predictedLabels = trueLabels;

reset(adsValidation)

scorer = ;
for ii = 1:numel(trueLabels)

    audioIn = read(adsValidation);

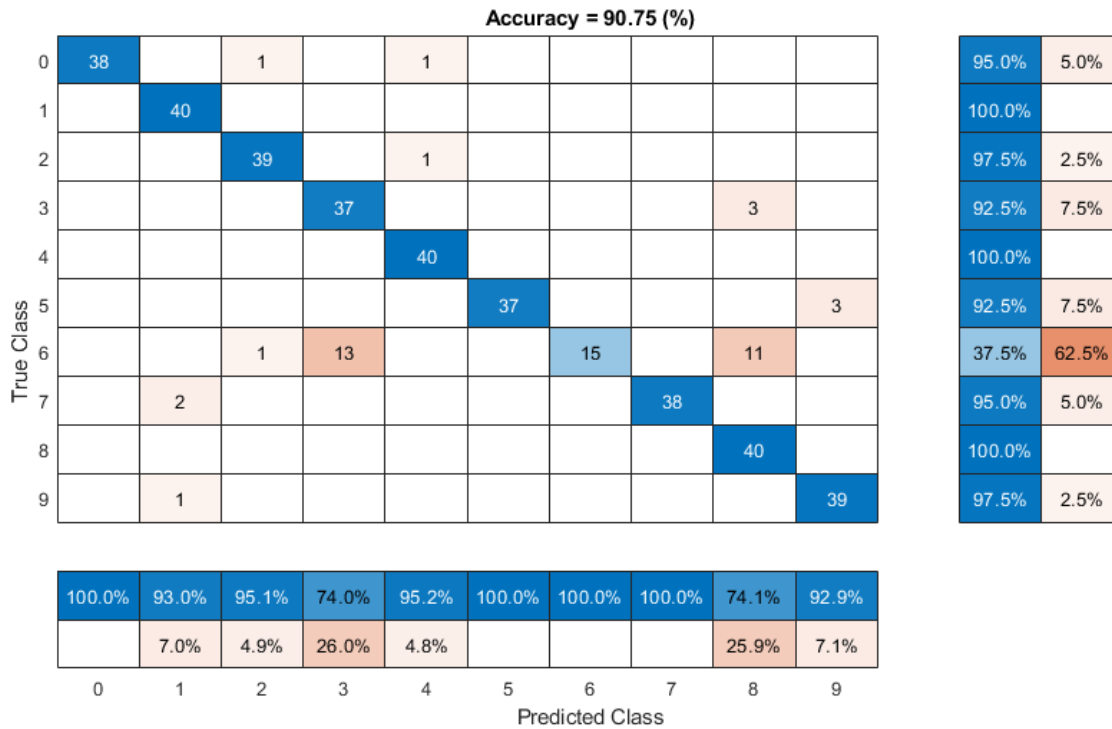
    to = identify(wordRecognizer, audioIn, scorer);

    predictedLabels(ii) = to.Label(1);

end
```

Display a confusion chart of the i-vector system's performance on the validation set.

```
figure(Units="normalized", Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels, predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%)', 100*mean(predictedLabels==trueLabels)))
```



Evaluate Deep Learning Backend Performance

Next, train a fully-connected network using i-vectors as input.

```
ivectorsTrain = (ivector(wordRecognizer,adsTrain))';
ivectorsValidation = (ivector(wordRecognizer,adsValidation))';
```

Define a fully connected network.

```
layers = [ ...
    featureInputLayer(size(ivectorsTrain,2),Normalization="none")
    fullyConnectedLayer(128)
    dropoutLayer(0.4)
    fullyConnectedLayer(256)
    dropoutLayer(0.4)
    fullyConnectedLayer(256)
    dropoutLayer(0.4)
    fullyConnectedLayer(128)
    dropoutLayer(0.4)
    fullyConnectedLayer(numel(unique(adsTrain.Labels)))
    softmaxLayer
    classificationLayer];
```

Define training parameters.

```
miniBatchSize = 256;
validationFrequency = floor(numel(adsTrain.Labels)/miniBatchSize);
options = trainingOptions("adam", ...
    MaxEpochs=10, ...
    MiniBatchSize=miniBatchSize, ...
```

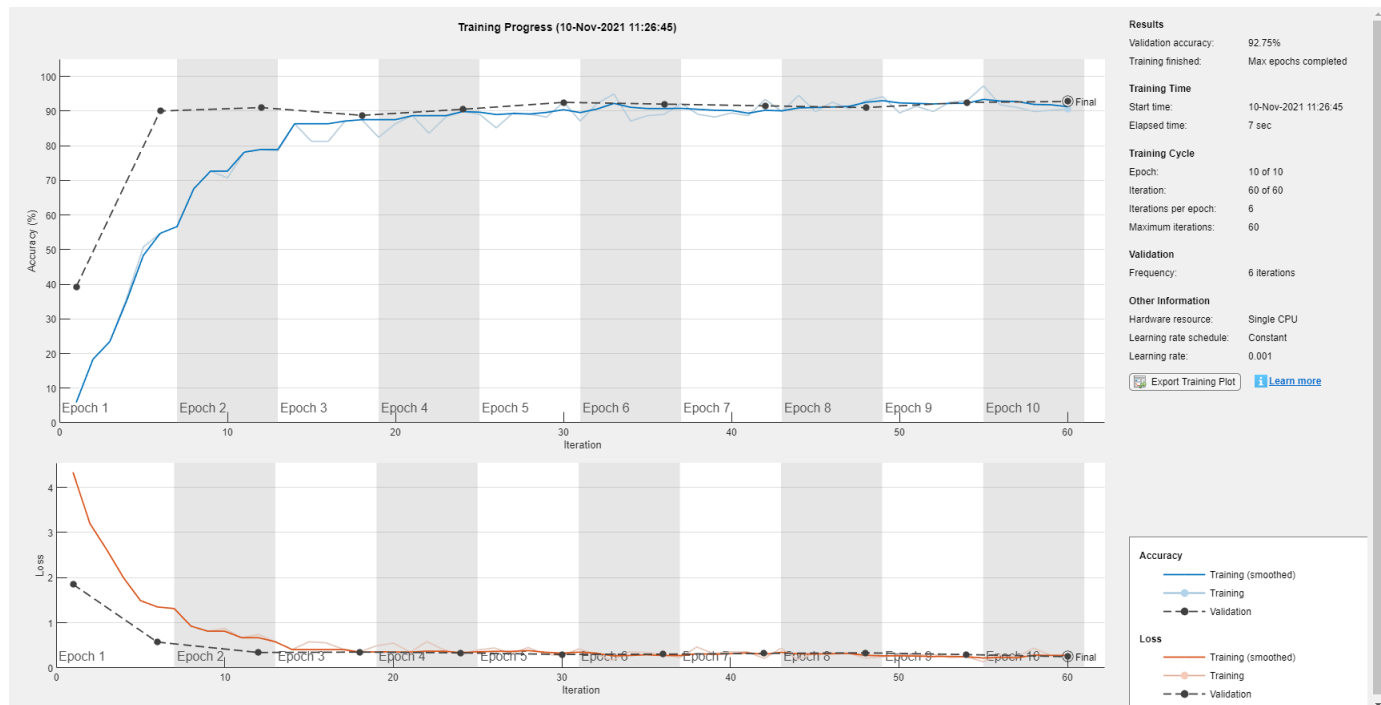
```

Plots="training-progress", ...
Verbose=false, ...
Shuffle="every-epoch", ...
ValidationData={ivectorsValidation,adsValidation.Labels}, ...
ValidationFrequency=validationFrequency);

```

Train the network.

```
net = trainNetwork(ivectorsTrain,adsTrain.Labels, layers, options);
```



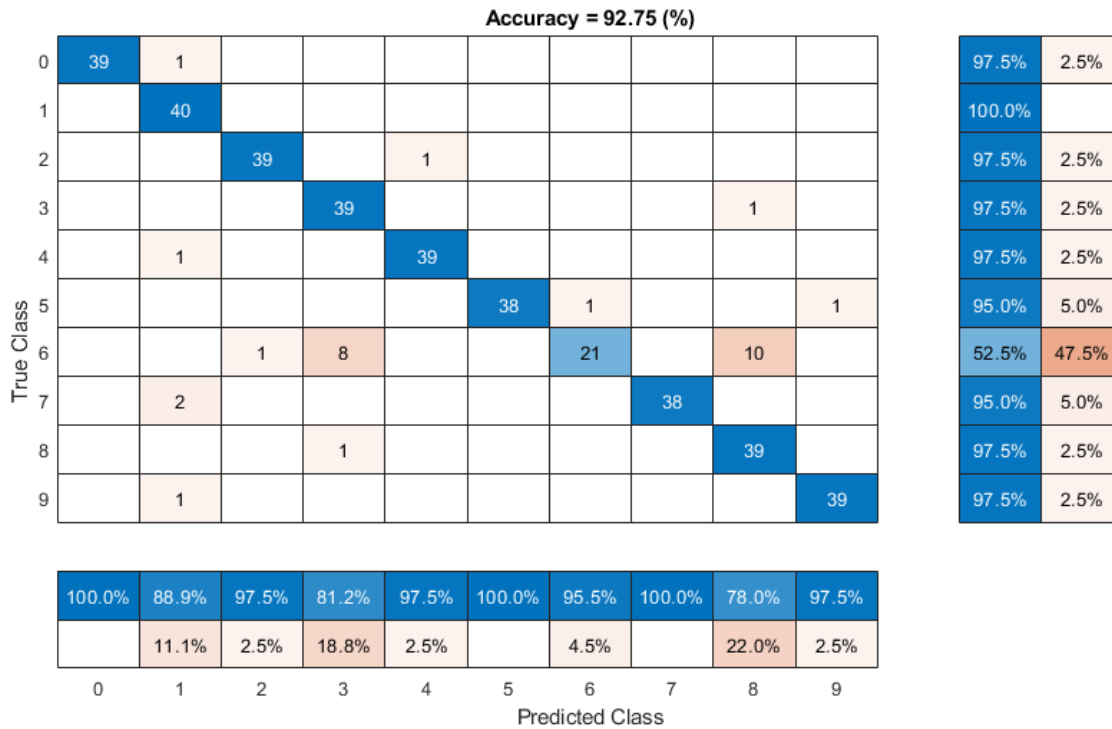
Evaluate the performance of the deep learning backend using a confusion chart.

```

predictedLabels = classify(net,ivectorsValidation);
trueLabels = adsValidation.Labels;

figure(Units="normalized",Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels,predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%)',100*mean(predictedLabels==trueLabels)))

```



Evaluate KNN Backend Performance

Train and evaluate i-vectors with a k -nearest neighbor (KNN) backend.

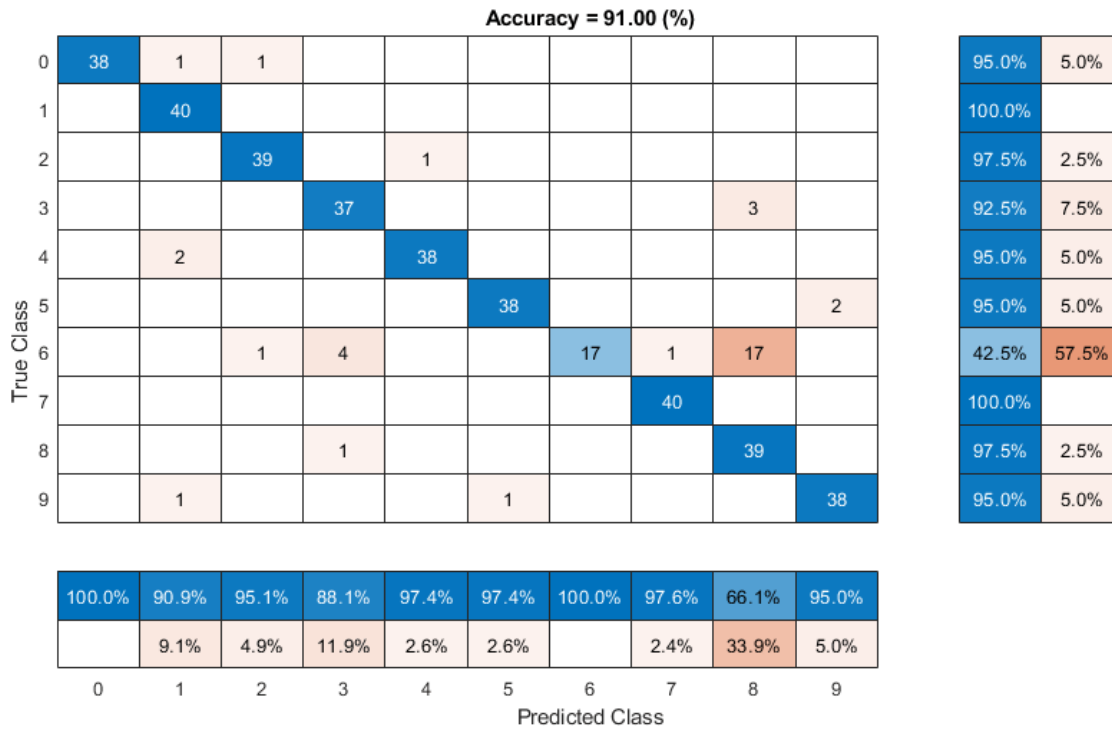
Use `fitcknn` to train a KNN model.

```
classificationKNN = fitcknn(...
    ivectorsTrain, ...
    adsTrain.Labels, ...
    Distance="Euclidean", ...
    Exponent=[], ...
    NumNeighbors=10, ...
    DistanceWeight="SquaredInverse", ...
    Standardize=true, ...
    ClassNames=unique(adsTrain.Labels));
```

Evaluate the KNN backend.

```
predictedLabels = predict(classificationKNN,ivectorsValidation);
trueLabels = adsValidation.Labels;

figure(Units="normalized",Position=[0.2 0.2 0.5 0.5])
confusionchart(trueLabels,predictedLabels, ...
    ColumnSummary="column-normalized", ...
    RowSummary="row-normalized", ...
    Title=sprintf('Accuracy = %0.2f (%)',100*mean(predictedLabels==trueLabels)))
```



References

[1] Jakobovski. "Jakobovski/Free-Spoken-Digit-Dataset." GitHub, May 30, 2019. <https://github.com/Jakobovski/free-spoken-digit-dataset>.

Input Arguments

ivs — i-vector system

ivectorSystem object

i-vector system, specified as an object of type ivectorSystem.

data — Data to transform

column vector | cell array | audioDatastore | signalDatastore | TransformedDatastore

Data to transform, specified as a cell array or as an audioDatastore, signalDatastore, or TransformedDatastore object.

- If InputType is set to "audio" when the i-vector system is created, specify data as one of these:
 - A column vector with underlying type single or double.
 - A cell array of single-channel audio signals, each specified as a column vector with underlying type single or double.
 - An audioDatastore object or a signalDatastore object that points to a data set of mono audio signals.

- A `TransformedDatastore` with an underlying `audioDatastore` or `signalDatastore` that points to a data set of mono audio signals. The output from calls to `read` from the transform datastore must be mono audio signals with underlying data type `single` or `double`.
- If `InputType` is set to "features" when the i-vector system is created, specify `data` as one of these:
 - A matrix with underlying type `single` or `double`. The matrix must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A cell array of matrices with underlying type `single` or `double`. The matrices must consist of audio features where the number of features (columns) is locked the first time `trainExtractor` is called and the number of hops (rows) is variable-sized. The number of features input in any subsequent calls to any of the object functions must be equal to the number of features used when calling `trainExtractor`.
 - A `TransformedDatastore` object with an underlying `audioDatastore` or `signalDatastore` whose `read` function has output as described in the previous bullet.
 - A `signalDatastore` object whose `read` function has output as described in the first bullet.

Data Types: `cell` | `audioDatastore` | `signalDatastore`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1, ..., NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` in quotes.

Example:

```
ivector(ivs,data,ApplyProjectionMatrix=false,ExecutionEnvironment="parallel")
```

ApplyProjectionMatrix — Option to apply projection matrix

`true` | `false`

Option to apply projection matrix, specified as a logical value. This argument specifies whether to apply the linear discriminant analysis (LDA) and within-class covariance normalization (WCCN) projection matrix determined using `trainClassifier`.

- If the projection matrix was trained, then `ApplyProjectionMatrix` defaults to `true`.
- If the projection matrix was not trained, then `ApplyProjectionMatrix` defaults to `false` and cannot be set to `true`.

Data Types: `logical`

ExecutionEnvironment — Hardware resource for execution

"auto" (default) | "cpu" | "gpu" | "multi-gpu" | "parallel"

Hardware resource for execution, specified as one of these:

- "auto" — Use the GPU if it is available. Otherwise, use the CPU.
- "cpu" — Use the CPU.

- "gpu" — Use the GPU. This option requires Parallel Computing Toolbox.
- "multi-gpu" — Use multiple GPUs on one machine, using a local parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts a parallel pool with pool size equal to the number of available GPUs. This option requires Parallel Computing Toolbox.
- "parallel" — Use a local or remote parallel pool based on your default cluster profile. If there is no current parallel pool, the software starts one using the default cluster profile. If the pool has access to GPUs, then only workers with a unique GPU perform training computation. If the pool does not have GPUs, then the training takes place on all available CPU workers. This option requires Parallel Computing Toolbox.

Data Types: char | string

DispatchInBackground — Option to use prefetch queuing

false (default) | true

Option to use prefetch queuing when reading from a datastore, specified as a logical value. This argument requires Parallel Computing Toolbox.

Data Types: logical

Output Arguments

w — i-vectors

column vector | matrix

Extracted i-vectors, returned as a column vector or a matrix. The number of columns of w is equal to the number of input signals. The number of rows of w is the dimension of the i-vector.

See Also

trainExtractor | trainClassifier | calibrate | enroll | unenroll |
detectionErrorTradeoff | verify | identify | info | addInfoHeader | release |
ivectorSystem | speakerRecognition

Introduced in R2021a

info

Return training configuration and data info

Syntax

```
ivInfo = info(ivs)
```

```
info(ivs)
```

Description

`ivInfo = info(ivs)` returns a structure containing information about the `ivs` object.

`info(ivs)`, with no output arguments, displays information about the `ivs` object.

Examples

Train Speaker Verification System

Use the Pitch Tracking Database from Graz University of Technology (PTDB-TUG) [1] on page 4-0 . The data set consists of 20 English native speakers reading 2342 phonetically rich sentences from the TIMIT corpus. Download and extract the data set. Depending on your system, downloading and extracting the data set can take approximately 1.5 hours.

```
url = "https://www2.spsc.tugraz.at/databases/PTDB-TUG/SPEECH_DATA_ZIPPED.zip";
downloadFolder = tempdir;
datasetFolder = fullfile(downloadFolder,"PTDB-TUG");

if ~exist(datasetFolder,"dir")
    disp("Downloading PTDB-TUG (3.9 G) ...")
    unzip(url,datasetFolder)
end
```

Create an `audioDatastore` object that points to the data set. The data set was originally intended for use in pitch-tracking training and evaluation and includes laryngograph readings and baseline pitch decisions. Use only the original audio recordings.

```
ads = audioDatastore([fullfile(datasetFolder,"SPEECH DATA","FEMALE","MIC"),fullfile(datasetFolder,
    IncludeSubfolders=true, ...
    FileExtensions=".wav");
```

The file names contain the speaker IDs. Decode the file names to set the labels in the `audioDatastore` object.

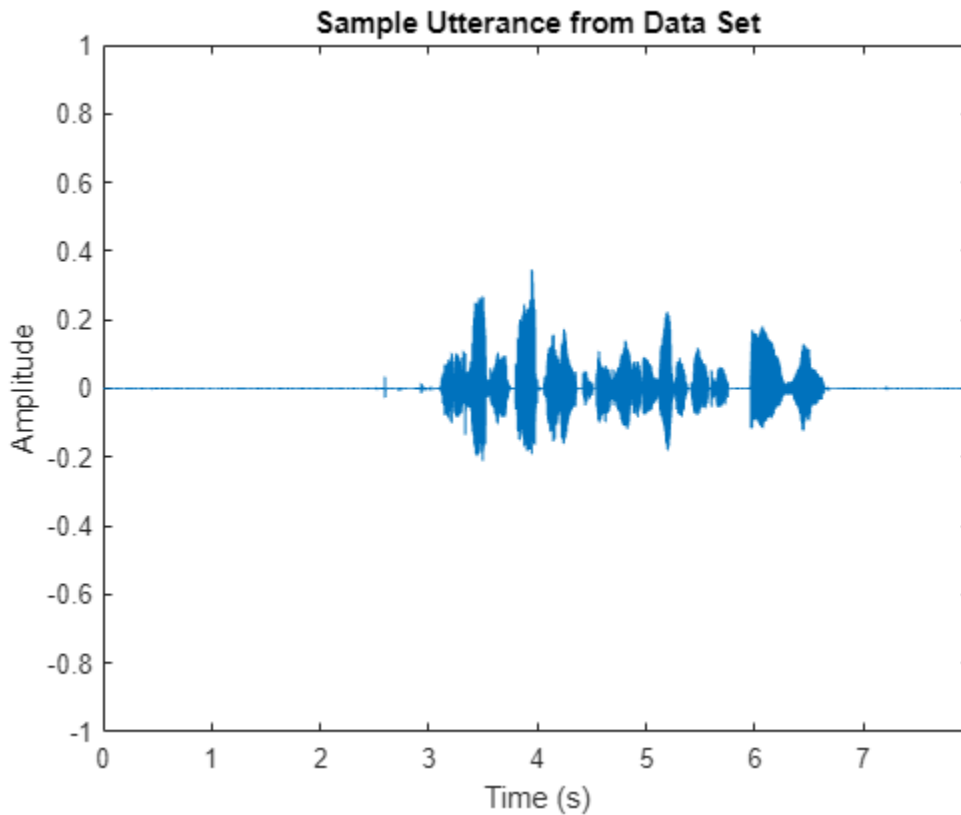
```
ads.Labels = extractBetween(ads.Files,"mic_","_");
countEachLabel(ads)
```

```
ans=20x2 table
    Label    Count
    _____
```


F01	236
F02	236
F03	236
F04	236
F05	236
F06	236
F07	236
F08	234
F09	236
F10	236
M01	236
M02	236
M03	236
M04	236
M05	236
M06	236
:	

Read an audio file from the data set, listen to it, and plot it.

```
[audioIn, audioInfo] = read(ads);  
fs = audioInfo.SampleRate;  
  
t = (0:size(audioIn,1)-1)/fs;  
sound(audioIn, fs)  
plot(t, audioIn)  
xlabel("Time (s)")  
ylabel("Amplitude")  
axis([0 t(end) -1 1])  
title("Sample Utterance from Data Set")
```



Separate the `audioDatastore` object into four: one for training, one for enrollment, one to evaluate the detection-error tradeoff, and one for testing. The training set contains 16 speakers. The enrollment, detection-error tradeoff, and test sets contain the other four speakers.

```
speakersToTest = categorical(["M01", "M05", "F01", "F05"]);
adsTrain = subset(ads, ~ismember(ads.Labels, speakersToTest));
ads = subset(ads, ismember(ads.Labels, speakersToTest));
[adsEnroll, adsTest, adsDET] = splitEachLabel(ads, 3, 1);
```

Display the label distributions of the `audioDatastore` objects.

```
countEachLabel(adsTrain)
```

```
ans=16x2 table
  Label    Count
  _____  _____
  F02      236
  F03      236
  F04      236
  F06      236
  F07      236
  F08      234
  F09      236
  F10      236
  M02      236
```

```

M03      236
M04      236
M06      236
M07      236
M08      236
M09      236
M10      236

```

```
countEachLabel(adsEnroll)
```

```
ans=4x2 table
```

Label	Count
F01	3
F05	3
M01	3
M05	3

```
countEachLabel(adsTest)
```

```
ans=4x2 table
```

Label	Count
F01	1
F05	1
M01	1
M05	1

```
countEachLabel(adsDET)
```

```
ans=4x2 table
```

Label	Count
F01	232
F05	232
M01	232
M05	232

Create an i-vector system. By default, the i-vector system assumes the input to the system is mono audio signals.

```
speakerVerification = ivectorSystem(SampleRate=fs)
```

```
speakerVerification =
  ivectorSystem with properties:
```

```

    InputType: 'audio'
    SampleRate: 48000
    DetectSpeech: 1
    Verbose: 1
    EnrolledLabels: [0x2 table]

```

To train the extractor of the i-vector system, call `trainExtractor`. Specify the number of universal background model (UBM) components as 128 and the number of expectation maximization iterations as 5. Specify the total variability space (TVS) rank as 64 and the number of iterations as 3.

```
trainExtractor(speakerVerification,adsTrain, ...
    UBMNumComponents=128,UBMNumIterations=5, ...
    TVSRank=64,TVSNumIterations=3)
```

```
Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.
```

To train the classifier of the i-vector system, use `trainClassifier`. To reduce dimensionality of the i-vectors, specify the number of eigenvectors in the projection matrix as 16. Specify the number of dimensions in the probabilistic linear discriminant analysis (PLDA) model as 16, and the number of iterations as 3.

```
trainClassifier(speakerVerification,adsTrain,adsTrain.Labels, ...
    NumEigenvectors=16, ...
    PLDANumDimensions=16,PLDANumIterations=3)
```

```
Extracting i-vectors ...done.
Training projection matrix ....done.
Training PLDA model .....done.
i-vector classifier training complete.
```

To calibrate the system so that scores can be interpreted as a measure of confidence in a positive decision, use `calibrate`.

```
calibrate(speakerVerification,adsTrain,adsTrain.Labels)
```

```
Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibrating PLDA scorer ...done.
Calibration complete.
```

To inspect parameters used previously to train the i-vector system, use `info`.

```
info(speakerVerification)
```

```
i-vector system input
Input feature vector length: 60
Input data type: double
```

```
trainExtractor
Train signals: 3774
UBMNumComponents: 128
UBMNumIterations: 5
TVSRank: 64
TVSNumIterations: 3
```

```
trainClassifier
Train signals: 3774
Train labels: F02 (236), F03 (236) ... and 14 more
NumEigenvectors: 16
PLDANumDimensions: 16
PLDANumIterations: 3
```

```
calibrate
  Calibration signals: 3774
  Calibration labels: F02 (236), F03 (236) ... and 14 more
```

Split the enrollment set.

```
[adsEnrollPart1,adsEnrollPart2] = splitEachLabel(adsEnroll,1,2);
```

To enroll speakers in the i-vector system, call `enroll`.

```
enroll(speakerVerification,adsEnrollPart1,adsEnrollPart1.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

When you enroll speakers, the read-only `EnrolledLabels` property is updated with the enrolled labels and corresponding template i-vectors. The table also keeps track of the number of signals used to create the template i-vector. Generally, using more signals results in a better template.

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          1
  F05      {16x1 double}          1
  M01      {16x1 double}          1
  M05      {16x1 double}          1
```

Enroll the second part of the enrollment set and then view the enrolled labels table again. The i-vector templates and the number of samples are updated.

```
enroll(speakerVerification,adsEnrollPart2,adsEnrollPart2.Labels)
```

```
Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.
```

```
speakerVerification.EnrolledLabels
```

```
ans=4x2 table
           ivector      NumSamples
           _____      _____
  F01      {16x1 double}          3
  F05      {16x1 double}          3
  M01      {16x1 double}          3
  M05      {16x1 double}          3
```

To evaluate the i-vector system and determine a decision threshold for speaker verification, call `detectionErrorTradeoff`.

```
[results, eerThreshold] = detectionErrorTradeoff(speakerVerification,adsDET,adsDET.Labels);
```

```

Extracting i-vectors ...done.
Scoring i-vector pairs ...done.
Detection error tradeoff evaluation complete.

```

The first output from `detectionErrorTradeoff` is a structure with two fields: CSS and PLDA. Each field contains a table. Each row of the table contains a possible decision threshold for speaker verification tasks, and the corresponding false alarm rate (FAR) and false rejection rate (FRR). The FAR and FRR are determined using the enrolled speaker labels and the data input to the `detectionErrorTradeoff` function.

```
results
```

```

results = struct with fields:
  PLDA: [1000x3 table]
  CSS: [1000x3 table]

```

```
results.CSS
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
1.7736e-09	1	0
1.8233e-09	0.99964	0
1.8745e-09	0.99964	0
1.927e-09	0.99964	0
1.9811e-09	0.99964	0
2.0366e-09	0.99964	0
2.0937e-09	0.99964	0
2.1524e-09	0.99964	0
2.2128e-09	0.99964	0
2.2748e-09	0.99964	0
2.3386e-09	0.99964	0
2.4042e-09	0.99964	0
2.4716e-09	0.99964	0
2.5409e-09	0.99964	0
2.6122e-09	0.99964	0
2.6854e-09	0.99964	0
:		

```
results.PLDA
```

```
ans=1000x3 table
```

Threshold	FAR	FRR
4.7045e-34	1	0
5.143e-34	0.99964	0
5.6225e-34	0.99964	0
6.1466e-34	0.99964	0
6.7197e-34	0.99964	0
7.3461e-34	0.99964	0
8.0309e-34	0.99964	0
8.7796e-34	0.99964	0
9.5981e-34	0.99964	0
1.0493e-33	0.99964	0
1.1471e-33	0.99964	0

```

1.254e-33    0.99964    0
1.371e-33    0.99964    0
1.4988e-33   0.99964    0
1.6385e-33   0.99964    0
1.7912e-33   0.99964    0
⋮

```

The second output from `detectionErrorTradeoff` is a structure with two fields: `CSS` and `PLDA`. The corresponding value is the decision threshold that results in the equal error rate (when FAR and FRR are equal).

`eerThreshold`

```

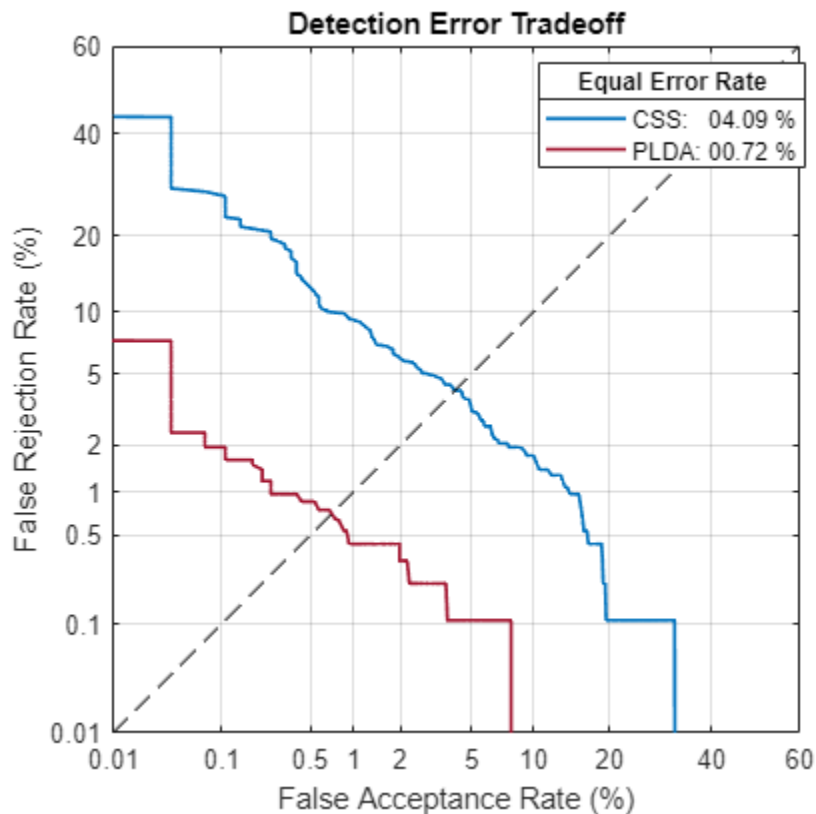
eerThreshold = struct with fields:
  PLDA: 0.0021
  CSS: 0.9366

```

The first time you call `detectionErrorTradeoff`, you must provide data and corresponding labels to evaluate. Subsequently, you can get the same information, or a different analysis using the same underlying data, by calling `detectionErrorTradeoff` without data and labels.

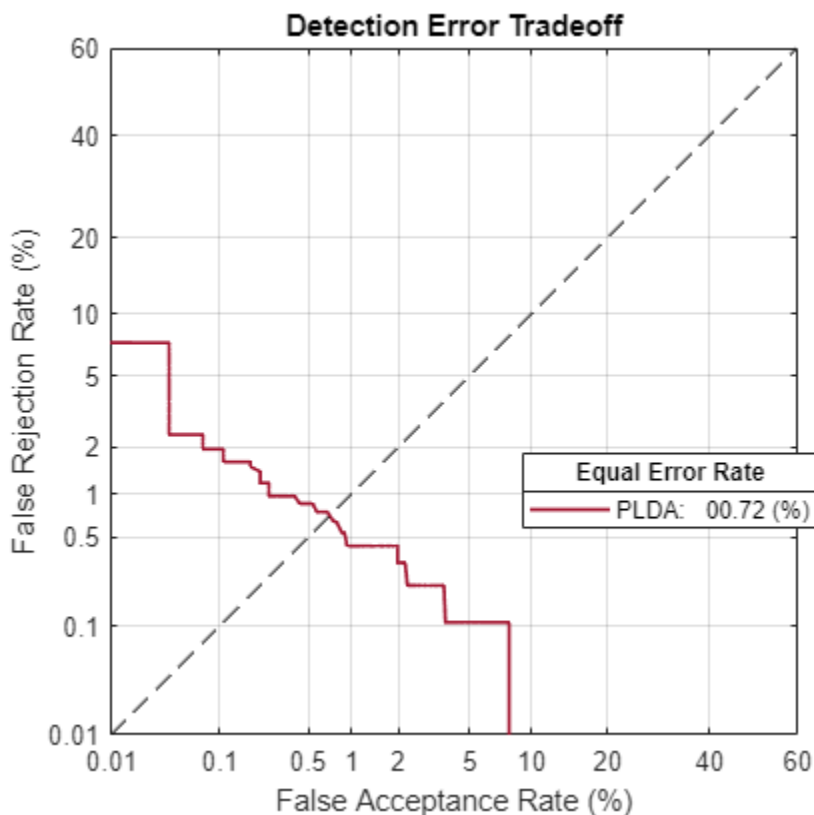
Call `detectionErrorTradeoff` a second time with no data arguments or output arguments to visualize the detection-error tradeoff.

`detectionErrorTradeoff(speakerVerification)`



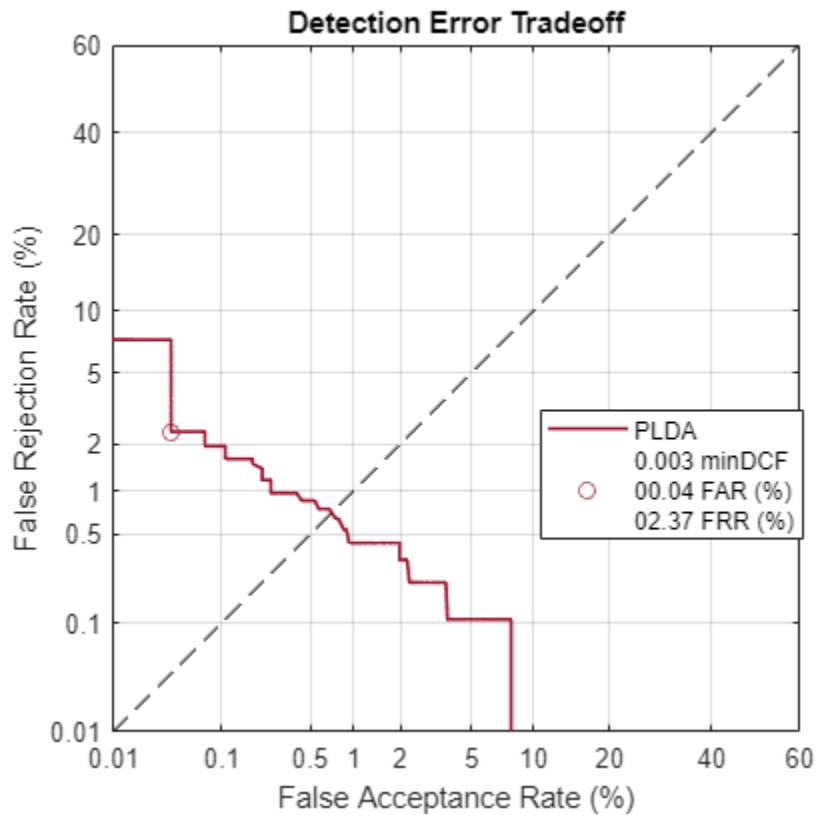
Call `detectionErrorTradeoff` again. This time, visualize only the detection-error tradeoff for the PLDA scorer.

```
detectionErrorTradeoff(speakerVerification, Scorer="plda")
```



Depending on your application, you may want to use a threshold that weights the error cost of a false alarm higher or lower than the error cost of a false rejection. You may also be using data that is not representative of the prior probability of the speaker being present. You can use the `minDCF` parameter to specify custom costs and prior probability. Call `detectionErrorTradeoff` again, this time specify the cost of a false rejection as 1, the cost of a false acceptance as 2, and the prior probability that a speaker is present as 0.1.

```
costFR = 1;
costFA = 2;
priorProb = 0.1;
detectionErrorTradeoff(speakerVerification, Scorer="plda", minDCF=[costFR, costFA, priorProb])
```

Call `detectionErrorTradeoff` again. This time, get the `minDCF` threshold for the PLDA scorer and the parameters of the detection cost function.

```
[~,minDCFThreshold] = detectionErrorTradeoff(speakerVerification,Scorer="plda",minDCF=[costFR,cos
minDCFThreshold = 0.0595
```

Test Speaker Verification System

Read a signal from the test set.

```
adsTest = shuffle(adsTest);
[audioIn,audioInfo] = read(adsTest);
knownSpeakerID = audioInfo.Label
```

```
knownSpeakerID = 1x1 cell array
    {'F05'}
```

To perform speaker verification, call `verify` with the audio signal and specify the speaker ID, a scorer, and a threshold for the scorer. The `verify` function returns a logical value indicating whether a speaker identity is accepted or rejected, and a score indicating the similarity of the input audio and the template i-vector corresponding to the enrolled label.

```
[tf,score] = verify(speakerVerification,audioIn,knownSpeakerID,"plda",eerThreshold.PLDA);
if tf
    fprintf('Success!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
```

```
    fprintf('Failure!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker accepted.
Similarity score = 1.00

Call speaker verification again. This time, specify an incorrect speaker ID.

possibleSpeakers = speakerVerification.EnrolledLabels.Properties.RowNames;
imposterIdx = find(~ismember(possibleSpeakers,knownSpeakerID));
imposter = possibleSpeakers(imposterIdx(randperm(numel(imposterIdx),1)))

imposter = 1x1 cell array
    {'F01'}

[tf,score] = verify(speakerVerification,audioIn,imposter,"plda",eerThreshold.PLDA);
if tf
    fprintf('Failure!\nSpeaker accepted.\nSimilarity score = %0.2f\n\n',score)
else
    fprintf('Success!\nSpeaker rejected.\nSimilarity score = %0.2f\n\n',score)
end

Success!
Speaker rejected.
Similarity score = 0.00
```

References

[1] Signal Processing and Speech Communication Laboratory. <https://www.spsc.tugraz.at/databases-and-tools/ptdb-tug-pitch-tracking-database-from-graz-university-of-technology.html>. Accessed 12 Dec. 2019.

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

Output Arguments

ivInfo — i-vector information

structure

Information about how the i-vector system was trained and evaluated, returned as a structure.

Data Types: `struct`

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `unenroll` | `enroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `addInfoHeader` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021a

addInfoHeader

Add custom information about i-vector system

Syntax

```
addInfoHeader(ivs, str)
addInfoHeader(ivs)
```

Description

`addInfoHeader(ivs, str)` adds a field called `Header` to the structure output by `info(ivs)` and populates it with `str`.

`addInfoHeader(ivs)` clears the custom information from the i-vector system `ivs`.

Examples

Add Custom Header Information

Create a default i-vector system.

```
ivs = ivectorSystem;
```

Add custom header information to the object. Use the `info` function to display the information.

```
addInfoHeader(ivs, 'Custom Header Information')
```

```
info(ivs)
```

```
Header
  Custom Header Information
```

Input Arguments

ivs — i-vector system

`ivectorSystem` object

i-vector system, specified as an object of type `ivectorSystem`.

str — Custom information

character vector | string scalar

Custom information about i-vector system, specified as a character vector or string scalar.

Data Types: `char` | `string`

See Also

`trainExtractor` | `trainClassifier` | `unenroll` | `enroll` | `detectionErrorTradeoff` | `verify` | `identify` | `ivector` | `info` | `release` | `ivectorSystem` | `speakerRecognition`

Introduced in R2021b

release

Allow property values and input characteristics to change

Syntax

```
release(ivs)
```

Description

`release(ivs)` allows property values and input characteristics of the i-vector system `ivs` to change.

Examples

Train Environmental Sound Classification System

Download and unzip the environment sound classification data set. This data set consists of recordings labeled as one of 10 different audio sound classes (ESC-10).

```
loc = matlab.internal.examples.downloadSupportFile("audio","ESC-10.zip");
unzip(loc,pwd)
```

Create an `audioDatastore` object to manage the data and split it into training and validation sets. Call `countEachLabel` to display the distribution of sound classes and the number of unique labels.

```
ads = audioDatastore(pwd,IncludeSubfolders=true,LabelSource="foldernames");
countEachLabel(ads)
```

```
ans=10×2 table
      Label      Count
-----
chainsaw      40
clock_tick    40
crackling_fire 40
crying_baby   40
dog           40
helicopter    40
rain          40
rooster       38
sea_waves     40
sneezing      40
```

Listen to one of the files.

```
[audioIn,audioInfo] = read(ads);
fs = audioInfo.SampleRate;
sound(audioIn,fs)
audioInfo.Label
```

```
ans = categorical
      chainsaw
```

Split the datastore into training and test sets.

```
[adsTrain,adsTest] = splitEachLabel(ads,0.8);
```

Create an `audioFeatureExtractor` to extract all possible features from the audio.

```
afe = audioFeatureExtractor(SampleRate=fs, ...
    Window=hamming(round(0.03*fs),"periodic"), ...
    OverlapLength=round(0.02*fs));
params = info(afe,"all");
params = structfun(@(x)true,params,UniformOutput=false);
set(afe,params);
afe
```

```
afe =
  audioFeatureExtractor with properties:
```

Properties

```
      Window: [1323x1 double]
  OverlapLength: 882
      SampleRate: 44100
      FFTLength: []
SpectralDescriptorInput: 'linearSpectrum'
  FeatureVectorLength: 862
```

Enabled Features

```
linearSpectrum, melSpectrum, barkSpectrum, erbSpectrum, mfcc, mfccDelta
mfccDeltaDelta, gtcc, gtccDelta, gtccDeltaDelta, spectralCentroid, spectralCrest
spectralDecrease, spectralEntropy, spectralFlatness, spectralFlux, spectralKurtosis, spectralSkewness, spectralSlope, spectralSpread, pitch, harmonicRatio, zerocrossrate
shortTimeEnergy
```

Disabled Features

```
none
```

To extract a feature, set the corresponding property to true.

For example, `obj.mfcc = true`, adds `mfcc` to the list of enabled features.

Create two directories in your current folder: `train` and `test`. Extract features from the training and the test data sets and write the features as MAT files to the respective directories. Pre-extracting features can save time when you want to evaluate different feature combinations or training configurations.

```
if ~isdir("train")
    mkdir("train")
    mkdir("test")

    outputType = ".mat";
    writeall(adsTrain,"train",WriteFcn=@(x,y,z)writeFeatures(x,y,z,afe))
    writeall(adsTest,"test",WriteFcn=@(x,y,z)writeFeatures(x,y,z,afe))
end
```

Create signal datastores to point to the audio features.

```
sdsTrain = signalDatastore("train",IncludeSubfolders=true);
sdsTest = signalDatastore("test",IncludeSubfolders=true);
```

Create label arrays that are in the same order as the signalDatastore files.

```
labelsTrain = categorical(extractBetween(sdsTrain.Files,"ESC-10"+filesep,filesep));
labelsTest = categorical(extractBetween(sdsTest.Files,"ESC-10"+filesep,filesep));
```

Create a transform datastore from the signal datastores to isolate and use only the desired features. You can use the output from `info` on the `audioFeatureExtractor` to map your chosen features to the index in the features matrix. You can experiment with the example by choosing different features.

```
featureIndices = info(afe)
```

```
featureIndices = struct with fields:
```

```
    linearSpectrum: [1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100]
    melSpectrum: [663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    barkSpectrum: [695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    erbSpectrum: [727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782]
    mfcc: [770 771 772 773 774 775 776 777 778 779 780 781 782]
    mfccDelta: [783 784 785 786 787 788 789 790 791 792 793 794 795]
    mfccDeltaDelta: [796 797 798 799 800 801 802 803 804 805 806 807 808]
    gtcc: [809 810 811 812 813 814 815 816 817 818 819 820 821]
    gtccDelta: [822 823 824 825 826 827 828 829 830 831 832 833 834]
    gtccDeltaDelta: [835 836 837 838 839 840 841 842 843 844 845 846 847]
    spectralCentroid: 848
    spectralCrest: 849
    spectralDecrease: 850
    spectralEntropy: 851
    spectralFlatness: 852
    spectralFlux: 853
    spectralKurtosis: 854
    spectralRolloffPoint: 855
    spectralSkewness: 856
    spectralSlope: 857
    spectralSpread: 858
    pitch: 859
    harmonicRatio: 860
    zerocrossrate: 861
    shortTimeEnergy: 862
```

```
idxToUse = [...
    featureIndices.harmonicRatio ...
    ,featureIndices.spectralRolloffPoint ...
    ,featureIndices.spectralFlux ...
    ,featureIndices.spectralSlope ...
];
tdsTrain = transform(sdsTrain,@(x)x(:,idxToUse));
tdsTest = transform(sdsTest,@(x)x(:,idxToUse));
```

Create an i-vector system that accepts feature input.

```
soundClassifier = ivectorSystem(InputType="features");
```

Train the extractor and classifier using the training set.

```
trainExtractor(soundClassifier,tdsTrain,UBMNumComponents=128,TVSRank=64);
```



```

Calculating standardization factors ....done.
Training universal background model .....done.
Training total variability space .....done.
i-vector extractor training complete.

```

```
trainClassifier(soundClassifier,tdsTrain,labelsTrain,NumEigenvectors=32,PLDANumIterations=0)
```

```

Extracting i-vectors ...done.
Training projection matrix .....done.
i-vector classifier training complete.

```

Enroll the labels from the training set to create i-vector templates for each of the environmental sounds.

```
enroll(soundClassifier,tdsTrain,labelsTrain)
```

```

Extracting i-vectors ...done.
Enrolling i-vectors .....done.
Enrollment complete.

```

Calibrate the i-vector system.

```
calibrate(soundClassifier,tdsTrain,labelsTrain)
```

```

Extracting i-vectors ...done.
Calibrating CSS scorer ...done.
Calibration complete.

```

Use the `identify` function on the test set to return the system's inferred label.

```

inferredLabels = labelsTest;
inferredLabels(:) = inferredLabels(1);
for ii = 1:numel(labelsTest)
    features = read(tdsTest);
    tableOut = identify(soundClassifier,features,"css",NumCandidates=1);
    inferredLabels(ii) = tableOut.Label(1);
end

```

Create a confusion matrix to visualize performance on the test set.

```

uniqueLabels = unique(labelsTest);
cm = zeros(numel(uniqueLabels),numel(uniqueLabels));
for ii = 1:numel(uniqueLabels)
    for jj = 1:numel(uniqueLabels)
        cm(ii,jj) = sum((labelsTest==uniqueLabels(ii)) & (inferredLabels==uniqueLabels(jj)));
    end
end
labelStrings = replace(string(uniqueLabels),"_"," ");
heatmap(labelStrings,labelStrings,cm)
colorbar off
ylabel("True Labels")
xlabel("Predicted Labels")
accuracy = mean(inferredLabels==labelsTest);
title(sprintf("Accuracy = %0.2f %%",accuracy*100))

```

Accuracy = 73.75 %

True Labels	chainsaw	7	0	0	0	0	1	0	0	0	0
	clock tick	0	7	1	0	0	0	0	0	0	0
	crackling fire	0	1	4	0	0	1	1	0	1	0
	crying baby	0	0	0	8	0	0	0	0	0	0
	dog	0	0	0	0	7	0	0	1	0	0
	helicopter	1	1	0	0	0	6	0	0	0	0
	rain	0	1	0	0	0	0	7	0	0	0
	rooster	0	0	0	1	4	0	0	3	0	0
	sea waves	0	0	0	0	0	1	1	0	6	0
	sneezing	0	0	0	1	1	0	0	2	0	4
		Predicted Labels									

Release the i-vector system.

```
release(soundClassifier)
```

Supporting Functions

```
function writeFeatures(audioIn,info,~,afe)
    % Convert to single-precision
    audioIn = single(audioIn);

    % Extract features
    features = extract(afe,audioIn);

    % Replace the file extension of the suggested output name with MAT.
    filename = strrep(info.SuggestedOutputName, ".wav", ".mat");

    % Save the MFCC coefficients to the MAT file.
    save(filename, "features")
end
```

Input Arguments

ivs — i-vector system

ivectorSystem object

i-vector system, specified as an object of type ivectorSystem.

See Also

`trainExtractor` | `trainClassifier` | `calibrate` | `enroll` | `unenroll` |
`detectionErrorTradeoff` | `verify` | `identify` | `info` | `addInfoHeader` | `ivector` |
`ivectorSystem` | `speakerRecognition`

Introduced in R2021a

Blocks

Voice Activity Detector

Detect presence of speech in audio signal

Library: Audio Toolbox / Measurements



Description

The Voice Activity Detector block detects the presence of speech in an audio signal. You can also use the Voice Activity Detector block to output an estimate of the noise variance per frequency bin.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

SilenceToSpeech — Threshold (dB)

scalar in the range [0, 1]

Dependencies

To enable this port, select **Specify silence-to-speech probability from input port** for the “Probability of transition from a silence frame to a speech frame” on page 5-0 parameter.

Data Types: `single` | `double`

SpeechToSilence — Threshold (dB)

scalar in the range [0, 1]

Dependencies

To enable this port, select **Specify speech-to-silence probability from input port** for the “Probability of transition from a speech frame to a silence frame” on page 5-0 parameter.

Data Types: `single` | `double`

Output

P — Probability that speech is present

scalar | row vector

The block outputs a scalar or row vector with the same number of columns as the input signal.

This port is unnamed until you select the **Output noise variance** parameter.

Data Types: single | double

N — Estimate of noise variance per frequency bin

column vector | matrix

The block outputs a column vector or a matrix with the same number of columns as the input signal.

Dependencies

To enable this port, select the **Output noise variance** parameter.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Domain of the input — Domain of the input

Time (default) | Frequency

Window — Windowing function applied before FFT

Hann (default) | Chebyshev | Flat Top | Hamming | Kaiser | Rectangular

The window function is designed using the algorithms of the following functions:

- Hann -- hann
- Chebyshev -- chebwin
- Flat Top -- flattopwin
- Hamming -- hamming
- Kaiser -- kaiser

Tunable: No

Dependencies

To enable this parameter, set **Domain of the input** to Time.

Sidelobe attenuation of the window (dB) — Sidelobe attenuation of the window (dB)

60 (default) | positive finite scalar

Dependencies

To enable this parameter, set **Domain of the input** to Time and **Window** to Chebyshev or Kaiser.

Data Types: single | double

Inherit FFT length from input dimensions — Set FFT length to number of input samples

on (default) | off

Tunable: No

Dependencies

To enable this parameter, set **Domain of the input** to Time.

FFT length — Number of bins in frequency domain

1024 (default) | positive integer

Tunable: No**Dependencies**

To enable this parameter, set **Domain of the input** to Time and clear the **Inherit FFT length from input dimensions** parameter.

Data Types: single | double

Probability of transition from a silence frame to a speech frame — Probability that a speech frame follows a silence frame

0.2 (default) | scalar in the range [0,1]

To specify **Probability of transition from a silence frame to a speech frame** from an input port, select **Specify silence-to-speech probability from input port**.

Tunable: Yes

Data Types: single | double

Probability of transition from a speech frame to a silence frame — Probability that a silence frame follows a speech frame

0.1 (default) | scalar in the range [0,1]

To specify **Probability of transition from a speech frame to a silence frame** from an input port, select **Specify speech-to-silence probability from input port**.

Tunable: Yes

Data Types: single | double

Output noise variance — Output estimate of noise variance per frequency bin

off (default) | on

When you select this parameter, an additional output port, N, is added to the block.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** - Simulate the model using generated C code. The first time you run a simulation, Simulink® generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** - Simulate the model using the MATLAB interpreter. This option reduces startup time, but has a slower simulation speed than **Code generation**. In this mode, you can debug the source code of the block.

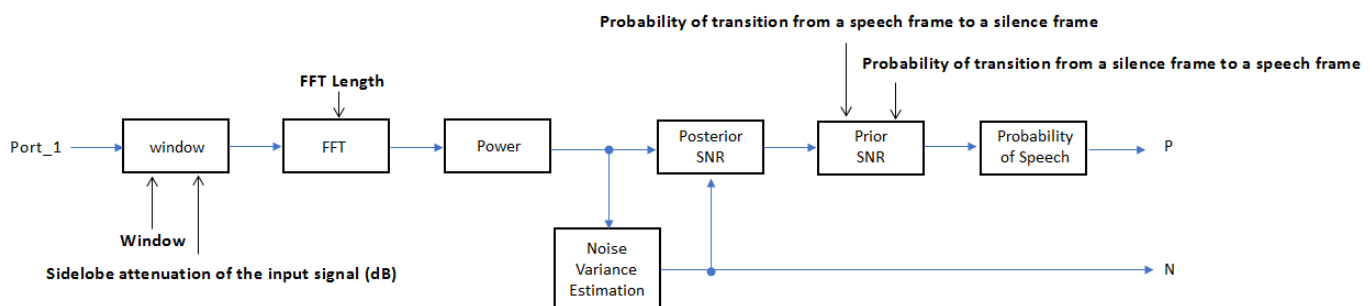
Tunable: No**Block Characteristics**

Data Types	double single
-------------------	-----------------

Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

The Voice Activity Detector implements the algorithm described in [1].



If **Domain of the input** is specified as Time, the input signal is windowed and then converted to the frequency domain according to the **Window**, **Sidelobe attenuation of the window (dB)**, and **FFT length** parameters. If **Domain of the input** is specified as Frequency, the input is assumed to be a windowed discrete time Fourier transform (DTFT) of an audio signal. The signal is then converted to the power domain. Noise variance is estimated according to [2]. The posterior and prior SNR are estimated according to the Minimum Mean-Square Error (MMSE) formula described in [3]. A log likelihood ratio test with a Hidden Markov Model (HMM)-based hang-over scheme is used, according to [1].

References

- [1] Sohn, Jongseo., Nam Soo Kim, and Wonyong Sung. "A Statistical Model-Based Voice Activity Detection." *Signal Processing Letters IEEE*. Vol. 6, No. 1, 1999.
- [2] Martin, R. "Noise Power Spectral Density Estimation Based on Optimal Smoothing and Minimum Statistics." *IEEE Transactions on Speech and Audio Processing*. Vol. 9, No. 5, 2001, pp. 504-512.
- [3] Ephraim, Y., and D. Malah. "Speech Enhancement Using a Minimum Mean-Square Error Short-Time Spectral Amplitude Estimator." *IEEE Transactions on Acoustics, Speech, and Signal Processing*. Vol. 32, No. 6, 1984, pp. 1109-1121.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

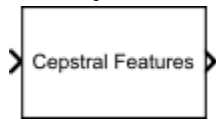
voiceActivityDetector

Introduced in R2018a

Cepstral Feature Extractor

Extract cepstral features from audio segment

Library: Audio Toolbox / Measurements



Description

The Cepstral Feature Extractor block extracts cepstral features from an audio segment. Cepstral features are commonly used to characterize speech and music signals.

Ports

Input

Port_1 — Audio input to cepstral feature extractor

column vector | matrix

Audio input to the cepstral feature extractor, specified as a column vector or a matrix. If specified as a matrix, the columns are treated as independent audio channels.

Data Types: single | double

Output

coeffs — Cepstral coefficients

column vector | matrix

Cepstral coefficients, returned as a column vector or a matrix. If the coefficients matrix is an N -by- M matrix, N is determined by the values you specify in the **Number of coefficients to return** and **Log energy usage** parameters. M equals the number of input audio channels.

When the **Log energy usage** parameter is set to:

- **Append** -- The block prepends the log energy value to the coefficients vector. The length of the coefficients vector is $1 + NumCoeffs$, where $NumCoeffs$ is the value specified in the **Number of coefficients to return** parameter.
- **Replace** -- The block replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is $NumCoeffs$.
- **Ignore** -- The block does not calculate or return the log energy.

This port is unnamed until you select **Output delta** parameter, the **Output delta-delta** parameter, or both.

Data Types: single | double

delta — Change in coefficients

column vector | matrix

Change in coefficients over consecutive calls to the algorithm, returned as a column vector or a matrix. The **delta** array is of the same size and data type as the **coeffs** array.

Dependencies

To enable this port, select the **Output delta** parameter.

Data Types: `single` | `double`

deltaDelta — Change in delta values

column vector | matrix

Change in **delta** values over consecutive calls to the algorithm, returned as a column vector or a matrix. The **deltaDelta** array is the same size and data type as the **coeffs** and **delta** arrays.

Dependencies

To enable this port, select the **Output delta-delta** parameter.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Filter bank type — Type of filter bank

Mel (default) | Gammatone

Type of filter bank, specified as either Mel or Gammatone:

- Mel -- The block computes the mel frequency cepstral coefficients (MFCC).
- Gammatone -- The block computes the gammatone cepstral coefficients (GTCC).

Tunable: No

Domain of the input signal — Input signal domain

Time (default) | Frequency

Input signal domain, specified as either Time or Frequency.

Tunable: No

Number of coefficients to return — Number of coefficients to return

13 (default) | positive integer

Number of coefficients to return, specified as an integer in the range $[2, v]$, where v is the number of valid passbands. The number of valid passbands depends on the type of filter bank:

- Mel -- The number of valid passbands is defined as $\text{sum}(\kappa \leq \text{floor}(fs/2)) - 2$, where κ is the number of band edges in the mel filter bank and fs is the sample rate.
- Gammatone -- The number of valid passbands is defined as $\text{ceil}(\text{hz2erb}(R(2)) - \text{hz2erb}(R(1)))$, where R is the frequency range of the gammatone filter bank.

Tunable: No

Data Types: `single` | `double`

Nonlinear rectification — Type of nonlinear rectification

Log (default) | Cubic-Root

Type of nonlinear rectification applied prior to the discrete cosine transform.

Tunable: No**Inherit FFT length from input dimensions — Inherit FFT length from input**

on (default) | off

When you select this parameter, the FFT length is equal to the number of rows in the input signal.

Tunable: No**Dependencies**

To enable this parameter, set **Domain of the input signal** to Time.

FFTLength — FFT length

[] (default) | positive integer

FFT length, specified as a positive integer. The default, [], means that the FFT length is equal to the number of rows in the input signal.

Tunable: No**Dependencies**

To enable this parameter, set **Domain of the input signal** to Time and select the **Inherit FFT length from input dimensions** parameter.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Log energy usage — Specify how the log energy is shown

Append (default) | Replace | Ignore

Specify how the log energy is shown in the coefficients vector output, specified as:

- **Append** -- The block prepends the log energy to the coefficients vector. The length of the coefficients vector is $1 + NumCoeffs$, where *NumCoeffs* is the value specified in the **Number of coefficients to return** parameter.
- **Replace** -- The block replaces the first coefficient with the log energy of the signal. The length of the coefficients vector is *NumCoeffs*.
- **Ignore** -- The block does not calculate or return the log energy.

Tunable: No**Output delta — Output delta values**

off (default) | on

When you select this parameter, an additional output port, **delta**, is added to the block. This port outputs the change in coefficients over consecutive calls to the algorithm.

Tunable: No**Output delta-delta — Output delta-delta values**

off (default) | on

When you select this parameter, an additional output port, **deltaDelta**, is added to the block. This port outputs the change in delta values over consecutive calls to the algorithm.

Tunable: No

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)** parameter.

Tunable: No

Input sample rate (Hz) — Sample rate of input

16000 (default) | positive scalar

Input sample rate in Hz, specified as a real positive scalar.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than **Code generation**. In this mode, you can debug the source code of the block.

Tunable: No

Advanced Tab

Gammatone frequency range (Hz) — Frequency range of gammatone filter bank (Hz)

[50 8000] (default) | two-element row vector

Frequency range of the gammatone filter bank in Hz, specified as a positive, monotonically increasing two-element row vector. The maximum frequency range can be any finite number. The center frequencies of the filter bank are equally spaced across the frequency range on the ERB scale.

Tunable: No

Dependencies

To enable this parameter, set **Filter bank type** to Gammatone.

Band edges of Mel filter bank (Hz) — Band edges of mel filter bank

row vector

Band edges of the filter bank in Hz, specified as a nonnegative monotonically increasing row vector in the range $[0, \infty)$. The maximum bandedge frequency can be any finite number. The number of bandedges must be in the range $[4, 80]$.

The default band edges are spaced linearly for the first ten and then logarithmically thereafter. The default band edges are set as recommended by [1].

Tunable: No

Dependencies

To enable this parameter, set **Filter bank type** to Mel.

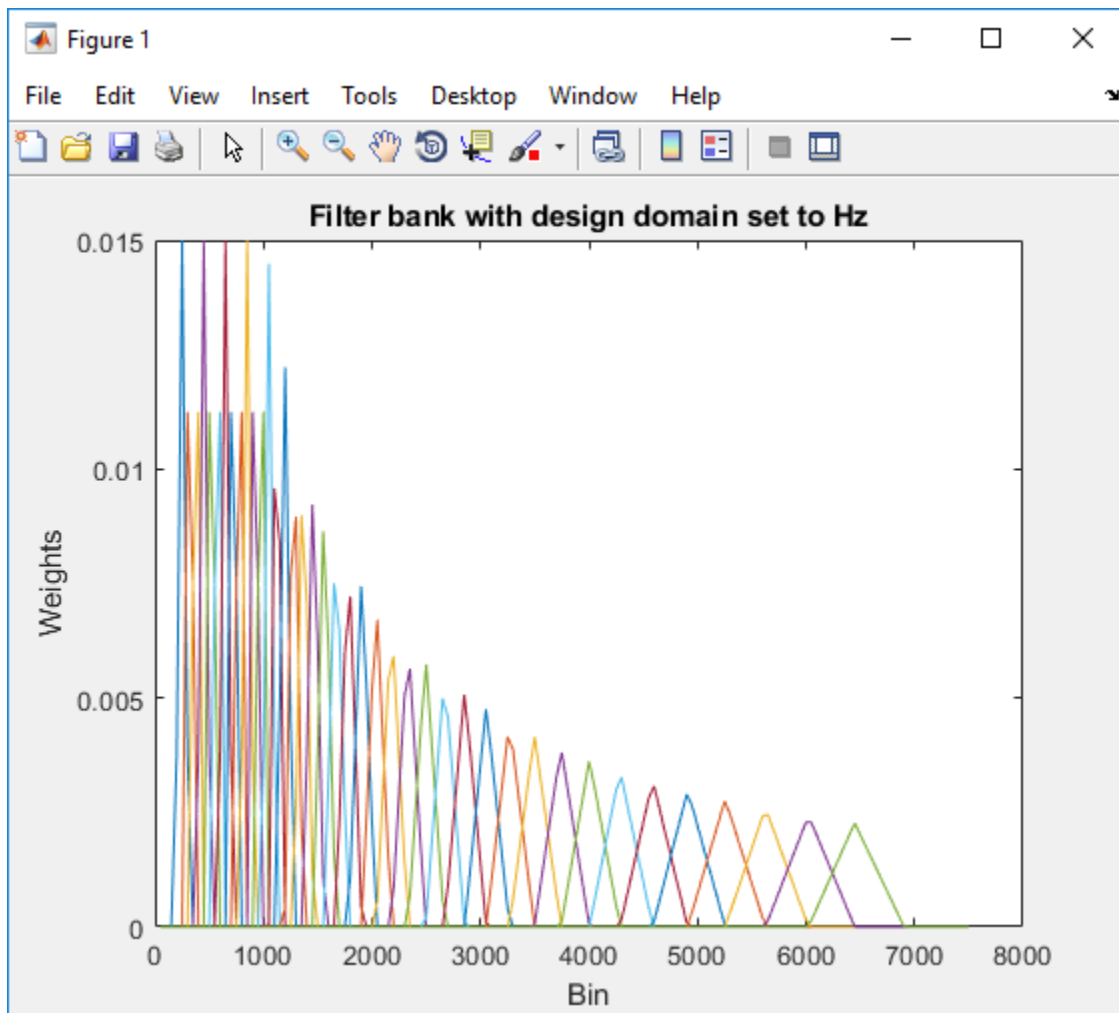
Domain for Mel filter bank design – Mel filter bank design domain

Hz (default) | Bin

Mel filter bank design domain, specified as either Hz or Bin. The filter bank is designed as overlapped triangles with band edges specified by the **Band edges of filter bank (Hz)** parameter.

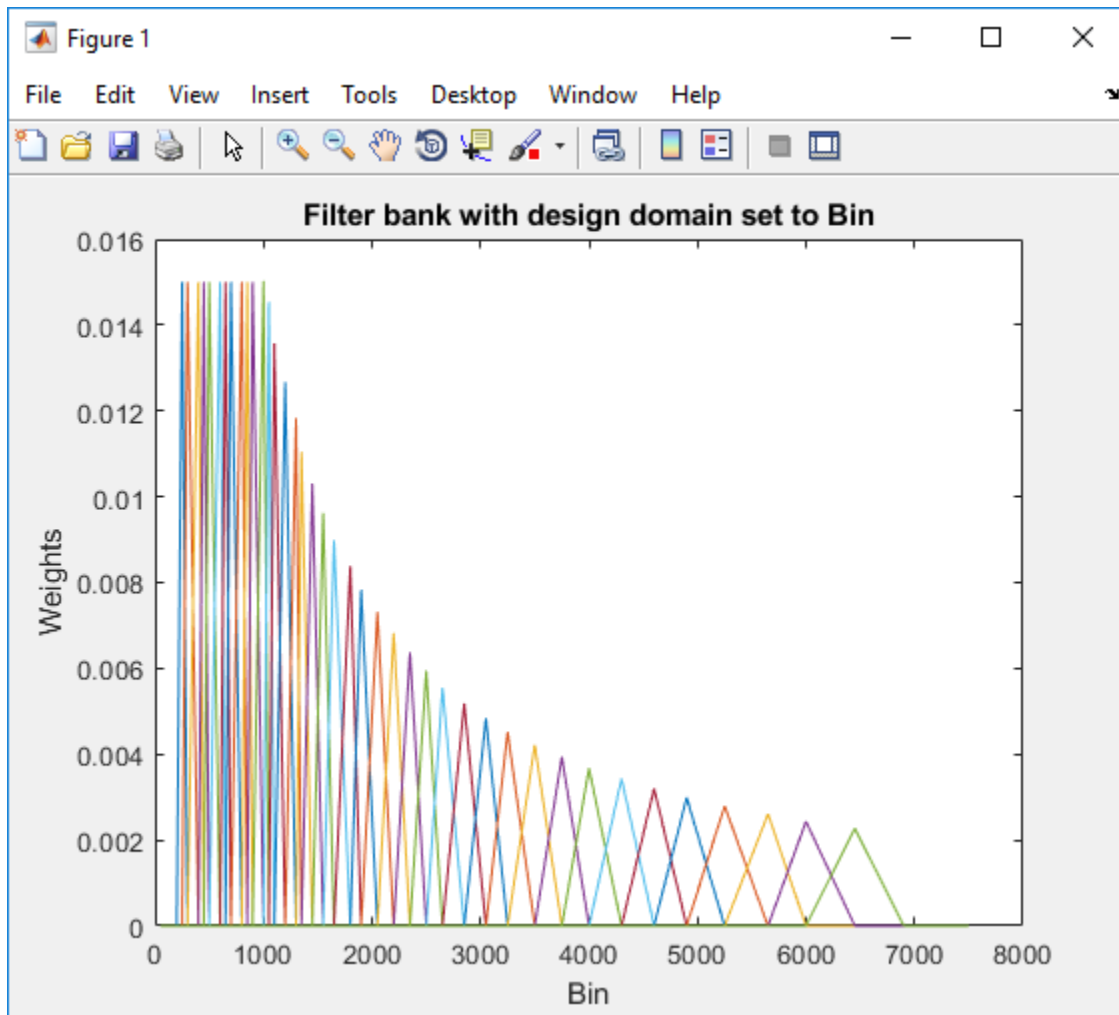
The band edges are specified in Hz. When you set the design domain to:

- Hz -- Filter bank triangles are drawn in Hz and are mapped onto bins.



For details, see [1].

- **Bin** -- The band edge frequencies in Hz are converted to bins. The filter bank triangles are drawn symmetrically in bins.



For details, see [2].

Tunable: No

Dependencies

To enable this parameter, set **Filter bank type** to Mel.

Filter bank normalization — Normalize filter bank

Bandwidth (default) | Area | None

Normalization technique used to normalize the weights of the filter bank, specified as:

- **Bandwidth** -- The weights of each bandpass filter are normalized by the corresponding bandwidth of the filter.
- **Area** -- The weights of each bandpass filter are normalized by the corresponding area of the bandpass filter.

- None -- The weights of the filter are not normalized.

Tunable: No

Block Characteristics

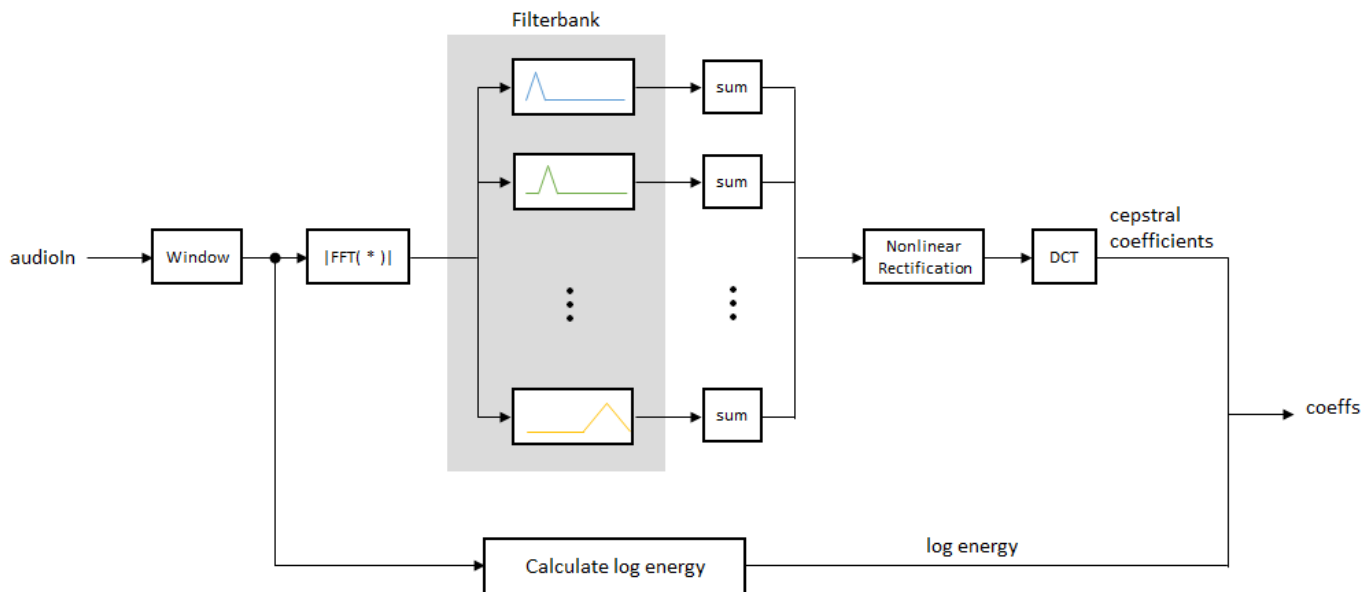
Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

Auditory Cepstrum Coefficients

Auditory cepstrum coefficients are popular features extracted from speech signals for use in recognition tasks. In the source-filter model of speech, cepstral coefficients are understood to represent the filter (vocal tract). The vocal tract frequency response is relatively smooth, whereas the source of voiced speech can be modeled as an impulse train. As a result, the vocal tract can be estimated by the spectral envelope of a speech segment.

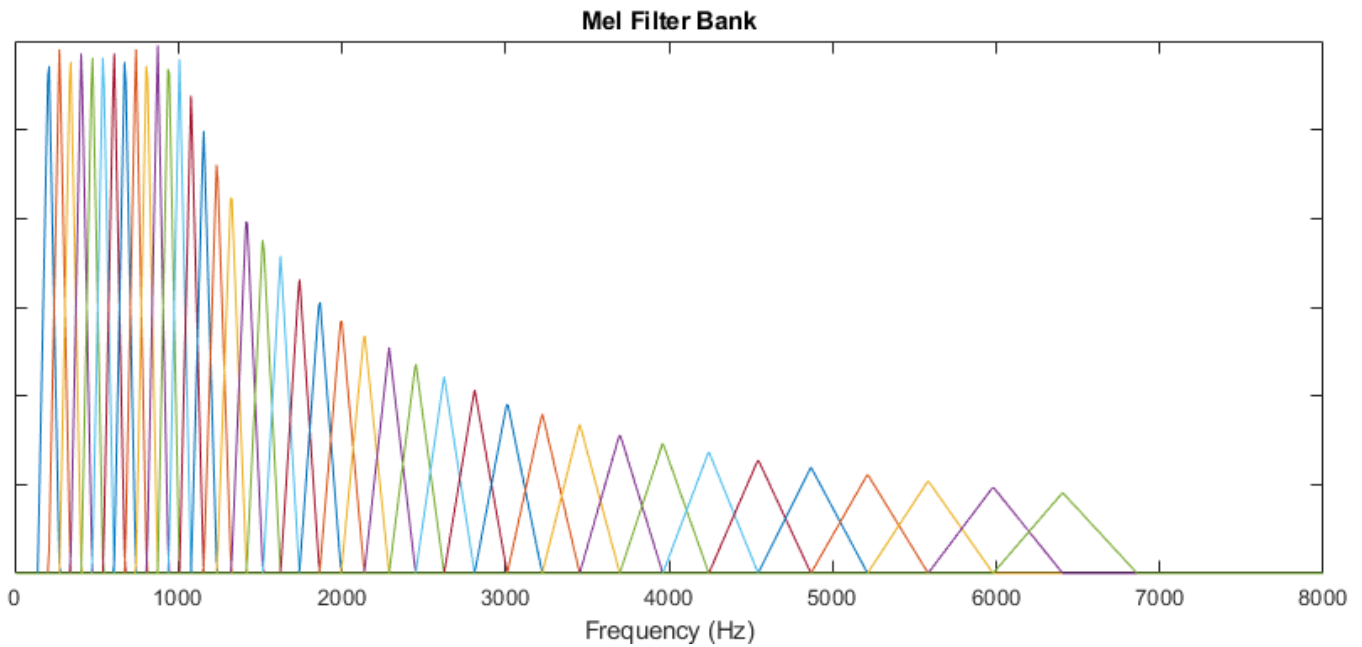
The motivating idea of cepstral coefficients is to compress information about the vocal tract (smoothed spectrum) into a small number of coefficients based on an understanding of the cochlea. Although there is no hard standard for calculating the coefficients, the basic steps are outlined by the diagram.



Two popular implementations of the filter bank are the mel filter bank and the gammatone filter bank.

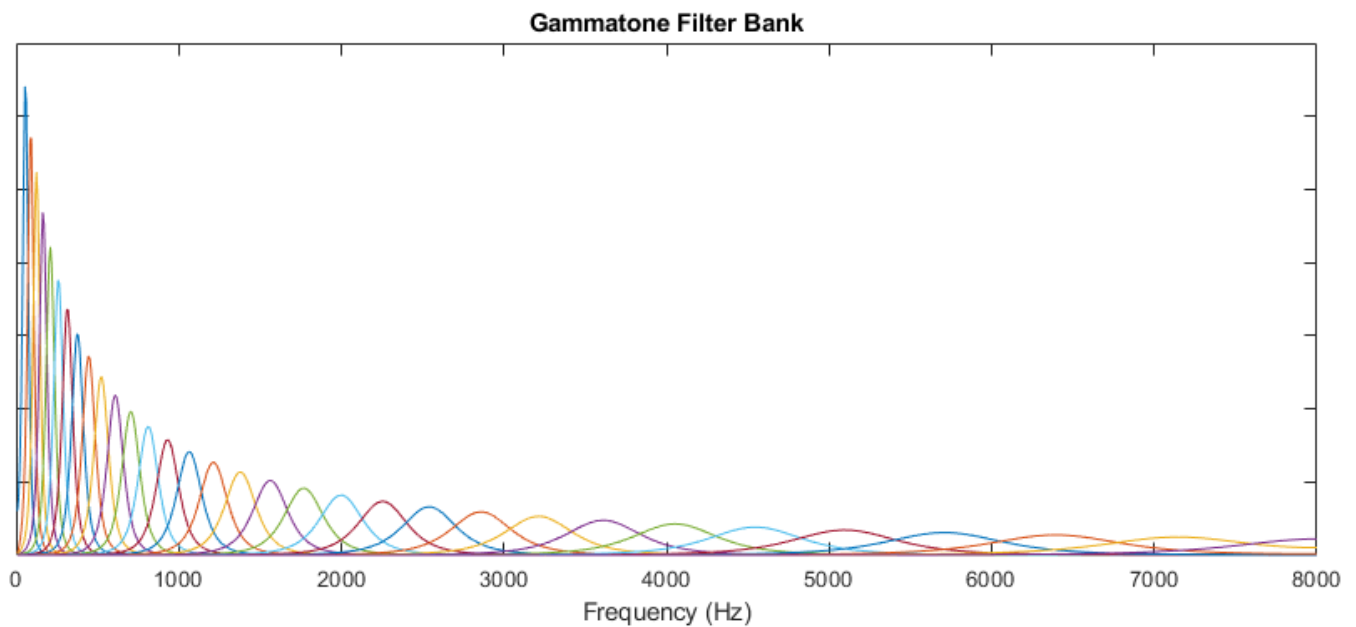
Mel Filter Bank

The default mel filter bank linearly spaces the first 10 triangular filters and logarithmically spaces the remaining filters.



Gammatone Filter Bank

The default gammatone filter bank is composed of gammatone filters spaced linearly on the ERB scale between 50 and 8000 Hz. The filter bank is designed by `gammatoneFilterBank`.



Log Energy

If the input (x) is a time-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(x^2))$$

If the input (x) is a frequency-domain signal, the log energy is computed using the following equation:

$$\log E = \log(\text{sum}(|x|^2)/\text{FFTLength})$$

References

- [1] Auditory Toolbox. <https://engineering.purdue.edu/~malcolm/interval/1998-010/AuditoryToolboxTechReport.pdf>
- [2] ETSI ES 201 108 V1.1.3 (2003-09). https://www.etsi.org/deliver/etsi_es/201100_201199/201108/01.01.03_60/es_201108v010103p.pdf

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

[mfcc](#) | [pitch](#) | [voiceActivityDetector](#) | [cepstralFeatureExtractor](#) | [Voice Activity Detector](#)

Topics

“Speaker Identification Using Pitch and MFCC”

Introduced in R2018a

Audio Device Reader

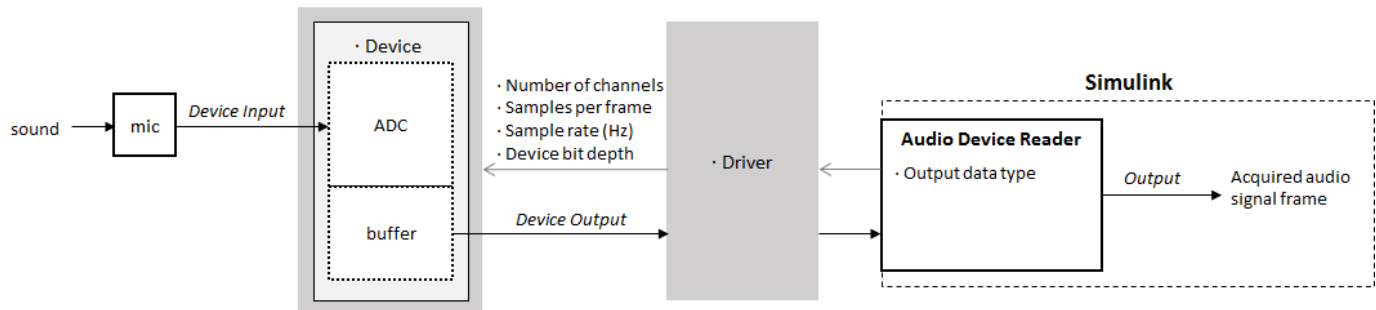
Record from sound card

Library: Audio Toolbox / Sources



Description

The Audio Device Reader block reads audio samples using your computer's audio device. The Audio Device Reader block specifies the driver, the device and its attributes, and the data type and size output from your Audio Device Reader block.



Ports

Output

A — Output signal

scalar | vector | matrix

The output of the Audio Device Reader block is determined by the block's parameters. If the block output is a matrix, the columns correspond to independent channels.

Data Types: single | double | int16 | int32 | uint8

0 — Number of samples overrun

scalar

This port outputs the number of samples overrun while acquiring a frame of data (one output matrix).

Dependencies

To enable this port, select the **Output number of samples overrun** parameter.

Data Types: uint32

Parameters

Main Tab

Driver — Driver used to access your audio device

DirectSound (default) | ASIO | WASAPI

- ASIO drivers do not come pre-installed on Windows machines. To use the ASIO driver option, install an ASIO driver outside of MATLAB.

Note If **Driver** is set to ASIO, open the ASIO UI outside of MATLAB to set the sound card buffer size to the value specified by the **Samples per frame** parameter. See the documentation of your ASIO driver for more information.

- WASAPI drivers are supported for exclusive-mode only.

ASIO and WASAPI drivers do not provide sample rate conversion. For ASIO and WASAPI drivers, set **Sample rate (Hz)** to a sample rate supported by your audio device.

This parameter applies only on Windows machines. Linux machines always use the ALSA driver. Mac machines always use the CoreAudio driver.

Device — Device used to acquire audio samples

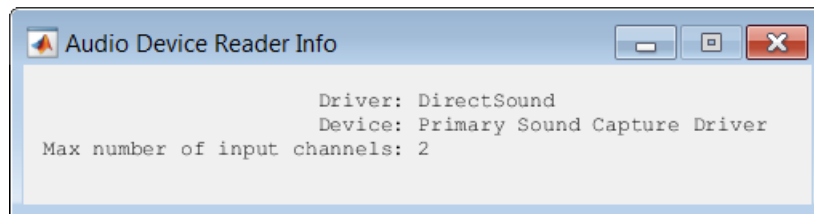
default audio device (default)

The device list is populated with devices available on your computer.

Info — View information about your audio input configuration

button

This button opens a dialog box that lists your selected audio driver, the full name of your audio device, and the maximum input channels for your configuration. For example:



Sample rate (Hz) — Sample rate your device uses to acquire audio data

44100 (default) | integer

The possible range of **Sample rate (Hz)** depends on your audio hardware.

Number of channels — Number of channels acquired by your audio device

1 (default) | integer

The number of input channels is also the number of channels (matrix columns) output by the Audio Device Reader block.

Dependencies

To specify which input channels your audio device acquires, on the **Advanced** tab, select the **Use default channel mapping** parameter.

Samples per frame — Frame size read from audio device

1024 (default) | integer

Samples per frame is also the device buffer size, and the frame size (number of matrix rows) output by the Audio Device Reader block.

Advanced Tab**Device bit depth — Data type used by device to acquire audio data**

16-bit integer (default) | 8-bit integer | 16-bit integer | 24-bit integer | 32-bit integer

Data type used by device to acquire audio data, specified as a character vector or string.

Use default channel mapping — Toggle channel mapping source

on (default) | off

When you select this parameter, the block uses the default mapping between the sound card's input channels and the matrix columns output by this block. When you clear this parameter, you specify the mapping in **Device input channels**.

Device input channels — Specify nondefault channel mapping

[1:MaximumInputChannels] (default) | scalar | vector

Nondefault map of device channels and matrix output by the Audio Device Reader block, specified as a scalar or vector. For example:

If **Device input channels** is specified as 1:3, then:

- Channel 1 maps to the first column of the output matrix.
- Channel 2 maps to the second column of the output matrix.
- Channel 3 maps to the third column of the output matrix.

If **Device input channels** is specified as [3, 1, 2], then:

- Channel 3 maps to the first column of the output matrix.
- Channel 1 maps to the second column of the output matrix.
- Channel 2 maps to the third column of the output matrix.

Dependencies

To specify a nondefault mapping, clear the **Use default mapping between sound card's input channels and columns of output of this block** parameter.

Output number of samples overrun — Specify additional output port for number of samples overrun

off (default) | on

When you select this parameter, an additional output port, **O**, is added to the block. The **O** port outputs the number of samples overrun while acquiring a frame of data (one output matrix).

Output data type — Data type output from block

double (default) | single | int32 | int16 | uint8

Data type of the output.

Note If this parameter is specified as `double` or `single`, the block outputs data in the range $[-1, 1]$. For other data types, the range is $[\text{min}, \text{max}]$ of the specified data type.

Block Characteristics

Data Types	<code>double</code> <code>integer^a</code> <code>single</code>
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

^a Supports 16- and 32-bit signed and 8-bit unsigned integers.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

The executable generated from this block relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGo` function to package the code generated from this object and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

`audioDeviceReader` | `audioDeviceWriter` | Audio Device Writer

Topics

“Run Audio I/O Features Outside MATLAB and Simulink”

“Audio I/O: Buffering, Latency, and Throughput”

Introduced in R2016a

Audio Device Writer

Play to sound card

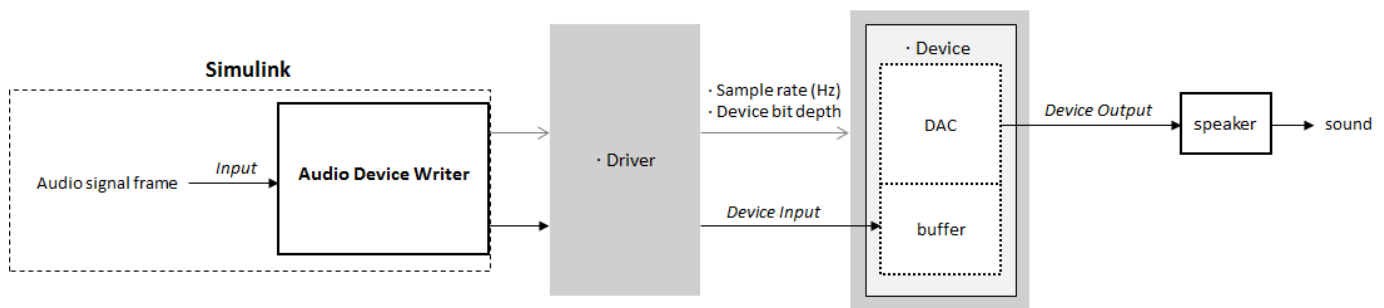
Library: Audio Toolbox / Sinks
DSP System Toolbox / Sinks



Description

The Audio Device Writer block writes audio samples to an audio output device.

Parameters of the Audio Device Writer block specify the driver, the device, and device attributes such as sample rate and bit depth.



Ports

Input

Port_1 — Input signal

scalar | vector | matrix

If input to the Audio Device Writer block is of data type `double` or `single`, the block clips values outside the range $[-1, 1]$. For other data types, the allowed input range is $[\text{min}, \text{max}]$ of the specified data type.

Data Types: `single` | `double` | `int16` | `int32` | `uint8`

Output

Port_1 — Number of samples underrun

scalar

This port outputs the number of samples underrun while writing a frame of data (one input matrix).

Dependencies

To enable this port, select the **Output number of samples underrun** parameter.

Data Types: `uint32`

Parameters

Main Tab

Driver — Driver used to access your audio device

DirectSound (default) | ASIO | WASAPI

- ASIO drivers do not come pre-installed on Windows machines. To use the ASIO driver option, install an ASIO driver outside of MATLAB.

Note If **Driver** is set to ASIO, open the ASIO UI outside of MATLAB to set the sound card buffer size to the frame size (number of rows) input to the Audio Device Writer block. See the documentation of your ASIO driver for more information.

- WASAPI drivers are supported for exclusive-mode only.

ASIO and WASAPI drivers do not provide sample rate conversion. For ASIO and WASAPI drivers, supply an audio stream with a sample rate supported by your audio device.

This parameter applies only on Windows machines. Linux machines always use the ALSA driver. Mac machines always use the CoreAudio driver.

To specify nondefault **Driver** values, you must install Audio Toolbox. If the toolbox is not installed, specifying nondefault **Driver** values returns an error.

Device — Device used to play audio samples

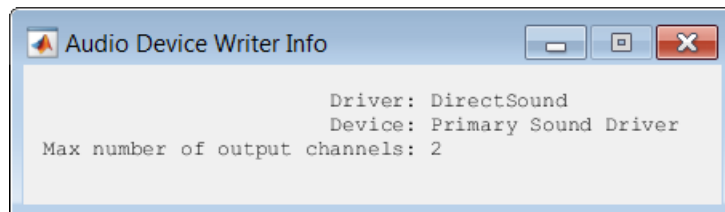
default audio device (default)

The device list is populated with devices available on your computer.

Info — View information about your audio output configuration

button

This button opens a dialog box that lists your selected audio driver, the full name of your audio device, and the maximum output channels for your configuration. For example:



Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Sample rate (Hz)**.

Sample rate (Hz) — Sample rate used by device to play audio data

44100 (default) | positive scalar

The possible range of **Sample rate (Hz)** depends on your audio hardware.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Advanced Tab**Device bit depth — Data type used by device to perform digital-to-analog conversion**

16-bit integer (default) | 8-bit integer | 24-bit integer | 32-bit float

Before performing digital-to-analog conversion, the input data is cast to a data type specified by this parameter.

Note To specify a nondefault **Device bit depth**, you must install Audio Toolbox. If the toolbox is not installed, specifying a nondefault **Device bit depth** returns an error.

Use default channel mapping — Toggle channel mapping source

on (default) | off

When you select this parameter, the block uses the default mapping between columns of the matrix input to this block and the channels of your device. When you clear this parameter, you specify the mapping in **Device output channels**.

Device output channels — Specify nondefault channel mapping

[1:MaximumOutputChannels] (default) | scalar | vector

Nondefault mapping between columns of matrix input to the Audio Device Writer block and channels of output device, specified as a scalar or vector. For example:

If **Device output channels** is specified as 1:3, then:

- The first column of the input matrix maps to channel 1.
- The second column of the input matrix maps to channel 2.
- The third column of the input matrix maps to channel 3.

If **Device output channels** is specified as [3, 1, 2], then:

- The first column of the input matrix maps to channel 3.
- The second column of the input matrix maps to channel 1.
- The third column of the input matrix maps to channel 2.

Note To selectively map between columns of the input matrix and your sound card's output channels, you must install Audio Toolbox. If the toolbox is not installed, specifying nondefault values for **Device output channels** returns an error.

Dependencies

To enable this parameter, clear the **Use default mapping between columns of input of this block and sound card's output channels** parameter.

Output number of samples underrun — Specify output port for number of samples underrun

off (default) | on

When you select this parameter, an output port is added to the block. The port outputs the number of samples underrun while writing a frame of data (one input matrix).

Block Characteristics

Data Types	double integer ^a single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

^a Supports 16- and 32-bit signed and 8-bit unsigned integers.

Extended Capabilities**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

The following code generation limitations apply:

- Host computer only. Excludes Simulink Desktop Real-Time™ code generation.
- The executable generated from this block relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGo` function to package the code generated from this block and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

Audio Device Reader | Binary File Reader | `audioDeviceWriter` | `audioDeviceReader`

Topics

“Run Audio I/O Features Outside MATLAB and Simulink”

“Audio I/O: Buffering, Latency, and Throughput”

Introduced in R2016a

Auditory Spectrogram

Extract mel, Bark, or ERB spectrogram from audio

Library: Audio Toolbox / Features



Description

The Auditory Spectrogram block extracts a spectrogram from the audio input signal. A spectrogram contains an estimate of the short-term, time-localized frequency content of the input signal.

Ports

Input

Port_1 — Audio input

column vector | matrix

Audio input signal, specified as a column vector or a matrix. When you specify a matrix, the block treats columns as independent audio channels.

Data Types: `single` | `double`

Output

spec — Spectrogram

matrix | 3-D array

Spectrogram, returned as a matrix or 3-D array. The dimensions of **spec** are L -by- M -by- N , where:

- L is the number of spectra, which is determined by the **Number of spectra** parameter.
- M is the number of bands, which is determined by the **Auto-determine number of bands** and **Number of bands** parameters.
- N is the number of channels in the input audio signal.

Trailing singleton dimensions are removed from the output.

This port is unnamed until you select the **Output center frequencies** parameter.

Data Types: `single` | `double`

fvec — Center frequencies

row vector

Center frequencies of the bandpass filters in Hz, returned as a row vector with number of elements equal to the number of bands.

Dependencies

To enable this port, select the **Output center frequencies** parameter.

Data Types: `single` | `double`

Parameters

Filter Bank Parameters

Frequency scale — Frequency scale of filter bank

`mel` (default) | `bark` | `erb`

Frequency scale used to design the auditory filter bank, specified as `mel`, `bark`, or `erb`.

- `mel` -- Design the filter bank as half-overlapped triangles equally spaced on the mel scale.
- `bark` -- Design the filter bank as half-overlapped triangles equally spaced on the Bark scale.
- `erb` -- Design the filter bank as gammatone filters whose center frequencies are equally spaced on the ERB scale.

Auto-determine number of bands — Automatically determine number of bandpass filters

`on` (default) | `off`

When you select this parameter, the block automatically determines the number of bandpass filters based on the **Frequency scale** parameter.

- If you set **Frequency scale** to `mel` or `bark`, then the number of bands is 32.
- If you set **Frequency scale** to `erb`, then the number of bands is equal to $\text{ceil}(\text{hz2erb}(\text{fr}(2)) - \text{hz2erb}(\text{fr}(1)))$, where `fr` is specified using **Frequency range (Hz)**.

Number of bands — Number of bandpass filters

32 (default) | positive integer

Number of bandpass filters, specified as a positive integer.

Dependencies

To enable this parameter, clear the **Auto-determine number of bands** parameter.

Auto-determine frequency range — Automatically determine frequency range

`on` (default) | `off`

When you select this parameter, the block sets the **Frequency range** to $[0, f_s/2]$, where `fs` is the sample rate. The sample rate is determined by the **Inherit sample rate from input** and **Input sample rate (Hz)** parameters.

Frequency range (Hz) — Frequency range over which to design auditory filter bank

`[0, 22050]` (default) | two-element row vector

Frequency range in Hz over which to design the auditory filter bank, specified as a two-element row vector.

Dependencies

To enable this parameter, clear the **Auto-determine frequency range** parameter.

Filter bank design domain — Domain to design filter bank

`linear` (default) | `warped`

Domain in which the block designs the filter bank, specified as `linear` or `warped`. Set the filter bank design domain to `linear` to design the bandpass filters in the linear (Hz) domain. Set the filter bank design domain to `warped` to design the bandpass filters in the warped (mel or Bark) domain.

Dependencies

To enable this parameter, set **Frequency scale** to `mel` or `bark`.

Filter bank normalization — Normalization technique for filter bank

`bandwidth` (default) | `area` | `none`

Normalization technique used for the filter bank weights, specified as `bandwidth`, `area`, or `none`.

- `bandwidth` -- Normalize the weights of each bandpass filter by the corresponding bandwidth of the filter.
- `area` -- Normalize the weights of each bandpass filter by the corresponding area of the bandpass filter.
- `none` -- The block does not normalize the weights of the filters.

Output center frequencies — Specify additional output port for center frequencies

`off` (default) | `on`

When you select this parameter, the block displays an additional output port, **fvec**. This port outputs the center frequencies of the bandpass filters.

Visualize filter bank — Open plot to visualize filter bank

`button`

Open plot to visualize the filters in the frequency domain.

Spectrogram Parameters

Window — Analysis window

`hamming(1024, 'periodic')` (default) | real vector

Analysis window applied in the time domain, specified as a real vector.

Normalize window — Normalize analysis window

`on` (default) | `off`

When you select this parameter, the block applies window normalization.

Overlap length — Overlap length of adjacent analysis windows

`512` (default) | integer in the range `[0, windowLength)`

Overlap length of adjacent analysis windows, specified as an integer in the range `[0, windowLength)`, where `windowLength` is the length of the analysis window, which is specified by **Window**.

Auto-determine FFT length — Automatically determine FFT length

`on` (default) | `off`

When you select this parameter, the block automatically sets the FFT length to the window length `numel(Window)`.

FFT length — Number of DFT points

`1024` (default) | positive integer

Number of points used to calculate the DFT, specified as a positive integer.

Dependencies

To enable this parameter, clear the **Auto-determine FFT length** parameter.

Spectrum type — Type of spectrum

magnitude (default) | power

Type of spectrum, specified as magnitude or power.

Number of spectra — Number of spectra

1 (default) | positive integer

Number of spectra in the spectrogram, specified as a positive integer.

Number of spectra overlap — Number of overlapped spectra

0 (default) | integer in the range [0, **Number of spectra**)

Number of spectra overlapped across consecutive spectrograms, specified as an integer in the range [0, **Number of spectra**).

Simulation Parameters

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in the **Input sample rate (Hz)** parameter.

Input sample rate (Hz) — Sample rate of input

44.1e3 (default) | positive scalar

Input sample rate in Hz, specified as a real positive scalar.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Design Auditory Filter Bank | Design Mel Filter Bank | Mel Spectrogram

Functions

designAuditoryFilterBank | melSpectrogram

Objects

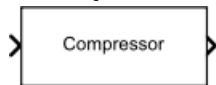
audioFeatureExtractor

Introduced in R2022a

Compressor

Dynamic range compressor

Library: Audio Toolbox / Dynamic Range Control



Description

The Compressor block performs dynamic range compression independently across each input channel. Dynamic range compression attenuates the volume of loud sounds that cross a given threshold. The block uses specified attack and release times to achieve a smooth applied gain curve.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

T — Threshold (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Threshold (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

R — Ratio

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Ratio” on page 5-0 parameter.

Data Types: `single` | `double`

K — Knee width (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Knee width (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

AT — Attack time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Attack time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

RT — Release time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Release time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

Output

Y — Output signal

matrix

The Compressor block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

Data Types: `single` | `double`

G — Gain applied to each input sample

matrix

Dependencies

To enable this port, select the **Output gain (dB)** parameter.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Main Tab

Threshold (dB) — Operation threshold

-10 (default) | scalar in the range -50 to 0 inclusive

Operation threshold is the level above which gain is applied to the input signal.

To specify **Threshold (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Ratio – Compression ratio

5 (default) | scalar in the range 1 to 50 inclusive

Compression ratio is the input/output ratio for signals that overshoot the operation threshold.

Assuming a hard knee characteristic and a steady-state input such that $x[n]$ dB > **Threshold (dB)**, the compression ratio is defined as $R = \frac{(x[n] - T)}{(y[n] - T)}$, where

- R is the compression ratio.
- $x[n]$ is the input signal in dB.
- $y[n]$ is the output signal in dB.
- T is the threshold in dB.

To specify **Ratio** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Knee width (dB) – Transition area in compression characteristic

0 (default) | scalar in the range 0 to 20 inclusive

For soft knee characteristics, the transition area is defined by the relation

$$y = x + \frac{\left(\frac{1}{R} - 1\right) \times \left(x - T + \frac{W}{2}\right)^2}{(2 \times W)}$$

for the range $(2 \times |x - T|) \leq W$, where

- y is the output level in dB.
- x is the input level in dB.
- R is the compression ratio.
- T is the threshold in dB.
- W is the knee width in dB.

To specify **Knee width (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

View static characteristic – Open static characteristic plot of dynamic range compressor

button

The plot is updated automatically when parameters of the Compressor block change.

Tunable: Yes

Attack time (s) – Time for applied gain to ramp up

0.05 (default) | scalar in the range 0 to 4 inclusive

Attack time is the time the compressor gain takes to rise from 10% to 90% of its final value when the input goes above the threshold. The **Attack time (s)** parameter smooths the applied gain curve.

To specify **Attack time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Release time (s) — Time for applied gain to ramp down

0.2 (default) | scalar in the range 0 to 4 inclusive

Release time is the time the compressor gain takes to drop from 90% to 10% of its final value when the input goes below the threshold. The **Release time (s)** parameter smooths the applied gain curve.

To specify **Release time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Make-up gain mode — Make-up gain mode

Property (default) | Auto

- Property -- Make-up gain is set to the value specified by the **Make-up gain (dB)** parameter.
- Auto -- Make-up gain is applied at the output of the Compressor block such that a steady-state 0 dB input has a 0 dB output.

Tunable: No

Make-up gain (dB) — Applied make-up gain

0 (default) | scalar in the range -10 to 24 inclusive

Make-up gain compensates for gain lost during compression. It is applied at the output of the Compressor block.

Tunable: Yes

Dependencies

To enable this parameter, set the **Make-up gain mode** parameter to Property.

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, specify the sample rate in the **Input sample rate (Hz)** parameter.

Tunable: No

Input sample rate (Hz) — Sample rate of input

44100 (default) | positive scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Advanced Tab

Output gain (dB) — Gain applied on each input sample

off (default) | on

When you select this parameter, an additional output port, **G**, is added to the block. The **G** port outputs the gain applied on each input channel in dB.

Tunable: No

Sidechain — Enable sidechain input

off (default) | on

When you select this parameter, an additional input port **SC** is added to the block. The **SC** port enables dynamic range compression of the input signal **x** using a separate sidechain signal.

The datatype and (frame) length input to the **SC** port must be the same as the input to the **x** port.

The number of channels of the sidechain input must be equal to the number of channels of **x** or be equal to one.

- Sidechain channel count is equal to one -- The computed gain, **G**, based on this channel is applied to all channels of **x**.
- Sidechain channel count is equal to channel count of **x** -- The computed gain, **G**, for each sidechain channel is applied to the corresponding channel of **x**.

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- Interpreted execution -- Simulate model using the MATLAB interpreter. This option shortens startup time and has a simulation speed comparable to Code generation. In this mode, you can debug the source code of the block.
- Code generation -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to Interpreted execution.

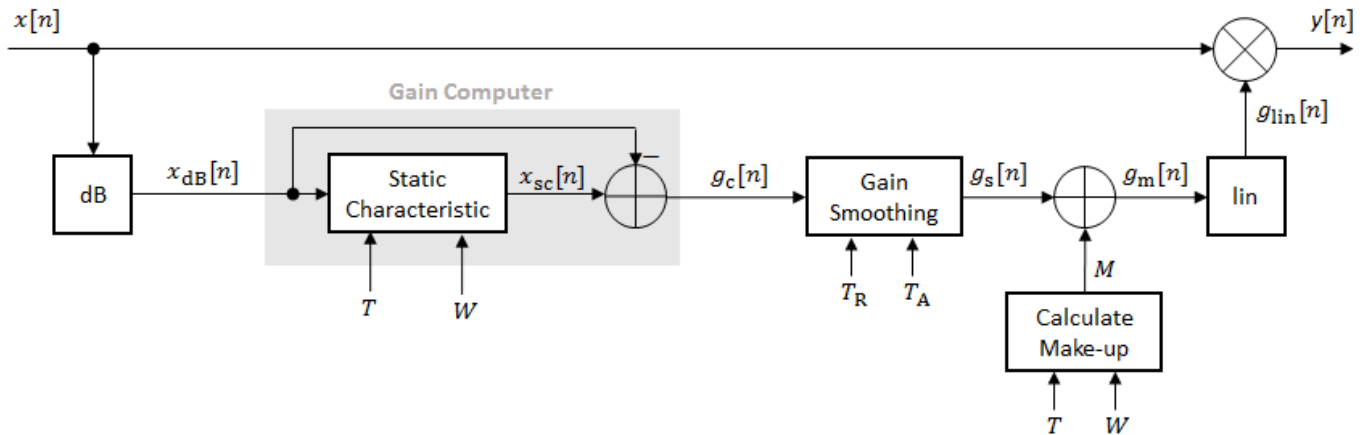
Tunable: No

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Compressor block processes a signal frame by frame and element by element.



- 1 The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$

- 2 $x_{dB}[n]$ passes through the gain computer. The gain computer uses the static compression characteristic of the Compressor block to attenuate gain that is above the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} + \frac{\left(\frac{1}{R} - 1\right)\left(x_{dB} - T + \frac{W}{2}\right)^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ T + \frac{(x_{dB} - T)}{R} & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases},$$

where T is the threshold, R is the compression ratio, and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < T \\ T + \frac{(x_{dB} - T)}{R} & x_{dB} \geq T \end{cases}$$

- 3 The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$

- 4 $g_c[n]$ is smoothed using specified attack and release time parameters:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n], & g_c[n] \leq g_s[n-1] \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n], & g_c[n] > g_s[n-1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{FS \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the **Attack time (s)** parameter. T_R is the release time period, specified by the **Release time (s)** parameter. F_S is the input sampling rate, specified by the **Inherit sample rate from input** or the **Input sample rate (Hz)** parameter.

- 5 If **Make-up gain (dB)** is set to Auto, the make-up gain is calculated as the negative of the computed gain for a 0 dB input:

$$M = -x_{sc}|_{x_{dB} = 0}.$$

Given a steady-state input of 0 dB, this configuration achieves a steady-state output of 0 dB. The make-up gain is determined by the **Threshold (dB)**, **Ratio**, and **Knee width (dB)** parameters. It does not depend on the input signal.

- 6 The make-up gain, M , is added to the smoothed gain, $g_s[n]$:

$$g_m[n] = g_s[n] + M$$

- 7 The calculated gain in dB, $g_{dB}[n]$, is translated to a linear domain:

$$g_{lin}[n] = 10\left(\frac{g_m[n]}{20}\right)$$

- 8 The output of the dynamic range compressor is given as

$$y[n] = x[n] \times g_{lin}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial And Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

compressor | Limiter | Expander | Noise Gate

Topics

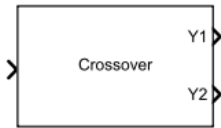
"Dynamic Range Control"

Introduced in R2016a

Crossover Filter

Audio crossover filter

Library: Audio Toolbox / Filters



Description

The Crossover Filter block implements an audio crossover filter, which is used to split an audio signal into two or more frequency bands. Crossover filters are multiband filters whose overall magnitude frequency response is flat.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

F1 — Crossover frequency (Hz)

real scalar in the range 20 to 20000

Dependencies

To enable this port, select **Specify from input port** for the “Crossover frequency (Hz)” on page 5-0 parameter.

Data Types: `single` | `double`

O1 — Crossover order

integer in the range 0 to 8

Dependencies

To enable this port, select **Specify from input port** for the “Crossover order” on page 5-0 parameter.

Data Types: `single` | `double`

F2 — Crossover frequency (Hz)

real scalar in the range 20 to 20000

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover frequency (Hz)” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 2, 3 or 4.

Data Types: single | double

02 – Crossover order

integer in the range 0 to 8

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover order” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 2, 3 or 4.

Data Types: single | double

F3 – Crossover frequency (Hz)

real scalar in the range 20 to 20000

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover frequency (Hz)” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 3 or 4.

Data Types: single | double

03 – Crossover order

integer in the range 0 to 8

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover order” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 3 or 4.

Data Types: single | double

F4 – Crossover frequency (Hz)

real scalar in the range 20 to 20000

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover frequency (Hz)” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 4.

Data Types: single | double

04 — Crossover order

integer in the range 0 to 8

Dependencies

To enable this port, you need to both:

- Select **Specify from input port** for the “Crossover order” on page 5-0 parameter.
- Set “Number of crossovers” on page 5-0 to 4.

Data Types: `single` | `double`

Output**Y1 — Output signal**

matrix

Port **Y1** always corresponds to a lowpass filter.

Dependencies

Available if **Number of crossovers** is set to 1, 2, 3, or 4.

Data Types: `single` | `double`

Y2 — Output signal

matrix

Depending on the number of crossovers specified, port **Y2** outputs the original audio signal passed through a bandpass or highpass filter.

Dependencies

Available if **Number of crossovers** is set to 1, 2, 3, or 4.

Data Types: `single` | `double`

Y3 — Output signal

matrix

Depending on the number of crossovers specified, port **Y3** corresponds to a bandpass or highpass filter of the original audio signal.

Dependencies

Available if **Number of crossovers** is set to 2, 3, or 4.

Data Types: `single` | `double`

Y4 — Output signal

matrix

Dependencies

Available if **Number of crossovers** is set to 3 or 4.

Data Types: `single` | `double`

Y5 — Output signal

matrix

Dependencies

Available if **Number of crossovers** is set to 4.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Number of crossovers — Number of magnitude response band crossings

1 (default) | 2 | 3 | 4

If you specify multiple crossovers, the corresponding **Crossover frequency (Hz)** and **Crossover order** parameters populate in the dialog box automatically.

The number of bands output by the Crossover Filter block is one more than the **Number of crossovers**.

Number of Crossovers	Number of Bands in Output
1	Two
2	Three
3	Four
4	Five

Crossover frequency (Hz) — Intersections of magnitude response bands

100 (default) | real scalar in the range 20 to 20000

Crossover frequencies are the intersections of magnitude response bands of the individual two-band crossover filters used in the multiband crossover filter.

Tunable: Yes

Crossover order — Order of individual crossover filters

2 (default) | integer in the range [0, 8]

The crossover filter order relates to the crossover filter slope in dB/octave: $slope = N \times 6$, where N is the crossover order.

Tunable: Yes

View filter response — Open plot of magnitude response of each filter band

button

The plot is updated automatically when parameters of the Crossover Filter block change.

Tunable: Yes

Variable name — Variable name of exported filter

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists – Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace – Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.

Tips

- You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.
- You cannot export the filter if you are specifying filter characteristics from input ports.

Inherit sample rate from input – Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Input sample rate (Hz) – Sample rate of input

44100 (default) | positive scalar

Tunable: Yes**Dependencies**

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using – Specify type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** - Simulate the model using the MATLAB interpreter. This option reduces startup time and the simulation speed is comparable to **Code generation**. In this mode, you can debug the source code of the block.
- **Code generation** - Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.

Tunable: No**Block Characteristics**

Data Types	double single
Direct Feedthrough	no

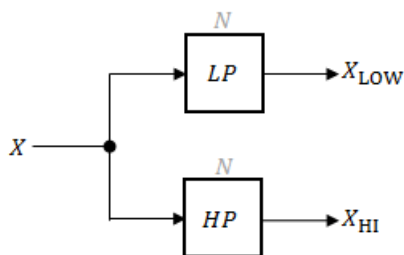
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Crossover Filter block is implemented as a binary tree of crossover pairs with additional phase-compensating sections [1]. Odd-order crossovers are implemented with Butterworth filters, while even-order crossovers are implemented with cascaded Butterworth filters (Linkwitz-Riley filters).

Odd-Order Crossover Pair

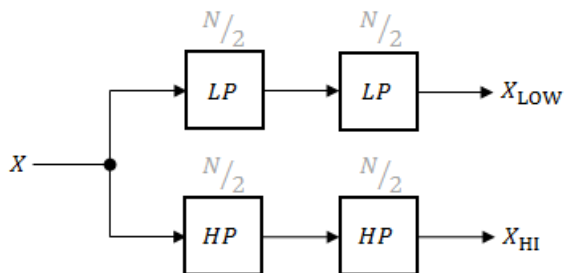
Odd-order two-band (one crossover) filters are implemented as parallel complementary highpass and lowpass filters.



LP and *HP* are Butterworth filters of order N , implemented as direct-form II transposed second-order sections. The shared cutoff frequency used in their design corresponds to the crossover of the resulting bands.

Even-Order Crossover Pair

Even-order two-band (one crossover) filters are implemented as parallel complementary highpass and lowpass filters.

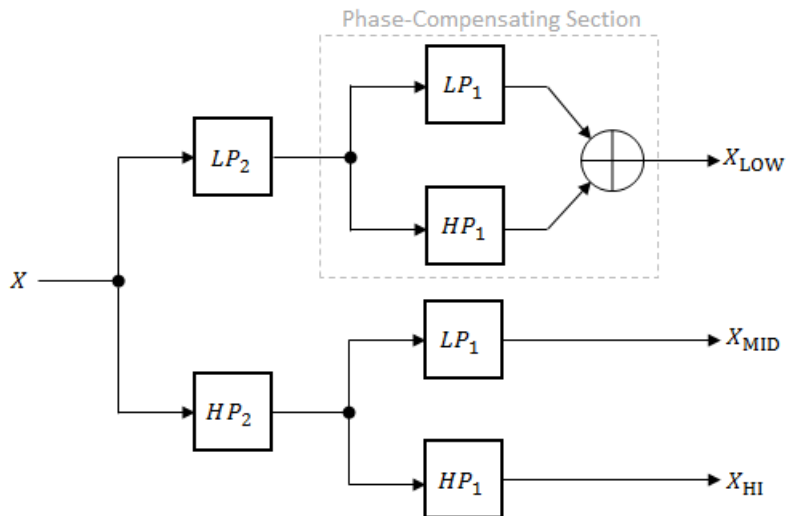


LP and *HP* are Butterworth filters of order $N/2$, where N is the order of the overall filter. The filters are implemented as direct-form II transposed second-order sections.

For overall filters of orders 2 and 6, X_{HI} is multiplied by -1 internally so that the branches of your crossover pair are in-phase.

Even-Order Three-Band Filter

Even-order three-band (two crossovers) filters are implemented as parallel complementary highpass and lowpass filters organized in a tree structure.



The phase-compensating section is equivalent to an allpass filter.

The design of four-band and five-band filters (three and four crossovers) are extensions of the pattern developed for even-order and odd-order crossovers and the tree structure specified for three-band (two crossover) filters.

References

- [1] D'Appolito, Joseph A. "Active Realization of Multiway All-Pass Crossover Systems." *Journal of Audio Engineering Society*. Vol. 35, Issue 4, 1987, pp. 239-245.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

`crossoverFilter`

Topics

"Multiband Dynamic Range Compression"

Introduced in R2016a

Design Auditory Filter Bank

Design frequency-domain auditory filter bank

Library: Audio Toolbox / Features



Description

The Design Auditory Filter Bank block outputs a frequency-domain auditory filter bank. You can use an auditory filter bank to decompose an audio signal into separate frequency bands for feature extraction.

Ports

Output

fb — Filter bank

column vector | matrix

Auditory filter bank, returned as an M -by- N matrix, where:

- M is the number of bands, which is determined by the **Auto-determine number of bands** and **Number of bands** parameters.
- N is the number of points in the spectrum. If you select **Design one-sided filter bank**, then N is equal to $\text{ceil}(\text{NFFT}/2)$, where **NFFT** is the **FFT length**. If you do not select **Design one-sided filter bank**, then N is equal to the **FFT length**.

This port is unnamed until you select the **Output center frequencies** parameter.

Data Types: `single` | `double`

fvec — Center frequencies

row vector

Center frequencies of the bandpass filters in Hz, returned as a row vector with number of elements equal to the number of bands.

Dependencies

To enable this port, select the **Output center frequencies** parameter.

Data Types: `single` | `double`

Parameters

Frequency scale — Frequency scale of filter bank

`mel` (default) | `bark` | `erb`

Frequency scale used to design the auditory filter bank, specified as `mel`, `bark`, or `erb`.

- `mel` -- Design the filter bank as half-overlapped triangles equally spaced on the mel scale.
- `bark` -- Design the filter bank as half-overlapped triangles equally spaced on the Bark scale.
- `erb` -- Design the filter bank as gammatone filters whose center frequencies are equally spaced on the ERB scale.

FFT length — Number of DFT points

1024 (default) | positive integer

Number of points used to calculate the DFT, specified as a positive integer.

Design one-sided filter bank — Design one-sided or two-sided filter bank

on (default) | off

When you select this parameter, the block designs a one-sided filter bank. Otherwise, the filter bank is two sided.

Auto-determine number of bands — Automatically determine number of bandpass filters

on (default) | off

When you select this parameter, the block automatically determines the number of bandpass filters based on the **Frequency scale** parameter.

- If you set **Frequency scale** to `mel` or `bark`, then the number of bands is 32.
- If you set **Frequency scale** to `erb`, then the number of bands is equal to $\text{ceil}(\text{hz2erb}(fr(2)) - \text{hz2erb}(fr(1)))$, where `fr` is specified using **Frequency range (Hz)**.

Number of bands — Number of bandpass filters

32 (default) | positive integer

Number of bandpass filters, specified as a positive integer.

Dependencies

To enable this parameter, clear the **Auto-determine number of bands** parameter.

Auto-determine frequency range — Automatically determine frequency range

on (default) | off

When you select this parameter, the block sets the **Frequency range** to $[0, fs/2]$, where `fs` is specified using **Sample rate (Hz)**.

Frequency range (Hz) — Frequency range over which to design auditory filter bank

$[0, 22050]$ (default) | two-element row vector

Frequency range in Hz over which to design the auditory filter bank, specified as a two-element row vector.

Dependencies

To enable this parameter, clear the **Auto-determine frequency range** parameter.

Filter bank design domain — Domain to design filter bank

linear (default) | warped

Domain in which the block designs the filter bank, specified as `linear` or `warped`. Set the filter bank design domain to `linear` to design the bandpass filters in the linear (Hz) domain. Set the filter bank design domain to `warped` to design the bandpass filters in the warped (mel or Bark) domain.

Dependencies

To enable this parameter, set **Frequency scale** to `mel` or `bark`.

Filter bank normalization — Normalization technique for filter bank

`bandwidth` (default) | `area` | `none`

Normalization technique used for the filter bank weights, specified as `bandwidth`, `area`, or `none`.

- `bandwidth` -- Normalize the weights of each bandpass filter by the corresponding bandwidth of the filter.
- `area` -- Normalize the weights of each bandpass filter by the corresponding area of the bandpass filter.
- `none` -- The block does not normalize the weights of the filters.

Output data type — Data type of output

`double` (default) | `single`

Data type of output, specified as `double` or `single`.

Sample rate (Hz) — Sample rate

`44.1e3` (default) | positive scalar

Sample rate in Hz of the filter design, specified as a positive scalar.

Visualize filter bank — Open plot to visualize filter bank

`button`

Open plot to visualize the filters in the frequency domain.

Output center frequencies — Specify additional output port for center frequencies

`off` (default) | `on`

When you select this parameter, the block displays an additional output port, **fvec**. This port outputs the center frequencies of the bandpass filters.

Block Characteristics

Data Types	<code>double</code> <code>single</code>
Direct Feedthrough	<code>no</code>
Multidimensional Signals	<code>no</code>
Variable-Size Signals	<code>no</code>
Zero-Crossing Detection	<code>no</code>

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Auditory Spectrogram | Design Mel Filter Bank | Mel Spectrogram

Functions

designAuditoryFilterBank | melSpectrogram

Objects

audioFeatureExtractor

Introduced in R2022a

Design Mel Filter Bank

Design frequency-domain mel filter bank

Library: Audio Toolbox / Features



Description

The Design Mel Filter Bank block outputs a frequency-domain auditory filter bank using the mel frequency scale. You can use a mel filter bank to decompose an audio signal into separate frequency bands in the mel frequency scale, which mimics the nonlinear human perception of sound.

Ports

Output

fb — Filter bank

column vector | matrix

Mel filter bank, returned as an M -by- N matrix, where:

- M is the number of bands, which is determined by the **Auto-determine number of bands** and **Number of bands** parameters.
- N is the number of points in the spectrum. If you select **Design one-sided filter bank**, then N is equal to $\text{ceil}(\text{NFFT}/2)$, where NFFT is the **FFT length**. If you do not select **Design one-sided filter bank**, then N is equal to the **FFT length**.

This port is unnamed until you select the **Output center frequencies** parameter.

Data Types: single | double

fvec — Center frequencies

row vector

Center frequencies of the bandpass filters in Hz, returned as a row vector with number of elements equal to the number of bands.

Dependencies

To enable this port, select the **Output center frequencies** parameter.

Data Types: single | double

Parameters

FFT length — Number of DFT points

1024 (default) | positive integer

Number of points used to calculate the DFT, specified as a positive integer.

Design one-sided filter bank — Design one-sided or two-sided filter bank

on (default) | off

When you select this parameter, the block designs a one-sided filter bank. Otherwise, the filter bank is two sided.

Number of bands — Number of bandpass filters

32 (default) | positive integer

Number of bandpass filters, specified as a positive integer.

Auto-determine frequency range — Automatically determine frequency range

on (default) | off

When you select this parameter, the block sets the **Frequency range** to $[0, f_s/2]$, where f_s is specified using **Sample rate (Hz)**.

Frequency range (Hz) — Frequency range over which to design filter bank $[0, 22050]$ (default) | two-element row vector

Frequency range in Hz over which to design the filter bank, specified as a two-element row vector.

Dependencies

To enable this parameter, clear the **Auto-determine frequency range** parameter.

Filter bank design domain — Domain to design filter bank

linear (default) | warped

Domain in which the block designs the filter bank, specified as `linear` or `warped`. Set the filter bank design domain to `linear` to design the bandpass filters in the linear (Hz) domain. Set the filter bank design domain to `warped` to design the bandpass filters in the warped (mel) domain.

Filter bank normalization — Normalization technique for filter bank

bandwidth (default) | area | none

Normalization technique used for the filter bank weights, specified as `bandwidth`, `area`, or `none`.

- `bandwidth` -- Normalize the weights of each bandpass filter by the corresponding bandwidth of the filter.
- `area` -- Normalize the weights of each bandpass filter by the corresponding area of the bandpass filter.
- `none` -- The block does not normalize the weights of the filters.

Output data type — Data type of output

double (default) | single

Data type of output, specified as `double` or `single`.

Sample rate (Hz) — Sample rate

44.1e3 (default) | positive scalar

Sample rate in Hz of the filter design, specified as a positive scalar.

Visualize filter bank — Open plot to visualize filter bank

button

Open plot to visualize the filters in the frequency domain.

Output center frequencies — Specify additional output port for center frequencies

off (default) | on

When you select this parameter, the block displays an additional output port, **fvec**. This port outputs the center frequencies of the bandpass filters.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Auditory Spectrogram | Design Auditory Filter Bank | Mel Spectrogram

Functions

designAuditoryFilterBank | melSpectrogram

Objects

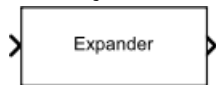
audioFeatureExtractor

Introduced in R2022a

Expander

Dynamic range expander

Library: Audio Toolbox / Dynamic Range Control



Description

The Expander block performs dynamic range expansion independently across each input channel. Dynamic range expansion attenuates the volume of quiet sounds below a given threshold. The block uses specified attack, release, and hold times to achieve a smooth applied gain curve.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

R — Ratio

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Ratio” on page 5-0 parameter.

Data Types: `single` | `double`

T — Threshold (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Threshold (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

K — Knee width (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Knee width (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

AT — Attack time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Attack time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

RT — Release time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Release time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

HT — Hold time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Hold time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

Output

Y — Output signal

matrix

The Expander block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

This port is unnamed until you select the **Output gain (dB)** parameter.

Data Types: `single` | `double`

G — Gain applied to each input sample

matrix

Dependencies

To enable this port, select the **Output gain (dB)** parameter.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Main Tab**Ratio — Expansion ratio**

5 (default) | scalar in the range 1 to 50 inclusive

Expansion ratio is the input/output ratio for signals that undershoot the operation threshold.

Assuming a hard knee characteristic and a steady-state input such that $x[n]$ dB < **Threshold (dB)**, the expansion ratio is defined as $R = \frac{(y[n] - T)}{(x[n] - T)}$, where

- R is the expansion ratio.
- $y[n]$ is the output signal in dB.
- $x[n]$ is the input signal in dB.
- T is the threshold in dB.

To specify **Ratio** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Threshold (dB) — Operation threshold

-10 (default) | scalar in the range -140 to 0 inclusive

Operation threshold is the level below which gain is applied to the input signal.

To specify **Threshold (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Knee width (dB) — Transition area in the compression characteristic

0 (default) | scalar in the range 0 to 20

For soft knee characteristics, the transition area is defined by the relation

$$y = x + \frac{(1 - R) \times \left(x - T - \frac{W}{2}\right)^2}{(2 \times W)}$$

for the range $(2 \times |x - T|) \leq W$, where

- y is the output level in dB.
- x is the input level in dB.
- R is the expansion ratio.
- T is the threshold in dB.
- W is the knee width in dB.

To specify **Knee width (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

View static characteristic — Open static characteristic plot of dynamic range expander

button

The plot is updated automatically when parameters of the Expander block change.

Tunable: Yes

Attack time (s) — Time for applied gain to ramp up

0.05 (default) | scalar in the range 0 to 4 inclusive

Attack time is the time the expander gain takes to rise from 10% to 90% of its final value when the input goes below the threshold. The **Attack time (s)** parameter smooths the applied gain curve.

To specify **Attack time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Release time (s) — Time for applied gain to ramp down

0.2 (default) | scalar in the range 0 to 4 inclusive

Release time is the time the expander gain takes to drop from 90% to 10% of its final value when the input goes above the threshold. The **Release time (s)** parameter smooths the applied gain curve.

To specify **Release time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Hold time (s) — Time during which applied gain holds steady

0.05 (default) | scalar in the range 0 to 4 inclusive

Hold time is the period for which the (negative) gain is held before starting to decrease towards its steady state value when the input level drops below the threshold.

To specify **Hold time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, specify the sample rate in the **Input sample rate (Hz)** parameter.

Tunable: No

Input sample rate (Hz) — Sample rate of input

44100 (default) | positive scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Advanced Tab

Output gain (dB) — Gain applied on each input sample

off (default) | on

When you select this parameter, an additional output port, **G**, is added to the block. The **G** port outputs the gain applied on each input channel in dB.

Tunable: No

Sidechain — Enable sidechain input

off (default) | on

When you select this parameter, an additional input port **SC** is added to the block. The **SC** port enables dynamic range expansion of the input signal **x** using a separate sidechain signal.

The datatype and (frame) length input to the **SC** port must be the same as the input to the **x** port.

The number of channels of the sidechain input must be equal to the number of channels of **x** or be equal to one.

- Sidechain channel count is equal to one -- The computed gain, **G**, based on this channel is applied to all channels of **x**.
- Sidechain channel count is equal to channel count of **x** -- The computed gain, **G**, for each sidechain channel is applied to the corresponding channel of **x**.

Tunable: No

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- Interpreted execution -- Simulate model using the MATLAB interpreter. This option shortens startup time and has a simulation speed comparable to Code generation. In this mode, you can debug the source code of the block.
- Code generation -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to Interpreted execution.

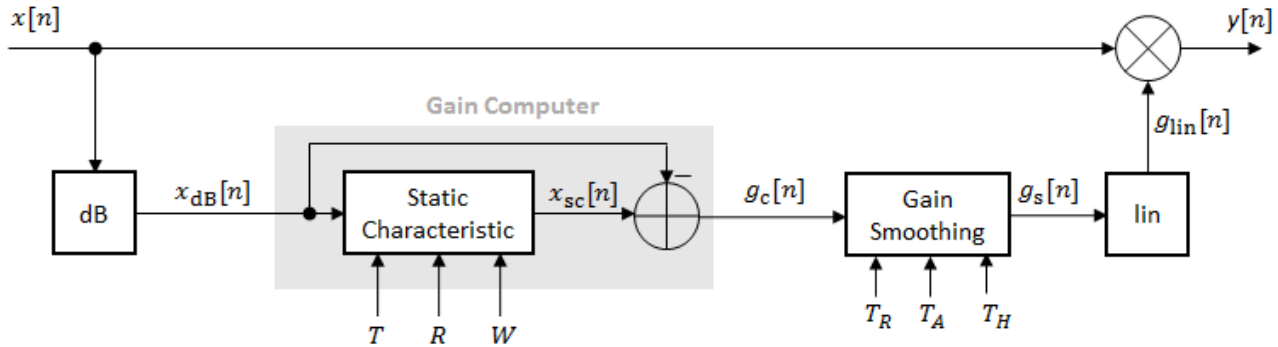
Tunable: No

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Expander block processes a signal frame by frame and element by element.



- 1 The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$
- 2 $x_{dB}[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range expander to attenuate gain that is below the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} T + (x_{dB} - T) \times R & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} + \frac{(1 - R)(x_{dB} - T - \frac{W}{2})^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ x_{dB} & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases} ,$$

where T is the threshold, R is the expansion ratio, and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} T + (x_{dB} - T) \times R & x_{dB} < T \\ x_{dB} & x_{dB} \geq T \end{cases}$$

- 3 The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$
- 4 $g_c[n]$ is smoothed using specified attack, release, and hold time parameters:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n] & (C_A > T_H) \ \& \ (g_c[n] \leq g_s[n-1]) \\ g_s[n-1] & C_A \leq T_H \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n] & g_c[n] > g_s[n-1] \end{cases}$$

C_A is the hold counter for attack. The limit, T_H , is determined by the **Hold time (s)** parameter.

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{FS \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the **Attack time (s)** parameter. T_R is the release time period, specified by the **Release time (s)** parameter. F_S is the input sampling rate, specified by the **Inherit sample rate from input** or **Input sample rate (Hz)** parameter.

- 5 The smoothed gain in dB, $g_s[n]$, is translated to a linear domain:

$$g_{\text{lin}}[n] = 10^{\left(\frac{g_s[n]}{20}\right)}.$$

- 6 The output of the dynamic range expander is given as

$$y[n] = x[n] \times g_{\text{lin}}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial And Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

expander | Limiter | Compressor | Noise Gate

Topics

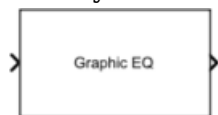
"Dynamic Range Control"

Introduced in R2016a

Graphic EQ

Standards-based graphic equalizer

Library: Audio Toolbox / Filters



Description

The Graphic EQ block implements a graphic equalizer that can tune the gain on individual octave or fractional octave bands. The block filters the data independently across each input channel over time using the filter specifications. Center frequencies for bands in the graphic equalizer are based on the ANSI S1.11-2004 standard.

Ports

Input

Port_1 — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a signal channel.

Data Types: single | double

Output

Port_1 — Output signal

matrix

The Graphic EQ block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector input.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

EQ Order — Order of individual equalizer bands

2 (default) | positive even integer

Specify the order of individual equalizer bands as a positive even integer. All equalizer bands have the same order.

Tunable: Yes

Bandwidth — Filter bandwidth (octaves)

1 octave (default) | 2/3 octave | 1/3 octave

Specify the filter bandwidth as 1 octave, 2/3 octave, or 1/3 octave.

The ANSI S1.11-2004 standard defines the center and edge frequencies of your equalizer. The ISO 266:1997(E) standard specifies corresponding preferred frequencies for labeling purposes.

1-Octave Bandwidth

Center frequencies	32 63 126 251 501 1000 1995 3981 7943 15849
Edge frequencies	22 45 89 178 355 708 1413 2818 5623 1122 22387
Preferred frequencies	31.5 63 125 250 500 1000 2000 4000 8000 16000

2/3-Octave Bandwidth

Center frequencies	25 40 63 100 158 251 398 631 1000 1585 2512 3981 6310 10000 15849
Edge frequencies	20 32 50 79 126 200 316 501 794 1259 1995 3162 5012 7943 12589 19953
Preferred frequencies	25 40 63 100 160 250 400 630 1000 1600 2500 4000 6300 10000 16000

1/3-Octave Bandwidth

Center frequencies	25 32 40 50 63 79 100 126 158 200 251 316 398 501 631 794 1000 1259 1585 1995 2512 3162 3981 5012 6310 7943 10000 12589 15849 19953
Edge frequencies	22 28 35 45 56 71 89 112 141 178 224 282 355 447 562 708 891 1122 1413 1778 2239 2818 3548 4467 5623 7079 8913 11220 14125 17783 22387
Preferred frequencies	25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1000 1250 1600 2000 2500 3150 4000 5000 6300 8000 10000 12500 16000 20000

Tunable: Yes

Structure — Type of implementation

Cascade (default) | Parallel

Specify the type of implementation as Cascade or Parallel. See “Algorithms” on page 5-60 and “Graphic Equalization” for information about these implementation structures.

Tunable: No

Gains — Gain of each octave or fractional octave band (dB)

0 | scalar

Specify the gain of each octave or fractional octave band in dB. The number and position of filters in the graphic equalizer depends on the **Bandwidth** on page 5-0 parameter.

Tunable: Yes**Variable name — Variable name of exported filter**

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is var and it already exists, the exported variable will be named var_1.

Export filter to workspace — Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.

Tips

You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, specify the sample rate in **Input sample rate (Hz)** on page 5-0 .

Tunable: No**Input sample rate (Hz) — Sample rate of input**

44100 (default) | scalar

Tunable: Yes**Dependencies**

To enable this parameter, clear the **Inherit sample rate from input** on page 5-0 parameter.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time and has simulation speed comparable to **Code generation**. In this mode, you can debug the source code of the block.

- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is faster than **Interpreted execution**.

Tunable: No

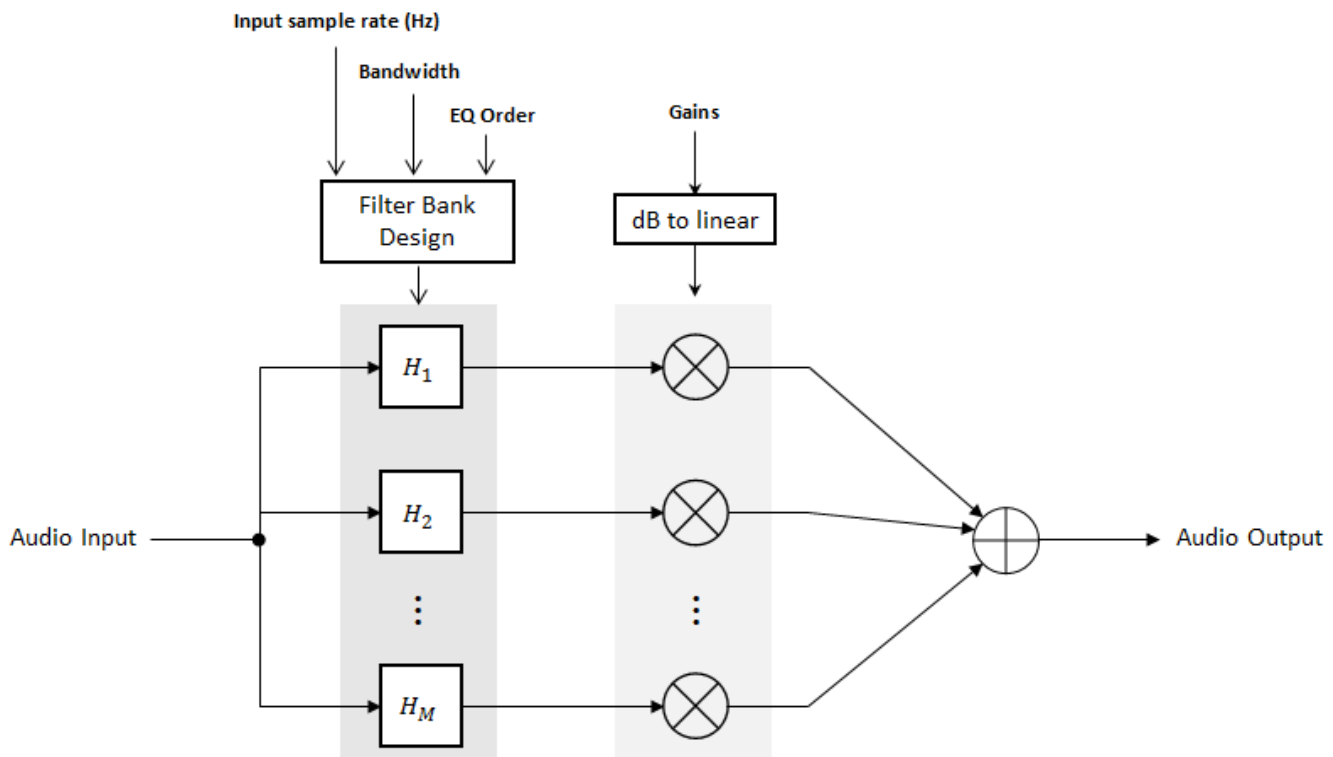
Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The implementation of your graphic equalizer depends on the **Structure** on page 5-0 parameter. See “Graphic Equalization” for a discussion of the pros and cons of the parallel and cascade implementations. Refer to the following sections to understand how these algorithms are implemented in Audio Toolbox.

Parallel Structure



Filter Bank Design

The parallel implementation designs the individual equalizers using the `octaveFilter` design method and spaces them on the spectrum according to the ANSI S1.11-2004 standard.

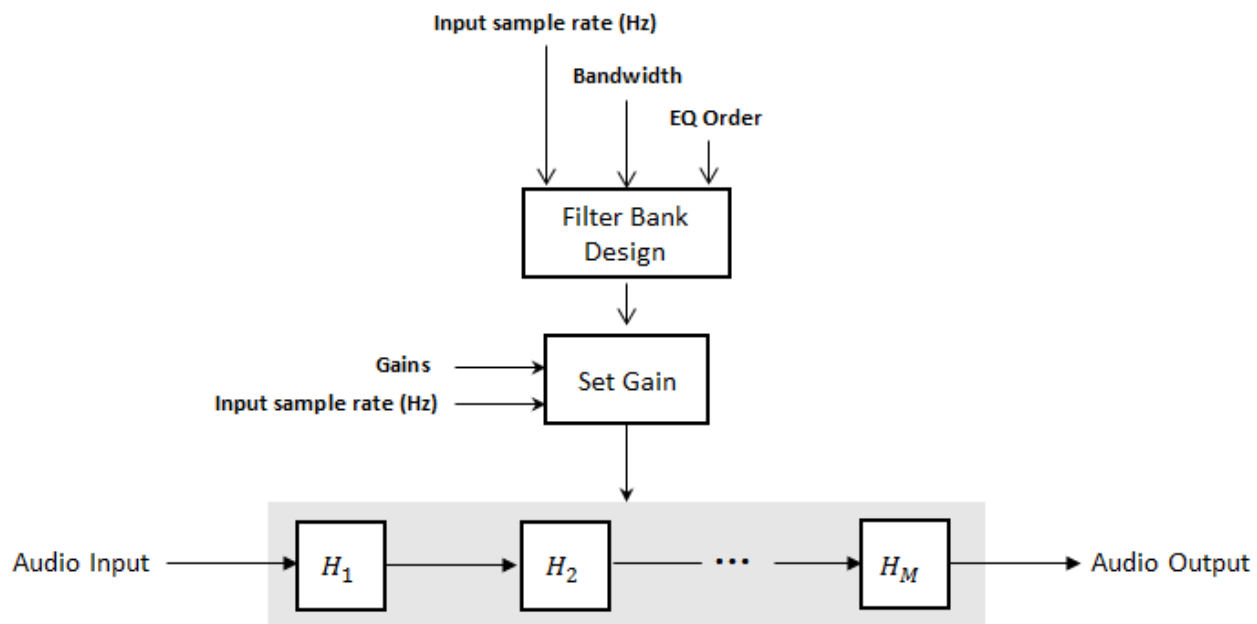
If you set the **Input sample rate (Hz)** parameter so that the Nyquist frequency (**Input sample rate (Hz)**/2) is less than the final bandpass edge defined by the ANSI S1.11-2004 standard, then:

- The final bandpass filter is the one whose upper bandpass edge is less than the Nyquist frequency.
- The final filter is implemented as a highpass filter designed by the `designParamEQ` function.

Real-Time Computation

- 1 The input signal is fed into a filterbank of M filters, where M depends on the specified **Bandwidth** and **Input sample rate (Hz)** parameters.
- 2 Each branch of the filterbank is multiplied by the linear form of the corresponding element of the **Gains** parameter.
- 3 The branches are summed and the output signal is returned.

Cascade Structure



Filter Bank Design

The cascade implementation designs the graphic equalizer filter bank using the `multibandParametricEQ` System object.

Gain Setting

If the **EQ Order** on page 5-0 parameter is set to 2, then a gain correction is calculated according to [1]. The gain correction is independent of the requested gains. The gain correction is recomputed during the real-time processing only if the **Input sample rate (Hz)** parameter is modified.

If the **EQ Order** parameter is not set to 2, no gain correction is applied and the requested gains are passed on to the `multibandParametricEQ` object.

Real-Time Computation

The input signal is fed into a cascade of M biquad filters, where M depends on the specified **Bandwidth** and **Input sample rate (Hz)** parameters.

References

- [1] Oliver, Richard J., and Jean-Marc Jot. "Efficient Multi-Band Digital Audio Graphic Equalizer with Accurate Frequency Response Control." Presented at the 139th Convention of the AES, New York, October 2015.
- [2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters*. ANSI S1.11-2004. Melville, NY: Acoustical Society of America, 2009.
- [3] International Organization for Standardization. *Acoustics -- Preferred frequencies*. ISO 266:1997(E). Second Edition. 1997.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Single-Band Parametric EQ | Multiband Parametric EQ | `graphicEQ` | `multibandParametricEQ` | `designVarSlopeFilter` | `designParamEQ` | `designShelvingEQ`

Topics

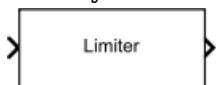
"Graphic Equalization"
"Equalization"

Introduced in R2017b

Limiter

Dynamic range limiter

Library: Audio Toolbox / Dynamic Range Control



Description

The Limiter block performs dynamic range limiting independently across each input channel. Dynamic range limiting suppresses the volume of loud sounds that cross a given threshold. The block uses specified attack and release times to achieve a smooth applied gain curve.

Ports

Input

x — Input signal

1-D vector | matrix

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

T — Threshold (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Threshold (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

K — Knee width (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Knee width (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

AT — Attack time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Attack time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

RT — Release time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Release time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

Output**Y — Output signal**

matrix

The Limiter block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

This port is unnamed until you select the **Output gain (dB)** parameter.

Data Types: `single` | `double`

G — Gain applied to each input sample

matrix

Dependencies

To enable this port, select the **Output gain (dB)** parameter.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Main Tab**Threshold (dB) — Operation threshold**

-10 (default) | scalar in the range -50 to 0 inclusive

Operation threshold is the level above which gain is applied to the input signal.

To specify **Threshold (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Knee width (dB) — Transition area in the limiter characteristic

0 (default) | scalar in the range 0 to 20 inclusive

For soft knee characteristics, the transition area is defined by the relation

$$y = x - \frac{\left(x - T + \frac{W}{2}\right)^2}{(2 \times W)}$$

for the range $(2 \times |x - T|) \leq W$, where

- y is the output level in dB.
- x is the input level in dB.
- T is the threshold in dB.
- W is the knee width in dB.

To specify **Knee width (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

View static characteristic — Open static characteristic plot of dynamic range limiter
button

The plot is updated automatically when parameters of the Limiter block change.

Tunable: Yes

Attack time (s) — Time for applied gain to ramp up

0 (default) | scalar in the range 0 to 4 inclusive

Attack time is the time the limiter gain takes to rise from 10% to 90% of its final value when the input goes above the threshold. The **Attack time (s)** parameter smooths the applied gain curve.

To specify **Attack time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Release time (s) — Time for applied gain to ramp down

0.2 (default) | scalar in the range 0 to 4 inclusive

Release time is the time the limiter gain takes to drop from 90% to 10% of its final value when the input goes below the threshold. The **Release time (s)** parameter smooths the applied gain curve.

To specify **Release time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Make-up gain mode — Make-up gain mode

Property (default) | Auto

- Property -- Make-up gain is set to the value specified by the **Make-up gain (dB)** parameter.
- Auto -- Make-up gain is applied at the output of the Limiter block such that a steady-state 0 dB input has a 0 dB output.

Tunable: No

Make-up gain (dB) — Applied make-up gain

0 (default) | scalar in the range -10 to 24 inclusive

Make-up gain compensates for gain lost during limiting. It is applied at the output of the Limiter block.

Tunable: Yes

Dependencies

To enable this parameter, set the **Make-up gain mode** parameter to Property.

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, specify the sample rate in the **Input sample rate (Hz)** parameter.

Tunable: No

Input sample rate (Hz) — Specify input sample rate

44100 (default) | positive scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Advanced Tab

Output gain (dB) — Gain applied on each input sample

off (default) | on

When you select this parameter, an additional output port, **G**, is added to the block. The **G** port outputs the gain applied on each input channel in dB.

Tunable: No

Sidechain — Enable sidechain input

off (default) | on

When you select this parameter, an additional input port **SC** is added to the block. The **SC** port enables dynamic range limiting of the input signal **x** using a separate sidechain signal.

The datatype and (frame) length input to the **SC** port must be the same as the input to the **x** port.

The number of channels of the sidechain input must be equal to the number of channels of **x** or be equal to one.

- Sidechain channel count is equal to one -- The computed gain, **G**, based on this channel is applied to all channels of **x**.
- Sidechain channel count is equal to channel count of **x** -- The computed gain, **G**, for each sidechain channel is applied to the corresponding channel of **x**.

Tunable: No

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time and has a simulation speed comparable to Code generation. In this mode, you can debug the source code of the block.
- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to Interpreted execution.

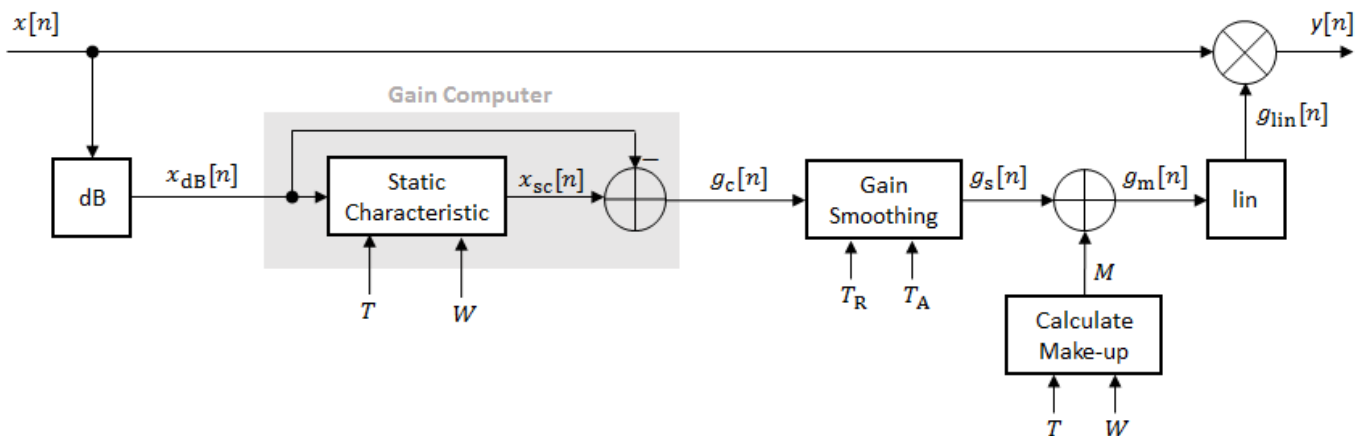
Tunable: No

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Limiter block processes a signal frame by frame and element by element.



- 1 The N -point signal, $x[n]$, is converted to decibels:

$$x_{dB}[n] = 20 \times \log_{10}|x[n]|$$
- 2 $x_{dB}[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range limiter to brickwall gain that is above the threshold.

If you specified a soft knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < \left(T - \frac{W}{2}\right) \\ x_{dB} - \frac{\left(x_{dB} - T + \frac{W}{2}\right)^2}{2W} & \left(T - \frac{W}{2}\right) \leq x_{dB} \leq \left(T + \frac{W}{2}\right) \\ T & x_{dB} > \left(T + \frac{W}{2}\right) \end{cases} ,$$

where T is the threshold and W is the knee width.

If you specified a hard knee, the gain computer has the following static characteristic:

$$x_{sc}(x_{dB}) = \begin{cases} x_{dB} & x_{dB} < T \\ T & x_{dB} \geq T \end{cases}$$

- 3** The computed gain, $g_c[n]$, is calculated as

$$g_c[n] = x_{sc}[n] - x_{dB}[n].$$

- 4** $g_c[n]$ is smoothed using specified attack and release time parameters:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n], & g_c[n] \leq g_s[n-1] \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n], & g_c[n] > g_s[n-1] \end{cases}$$

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{F_S \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the **Attack time (s)** parameter. T_R is the release time period, specified by the **Release time (s)** parameter. F_S is the input sampling rate, specified by the **Inherit sample rate from input** or **Input sample rate (Hz)** parameter.

- 5** If the **Make-up gain (dB)** parameter is set to Auto, the make-up gain is calculated as the negative of the computed gain for a 0 dB input:

$$M = -x_{sc}(x_{dB} = 0)$$

Given a steady-state input of 0 dB, this configuration achieves a steady-state output of 0 dB. The make-up gain is determined by the **Threshold (dB)** and **Knee width (dB)** parameters. It does not depend on the input signal.

- 6** The make-up gain, M , is added to the smoothed gain, $g_s[n]$:

$$g_m[n] = g_s[n] + M$$

- 7** The calculated gain in dB, $g_m[n]$, is translated to a linear domain:

$$g_{lin}[n] = 10\left(\frac{g_m[n]}{20}\right)$$

- 8** The output of the dynamic range limiter is given as

$$y[n] = x[n] \times g_{\text{lin}}[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial And Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Compressor | Expander | Noise Gate | `limiter`

Topics

"Dynamic Range Control"

Introduced in R2016a

Loudness Meter

Standard-compliant loudness measurements

Library: Audio Toolbox / Measurements



Description

The Loudness Meter block measures the loudness and true-peak of an audio signal based on EBU R 128 and ITU-R BS.1770-4 standards.

Ports

Input

Port_1 — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel. If you use the default **Channel weights**, specify the input channels in order: [Left, Right, Center, Left surround, Right surround].
- 1-D vector input -- The input is treated as a single channel.

Data Types: single | double

Output

M — Momentary loudness measurement

column vector

The block outputs a column vector with the same data type and number of rows as the input signal.

Data Types: single | double

S — Short-term loudness measurement

column vector

The block outputs a column vector with the same data type and number of rows as the input signal.

Data Types: single | double

TP — True-peak value

real scalar

The block outputs a real scalar with the same data type as the input signal.

Dependencies

To enable this port, select the **Output true-peak value** parameter.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Channel weights — Linear weighting applied to each input channel

[1, 1, 1, 1.41, 1.41] (default) | nonnegative row vector

The number of elements of the row vector must be equal to or greater than the number of input channels. Excess values in the vector are ignored.

The default channel weights follow the ITU-R BS.1170-4 standard. To use the default channel weights, specify the input to the Loudness Meter block as a matrix whose columns correspond to channels in this order: [Left, Right, Center, Left surround, Right surround].

It is a best practice to specify the channel weights in order: [Left, Right, Center, Left surround, Right surround].

Tunable: Yes

Use relative scale for loudness measurements — Specify block to output loudness measurements relative to target level

off (default) | on

- On — The loudness measurements are relative to the value specified by **Target loudness level (LUFS)**. The output of the block is returned in loudness units (LU).
- Off — The loudness measurements are absolute, and returned in loudness units full scale (LUFS).

Tunable: No

Target loudness level (LUFS) — Reference level for relative loudness measurements

-23 (default) | real scalar

For example, if the **Target loudness level (LUFS)** is -23, then a loudness value of -24 LUFS is reported as -1 LU.

Tunable: Yes

Dependencies

To enable this parameter, select the **Use relative scale for loudness measurements** parameter.

Output true-peak value — Add output port for true-peak value

off (default) | on

When you select this parameter, an additional output port, **TP**, is added to the block. The **TP** port outputs the true-peak value of the input frame.

Tunable: No

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Tunable: No

Input sample rate (Hz) — Sample rate of input

44100 (default) | scalar

Tunable: Yes**Dependencies**To enable this parameter, clear the **Inherit sample rate from input** parameter.**Simulate using — Specify type of simulation to run**

Code generation (default) | Interpreted execution

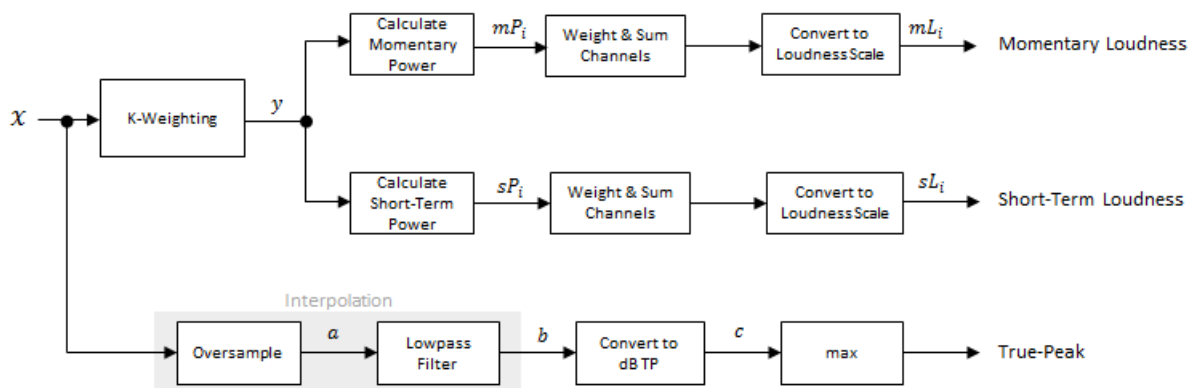
- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than **Code generation**. In this mode, you can debug the source code of the block.

Tunable: No**Block Characteristics**

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Loudness Meter block calculates the momentary loudness, short-term loudness, and true-peak value of an audio signal. You can specify any number of channels and nondefault channel weights used for loudness measurements. The block algorithm is described for the general case of n channels and default channel weights.



Loudness Measurements

The input channels, x , pass through a K-weighted filter implemented using the algorithm of the Weighting Filter block. The K-weighted filter shapes the frequency spectrum to reflect perceived loudness.

Momentary Loudness

- 1 The K-weighted channels, y , are divided into 0.4-second segments with 0.3-second overlap. If the required number of samples have not been collected yet, the Loudness Meter block returns the last computed value for momentary loudness. If enough samples have been collected, then the power (mean square) of each segment of the K-weighted channels is calculated:

$$mP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- mP_i is the momentary power of the i th segment.
 - w is the segment length in samples.
- 2 The momentary loudness, mL , is computed for each segment:

$$mL_i = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times mP_{(i,c)} \right) \text{ LUFS}$$

- G_c is the weighting for channel c .

mL is the momentary loudness returned by your Loudness Meter block.

Short-Term Loudness

- 1 The K-weighted channels, y , are divided into 3-second segments with 2.9-second overlap. If the required number of samples have not been collected yet, the Loudness Meter block returns the last computed values for short-term loudness and loudness range. If enough samples have been collected, then the power (mean square) of each K-weighted channel is calculated:

$$sP_i = \frac{1}{w} \sum_{k=1}^w y_i^2[k]$$

- sP_i is the short-term power of the i th segment of a channel.
 - w is the segment length in samples.
- 2 The short-term loudness, sL , is computed for each segment:

$$sL_i = -0.691 + 10 \log_{10} \left(\sum_{c=1}^n G_c \times sP_{(i,c)} \right) \text{ LUFS}$$

- G_c is the weighting for channel c .

sL is the short-term loudness returned by your Loudness Meter block.

True-Peak

The *true-peak* measurement considers only the current input frame of a call to your loudness meter.

- 1 The signal is oversampled to at least 192 kHz. To optimize processing, the input sample rate determines the exact oversampling. An input sample rate below 750 Hz is not considered.

Input Sample Rate (kHz)	Upsample Factor
[0.75,1.5)	256
[1.5,3)	128
[3,6)	64
[6,12)	32
[12,24)	16
[24,48)	8
[48,96)	4
[96,192)	2
[192,∞)	not required

- 2 The oversampled signal, a , passes through a lowpass filter with a half-polyphase length of 12 and stopband attenuation of 80 dB. The filter design uses `designMultirateFIR`.
- 3 The filtered signal, b , is rectified and converted to the dB TP scale:

$$c = 20 \times \log_{10}(|b|)$$
- 4 The true-peak is determined as the maximum of the converted signal, c .

References

- [1] International Telecommunication Union; Radiocommunication Sector. *Algorithms to Measure Audio Programme Loudness and True-Peak Audio Level*. ITU-R BS.1770-4. 2015.
- [2] European Broadcasting Union. *Loudness Normalisation and Permitted Maximum Level of Audio Signals*. EBU R 128. 2014.
- [3] European Broadcasting Union. *Loudness Metering: 'EBU Mode' Metering to Supplement EBU R 128 Loudness Normalization*. EBU R 128 Tech 3341. 2014.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

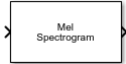
`integratedLoudness` | `loudnessMeter`

Introduced in R2016b

Mel Spectrogram

Extract mel spectrogram from audio

Library: Audio Toolbox / Features



Description

The Mel Spectrogram block extracts the mel spectrogram from the audio input signal. A mel spectrogram contains an estimate of the short-term, time-localized frequency content of the input signal in the mel frequency scale.

Ports

Input

Port_1 — Audio input

column vector | matrix

Audio input signal, specified as a column vector or a matrix. When you specify a matrix, the block treats columns as independent audio channels.

Data Types: `single` | `double`

Output

spec — Mel spectrogram

matrix | 3-D array

Mel spectrogram, returned as a matrix or 3-D array. The dimensions of **spec** are L -by- M -by- N , where:

- L is the number of spectra, which is determined by the **Number of spectra** parameter.
- M is the number of bands, which is determined by the **Number of bands** parameter.
- N is the number of channels in the input audio signal.

Trailing singleton dimensions are removed from the output.

This port is unnamed until you select the **Output center frequencies** parameter.

Data Types: `single` | `double`

fvec — Center frequencies

row vector

Center frequencies of the bandpass filters in Hz, returned as a row vector with number of elements equal to the number of bands.

Dependencies

To enable this port, select the **Output frequency vector** parameter.

Data Types: `single` | `double`

Parameters

Filter Bank Parameters

Number of bands — Number of bandpass filters

32 (default) | positive integer

Number of bandpass filters, specified as a positive integer.

Auto-determine frequency range — Automatically determine frequency range

on (default) | off

When you select this parameter, the block sets the **Frequency range** to $[0, f_s/2]$, where f_s is the sample rate. The sample rate is determined by the **Inherit sample rate from input** and **Input sample rate (Hz)** parameters.

Frequency range (Hz) — Frequency range over which to design auditory filter bank

$[0, 22050]$ (default) | two-element row vector

Frequency range in Hz over which to design the auditory filter bank, specified as a two-element row vector.

Dependencies

To enable this parameter, clear the **Auto-determine frequency range** parameter.

Filter bank design domain — Domain to design filter bank

linear (default) | warped

Domain in which the block designs the filter bank, specified as `linear` or `warped`. Set the filter bank design domain to `linear` to design the bandpass filters in the linear (Hz) domain. Set the filter bank design domain to `warped` to design the bandpass filters in the warped (mel) domain.

Filter bank normalization — Normalization technique for filter bank

bandwidth (default) | area | none

Normalization technique used for the filter bank weights, specified as `bandwidth`, `area`, or `none`.

- `bandwidth` -- Normalize the weights of each bandpass filter by the corresponding bandwidth of the filter.
- `area` -- Normalize the weights of each bandpass filter by the corresponding area of the bandpass filter.
- `none` -- The block does not normalize the weights of the filters.

Visualize filter bank — Open plot to visualize filter bank

button

Open plot to visualize the filters in the frequency domain.

Output frequency vector — Specify additional output port for center frequencies

off (default) | on

When you select this parameter, the block displays an additional output port, **fvec**. This port outputs the center frequencies of the bandpass filters.

Spectrogram Parameters

Window — Analysis window

hamming(1024, 'periodic') (default) | real vector

Analysis window applied in the time domain, specified as a real vector.

Normalize window — Normalize analysis window

on (default) | off

When you select this parameter, the block applies window normalization.

Overlap length — Overlap length of adjacent analysis windows

512 (default) | integer in the range [0, windowLength)

Overlap length of adjacent analysis windows, specified as an integer in the range [0, windowLength), where windowLength is the length of the analysis window, which is specified by **Window**.

Auto-determine FFT length — Automatically determine FFT length

on (default) | off

When you select this parameter, the block automatically sets the FFT length to the window length, numel(Window).

FFT length — Number of DFT points

1024 (default) | positive integer

Number of points used to calculate the DFT, specified as a positive integer.

Dependencies

To enable this parameter, clear the **Auto-determine FFT length** parameter.

Spectrum type — Type of spectrum

magnitude (default) | power

Type of spectrum, specified as magnitude or power.

Number of spectra — Number of spectra

1 (default) | positive integer

Number of spectra in the spectrogram, specified as a positive integer.

Number of spectra overlap — Number of overlapped spectra

0 (default) | integer in the range [0, Number of spectra).

Number of spectra overlapped across consecutive spectrograms, specified as an integer in the range [0, Number of spectra)

Simulation Parameters

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in the **Input sample rate (Hz)** parameter.

Input sample rate (Hz) — Sample rate of input

44.1e3 (default) | positive scalar

Input sample rate in Hz, specified as a real positive scalar.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Auditory Spectrogram | Design Auditory Filter Bank | Design Mel Filter Bank

Functions

designAuditoryFilterBank | melSpectrogram

Objects

audioFeatureExtractor

Introduced in R2022a

MIDI Controls

Output values from controls on MIDI control surface

Library: Audio Toolbox / Sources
DSP System Toolbox / Sources



Description

The MIDI Controls block outputs values from controls on a MIDI control surface in real time. Use the MIDI Controls block to interact with your audio processing model.

The MIDI Controls block combines the functionality of the general MIDI functions in MATLAB: `midicontrols`, `midiread`, `midisync`. Use the MATLAB `midiid` command to discover MIDI device names or MIDI device control numbers.

Ports

Output

Port_1 — Output signal

matrix

The output size of the MIDI Controls block is determined by the **MIDI controls** and **MIDI control numbers** parameters.

The output data type is determined by the **Output mode** parameter.

Data Type	Output Mode
double	Normalized (0-1)
uint8	RAW MIDI (0-127)

Data Types: double | uint8

Parameters

MIDI device — MIDI control surface your block listens to

Default (default) | Specify other

To set the default MIDI device, use the `setpref` function. For example, if the device is named `BCF2000`, at the MATLAB command line, enter:

```
setpref('midi', 'DefaultDevice', 'BCF2000');
```

MIDI device name — Device name of MIDI control surface your block listens to

character vector

The MIDI device name is assigned by the device manufacturer or host operating system, and specified as a character vector. Use `midiid` to interactively identify your MIDI device.

To enable this parameter, set **MIDI device** to Specify other.

MIDI controls — Specify if block responds to all controllers or specific controllers on MIDI surface

Respond to any control (default) | Respond to specified controls

This parameter also determines the size of the block output port. If you choose Respond to any control, then the block output is a scalar corresponding to the value of the most recently manipulated control.

MIDI control numbers — Control numbers associated with MIDI surface controllers that your block responds to

0 (default) | integer | array of integers

Use `midiid` to interactively identify the control numbers of your MIDI device. This parameter is available when you set **MIDI controls** to Respond to specified controls.

Initial values — Control numbers associated with MIDI surface controllers that your block responds to

0 (default) | scalar | array

If you specify **Initial values** as a scalar, all controls specified by **MIDI control numbers** are assigned that value.

If you specify **Initial values** as an array, the array must be the same size as **MIDI control numbers**.

Send initial values to device at start — Synchronize MIDI surface with values specified initial values

off (default) | on

Select this parameter to synchronize a MIDI device with values specified by the **Initial values** when simulation starts. If your MIDI device can receive and respond to messages, it adjusts its controls as specified. This parameter is valid only when **MIDI controls** is set to Respond to specified controls.

Many MIDI devices are not bidirectional. Selecting this parameter with a unidirectional device has no effect. The MIDI Controls block cannot tell whether a value is successfully sent to a device or even whether the device is bidirectional. If sending a value fails, no errors or warnings are generated.

Output Mode — Output mode for MIDI control value

Normalized (0-1) (default) | RAW MIDI (0-127)

Output mode for MIDI control value, specified as Normalized (0-1) or RAW MIDI (0-127).

Block Characteristics

Data Types	double integer
Direct Feedthrough	no

Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Tips

- The MIDI Controls block is not supported for rapid accelerator mode.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

The executable generated from this block relies on prebuilt dynamic library files (.dll files) included with MATLAB. Use the `packNGo` function to package the code generated from this object and all the relevant files in a compressed zip file. Using this zip file, you can relocate, unpack, and rebuild your project in another development environment where MATLAB is not installed. For more details, see “Run Audio I/O Features Outside MATLAB and Simulink”.

See Also

`parameterTuner` | **Audio Test Bench** | `mididid` | `midicontrols` | `midiread` | `midisync`

Topics

“MIDI Control Surface Interface”

Noise Gate

Dynamic range gate

Library: Audio Toolbox / Dynamic Range Control



Description

The Noise Gate block performs dynamic range gating independently across each input channel. Dynamic range gating suppresses signals below a given threshold. The block uses specified attack, release, and hold times to achieve a smooth applied gain curve.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

T — Threshold (dB)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Threshold (dB)” on page 5-0 parameter.

Data Types: `single` | `double`

AT — Attack time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Attack time (s)” on page 5-0 parameter.

Data Types: `single` | `double`

RT — Release time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Release time (s)” on page 5-0 parameter.

Data Types: single | double

HT — Hold time (s)

scalar

Dependencies

To enable this port, select **Specify from input port** for the “Hold time (s)” on page 5-0 parameter.

Data Types: single | double

Output

Y — Output signal

matrix

The Noise Gate block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

This port is unnamed until you select the **Output gain (dB)** parameter.

Data Types: single | double

G — Gain applied to each input sample

matrix

Dependencies

To enable this port, select the **Output gain (dB)** parameter.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Main Tab

Threshold (dB) — Operation threshold

-10 (default) | scalar in the range -140 to 0 inclusive

Operation threshold is the level below which gain is applied to the input signal.

To specify **Threshold (dB)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

View static characteristic — Open static characteristic plot of dynamic range gate

button

The plot is updated automatically when parameters of the Noise Gate block change.

Tunable: Yes

Attack time (s) – Time for applied gain to ramp up

0.05 (default) | scalar in the range 0 to 4 inclusive

Attack time is the time the applied gain takes to rise from 10% to 90% of its final value when the input goes below the threshold. The **Attack time (s)** parameter smooths the applied gain curve.

To specify **Attack time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Release time (s) – Time for applied gain to ramp down

0.2 (default) | scalar in the range 0 to 4 inclusive

Release time is the time the applied gain takes to drop from 90% to 10% of its final value when the input goes above the threshold. The **Release time (s)** parameter smooths the applied gain curve.

To specify **Release time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Hold time (s) – Time during which applied gain holds steady

0.05 (default) | scalar in the range 0 to 4

Hold time is the period for which the (negative) gain is held before starting to decrease towards its steady state value when the input level drops below the threshold.

To specify **Hold time (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Inherit sample rate from input – Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Tunable: No

Input sample rate (Hz) – Specify input sample rate

44100 (default) | scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Advanced Tab**Output gain (dB) – Gain applied on each input sample**

off (default) | on

When you select this parameter, an additional output port, **G**, is added to the block. The **G** port outputs the gain applied on each input channel in dB.

Tunable: No

Sidechain — Enable sidechain input

off (default) | on

When you select this parameter, an additional input port **SC** is added to the block. The **SC** port enables dynamic range gating of the input signal **x** using a separate sidechain signal.

The datatype and (frame) length input to the **SC** port must be the same as the input to the **x** port.

The number of channels of the sidechain input must be equal to the number of channels of **x** or be equal to one.

- Sidechain channel count is equal to one -- The computed gain, *G*, based on this channel is applied to all channels of **x**.
- Sidechain channel count is equal to channel count of **x** -- The computed gain, *G*, for each sidechain channel is applied to the corresponding channel of **x**.

Tunable: No

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- Interpreted execution -- Simulate model using the MATLAB interpreter. This option shortens startup time and has a simulation speed comparable to Code generation. In this mode, you can debug the source code of the block.
- Code generation -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to Interpreted execution.

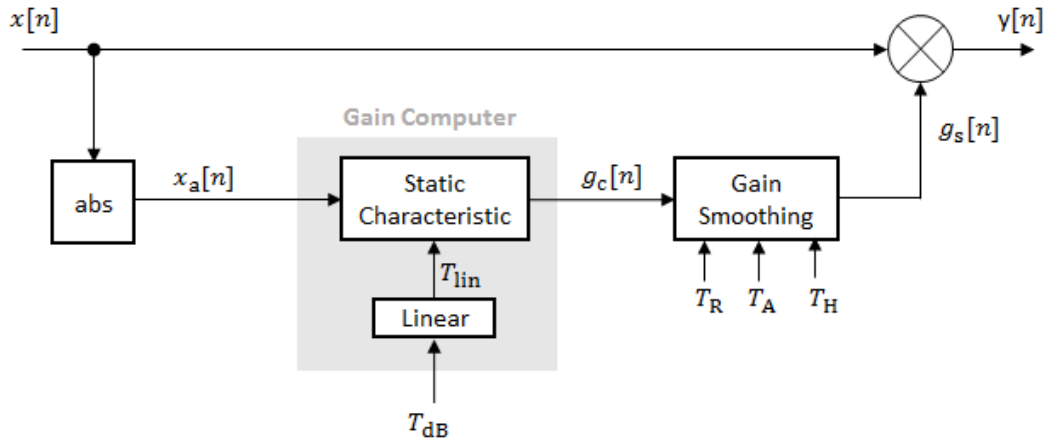
Tunable: No

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The Noise Gate block processes a signal frame by frame and element by element.



- 1 The N -point signal, $x[n]$, is converted to magnitude:

$$x_a[n] = |x[n]|$$

- 2 $x_a[n]$ passes through the gain computer. The gain computer uses the static characteristic properties of the dynamic range gate to apply a brickwall gain for signal below the threshold:

$$g_c(x_a) = \begin{cases} 0 & x_a < T_{\text{lin}} \\ 1 & x_a \geq T_{\text{lin}} \end{cases}$$

T_{lin} is the threshold property converted to a linear domain:

$$T_{\text{lin}} = 10^{(T_{\text{dB}}/20)}.$$

- 3 The computed gain, $g_c[n]$, is smoothed using specified attack, release, and hold time parameters:

$$g_s[n] = \begin{cases} \alpha_A g_s[n-1] + (1 - \alpha_A) g_c[n] & (C_A > T_H) \ \& \ (g_c[n] \leq g_s[n-1]) \\ g_s[n-1] & C_A \leq T_H \\ \alpha_R g_s[n-1] + (1 - \alpha_R) g_c[n] & g_c[n] > g_s[n-1] \end{cases}$$

C_A is the hold counter for attack. The limit, T_H , is determined by the **Hold time (s)** parameter.

The attack time coefficient, α_A , is calculated as

$$\alpha_A = \exp\left(\frac{-\log(9)}{F_S \times T_A}\right).$$

The release time coefficient, α_R , is calculated as

$$\alpha_R = \exp\left(\frac{-\log(9)}{F_S \times T_R}\right).$$

T_A is the attack time period, specified by the **Attack time (s)** parameter. T_R is the release time period, specified by the **Release time (s)** parameter. F_S is the input sampling rate, specified by the **Inherit sample rate from input** or **Input sample rate (Hz)** parameter.

- 4 The output of the dynamic range gate is given as

$$y[n] = x[n] \times g_s[n].$$

References

- [1] Giannoulis, Dimitrios, Michael Massberg, and Joshua D. Reiss. "Digital Dynamic Range Compressor Design -- A Tutorial And Analysis." *Journal of Audio Engineering Society*. Vol. 60, Issue 6, 2012, pp. 399-408.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

noiseGate | Compressor | Expander | Limiter

Topics

"Dynamic Range Control"

Introduced in R2016a

Octave Filter

Octave-band and fractional octave-band filter

Library: Audio Toolbox / Filters



Description

The Octave Filter block performs octave-band or fractional octave-band filtering independently across each input channel. An octave-band is a frequency band where the highest frequency is twice the lowest frequency. Octave-band and fractional octave-band filters are commonly used to mimic how humans perceive loudness. Octave filters are best understood when viewed on a logarithmic scale, which models how the human ear weights the spectrum.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

CF — Center frequency (Hz)

scalar in the range 3 to 22,000 inclusive

Dependencies

To enable this port, select **Specify from input port** for the “Center frequency (Hz)” on page 5-0 parameter.

Data Types: `single` | `double`

Output

Port_1 — Output signal

matrix

The Octave Filter block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Filter order — Order of octave filter

6 (default) | even integer

Tunable: No

Center frequency (Hz) — Center frequency of octave filter

1000 (default) | scalar in the range 3 to 22,000 inclusive

- The maximum center frequency is the value that causes the upper band edge to be equal to the Nyquist frequency, $F_s/2$. Frequencies above this value are saturated.
- The minimum center frequency is the value that causes the lower band edge to be equal to 1 Hz. Frequencies below this value are quantized to 1 Hz.

To specify **Center frequency (Hz)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Bandwidth — Filter bandwidth in octaves

1 octave (default) | 2/3 octave | 1/2 octave | 1/3 octave | 1/6 octave | 1/12 octave | 1/24 octave | 1/48 octave

Tunable: Yes

Oversample the input by 2 for this filter — Oversample toggle

off (default) | on

- off -- The Octave Filter block runs at the input sample rate.
- on -- The Octave Filter block runs at two times the input sample rate. Oversampling minimizes the frequency warping effects introduced by the bilinear transformation. An FIR halfband interpolator implements oversampling before octave filtering. A halfband decimator reduces the sample rate back the input sampling rate after octave filtering.

Tunable: No

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Tunable: No

Input sample rate (Hz) — Sample rate of input

44100 (default) | scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** -- Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** -- Simulate the model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than **Code generation**. In this mode, you can debug the source code of the block.

Tunable: No**Mask for attenuation limits — Create a mask for filter response visualization**

No mask (default) | Class 0 | Class 1 | Class 2

The mask attenuation limits are defined in the ANSI S1.11-2004 standard.

- If the mask is green, the design is compliant.
- If the mask is red, the design breaks compliance.

Tunable: Yes**Visualize filter response — Open plot to visualize magnitude response and compliance mask**

button

A 2048-point FFT is used to calculate the magnitude response.

Tunable: Yes**Variable name — Variable name of exported filter**

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace — Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.**Tips**

- You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.

- You cannot export the filter if you are specifying filter characteristics from input ports.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

More About

Band Edge

A band edge frequency refers to the lower or upper edge of the passband of a bandpass filter.

Center Frequency of Octave Filter

The center frequency of an octave filter is the geometric mean of the lower- and upper-band edge frequencies.

Algorithms

Octave Bandwidth to Band Edge Conversion

The Octave Filter block uses the specified center frequency and filter bandwidth in octaves to determine the normalized band edges [2].

First the block computes the upper and lower band edge frequencies:

$$f_{pa} = f_c \times G^{-1/2b}$$

$$f_{pb} = f_c \times G^{1/2b}$$

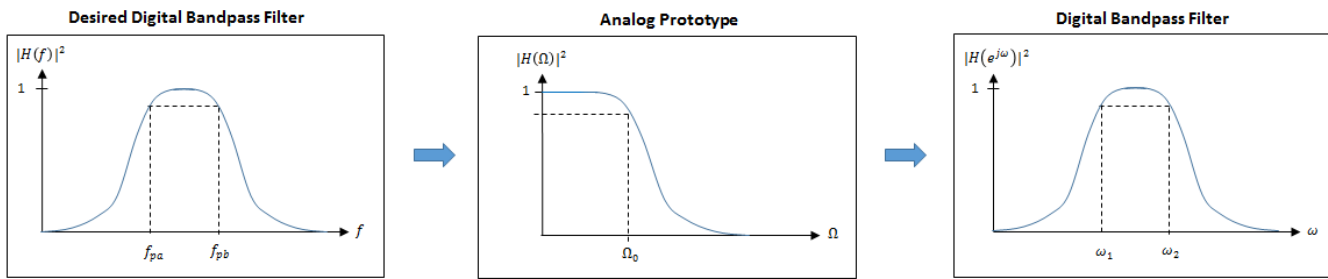
- f_c is the normalized center frequency specified by the **Center frequency (Hz)** parameter.
- b is the octave bandwidth specified by the **Bandwidth** parameter. For example, if **Bandwidth** is specified as 1/3 octave, the value of b is 3.
- G is a conversion constant:

$$G = 10^{3/10}.$$

Digital Filter Design

The Octave Filter block implements a higher-order digital bandpass filter design method as specified in [1].

In this design method, a desired digital bandpass filter maps to a Butterworth lowpass analog prototype, which is then mapped back to a digital bandpass filter:



- 1 The analog Butterworth filter is expressed as a cascade of second-order sections:

$H(s) = H_1(s)H_2(s)\dots H_{2N}(s)$, where:

- $H_i(s) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}}$, $i = 1, 2, \dots, 2N$
- $\theta_i = \frac{\pi}{2N}(N - 1 + 2i)$, $i = 1, 2, \dots, N, \dots, 2N$

N is the filter order specified by the **Filter order** parameter.

- 2 The analog Butterworth filter is mapped to a digital filter using a bandpass version of the bilinear transformation:

$$s = \frac{1 - cz^{-1} + z^{-2}}{1 - z^{-2}},$$

where

$$c = \frac{\sin(\omega_{pa} + \omega_{pb})}{\sin\omega_{pa} + \sin\omega_{pb}}.$$

This mapping results in the following substitution:

$$\Omega_0 = \frac{c - \cos\omega_{pb}}{\sin\omega_{pb}}$$

- 3 The analog prototype is evaluated:

$$H_i(z) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}} \Bigg|_{s = \frac{1 - 2cz^{-1} + z^{-2}}{1 - z^{-2}}}$$

Because s is second-order in z , the bandpass version of the bilinear transformation is fourth-order in z .

References

- [1] Orfanidis, Sophocles J. *Introduction to Signal Processing*. Englewood Cliffs, NJ: Prentice Hall, 2010.

[2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters: ANSI S1.11-2004*. Melville, NY: Acoustical Society of America, 2009.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

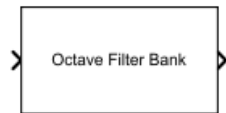
`octaveFilter` | `weightingFilter` | Weighting Filter | Octave Filter Bank

Introduced in R2016b

Octave Filter Bank

Octave-band and fractional octave-band filter bank

Library: Audio Toolbox / Filters



Description

The Octave Filter Bank block decomposes a signal into octave or fractional-octave subbands. An octave-band is a frequency band where the highest frequency is twice the lowest frequency. Octave-band and fractional octave-band filters are commonly used to mimic how humans perceive loudness.

Ports

Input

Port_1 — Input signal

vector | matrix

- Vector input -- The block treats the input as a single channel.
- Matrix input -- The block treats each column of the input as an independent channel.

Data Types: single | double

Output

Port_1 — Output signal

matrix | 3-D array

The Octave Filter Bank block outputs a signal with the same data type as the input signal. The shape of the output depends on the shape of the input, the number of filters in the bank, and whether or not you enable the **Bands as separate output ports** parameter.

If F is the number of filters in the bank, and the input signal is an L -by- C matrix, then the block returns an L -by- F -by- C array. If C is 1, then the block outputs a matrix.

- Vector input -- When you provide a vector input, the block outputs an L -by- F matrix, where L is the number of elements in the vector and F is the number of filters in the bank.
- Matrix input -- When you provide a matrix input, the block outputs a 3-D array with size L -by- F -by- C , where C is the number of channels in the matrix input.

Note When you enable the **Bands as separate output ports** parameter, each output is the same size as the input.

Data Types: single | double

Parameters

Bandwidth (octaves) — Bandwidth of filters specified in octaves

1 octave (default) | 2/3 octave | 1/2 octave | 1/3 octave | 1/6 octave | 1/12 octave | 1/24 octave | 1/48 octave

Filter bandwidth in octaves, specified as 1 octave, 2/3 octave, 1/2 octave, 1/3 octave, 1/6 octave, 1/12 octave, 1/24 octave, 1/48 octave.

Frequency range (Hz) — Frequency range of filter bank (Hz)

[22 22050] (default) | two-element row vector of positive monotonically increasing values

Frequency range of the filter bank in Hz, specified as a two-element row vector of positive monotonically increasing values. The block places filter bank center frequencies according to the **Bandwidth (octaves)**, **Reference frequency (Hz)**, and **Octave ratio base** parameters. Filters that have a center frequency outside of **Frequency range (Hz)** are ignored.

Reference frequency (Hz) — Reference frequency of filter bank (Hz)

1000 (default) | positive integer scalar

Reference frequency of the filter bank in Hz, specified as a positive integer scalar. The reference frequency defines one of the center frequencies. All other center frequencies are set relative to the reference frequency.

Filter order — Order of octave filters

12 (default) | positive even integer

Order of the octave filters, specified as a positive even integer. The filter order applies to each individual filter in the bank.

Note The default filter order for the `octaveFilterBank` object is 2.

Octave ratio — Distance between filters

Base ten (ANSI S1.11 preferred) (default) | Base two (musical scale)

Octave ratio base, specified as **Base ten (ANSI S1.11 preferred)** or **Base two (musical scale)**. The octave ratio base determines the distribution of the center frequencies of the octave filters. The ANSI S1.11 standard recommends base 10. Base 2 is popular for music applications. **Base two (musical scale)** defines an octave as a factor of 2, and **Base ten (ANSI S1.11 preferred)** defines an octave as a factor of $10^{0.3}$.

Inherit sample rate from input — Allow sample rate to be set by input signal

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in the **Input sample rate (Hz)** parameter.

Input sample rate (Hz) — Sample rate of input

44100 (default) | positive scalar

When you select this parameter, the block accepts the sample rate from the user.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Bands as separate output ports — One output port per filter band

off (default) | on

When you select this parameter, the block provides an output port for each filter in the bank. Each output port is labeled with the center frequency of the filter and has a size identical to the input signal.

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- **Code generation** -- Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time.
- **Interpreted execution** -- Simulate the model using the MATLAB interpreter. In this mode, you can debug the source code of the block.

View filter response — Open plot to visualize magnitude response

button

Octave filters are best understood when viewed on a logarithmic scale, which models how the human ear weights the spectrum. The block uses a 2048-point FFT to calculate the magnitude response. The filter bank's response is displayed on a log-frequency scale with a legend to indicate the center frequency of each filter.

Variable name — Variable name of exported filter bank

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter bank when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter bank overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter bank creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace — Export filter bank to workspace

button

Export the filter bank to the base workspace in the variable specified by the **Variable name** parameter.

Tips

You cannot export the filter bank if you have enabled the **Inherit sample rate from input** parameter and the model is not running.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

More About

Band Edge

A band edge frequency refers to the lower or upper edge of the passband of a bandpass filter.

Center Frequency of Octave Filter

The center frequency of an octave filter is the geometric mean of the lower- and upper-band edge frequencies.

Algorithms

The Octave Filter Bank block is implemented as a parallel structure of octave filters. Individual octave filters are designed as described by `octaveFilter`. By default, the octave filter bank center frequencies are placed as specified by the ANSI S1.11-2004 standard. You can modify the filter placements using the **Bandwidth (octaves)**, **Frequency range (Hz)**, **Reference frequency (Hz)**, and **Octave ratio** parameters.

Octave Bandwidth to Band Edge Conversion

The Octave Filter Bank block uses the specified **Frequency range (Hz)** and **Bandwidth (octaves)** to determine the normalized band edges [2].

First the block computes the upper and lower band edge frequencies:

$$f_{pa} = f_c \times G^{-1/2b}$$

$$f_{pb} = f_c \times G^{1/2b}$$

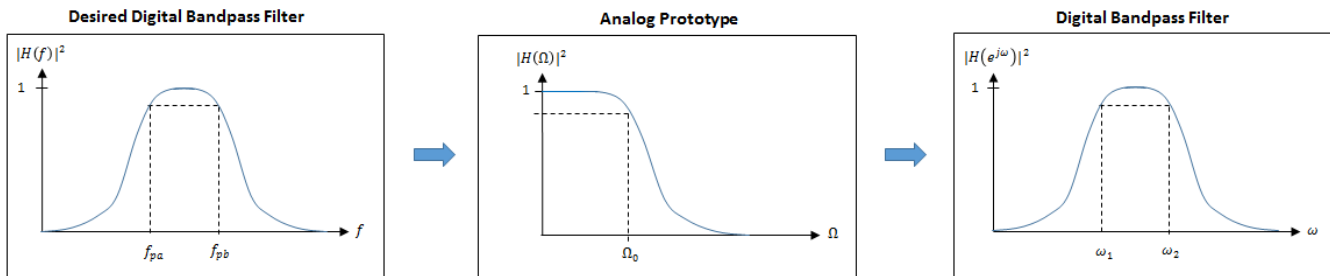
- f_c is the normalized center frequency specified by the **Bandwidth (octaves)** and **Frequency range (Hz)** parameters.
- b is the octave bandwidth specified by the **Bandwidth (octaves)** parameter. For example, if **Bandwidth (octaves)** is specified as 1/3 octave, the value of b is 3.
- G is a conversion constant:

$$G = 10^{3/10}.$$

Digital Filter Design

The Octave Filter Bank block implements a higher-order digital bandpass filter design method as specified in [1].

In this design method, a desired digital bandpass filter maps to a Butterworth lowpass analog prototype, which is then mapped back to a digital bandpass filter:



- 1 The analog Butterworth filter is expressed as a cascade of second-order sections:

$H(s) = H_1(s)H_2(s)\dots H_{2N}(s)$, where:

- $H_i(s) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}}$, $i = 1, 2, \dots, 2N$
- $\theta_i = \frac{\pi}{2N}(N - 1 + 2i)$, $i = 1, 2, \dots, N, \dots, 2N$

N is the filter order specified by the **Filter order** parameter.

- 2 The analog Butterworth filter is mapped to a digital filter using a bandpass version of the bilinear transformation:

$$s = \frac{1 - cz^{-1} + z^{-2}}{1 - z^{-2}},$$

where

$$c = \frac{\sin(\omega_{pa} + \omega_{pb})}{\sin\omega_{pa} + \sin\omega_{pb}}.$$

This mapping results in the following substitution:

$$\Omega_0 = \frac{c - \cos\omega_{pb}}{\sin\omega_{pb}}$$

- 3 The analog prototype is evaluated:

$$H_i(z) = \frac{1}{1 - 2\frac{s}{\Omega_0}\cos\theta_i + \frac{s^2}{\Omega_0^2}} \Bigg|_{s = \frac{1 - 2cz^{-1} + z^{-2}}{1 - z^{-2}}}$$

Because s is second-order in z , the bandpass version of the bilinear transformation is fourth-order in z .

References

- [1] Orfanidis, Sophocles J. *Introduction to Signal Processing*. Englewood Cliffs, NJ: Prentice Hall, 2010.
- [2] Acoustical Society of America. *American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters: ANSI S1.11-2004*. Melville, NY: Acoustical Society of America, 2009.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

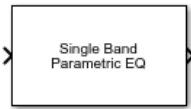
`octaveFilterBank` | `octaveFilter` | `weightingFilter` | Weighting Filter | Octave Filter

Introduced in R2021a

Single-Band Parametric EQ

Second-order parametric equalizer filter

Library: Audio Toolbox / Filters



Description

The Single-Band Parametric EQ block filters each channel of the input signal over time using a specified center frequency, bandwidth, and peak (dip) gain. This block offers tunable filter design parameters, which enable you to tune the filter characteristics while the simulation is running. The filter is designed using `designParamEQ` and implemented using `dsp.BiquadFilter`.

This block supports variable-size input, enabling you to change the channel length during simulation. To enable variable-size input, clear the **Inherit sample rate from input** parameter. The number of channels must remain constant.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a signal channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

Fc — Center frequency (Hz)

scalar

Specify the center frequency as a positive scalar that is less than half the sample rate of the input signal.

Dependencies

To enable this port, select **Specify from input port** for the **Center Frequency (Hz)** parameter.

Data Types: `single` | `double`

BW — Bandwidth (Hz)

scalar

Specify the filter bandwidth as a positive scalar that is less than or equal to half the sample rate of the input signal and 20 kHz.

Dependencies

To enable this port, select Bandwidth and Center Frequency for the **Filter specification** and **Specify from input port** for the **Filter Bandwidth (Hz)** parameter.

Data Types: single | double

GdB — Peak or dip gain (dB)

scalar

Specify the peak or dip gain in dB as a scalar.

Dependencies

To enable this port, select **Specify from input port** for the **Peak Gain (dB)** parameter.

Data Types: single | double

Q — Quality factor

scalar

Specify the quality factor as a positive scalar.

Dependencies

To enable this port, select Quality factor and center frequency for the **Filter Specification** and **Specify from input port** for the **Quality Factor** parameter.

Data Types: single | double

Output**Port_1 — Output signal**

matrix

The Single-Band Parametric EQ block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Filter order — Order of filter

2 (default) | positive even scalar

Tunable: No

Filter specification — Specify parameters used to design filter

Bandwidth and center frequency (default) | Quality factor and center frequency

- Bandwidth and center frequency -- Design the filter using **Filter Bandwidth (Hz)**, **Center Frequency (Hz)**, and **Peak Gain (dB)**.
- Quality factor and center frequency -- Design the filter using **Center Frequency (Hz)**, **Peak Gain (dB)**, and **Quality Factor**.

Tunable: No

Center Frequency (Hz) — Center frequency of filter

11025 (default) | positive scalar

Specify the center frequency as a positive scalar that is less than half the sample rate of the input signal.

To specify **Center Frequency (Hz)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Filter Bandwidth (Hz) — Bandwidth of filter

2205 (default) | positive scalar in the range [0, max(fs/2, 20,000)]

Specify the filter bandwidth as a positive scalar that is less than or equal to half the sample rate of the input signal or 20 kHz, whichever is larger.

To specify **Filter Bandwidth (Hz)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Dependencies

To enable this parameter, set **Filter specification** to Bandwidth and center frequency.

Quality Factor — Quality factor

5 (default) | scalar in the range [0.1, 20]

Specify the quality factor as a scalar in the range [0.1, 20].

To specify **Quality Factor** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Dependencies

To enable this parameter, set **Filter specification** to Quality factor and center frequency.

Peak Gain (dB) — Peak or dip gain of filter

6.0206 (default) | scalar in the range [-30, 30]

Specify the peak gain in dB as a scalar in the range [-30, 30].

Tunable: Yes

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Tunable: No

Input sample rate (Hz) — Sample rate of input

44100 (default) | scalar

Tunable: No

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time and has simulation speed comparable to **Code generation**. In this mode, you can debug the source code of the block.
- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is faster compared to **Interpreted execution**.

Tunable: No

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

References

- [1] Orfanidis, Sophocles J. "High-Order Digital Parametric Equalizer Design." *Journal of the Audio Engineering Society*. Vol. 53, November 2005, pp. 1026-1046.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

multibandParametricEQ | designParamEQ | designVarSlopeFilter | designShelvingEQ

Topics

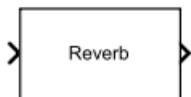
“Parametric Equalizer Design”
“Equalization”

Introduced in R2019a

Reverberator

Add reverberation to audio signal

Library: Audio Toolbox / Effects



Description

The Reverberator block adds reverberation to mono or stereo audio signals. You can tune parameters of the Reverberator block to mimic different acoustic environments.

Ports

Input

x — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

This port is unnamed unless you specify additional input ports.

Data Types: `single` | `double`

Delay — Pre-delay for reverberation (s)

scalar in the range [0,1]

Dependencies

To enable this port, select **Specify from input port** for the “Pre-delay (s)” on page 5-0 parameter.

Data Types: `single` | `double`

HighCut — Lowpass filter cutoff

positive scalar in the range [0, (Sample Rate)/2]

Dependencies

To enable this port, select **Specify from input port** for the “Highcut frequency (Hz)” on page 5-0 parameter.

Data Types: `single` | `double`

Diffusion — Density of reverb tail

scalar in the range [0,1]

Dependencies

To enable this port, select **Specify from input port** for the “Diffusion” on page 5-0 parameter.

Data Types: `single` | `double`

Decay — Decay factor of reverb tail

scalar in the range [0,1]

Dependencies

To enable this port, select **Specify from input port** for the “Decay factor” on page 5-0 parameter.

Data Types: single | double

Damping — High-frequency damping

scalar in the range [0,1]

Dependencies

To enable this port, select **Specify from input port** for the “High frequency damping” on page 5-0 parameter.

Data Types: single | double

WetDry — Ratio of wet (reverberated) signal to dry (original) signal

scalar in the range [0,1]

Dependencies

To enable this port, select **Specify from input port** for the “Wet/dry mix” on page 5-0 parameter.

Data Types: single | double

Output**Port_1 — Output signal**

matrix

The Reverberator block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix of the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

Data Types: single | double

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Pre-delay (s) — Pre-delay for reverberation

0 (default) | scalar in the range [0, 1]

Pre-delay for reverberation is the time between hearing direct sound and the first early reflection. The value of **Pre-delay (s)** is proportional to the size of the room being modeled.

To specify **Pre-delay (s)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Highcut frequency (Hz) — Lowpass filter cutoff

20000 (default) | scalar in the range [0, (Sample Rate)/2]

Lowpass filter cutoff is the -3 dB cutoff frequency for the single-pole lowpass filter at the front of the reverberator structure. It prevents the application of reverberation to high-frequency components of the input.

To specify **Highcut frequency (Hz)** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Diffusion — Density of reverb tail

0.50 (default) | scalar in the range [0, 1]

Diffusion is proportional to the rate at which the reverb tail builds in density. Increasing **Diffusion** pushes the reflections closer together, thickening the sound. Reducing **Diffusion** creates more discrete echoes.

To specify **Diffusion** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Decay factor — Decay factor of reverb tail

0.50 (default) | scalar in the range [0, 1]

Decay factor is inversely proportional to the time it takes for reflections to run out of energy. To model a large room, use a long reverb tail (low decay factor). To model a small room, use a short reverb tail (high decay factor).

To specify **Decay factor** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

High frequency damping — High-frequency damping

0.0005 (default) | scalar in the range [0, 1]

High frequency damping is proportional to the attenuation of high frequencies in the reverberation output. Setting **High frequency damping** to a large value makes high-frequency reflections decay faster than low-frequency reflections.

To specify **High frequency damping** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Wet/dry mix — Ratio of wet (reverberated) signal to dry (original) signal

0.3 (default) | scalar in the range [0, 1]

Wet/dry mix is the ratio of wet (reverberated) signal to dry (original) signal that your Reverberator block outputs.

To specify **Wet/dry mix** from an input port, select **Specify from input port** for the parameter.

Tunable: Yes

Inherit sample rate from input — Specify source of input sample rate

on (default) | off

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Input sample rate (Hz) — Sample rate of input

44100 (default) | positive scalar

Tunable: Yes

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** - Simulate the model using the MATLAB interpreter. This option reduces startup time and the simulation speed is comparable to **Code generation**. In this mode, you can debug the source code of the block.
- **Code generation** - Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.

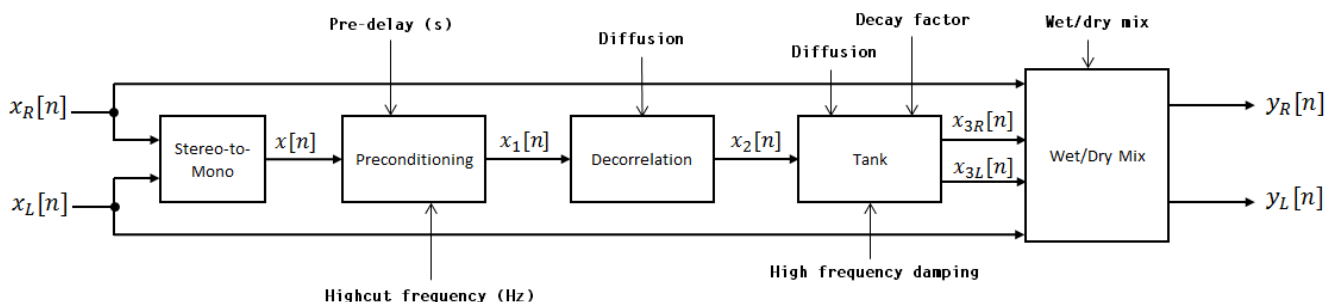
Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Algorithms

The algorithm to add reverberation follows the plate-class reverberation topology described in [1] and is based on a 29,761 Hz sample rate.

The algorithm has five stages.



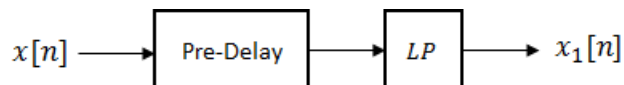
The description for the algorithm that follows is for a stereo input. A mono input is a simplified case.

Stereo-to-Mono

A stereo signal is converted to a mono signal: $x[n] = 0.5 \times (x_R[n] + x_L[n])$.

Preconditioning

A delay followed by a lowpass filter preconditions the mono signal.



- The pre-delay output is determined as $x_p[n] = x[n - k]$, where the **Pre-delay (s)** parameter determines the value of k .
- The signal is fed through a single-pole lowpass filter with transfer function

$$LP(z) = \frac{1 - \alpha}{1 - \alpha z^{-1}},$$

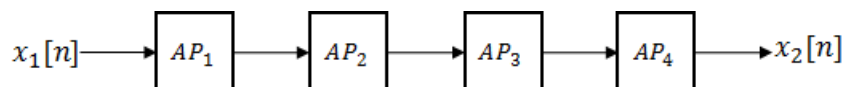
where

$$\alpha = \exp\left(-2\pi \times \frac{f_c}{f_s}\right).$$

- f_c is the cutoff frequency specified by the **Pre-delay (s)** parameter.
- f_s is the sampling frequency specified by the **Inherit sample rate from input** parameter or the **Input sample rate (Hz)** parameter.

Decorrelation

The signal is decorrelated by passing through a series of four allpass filters.



The allpass filters are of the form

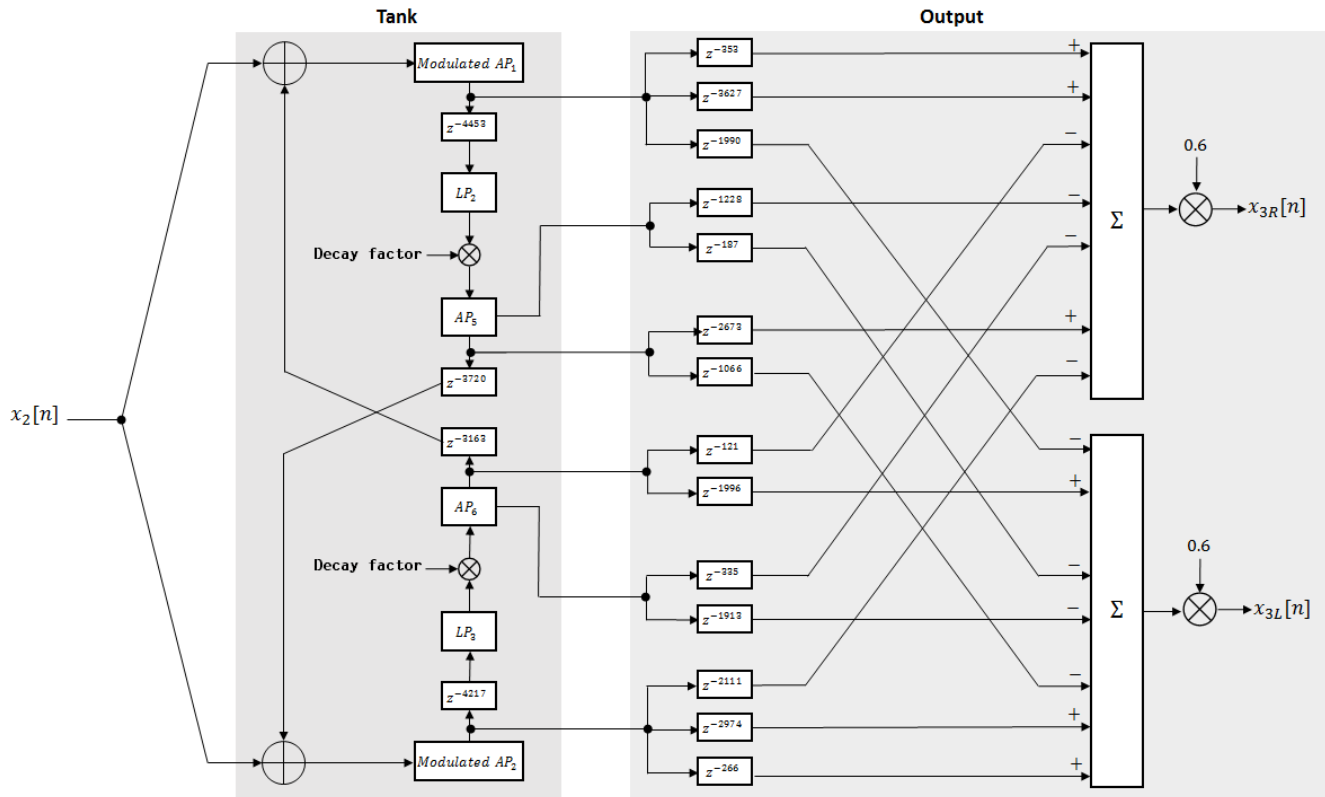
$$AP(z) = \frac{\beta + z^{-k}}{1 + \beta z^{-k}},$$

where β is the coefficient specified by the **Diffusion** property and k is the delay as follows:

- For AP_1 , $k = 142$.
- For AP_2 , $k = 107$.
- For AP_3 , $k = 379$.
- For AP_4 , $k = 277$.

Tank

The signal is fed into the tank, where it circulates to simulate the decay of a reverberation tail.



The following description tracks the signal as it progresses through the top of the tank. The signal progression through the bottom of the tank follows the same pattern, with different delay specifications.

- 1 The new signal enters the top of the tank and is added to the circulated signal from the bottom of the tank.
- 2 The signal passes through a modulated allpass filter:

$$\text{Modulated } AP_1(z) = \frac{-\beta + z^{-k}}{1 - \beta z^{-k}}$$

- β is the coefficient specified by the **Diffusion** parameter.
- k is the variable delay specified by a 1 Hz sinusoid with amplitude = $(8/29761) \times$ (sample rate). To account for fractional delay resulting from the modulating k , allpass interpolation is used [2].

- 3 The signal is delayed again, and then passes through a lowpass filter:

$$LP_2(z) = \frac{1 - \varphi}{1 - \varphi z^{-1}}$$

- φ is the coefficient specified by the **High frequency damping** parameter.
- 4 The signal is multiplied by a gain specified by the **Decay factor** parameter. The signal then passes through an allpass filter:

$$AP_5(z) = \frac{\beta + z^{-k}}{1 + \beta z^{-k}}.$$

- β is the coefficient specified by the **Diffusion** parameter.
 - k is set to 1800 for the top of the tank and 2656 for the bottom of the tank.
- 5 The signal is delayed again and then circulated to the bottom half of the tank for the next iteration.

A similar pattern is executed in parallel for the bottom half of the tank. The output of the tank is calculated as the signed sum of delay lines picked off at various points from the tank. The summed output is multiplied by 0.6.

Wet/Dry Mix

The wet (processed) signal is then added to the dry (original) signal:

$$y_R[n] = (1 - \kappa)x_R[n] + \kappa x_{3R}[n],$$

$$y_L[n] = (1 - \kappa)x_L[n] + \kappa x_{3L}[n],$$

where the **Wet/dry mix** parameter determines κ .

References

- [1] Dattorro, Jon. "Effect Design, Part 1: Reverberator and Other Filters." *Journal of the Audio Engineering Society*. Vol. 45, Issue 9, 1997, pp. 660-684.
- [2] Dattorro, Jon. "Effect Design, Part 2: Delay-Line Modulation and Chorus." *Journal of the Audio Engineering Society*. Vol. 45, Issue 10, 1997, pp. 764-788.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

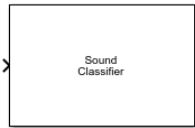
reverberator

Introduced in R2016a

Sound Classifier

Classify sounds in audio signal

Library: Audio Toolbox / Deep Learning



Description

The Sound Classifier block uses YAMNet to classify audio segments into sound classes described by the AudioSet ontology. The Sound Classifier block combines necessary audio preprocessing and YAMNet network inference. The block returns predicted sound labels, predicted scores from the sounds, and class labels for predicted scores.

Ports

Input

audioIn — Sound data

column vector

Sound data to classify, specified as a one-channel signal (column vector). If **Sample rate of input signal (Hz)** is 16e3, there are no restrictions on the input frame length. If **Sample rate of input signal (Hz)** is different from 16e3, then the input frame length must be a multiple of the decimation factor of the resampling operation that the block performs. If the input frame length does not satisfy this condition, the block throws an error message with information on the decimation factor.

Data Types: `single` | `double`

Output

sound — Predicted sound label

enumerated scalar

Predicted sound label, returned as an enumerated scalar.

Data Types: `enumerated`

scores — Predicted activations or scores

vector

Predicted activation or score values for each supported sound label, returned as a 1-by-521 vector, where 521 is the number of classes in YAMNet.

Data Types: `single`

labels — Class labels for predicted scores

vector

Class labels for predicted scores, returned as a 1-by-521 vector.

Data Types: enumerated

Parameters

Sample rate of input signal (Hz) — Sample rate of input signal in Hz

16e3 (default) | positive scalar

Specify the sample rate of the input signal as a positive scalar in Hz. If the sample rate is different from 16e3, then the block resamples the signal to 16e3, which is the sample rate that YAMNet supports.

Data Types: single | double

Overlap percentage (%) — Overlap percentage between consecutive mel spectrograms

50 (default) | [0 100)

Specify the overlap percentage between consecutive mel spectrograms as a scalar in the range [0 100).

Data Types: single | double

Classification — Select to output sound classification

on (default) | off

Enable the output port **sound**, which outputs the classified sound.

Predictions — Output all scores and associated labels

off (default) | on

Enable the output ports **scores** and **labels**, which output all predicted scores and associated class labels.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

The Sound Classifier block algorithm consists of two steps:

- 1 Preprocessing -- YAMNet specific preprocessing. Generates mel spectrograms.
- 2 Prediction -- Predicting the sounds, scores, and labels of the input signal using the YAMNet sound classification network.

Preprocessing

- 1 Cast **audioIn** to single and resample to 16 kHz.
- 2 Compute the one-sided short-time Fourier transform (STFT) using a 25 ms periodic Hann window (400 samples) with a 10 ms hop (160 samples) and a 512-point DFT.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude STFTs through a 64-band mel-spaced filter bank. Doing so converts the 257-length STFT vectors to 64-length vectors in the mel scale.
- 5 Convert the 64-length vectors to a log scale.
- 6 Buffer the vectors into outputs of size 96-by-64, where 96 is the number of 10 ms frames in each mel spectrogram and 64 is the number of mel bands. The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter.

Prediction

These 96-by-64 spectrograms are passed to the YAMNet block. The YAMNet block has a maximum of three outputs:

- **sound:** The label of the most likely sound. You get one "sound" for each 96-by-64 spectrogram input.
- **scores:** 1-by-512 vectors, with a score value for each supported sound label.
- **labels:** 1-by-521 vectors containing the sound labels.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Usage notes and limitations:

- To generate generic C code that does not depend on third-party libraries, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C.
- To generate C++ code, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C++. To specify the target library for code generation, in the **Code Generation > Interface** category, set the **Target Library** parameter. Setting this parameter to None generates generic C++ code that does not depend on third-party libraries.
- For ERT-based targets, the **Support: variable-size signals** parameter in the **Code Generation > Interface** pane must be enabled.
- For a list of networks and layers supported for code generation, see “Networks and Layers Supported for Code Generation” (MATLAB Coder).

See Also

Apps

Signal Labeler

Blocks

YAMNet | YAMNet Preprocess

Functions

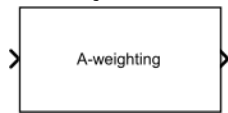
`classifySound` | `vggish` | `vggishFeatures` | `vggishPreprocess` | `yamnet` |
`yamnetPreprocess` | `yamnetGraph`

Introduced in R2021b

Weighting Filter

Weighted frequency response filter

Library: Audio Toolbox / Filters



Description

The Weighting Filter block performs frequency-weighted filtering independently across each input channel.

Ports

Input

Port_1 — Input signal

matrix | 1-D vector

- Matrix input -- Each column of the input is treated as an independent channel.
- 1-D vector input -- The input is treated as a single channel.

Data Types: `single` | `double`

Output

Port_1 — Output signal

matrix

The Weighting Filter block outputs a signal with the same data type as the input signal. The size of the output depends on the size of the input:

- Matrix input -- The block outputs a matrix the same size and data type as the input signal.
- 1-D vector input -- The block outputs an N -by-1 matrix (column vector), where N is the number of elements in the 1-D vector.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Weighting method — Type of frequency weighting

A-weighting (default) | C-weighting | K-weighting

See “A-Weighting” on page 5-118, “C-Weighting” on page 5-119, and “K-Weighting” on page 5-119 for the definition of the weighting curves.

Tunable: No

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Tunable: No**Input sample rate (Hz) — Sample rate of input**

44100 (default) | positive scalar

Tunable: Yes**Dependencies**

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is faster than **Interpreted execution**.
- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed compared to **Code generation**. In this mode, you can debug the source code of the block.

Tunable: No**Mask for attenuation limits — Creates a mask for filter response visualization**

No mask (default) | Class 1 | Class 2

The mask attenuation limits are defined in the IEC 61672-1:2002 standard.

- If the mask is green, the design is compliant.
- If the mask is red, the design breaks compliance.

Tunable: Yes**Dependencies**

To enable this parameter, set **Weighting method** to A-weighting or C-weighting.

Visualize filter response — Open plot to visualize magnitude response and compliance mask

button

A 2048-point FFT is used to calculate the magnitude response.

Tunable: Yes**Variable name — Variable name of exported filter**

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists – Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace – Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.

Tips

You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

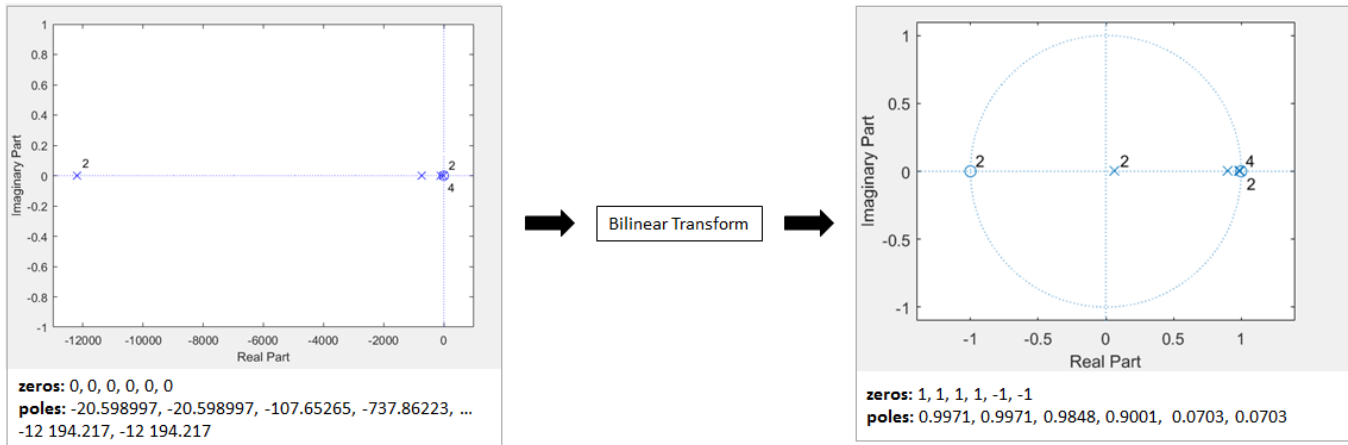
More About

A-Weighting

The A-curve is a wide bandpass filter centered at 2.5 kHz, with approximately 20 dB attenuation at 100 Hz and 10 dB attenuation at 20 kHz. A-weighted SPL measurements of noise level are increasingly found in sales literature for domestic appliances. In most countries, the use of A-weighting is mandated for the protection of workers against noise-induced deafness. The ISO and ICOA standards mandate A-weighting for all civil aircraft noise measurements.

The ANSI S1.42.2001 [1] defines this weighting curve. The IEC 61672-1:2002 [2] standard defines the minimum and maximum attenuation limits for an A-weighting filter.

ANSI S1.42.2001 defines the weighting curve by specifying analog poles and zeros. Audio Toolbox converts the specified poles and zeros to the digital domain using a bilinear transform:

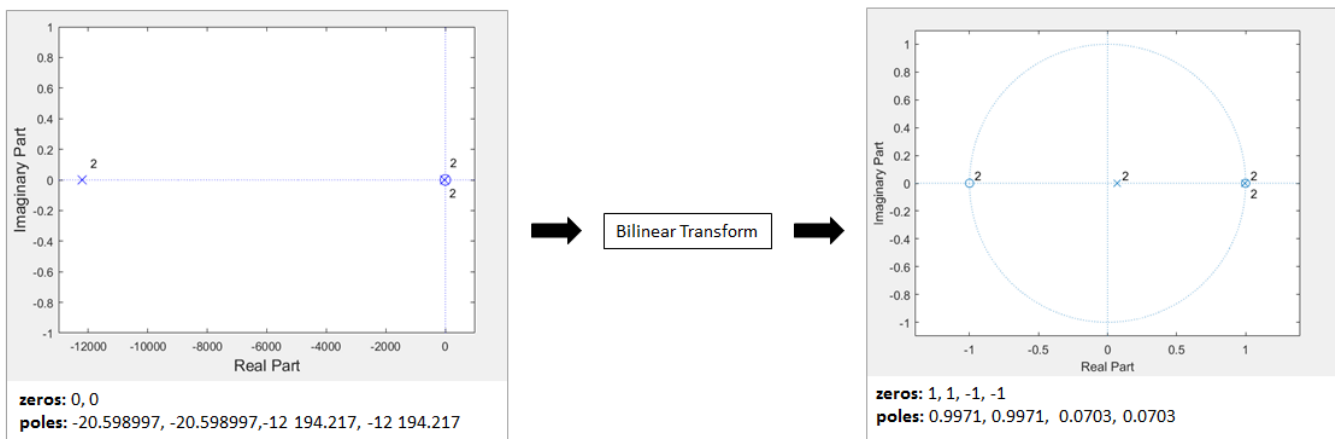


C-Weighting

The C-curve is "flat," but with limited bandwidth: It has -3 dB corners at 31.5 Hz and 8 kHz. C-curves are used in sound level meters for sounds that are louder than sounds intended for A-weighting filters.

The ANSI S1.42-2001 [1] defines the C-weighting curve. The IEC 61672-1:2002 [2] standard defines the minimum and maximum attenuation limits for C-weighting filters.

ANSI S1.42.2001 defines the weighting curve by specifying analog poles and zeros. Audio Toolbox converts the specified poles and zeros to the digital domain using a bilinear transform:

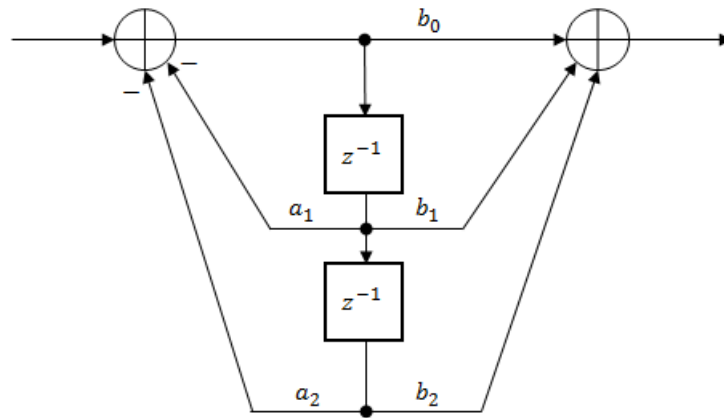


K-Weighting

The K-weighting filter is used for loudness normalization in broadcast. It is composed of two stages of filtering: a first stage shelving filter and a second stage highpass filter.

The ITU-R BS.1770-4 [3] standard defines this curve.

Assume a second-order filter.



The table shows the coefficients for the filters.

First Stage Shelving Coefficients	Second Stage Highpass Coefficients
$a_1 = -1.69065929318241$	$a_1 = -1.99004745483398$
$a_2 = 0.73248077421585$	$a_2 = 0.99007225036621$
$b_0 = 1.53512485958697$	$b_0 = 1.0$
$b_1 = -2.6916918940638$	$b_1 = -2.0$
$b_2 = 1.19839281085285$	$b_2 = 1.0$

The coefficients presented by ITU-R BS.1770-4 are defined for 48 kHz. These coefficients are recomputed for nonstandard sample rates using the algorithm described in [4].

References

- [1] Acoustical Society of America. *Design Response of Weighting Networks for Acoustical Measurements*. ANSI S1.42-2001. New York, NY: American National Standards Institute, 2001.
- [2] International Electrotechnical Commission. *Electroacoustics Sound Level Meters Part 1: Specifications*. First Edition. IEC 61672-1. 2002-2005.
- [3] International Telecommunication Union. *Algorithms to measure audio programme loudness and true-peak audio level*. ITU-R BS.1770-4. 2015.
- [4] Mansbridge, Stuart, Saoirse Finn, and Joshua D. Reiss. "Implementation and Evaluation of Autonomous Multi-track Fader Control." Paper presented at the 132nd Audio Engineering Society Convention, Budapest, Hungary, 2012.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

`weightingFilter` | `octaveFilter` | `loudnessMeter` | Octave Filter | Loudness Meter

Introduced in R2016b

Shelving Filter

Second-order IIR shelving filter

Library: Audio Toolbox / Filters



Description

The Shelving Filter block applies a shelving filter to the input signal. A shelving filter boosts or cuts the frequency spectrum of the input signal above or below a given cutoff frequency.

Ports

Input

x — Input signal

column vector | matrix

Input signal to be filtered, specified as a column vector or a matrix. If the input is a matrix, each column is treated as an independent channel.

Data Types: `single` | `double`

G — Peak gain (dB)

real scalar

This port specifies the value of the **Gain (dB)** parameter.

Dependencies

To enable this port, select the **Specify gain from input port** parameter.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

S — Slope

positive scalar

This port specifies the value of the **Slope** parameter.

Dependencies

To enable this port, select the **Specify slope from input port** parameter.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

F — Cutoff frequency

nonnegative scalar

This port specifies the value of the **Cutoff frequency (Hz)** parameter.

Dependencies

To enable this port, select the **Specify cutoff frequency from input port** parameter.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Output

Port_1 — Output signal

column vector | matrix

Filtered output signal, returned as a column vector or matrix that is the same size and data type as the input signal.

Data Types: single | double

Parameters

Specify gain from input port — Use additional input port to specify gain

off (default) | on

When you select this parameter, an additional input port, **G**, is added to the block. This port specifies the gain of the filter.

Gain (dB) — Peak gain (dB)

0 (default) | real scalar

Peak gain of the filter in dB, specified as a real scalar. The gain specifies how much the filter will boost (if the gain is positive) or cut (if the gain is negative) the frequency spectrum of the input signal.

Tunable: Yes

Dependencies

To enable this parameter, clear the **Specify gain from input port** parameter.

Specify slope from input port — Use additional input port to specify slope

off (default) | on

When you select this parameter, an additional input port, **S**, is added to the block. This port specifies the slope of the filter.

Slope — Filter slope

1.5 (default) | positive scalar

Slope of the filter specified as a positive scalar. The slope controls the width of the transition band in the filter response.

Tunable: Yes

Dependencies

To enable this parameter, clear the **Specify slope from input port** parameter.

Specify cutoff frequency from input port — Use additional input port to specify cutoff frequency

off (default) | on

When you select this parameter, an additional input port, **F**, is added to the block. This port specifies the cutoff frequency of the filter.

Cutoff frequency (Hz) — Filter cutoff frequency

200 (default) | nonnegative scalar

Cutoff frequency of the filter in Hz, specified as a nonnegative scalar in the range $[0, F_s/2]$, where F_s is the sample rate specified by the **Input sample rate (Hz)** and **Inherit sample rate from input** parameters. The cutoff frequency specifies the frequency at half of the peak gain of the filter, $G/2$ dB, where G is the peak gain.

Tunable: Yes

Dependencies

To enable this parameter, clear the **Specify cutoff frequency from input port** parameter.

Type — Type of filter

lowpass (default) | highpass

Type of shelving filter, specified as lowpass or highpass.

- **lowpass** -- Boost or cut the frequency spectrum below the cutoff frequency.
- **highpass** -- Boost or cut the frequency spectrum above the cutoff frequency.

Inherit sample rate from input — Specify source of input sample rate

off (default) | on

When you select this parameter, the block inherits its sample rate from the input signal. When you clear this parameter, you specify the sample rate in **Input sample rate (Hz)**.

Input sample rate (Hz) — Sample rate of input

44100 (default) | positive scalar

Sample rate of the input, specified as a positive scalar.

Dependencies

To enable this parameter, clear the **Inherit sample rate from input** parameter.

Visualize filter response — Open plot to visualize filter response

button

Open plot to visualize the magnitude response of the filter.

Variable name — Variable name of exported filter

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and

the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace — Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.

Tips

- You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.
- You cannot export the filter if you are specifying filter characteristics from input ports.

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time but has a slower simulation speed than **Code generation**. In this mode, you can debug the source code of the block.
- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

Graphic EQ | Multiband Parametric EQ

Functions

designParamEQ | designShelvingEQ | designVarSlopeFilter

Objects

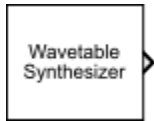
shelvingFilter | dsp.SOSFilter | graphicEQ | multibandParametricEQ

Introduced in R2022a

Wavetable Synthesizer

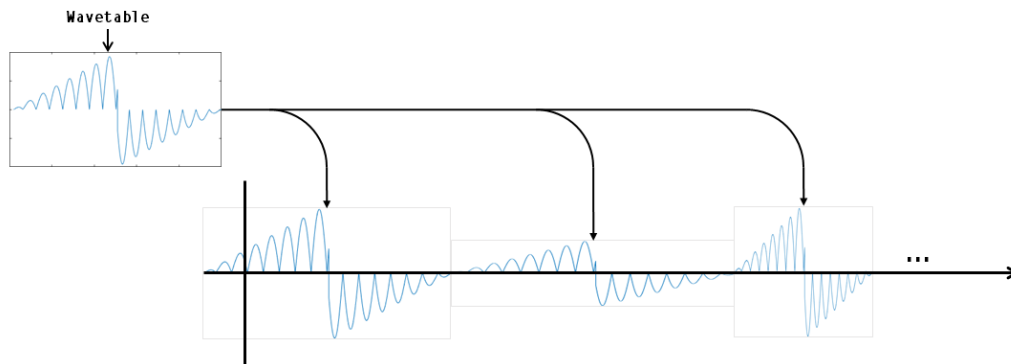
Generate periodic signal from single-cycle waveforms

Library: Audio Toolbox / Sources



Description

The Wavetable Synthesizer block generates a periodic signal with tunable parameters. The periodic signal is defined by a single-cycle waveform cached as the **Single-cycle waveform** parameter of your Wavetable Synthesizer block.



Ports

Input

WT — Single-cycle waveform

vector of real values

Dependencies

To enable this port, select **Specify wavetable from input port** for the “Single-cycle waveform” on page 5-0 parameter.

Data Types: `single` | `double`

F — Output wave frequency (Hz)

nonnegative scalar | vector of nonnegative values

Dependencies

To enable this port, select **Specify frequency from input port** for the “Output wave frequency (Hz)” on page 5-0 parameter.

Data Types: `single` | `double`

A — Output wave amplitude

nonnegative scalar

Dependencies

To enable this port, select **Specify amplitude from input port** for the “Output wave amplitude” on page 5-0 parameter.

Data Types: `single` | `double`

DC — Output wave DC offset

scalar

Dependencies

To enable this port, select **Specify DC offset from input port** for the “Output wave DC offset” on page 5-0 parameter.

Data Types: `single` | `double`

Output**Port_1 — Output signal**

vector | matrix

The Wavetable Synthesizer block outputs a periodic signal defined by the parameters of the block.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Single-cycle waveform — Wavetable

$\sin(2\pi*(0:511)/512)$ (default) | vector of real values

The Wavetable Synthesizer block indexes into the single-cycle waveform to synthesize a periodic wave.

To specify **Single-cycle waveform** from an input port, select **Specify wavetable from input port** for the parameter.

Tunable: Yes

Output wave frequency (Hz) — Frequency of generated signal

100 (default) | nonnegative scalar

The number of times the single-cycle waveform is repeated in one second.

To specify **Output wave frequency (Hz)** from an input port, select **Specify frequency from input port** for the parameter.

Tunable: Yes

Output wave amplitude — Amplitude of generated signal

1 (default) | nonnegative scalar

Amplitude scaling is applied before DC offset.

To specify **Output wave amplitude** from an input port, select **Specify amplitude from input port** for the parameter.

Tunable: Yes

Output wave phase offset — Normalized phase offset of generated signal

0 (default) | scalar in the range [0, 1]

The phase offset range, [0, 1], corresponds to a normalized 2π radians interval.

Output wave DC offset — Value added to each element of generated signal

0 (default) | scalar

To specify **Output wave DC offset** from an input port, select **Specify DC offset from input port** for the parameter.

Tunable: Yes

Samples per frame — Number of samples per frame output from block

512 (default) | positive integer scalar

Number of samples per frame output from block, specified as a positive integer scalar.

Tunable: No

Sample rate (Hz) — Sample rate of generated signal

44100 (default) | positive scalar

Sample rate of generated signal, specified as a positive scalar.

Tunable: No

Output data type — Data type of generated signal

double (default) | single

Data type of generated signal, specified as double or single.

Tunable: No

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** - Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** - Simulate the model using the MATLAB interpreter. This option reduces startup time and the simulation speed is comparable to **Code generation**. In this mode, you can debug the source code of the block.

Block Characteristics

Data Types	double single
-------------------	-----------------

Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

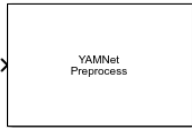
Audio Device Writer | Audio Oscillator | wavetableSynthesizer

Introduced in R2020a

YAMNet Preprocess

Preprocess audio for YAMNet classification

Library: Audio Toolbox / Deep Learning



Description

The YAMNet Preprocess block generates mel spectrograms from audio input that can be fed to the YAMNet pretrained network or to a network that accepts the same inputs as YAMNet.

Ports

Input

audioIn — Sound data

column vector

Sound data to classify, specified as a one-channel signal (column vector). If **Sample rate of input signal (Hz)** is 16e3, there are no restrictions on the input frame length. If **Sample rate of input signal (Hz)** is different from 16e3, then the input frame length must be a multiple of the decimation factor of the resampling operation that the block performs. If the input frame length does not satisfy this condition, the block throws an error message with information on the decimation factor.

Data Types: `single` | `double`

Output

features — Mel spectrograms that can be fed to YAMNet pretrained network

96-by-64 matrix

Mel spectrograms generated from **audioIn**, returned as a 96-by-64 matrix, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz

The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter.

Each 96-by-64 matrix represents a single mel spectrogram. For more details on how this block generates mel spectrograms, see “Algorithms” on page 5-132.

Data Types: `single`

Parameters

Sample rate of input signal (Hz) — Sample rate of input signal in Hz

16e3 (default) | positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Data Types: `single` | `double`

Overlap percentage (%) — Overlap percentage between consecutive mel spectrograms

50 (default) | [0 100)

Specify the overlap percentage between consecutive mel spectrograms as a scalar in the range [0 100).

Data Types: `single` | `double`

Block Characteristics

Data Types	<code>double</code> <code>single</code>
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

The YAMNet Preprocess block generates mel spectrograms from audio input. These mel spectrograms can be fed to a YAMNet pretrained network or to a network that accepts the same inputs as YAMNet.

Preprocessing steps

- 1 Cast **audioIn** to single and resample to 16 kHz.
- 2 Compute one-sided short-time Fourier transform using a 25 ms periodic Hann window (400 samples) with a 10 ms hop (160 samples) and a 512-point DFT.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude STFTs through a 64-band mel-spaced filter bank. Doing so converts the 257-length STFT vectors to 64-length vectors in the mel scale.
- 5 Convert the 64-length vectors to a log scale.
- 6 Buffer the vectors into outputs of size 96-by-64, where 96 is the number of spectra in the mel spectrogram and 64 is the number of mel bands. The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776–80. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952261.

- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. "CNN Architectures for Large-Scale Audio Classification." *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131–35. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet

Functions

classifySound | vggish | vggishEmbeddings | vggishPreprocess | yamnet | yamnetPreprocess | yamnetGraph

Introduced in R2021b

YAMNet

YAMNet sound classification network

Library: Audio Toolbox / Deep Learning



Description

The YAMNet block leverages a pretrained sound classification network that is trained on the AudioSet dataset to predict audio events from the AudioSet ontology.

Ports

Input

features — Mel spectrograms

96-by-64 matrix | 96-by-64-by-1-by- N array

Mel spectrograms, specified as a 96-by-64 matrix or a 96-by-64-by-1-by- N array, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz
- N -- Number of channels.

You can use the YAMNet Preprocess block to generate mel spectrograms. The dimensions of these spectrograms are 96-by-64.

Data Types: `single` | `double`

Output

sound — Predicted sound label

enumerated scalar

Predicted sound label, returned as an enumerated scalar.

Data Types: `enumerated`

scores — Predicted activations or scores

vector

Predicted activation or score values for each supported sound label, returned as a 1-by-521 vector, where 521 is the number of classes in YAMNet.

Data Types: `single`

labels — Class labels for predicted scores

vector

Class labels for predicted scores, returned as a 1-by-521 vector.

Data Types: enumerated

Parameters

Mini-batch size — Size of mini-batches

128 (default) | positive integer

Size of mini-batches to use for prediction, specified as a positive integer. Larger mini-batch sizes require more memory, but can lead to faster predictions.

Data Types: int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Classification — Select to output sound classification

on (default) | off

Enable the output port **sound**, which outputs the classified sound.

Predictions — Output all scores and associated labels

off (default) | on

Enable the output ports **scores** and **labels**, which output all predicted scores and associated class labels.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

Prediction

The block accepts mel spectrograms of size 96-by-64 or 96-by-64-by-1-by-*N*, and computes a maximum of three outputs using these spectrograms:

- **sound**: The label of the most likely sound. You get one "sound" for each 96-by-64 spectrogram input.
- **scores**: 1-by-512 vectors. Each element in the vector is a score value for each supported sound label.
- **labels**: 1-by-521 vectors. Each element in the vector is a sound label.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. "Audio Set: An Ontology and Human-Labeled Dataset"

for Audio Events.” *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 776–80. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952261.

- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. “CNN Architectures for Large-Scale Audio Classification.” *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, IEEE, 2017, pp. 131–35. *DOI.org (Crossref)*, doi:10.1109/ICASSP.2017.7952132.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Usage notes and limitations:

- To generate generic C code that does not depend on third-party libraries, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C.
- To generate C++ code, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C++. To specify the target library for code generation, in the **Code Generation > Interface** category, set the **Target Library** parameter. Setting this parameter to None generates generic C++ code that does not depend on third-party libraries.
- For ERT-based targets, the **Support: variable-size signals** parameter in the **Code Generation > Interface** pane must be enabled.
- For a list of networks and layers supported for code generation, see “Networks and Layers Supported for Code Generation” (MATLAB Coder).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish Embeddings | VGGish Preprocess | VGGish | YAMNet Preprocess

Functions

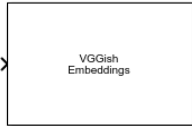
classifySound | vggish | vggishEmbeddings | vggishPreprocess | yamnet | yamnetPreprocess | yamnetGraph

Introduced in R2021b

VGGish Embeddings

Extract VGGish embeddings

Library: Audio Toolbox / Deep Learning



Description

The VGGish Embeddings block uses VGGish to extract feature embeddings from audio segments. The VGGish Embeddings block combines necessary audio preprocessing and VGGish network inference and returns feature embeddings that are a compact representation of audio data.

Ports

Input

Port_1 — Sound data

column vector

Sound data, specified as a one-channel signal (column vector). If **Sample rate of input signal (Hz)** is 16e3, there are no restrictions on the input frame length. If **Sample rate of input signal (Hz)** is different from 16e3, then the input frame length must be a multiple of the decimation factor of the resampling operation that the block performs. If the input frame length does not satisfy this condition, the block throws an error message with information on the decimation factor.

Data Types: `single` | `double`

Output

Port_1 — Embeddings

row vector of length 128

VGGish feature embeddings, returned as a row vector of length 128. The feature embeddings are a compact representation of audio data.

Data Types: `single`

Parameters

Sample rate of input signal (Hz) — Sample rate of input signal in Hz

16e3 (default) | positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Overlap percentage (%) — Overlap percentage between consecutive mel spectrograms

50 (default) | [0 100]

Specify the overlap percentage between consecutive mel spectrograms as a scalar in the range [0 100).

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

Preprocessing Steps

The VGGish Embeddings block preprocesses the audio data using the following steps to be in the format required by the VGGish network.

- 1 Cast the audio data to single precision and resample to 16 kHz.
- 2 Compute one-sided short-time Fourier transform using a 25 ms periodic Hann window (400 samples) with a 10 ms hop (160 samples) and a 512-point DFT.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude STFTs through a 64-band mel-spaced filter bank. Doing so converts the 257-length STFT vectors to 64-length vectors in the mel scale.
- 5 Convert the 64-length vectors to a log scale.
- 6 Buffer the vectors into outputs of size 96-by-64, where 96 is the number of spectra in the mel spectrogram and 64 is the number of mel bands. The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. "CNN Architectures for Large-Scale Audio Classification." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131–35. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Usage notes and limitations:

- To generate generic C code that does not depend on third-party libraries, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C.
- To generate C++ code, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C++. To specify the target library for code generation, in the **Code Generation > Interface** category, set the **Target Library** parameter. Setting this parameter to None generates generic C++ code that does not depend on third-party libraries.
- For ERT-based targets, the **Support: variable-size signals** parameter in the **Code Generation > Interface** pane must be enabled.
- For a list of networks and layers supported for code generation, see “Networks and Layers Supported for Code Generation” (MATLAB Coder).

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish | VGGish Preprocess | YAMNet | YAMNet Preprocess

Functions

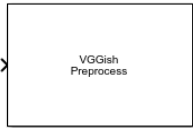
classifySound | vggish | vggishFeatures | vggishPreprocess | yamnet | yamnetPreprocess | yamnetGraph

Introduced in R2022a

VGGish Preprocess

Preprocess audio for VGGish feature extraction

Library: Audio Toolbox / Deep Learning



Description

The VGGish Preprocess block generates mel spectrograms from an audio input that you can then feed to the VGGish pretrained network or to a network that accepts the same inputs as VGGish.

Ports

Input

Port_1 — Sound data

column vector

Sound data, specified as a one-channel signal (column vector). If **Sample rate of input signal (Hz)** is 16e3, there are no restrictions on the input frame length. If **Sample rate of input signal (Hz)** is different from 16e3, then the input frame length must be a multiple of the decimation factor of the resampling operation that the block performs. If the input frame length does not satisfy this condition, the block throws an error message with information on the decimation factor.

Data Types: `single` | `double`

Output

Port_1 — Mel spectrogram

96-by-64 matrix

Mel spectrogram generated from the input audio signal, returned as a 96-by-64 matrix, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz

The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter. You can provide the mel spectrogram as an input to the VGGish pretrained network or to a network that accepts the same inputs as VGGish.

Data Types: `single`

Parameters

Sample rate of input signal (Hz) — Sample rate of input signal in Hz

16e3 (default) | positive scalar

Sample rate of the input signal in Hz, specified as a positive scalar.

Overlap percentage (%) — Overlap percentage between consecutive mel spectrograms 50 (default) | [0 100)

Specify the overlap percentage between consecutive mel spectrograms as a scalar in the range [0 100).

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Algorithms

Preprocessing Steps

The VGGish Embeddings block preprocesses the audio data using the following steps to be in the format required by the VGGish network.

- 1 Cast the audio data to single precision and resample to 16 kHz.
- 2 Compute one-sided short-time Fourier transform using a 25 ms periodic Hann window (400 samples) with a 10 ms hop (160 samples) and a 512-point DFT.
- 3 Convert the complex spectral values to magnitude and discard phase information.
- 4 Pass the one-sided magnitude STFTs through a 64-band mel-spaced filter bank. Doing so converts the 257-length STFT vectors to 64-length vectors in the mel scale.
- 5 Convert the 64-length vectors to a log scale.
- 6 Buffer the vectors into outputs of size 96-by-64, where 96 is the number of spectra in the mel spectrogram and 64 is the number of mel bands. The overlap between consecutive 96-by-64 mel spectrograms is determined by the value of the **Overlap percentage (%)** parameter.

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. "CNN Architectures for Large-Scale Audio Classification." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131–35. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Apps

Signal Labeler

Blocks

Sound Classifier | VGGish | VGGish Embeddings | YAMNet | YAMNet Preprocess

Functions

classifySound | vggish | vggishFeatures | vggishPreprocess | yamnet | yamnetPreprocess | yamnetGraph

Introduced in R2022a

VGGish

VGGish embeddings extraction network

Library: Audio Toolbox / Deep Learning



Description

The VGGish block leverages a pretrained convolutional neural network that is trained on the AudioSet data set to extract feature embeddings from audio signals.

Ports

Input

Port_1 — Mel spectrograms

96-by-64 matrix | 96-by-64-by-1-by- N array

Mel spectrograms, specified as a 96-by-64 matrix or a 96-by-64-by-1-by- N array, where:

- 96 -- Represents the number of 25 ms frames in each mel spectrogram
- 64 -- Represents the number of mel bands spanning 125 Hz to 7.5 kHz
- N -- Represents the number of mel spectrograms.

You can use the VGGish Preprocess block to generate mel spectrograms. All spectrograms are of the dimension 96-by-64.

Data Types: `single` | `double`

Output

Port_1 — Embeddings

N -by-128 matrix

VGGish feature embeddings, returned as an N -by-128 matrix, where N is the number of mel spectrograms in the input. The feature embeddings are a compact representation of audio data.

Data Types: `single`

Parameters

Mini-batch size — Size of mini-batches

128 (default) | positive integer

Size of mini-batches to use for prediction specified as a positive integer. Larger mini-batch sizes require more memory but can lead to faster predictions.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

References

- [1] Gemmeke, Jort F., Daniel P. W. Ellis, Dylan Freedman, Aren Jansen, Wade Lawrence, R. Channing Moore, Manoj Plakal, and Marvin Ritter. "Audio Set: An Ontology and Human-Labeled Dataset for Audio Events." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 776–80. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952261>.
- [2] Hershey, Shawn, Sourish Chaudhuri, Daniel P. W. Ellis, Jort F. Gemmeke, Aren Jansen, R. Channing Moore, Manoj Plakal, et al. "CNN Architectures for Large-Scale Audio Classification." In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 131–35. New Orleans, LA: IEEE, 2017. <https://doi.org/10.1109/ICASSP.2017.7952132>.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Usage notes and limitations:

- To generate generic C code that does not depend on third-party libraries, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C.
- To generate C++ code, in the **Configuration Parameters > Code Generation** general category, set the **Language** parameter to C++. To specify the target library for code generation, in the **Code Generation > Interface** category, set the **Target Library** parameter. Setting this parameter to None generates generic C++ code that does not depend on third-party libraries.
- For ERT-based targets, the **Support: variable-size signals** parameter in the **Code Generation > Interface** pane must be enabled.
- For a list of networks and layers supported for code generation, see "Networks and Layers Supported for Code Generation" (MATLAB Coder).

See Also

Apps
Signal Labeler

Blocks
Sound Classifier | VGGish Preprocess | VGGish Embeddings | YAMNet | YAMNet Preprocess

Functions

`classifySound` | `vggish` | `vggishEmbeddings` | `vggishPreprocess` | `yamnet` |
`yamnetPreprocess` | `yamnetGraph`

Introduced in R2022a

Audio Oscillator

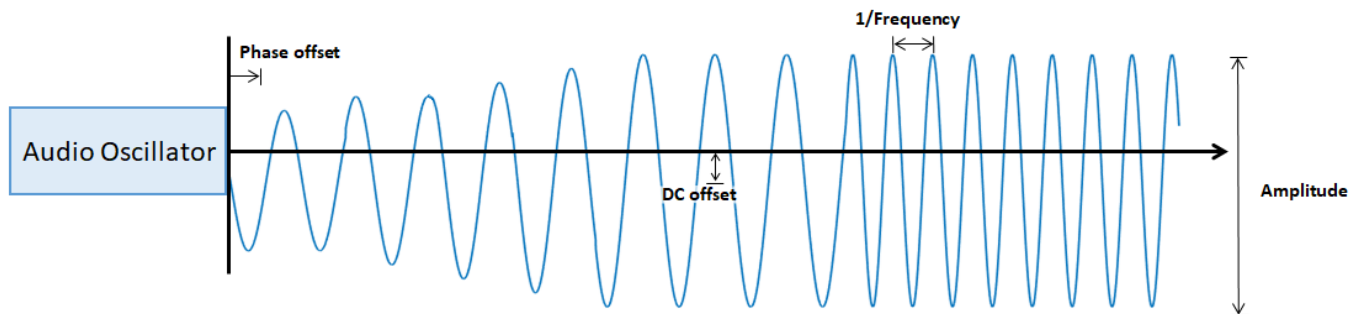
Generate sine, square, and sawtooth waveforms

Library: Audio Toolbox / Sources



Description

The Audio Oscillator block generates tunable waveforms. Typical uses include the generation of test signals for test benches, and the generation of control signals for audio effects. Parameters of the Audio Oscillator block specify the type of waveform generated.



Ports

Input

F — Frequency (Hz)

nonnegative scalar | vector of nonnegative values

Dependencies

To enable this port, select **Specify frequency from input port** for the “Frequency (Hz)” on page 5-0 parameter.

Data Types: single | double

A — Amplitude

nonnegative scalar | vector of nonnegative values

Dependencies

To enable this port, select **Specify amplitude from input port** for the “Amplitude” on page 5-0 parameter.

Data Types: single | double

DC — DC offset

scalar | vector

Dependencies

To enable this port, select **Specify DC offset from input port** for the “DC offset” on page 5-0 parameter.

Data Types: `single` | `double`

Output

Port_1 — Output signal

vector

The Audio Oscillator block outputs a periodic signal defined by the parameters of the block.

Data Types: `single` | `double`

Parameters

If a parameter is listed as tunable, then you can change its value during simulation.

Signal type — Type of generated waveform

`sine` (default) | `square` | `sawtooth`

The waveforms are generated using the algorithms specified by the `sin`, `square`, and `sawtooth` functions.

Frequency (Hz) — Frequency of generated waveform

100 (default) | nonnegative scalar | vector of nonnegative values

- If “Signal type” on page 5-0 is set to `sine`, specify **Frequency (Hz)** as a scalar or as a vector. If **Frequency (Hz)** is set to an N -element vector, then the output from the block is the single-channel sum of N sinusoids. If **Frequency (Hz)** is set to an N -element vector, then “Amplitude” on page 5-0, “Phase offset” on page 5-0, and “DC offset” on page 5-0 must be scalars or N -element vectors.
- For square waveforms, specify **Frequency (Hz)** as a scalar.
- For sawtooth waveforms, specify **Frequency (Hz)** as a scalar.

To specify **Frequency (Hz)** from an input port, select **Specify frequency from input port**.

Tunable: Yes

Amplitude — Amplitude of generated waveform

1 (default) | nonnegative scalar | vector of nonnegative values

- If “Signal type” on page 5-0 is set to `sine`, specify **Amplitude** as a scalar or as a vector. If **Amplitude** is set to an N -element vector, then the output from the block is the single-channel sum of N sinusoids. If **Amplitude** is set to an N -element vector, then “Frequency (Hz)” on page 5-0, “Phase offset” on page 5-0, and “DC offset” on page 5-0 must be scalars or N -element vectors.
- For square waveforms, specify **Amplitude** as a scalar.
- For sawtooth waveforms, specify **Amplitude** as a scalar.

To specify **Amplitude** from an input port, select **Specify amplitude from input port**.

Tunable: Yes

Phase offset — Normalized phase offset of generated waveform

0 (default) | scalar in the range [0, 1] | vector with values in the range [0, 1]

The phase offset range, [0, 1], corresponds to a normalized 2π radians interval.

- If “Signal type” on page 5-0 is set to sine, specify **Phase offset** as a scalar or as a vector. If **Phase offset** is set to an N -element vector, then the output from the block is the single-channel sum of N sinusoids. If **Phase offset** is set to an N -element vector, then “Frequency (Hz)” on page 5-0, “Amplitude” on page 5-0, and “DC offset” on page 5-0 must be scalars or N -element vectors.
- For square waveforms, specify **Amplitude** as a scalar.
- For sawtooth waveforms, specify **Amplitude** as a scalar.

DC offset — Value added to each element of generated waveform

0 (default) | scalar | vector

- If “Signal type” on page 5-0 is set to sine, specify **DC offset** as a scalar or as a vector. If **DC offset** is set to an N -element vector, then the output from the block is the single-channel sum of N sinusoids. If **DC offset** is set to an N -element vector, then “Frequency (Hz)” on page 5-0, “Amplitude” on page 5-0, and “Phase offset” on page 5-0 must be scalars or N -element vectors.
- For square waveforms, specify **Amplitude** as a scalar.
- For sawtooth waveforms, specify **Amplitude** as a scalar.

To specify **DC offset** from an input port, select **Specify DC offset from input port**.

Tunable: Yes

Duty cycle — Square waveform duty cycle

0.5 (default) | scalar in the range [0, 1]

Square waveform duty cycle is the percentage of one period in which the waveform is above the median amplitude. A duty cycle value of 1 or 0 is equivalent to a DC signal.

Dependencies

To enable this parameter, set **Signal type** to square.

Width — Sawtooth width

1 (default) | scalar in the range [0, 1]

Sawtooth width determines the point in a sawtooth waveform period at which the maximum occurs.

Dependencies

To enable this property, set **Signal type** to sawtooth.

Samples per frame — Number of samples per frame

512 (default) | positive integer

Number of samples per frame, specified as a positive integer.

Sample rate (Hz) — Sample rate of generated waveform

44100 (default) | positive scalar

The sample rate must be greater than twice the value specified in “Frequency (Hz)” on page 5-0 .

Output data type — Data type of generated waveform

double (default) | single

Data type of generated waveform, specified as double or single.

Tunable: No

Simulate using — Specify type of simulation to run

Code generation (default) | Interpreted execution

- **Code generation** - Simulate the model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations, as long as the model does not change. This option requires additional startup time, but the speed of the subsequent simulations is comparable to **Interpreted execution**.
- **Interpreted execution** - Simulate model using the MATLAB interpreter. This option reduces startup time and the simulation has speed comparable to **Code generation**. In this mode, you can debug the source code of the block.

Block Characteristics

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	no
Zero-Crossing Detection	no

Extended Capabilities**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

See Also

Wavetable Synthesizer | audioOscillator | Audio Device Writer

Introduced in R2020a

Multiband Parametric EQ

Multiband parametric equalizer

Library: Audio Toolbox / Filters



Description

The Multiband Parametric EQ block performs multiband parametric equalization independently across each channel of input using specified center frequencies, gains, and quality factors. You can configure this block with up to 10 bands. You can add low-shelf and high-shelf filters as well as highpass (low-cut) and lowpass (high-cut) filters.

Ports

Input

Port_1 — Audio input to equalizer

matrix | vector

Audio input to the equalizer, specified as one of the following:

- Matrix input -- The block treats each column of the input as an independent channel.
- Vector input -- The block treats the input as having a single channel.

Data Types: single | double

Output

Port_1 — Audio output from equalizer

matrix

Audio output from the equalizer, returned as a matrix. If you specify the input as a matrix, the block returns the output with the same size as matrix input. If you specify the input as a vector then the output is N-by-1 matrix.

Data Types: single | double

Parameters

Main

EQ order — Order of individual equalizer bands

2 (default) | even positive integer

Order of individual equalizer bands, specified as an even positive integer. All equalizer bands have the same order.

Number of bands — Number of equalizer bands

3 (default) | integer in the range [1, 10]

Number of equalizer bands, specified as an integer in the range [1, 10]. The number of equalizer bands does not include shelving filters, highpass filters, or lowpass filters.

Specify frequencies from input port — Specify frequencies from input port

off (default) | on

Select this parameter to specify frequencies from the input port.

Frequencies (Hz) — Center frequencies of equalizer bands

[100, 181, 325] (default) | row vector of length equal to Number of bands

Center frequencies of equalizer bands in Hz, specified as a row vector of length equal to **Number of bands**. The vector consists of real scalars in the range 0 to **Input sample rate (Hz)/2**.

Tunable: Yes

Dependencies

To enable this parameter, set **Specify input frequencies from input port** to off.

Specify peak gains from input port — Specify peak gains from input port

off (default) | on

Select this parameter to specify peak gains from input port.

Peak Gains (dB) — Peak or dip filter gains

[0, 0, 0] (default) | row vector of length equal to Number of bands

Peak or dip filter gains, specified as a row vector of length equal to **Number of bands** in dB. The vector consists of real scalars in the range $[-\infty, 20]$.

Tunable: Yes

Dependencies

To enable this parameter, set **Specify peak gains from input port** to off.

Specify quality factors from input port — Specify quality factors from input port

off (default) | on

Select this parameter to specify quality factors from the input port.

Quality factors — Quality factors of equalizer bands

[1.6, 1.6, 1.6] (default) | row vector

Quality factors of equalizer bands, specified as a row vector of length equal to **Number of bands**.

Tunable: Yes

Dependencies

To enable this parameter, set **Specify quality factor from input port** to off.

Inherit sample rate from input — Specify sample rate from input port

off (default) | on

Select this parameter to specify sample rate from the input port.

Input sample rate (Hz) — Input sample rate

44100 (default) | positive scalar

Input sample rate, specified as a positive scalar in Hz.

Tunable: Yes

Dependencies

To enable this parameter, set **Inherit sample rate from input port** to off.

Visualize filter response — Visualize magnitude response of equalizer

button

This button plots the filter responses of low-shelf, high-shelf, highpass (low-cut), and lowpass (high-cut) filters in a magnitude (dB) vs. frequencies (Hz) plot.

Note The block does not support filter visualization if any parameters are specified from input ports or the sample rate is inherited.

Variable name — Variable name of exported filter

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace — Export filter to workspace

button

Export the filter to the base workspace in the variable specified by the **Variable name** parameter.

Tips

- You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.
- You cannot export the filter if you are specifying filter characteristics from input ports.

Advanced**Add low-shelf filter — Add low-shelf filter to equalizer**

off (default) | on

Select this parameter to add a low-shelf filter to your equalizer.

Specify low-shelf cutoff from input port — Specify low-shelf cutoff frequency from input port

off (default) | on

Select this parameter to specify the cutoff frequency of the low-shelf filter from the input port.

Dependencies

To enable this parameter, set **Add low-shelf filter** to on.

Low-shelf cutoff frequency (Hz) — Low-shelf cutoff frequency

200 (default) | scalar

The cutoff frequency of the low-shelf filter, specified as a scalar greater than or equal to 0 in Hz.

Tunable: Yes**Dependencies**

To enable this parameter, set **Add low-shelf filter** to on and **Specify low-shelf cutoff from input port** to off.

Specify low-shelf slope from input port — Specify low-shelf slope

off (default) | on

Select this parameter to specify low-shelf slope from the input port.

Dependencies

To enable this parameter, set **Add low-shelf filter** to on.

Low-shelf filter slope — Low-shelf slope

1.5 (default) | positive scalar

The slope of the low-shelf filter, specified as a positive scalar.

Tunable: Yes**Dependencies**

To enable this parameter, set **Add low-shelf filter** to on and **Specify low-shelf slope from input port** to off.

Specify low-shelf gain from input port — Specify low-shelf gain from input port

off (default) | on

Select this parameter to specify the gain of the low-shelf filter from the input port.

Dependencies

To enable this parameter, set **Add low-shelf filter** to on.

Low-shelf filter gain (dB) — Low-shelf gain

0 (default) | real scalar

The gain of the low-shelf filter, specified as a real scalar.

Tunable: Yes

Dependencies

To enable this parameter, set **Add low-shelf filter** to on and **Specify low-shelf gain from input port** to off.

Add high-shelf filter — Add high-shelf filter to equalizer

off (default) | on

Select this parameter to add a high-shelf filter to your equalizer.

Specify high-shelf cutoff from input port — Specify high-shelf cutoff frequency from input port

off (default) | on

Select this parameter to specify the cutoff frequency of the high-shelf filter from the input port.

Dependencies

To enable this parameter, set **Add high-shelf filter** to on.

High-shelf cutoff frequency (Hz) — High-shelf cutoff frequency

15e3 (default) | scalar

The cutoff frequency of the high-shelf filter, specified as a scalar greater than or equal to 0 in Hz.

Tunable: Yes

Dependencies

To enable this parameter, set **Add high-shelf filter** to on and **Specify high-shelf cutoff from input port** to off.

Specify high-shelf slope from input port — Specify high-shelf slope from input port

off (default) | on

Select this parameter to specify the slope of the high-shelf filter from the input port.

Dependencies

To enable this parameter, set **Add high-shelf filter** to on.

High-shelf filter slope — High-shelf slope

1.5 (default) | positive scalar

The slope of the high-shelf filter, specified as a positive scalar.

Tunable: Yes

Dependencies

To enable this parameter, set **Add high-shelf filter** to on and **Specify high-shelf slope from input port** to off.

Specify high-shelf gain from input port — Specify high-shelf gain from input port

off (default) | on

Select this parameter to specify the gain of the high-shelf filter from the input port.

Dependencies

To enable this parameter, set **Add high-shelf filter** to on.

High-shelf filter gain (dB) — High-shelf gain

0 (default) | real scalar

The gain of the high-shelf filter, specified as a real scalar.

Tunable: Yes

Dependencies

To enable this parameter, set **Add high-shelf filter** to on and **Specify high-shelf gain from input port** to off.

Add lowpass filter — Add lowpass filter to equalizer

off (default) | on

Select this parameter to add a lowpass filter to your equalizer.

Specify lowpass cutoff from input port — Specify lowpass cutoff frequency from input port

off (default) | on

Select this parameter to specify the cutoff frequency of the lowpass filter from the input port.

Dependencies

To enable this parameter, set **Add lowpass filter** to on.

Lowpass cutoff frequency (Hz) — Lowpass cutoff frequency

18e3 (default) | scalar

The cutoff frequency of the lowpass filter, specified as a scalar greater than or equal to 0 in Hz.

Tunable: Yes

Dependencies

To enable this parameter, set **Add lowpass filter** to on and **Specify lowpass cutoff from input port** to off.

Specify lowpass slope from input port — Specify lowpass slope from input port

off (default) | on

Select this parameter to specify the slope of the lowpass filter from the input port.

Dependencies

To enable this parameter, set **Add lowpass filter** to on.

Lowpass filter slope — Lowpass slope

12 (default) | real scalar in the range [0:6:48]

The slope of the lowpass filter, specified as a real scalar in the range [0:6:48] in dB/octave. Values that are not multiples of 6 are rounded to the nearest multiple of 6.

Tunable: Yes

Dependencies

To enable this parameter, set **Add lowpass filter** to on and **Specify lowpass slope from input port** to off.

Add highpass filter — Add highpass filter to equalizer

off (default) | on

Select this parameter to add a highpass filter to your equalizer.

Specify highpass cutoff from input port — Specify highpass cutoff frequency from input port

off (default) | on

Select this parameter to specify the cutoff frequency of the highpass filter cutoff from the input port.

Dependencies

To enable this parameter, set **Add highpass filter** to on.

Highpass cutoff frequency (Hz) — Highpass cutoff frequency

20 (default) | nonnegative real scalar

The cutoff frequency of the highpass filter, specified as a real scalar greater than or equal to 0 in Hz.

Tunable: Yes

Dependencies

To enable this parameter, set **Add highpass filter** to on and **Specify highpass cutoff from input port** to off.

Specify highpass slope from input port — Specify highpass slope from input port

off (default) | on

Select this parameter to specify the slope of the highpass filter from the input port.

Dependencies

To enable this parameter, set **Add highpass filter** to on.

Highpass filter slope — Highpass slope

30 (default) | real scalar in the range [0:6:48]

The slope of the highpass filter, specified as a real scalar in the range [0:6:48] in dB/octave. Values that are not multiples of 6 are rounded to the nearest multiple of 6.

Tunable: Yes

Dependencies

To enable this parameter, set **Add highpass filter** to on and **Specify highpass slope from input port** to off.

Oversample — Oversample toggle

off (default) | on

Oversample toggle, specified as one of the following:

- `off` -- Run the multiband parametric equalizer at the input sample rate.
- `on` -- Run the multiband parametric equalizer at two times the input sample rate. Oversampling minimizes the frequency-warping effects introduced by the bilinear transformation.

A halfband interpolator implements oversampling before equalization. A halfband decimator reduces the sample rate back to the input sampling rate after equalization.

Simulate using — Specify type of simulation to run

`Code generation` (default) | `Interpreted execution`

Type of simulation to run, specified as one of the following:

- `Interpreted execution` -- Simulate model using the MATLAB interpreter. This option shortens startup time and has simulation speed comparable to `Code generation`. In this mode, you can debug the source code of the block.
- `Code generation` -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is faster than `Interpreted execution`.

Tunable: No

Block Characteristics

Data Types	<code>double</code> <code>single</code>
Direct Feedthrough	<code>no</code>
Multidimensional Signals	<code>no</code>
Variable-Size Signals	<code>yes</code>
Zero-Crossing Detection	<code>no</code>

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

`multibandParametricEQ` | `Gammatone Filter Bank` | `Single-Band Parametric EQ`

Introduced in R2021b

Gammatone Filter Bank

Gammatone filter bank

Library: Audio Toolbox / Filters



Description

The Gammatone Filter Bank block decomposes a signal by passing it through a bank of gammatone filters equally spaced on the equivalent rectangular bandwidth (ERB) scale. Gammatone filter banks are designed to model the human auditory system.

Ports

Input

Port_1 — Audio input to filter bank

scalar | vector | matrix

Audio input to the filter bank, specified as a scalar, vector, or matrix. If you specify the input as a matrix, the block treats the columns as independent audio channels. If you specify the input as a vector, the block treats the input as containing a single channel.

Data Types: single | double

Output

Port_1 — Audio output from filter bank

scalar | vector | matrix | 3-D array

Audio output from the filter bank, returned as a scalar, vector, matrix, or 3-D array. The shape of output signal depends on the shape of input signal and **Number of filters**. If input is an M -by- N matrix, then output is an M -by-Number of filters-by- N array. If N is 1, then output is a matrix.

Data Types: single | double

Parameters

Frequency range (Hz) — Frequency range of filter bank

[50 8000] (default) | two-element row vector of monotonically increasing values

Frequency range of the filter bank, specified as a two-element row vector of monotonically increasing values in Hz.

Tunable: No

Number of filters — Number of filters

32 (default) | positive integer

Number of filters in the filter bank, specified as a positive integer.

Tunable: No

Inherit sample rate from input — Specify sample rate from input port

off (default) | on

Select this parameter to specify the sample rate from the input port.

Input sample rate (Hz) — Input sample rate

16000 (default) | positive integer

Input sample rate, specified as a positive integer in Hz.

Tunable: No

Dependencies

To enable this parameter, set **Inherit sample rate from input port** to off.

Bands as separate output port — Separate ports for each filter output

off (default) | on

Select this parameter to separate ports for each filter output.

Tunable: No

View Filter Response — Visualize filter bank responses

button

This button uses the `fvtool` function to visualize gammatone filter bank responses.

Variable name — Variable name of exported filter bank

myFilt (default) | valid variable name

Name of the variable in the base workspace to contain the filter bank when it is exported. The name must be a valid MATLAB variable name.

Overwrite variable if it already exists — Overwrite variable if it already exists

on (default) | off

When you select this parameter, exporting the filter bank overwrites the variable specified by the **Variable name** parameter if it already exists in the base workspace. If you do not select this parameter and the specified variable already exists in the workspace, exporting the filter bank creates a new variable with an underscore and a number appended to the variable name. For example, if the variable name is `var` and it already exists, the exported variable will be named `var_1`.

Export filter to workspace — Export filter bank to workspace

button

Export the filter bank to the base workspace in the variable specified by the **Variable name** parameter.

Tips

You cannot export the filter if you have enabled the **Inherit sample rate from input** parameter and the model is not running.

Simulate using — Specify type of simulation to run

Interpreted execution (default) | Code generation

Type of simulation to run, specified as one of the following:

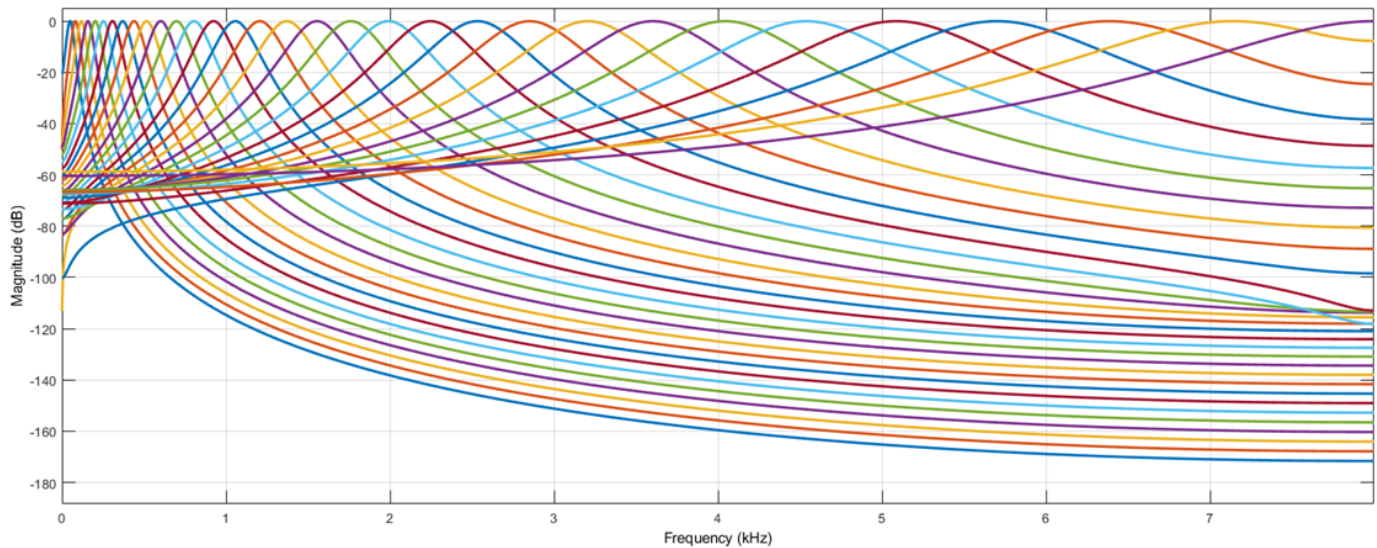
- **Interpreted execution** -- Simulate model using the MATLAB interpreter. This option shortens startup time and has simulation speed comparable to **Code generation**. In this mode, you can debug the source code of the block.
- **Code generation** -- Simulate model using generated C code. The first time you run a simulation, Simulink generates C code for the block. The C code is reused for subsequent simulations as long as the model does not change. This option requires additional startup time but the speed of the subsequent simulations is faster than **Interpreted execution**.

Tunable: No**Block Characteristics**

Data Types	double single
Direct Feedthrough	no
Multidimensional Signals	no
Variable-Size Signals	yes
Zero-Crossing Detection	no

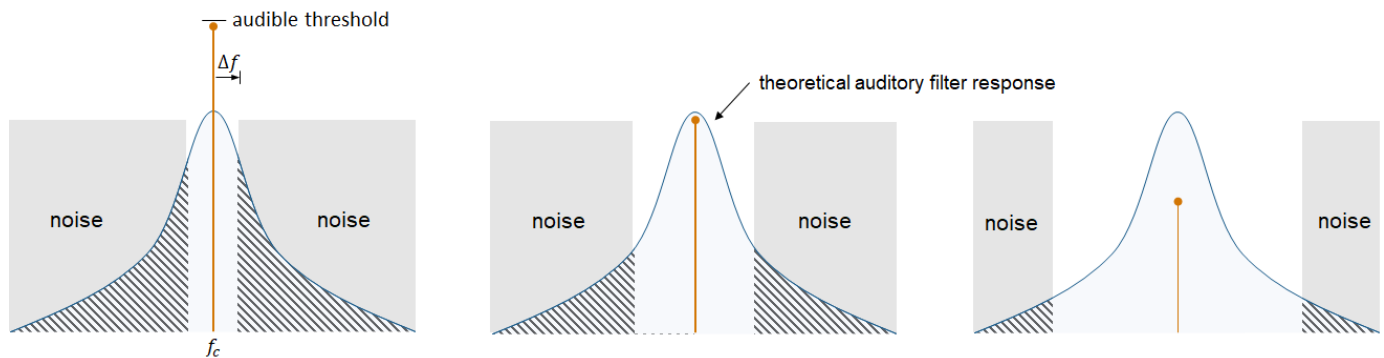
Algorithms**Applications**

A gammatone filter bank is often used as the front end of a cochlea simulation. A cochlea simulation transforms complex sounds into a multichannel activity pattern like the one observed in the auditory nerve [2]. The Gammatone Filter Bank block follows the algorithm described in [1]. The algorithm is an implementation of an idea proposed in [2]. The design of the gammatone filter bank can be described in two parts: the filter shape (gammatone) and the frequency scale. The equivalent rectangular bandwidth (ERB) scale defines the relative spacing and bandwidth of the gammatone filters. The derivation of the ERB scale also provides an estimate of the auditory filter response that closely resembles the gammatone filter.

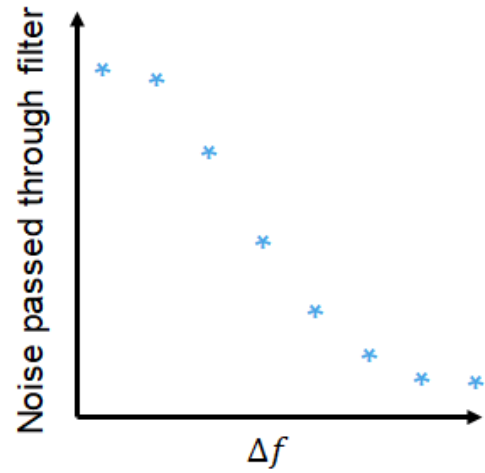
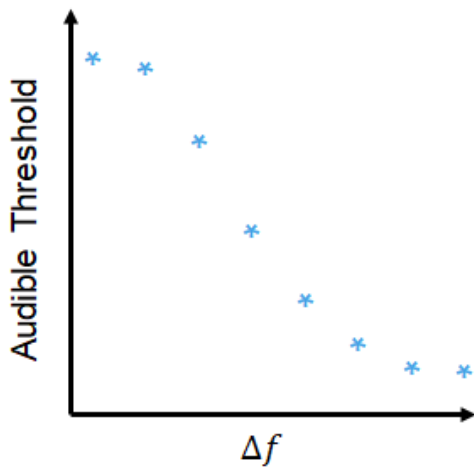


Frequency Scale

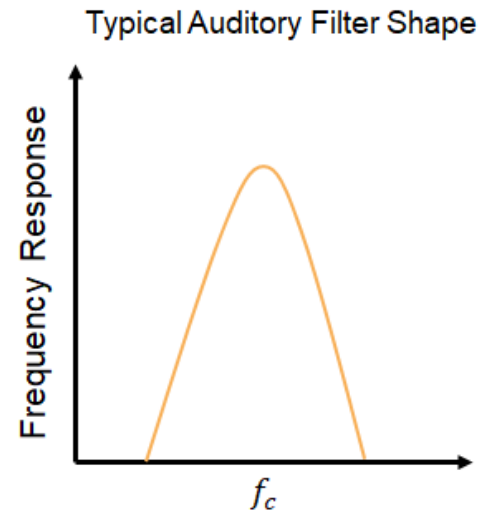
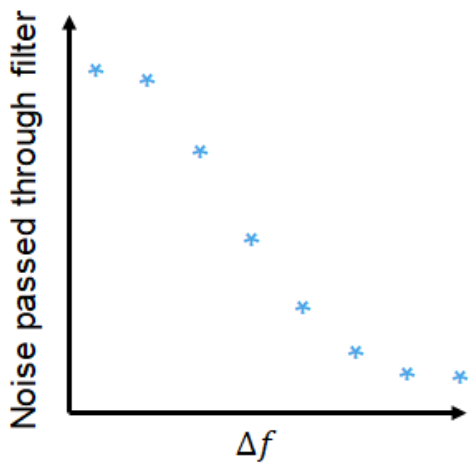
The block determines the ERB scale using the notched-noise masking method. This method involves a listening test wherein notched noise is centered on a tone. The power of the tone is tuned, and the audible threshold (the power required for the tone to be heard) is recorded. The experiment is repeated for different notch widths and center frequencies.



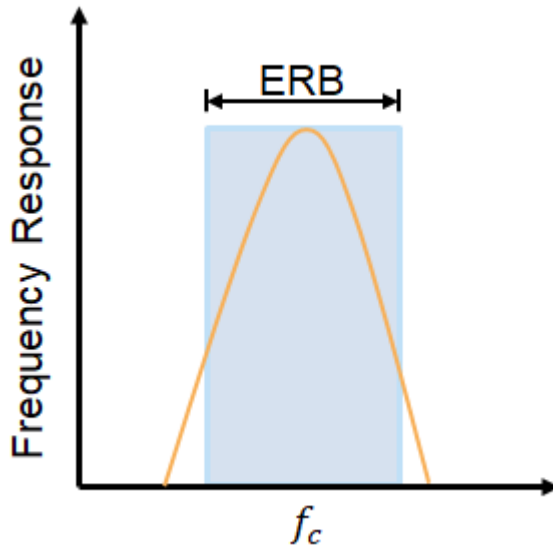
The notched-noise method assumes that the audible threshold corresponds to a constant signal-to-masker ratio at the output of the theoretical auditory filter. That is, the ratio of the power of the f_c tone and the shaded area is constant. Therefore, the relationship between the audible threshold and $2\Delta f$ (the notch bandwidth) is linearly related to the relationship between the noise passed through the filter and $2\Delta f$.



The derivative of the function relating Δf to the noise passed through the filter estimates the shape of the auditory filter. Because Δf has an inverse relationship with the noise power passed through the filter, the derivative of the function must be multiplied by -1. The resulting shape of the auditory filter is usually approximated as a roex filter.



The equivalent rectangular bandwidth of the auditory filter is defined as the width of a rectangular filter required to pass the same noise power as the auditory filter.



[4] defines ERB as a function of center frequency for young listeners with normal hearing and a moderate noise level:

$$\text{ERB} = 24.7(0.00437f_c + 1)$$

The ERB scale (ERBs) is an extension of the relationship between ERB and the center frequency, derived by integrating the reciprocal of the ERB function:

$$\text{ERBs} = 21.4 \log_{10}(0.00437f + 1)$$

To design a gammatone filter bank, [2] suggests distributing the center frequencies of the filters in proportion to their bandwidth. To accomplish this, Gammatone Filter Bank block defines the center frequencies as linearly spaced on the ERB scale, covering the specified frequency range with the desired number of filters. You can specify the frequency range and desired number of filters using the **Frequency range (Hz)** and **Number of filters** parameters.

Gammatone Filter

The gammatone filter was introduced in [3]. The continuous impulse response is:

$$g(t) = at^{n-1}e^{-2\pi bt} \cos(2\pi f_c t + \phi)$$

where

- a -- amplitude factor
- t -- time in seconds
- n -- filter order (set to four to model human hearing)
- f_c -- center frequency
- b -- bandwidth, set to $1.019 \text{ Hz} / 2 \text{erb}(f_c)$.
- ϕ -- phase factor

The gammatone filter is similar to the roex filter derived from the notched-noise experiment. The Gammatone Filter Bank block implements the digital filter as a cascade of four second-order sections, as described in [1].

References

- [1] Slaney, Malcolm. "An Efficient Implementation of the Patterson-Holdsworth Auditory Filter Bank." Apple Computer Technical Report 35, 1993.
- [2] Patterson, R.D., K. Robinson, J. Holdsworth, D. McKeown, C. Zhang, and M. Allerhand. "Complex Sounds and Auditory Images." *Auditory Physiology and Perception*. 1992, pp. 429-446.
- [3] Aertsen, A. M. H. J., and P. I. M. Johannesma. "Spectro-Temporal Receptive Fields of Auditory Neurons in the Grassfrog." *Biological Cybernetics*. Vol. 38, Issue 4, 1980, pp. 223-234.
- [4] Glasberg, Brian R., and Brian C. J. Moore. "Derivation of Auditory Filter Shapes from Notched-Noise Data." *Hearing Research*. Vol. 47. Issue 1-2, 1990, pp. 103-138.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

gammatoneFilterBank | Multiband Parametric EQ | Octave Filter Bank

Introduced in R2021b