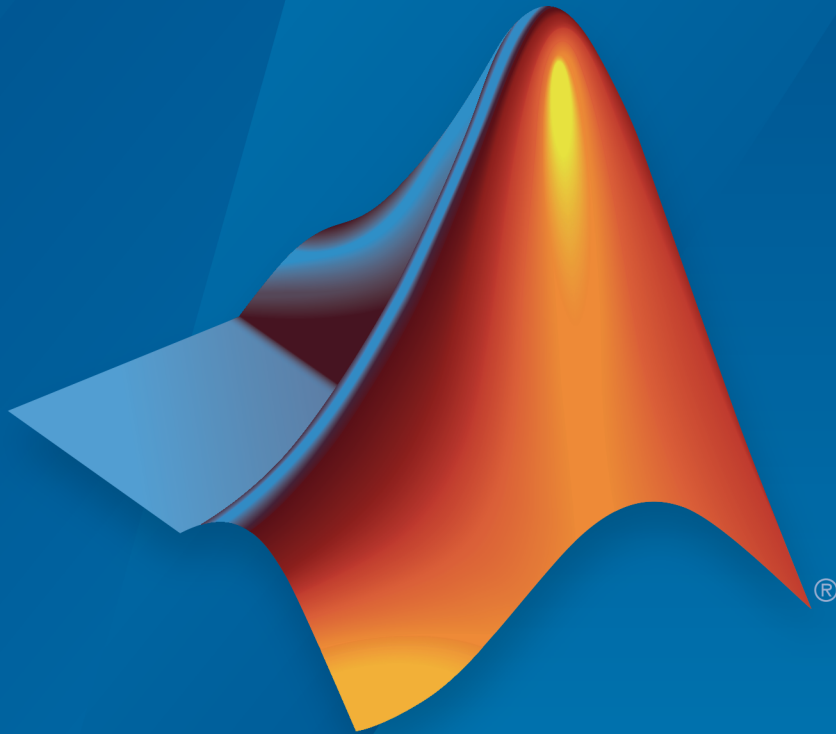


# Computer Vision System Toolbox™

## User's Guide



# MATLAB®

R2015a



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*Computer Vision System Toolbox™ User's Guide*

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# Using the Installer for Computer Vision System Toolbox Product

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- “Install Computer Vision System Toolbox Support Packages” on page 1-2
- “OCR Language Data” on page 1-5
- “OpenCV Interface” on page 1-8

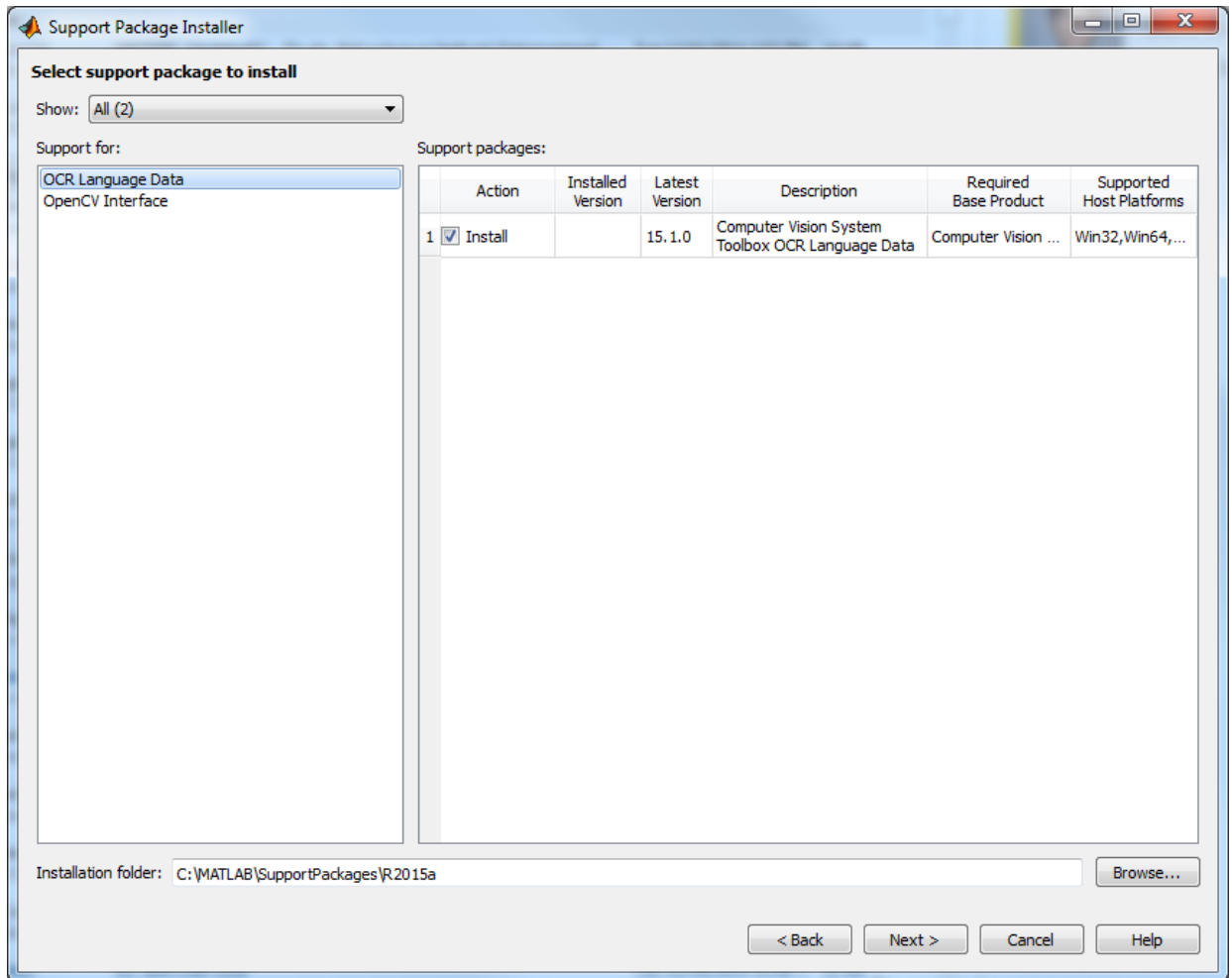
## Install Computer Vision System Toolbox Support Packages

This example shows how to add third-party data files. After you complete this process, you can use the data with the Computer Vision System Toolbox™ product.

- 1 In a MATLAB® Command Window, type:  

```
visionSupportPackages
```
- 2 In the Support Package Installer, follow the instructions for installation. For more information about the options on a particular screen, click **Help**.
- 3 At **Select support package to install** select the data you want to add:
  - Computer Vision System Toolbox OCR Language Data
  - Computer Vision System Toolbox OpenCV Interface





- 4 Accept or change the installation folder and click **Next**.

---

**Note:** You must have write privileges for the Installation folder.

---

- 5 Follow the remaining prompts to download and install the support package.

The installation process adds one or both of these items:

- Computer Vision System Toolbox OCR Language Data
- Computer Vision System Toolbox OpenCV Interface

When a new version of MATLAB software is released, repeat this process to check for updates. You can also check for updates between releases.

## **More About**

- “OCR Language Data”
- “OpenCV Interface”

# OCR Language Data

## Install OCR Language Data

Use the `visionSupportPackages` function to launch the Support Package Installer. Follow the steps in the “Install Computer Vision System Toolbox Support Packages” directions.

## Pretrained Language Data and the `ocr` function

The OCR Language Data support package contains pretrained language data files from the OCR Engine page, `tesseract-ocr`, to use with the `ocr` function. After you install the pretrained language data files, you can specify one or more additional languages using the `Language` property of the `ocr` function. Use the appropriate language string with the property.

```
txt = ocr(img,'Language','Finnish');
```

### List of OCR language data in support package

- 'Afrikaans'
- 'Albanian'
- 'AncientGreek'
- 'Arabic'
- 'Azerbaijani'
- 'Basque'
- 'Belarusian'
- 'Bengali'
- 'Bulgarian'
- 'Catalan'
- 'Cherokee'
- 'ChineseSimplified'
- 'ChineseTraditional'
- 'Croatian'
- 'Czech'

- 'Danish'
- 'Dutch'
- 'English'
- 'Esperanto'
- 'EsperantoAlternative'
- 'Estonian'
- 'Finnish'
- 'Frankish'
- 'French'
- 'Galician'
- 'German'
- 'Greek'
- 'Hebrew'
- 'Hindi'
- 'Hungarian'
- 'Icelandic'
- 'Indonesian'
- 'Italian'
- 'ItalianOld'
- 'Japanese'
- 'Kannada'
- 'Korean'
- 'Latvian'
- 'Lithuanian'
- 'Macedonian'
- 'Malay'
- 'Malayalam'
- 'Maltese'
- 'MathEquation'
- 'MiddleEnglish'

- 'MiddleFrench'
- 'Norwegian'
- 'Polish'
- 'Portuguese'
- 'Romanian'
- 'Russian'
- 'SerbianLatin'
- 'Slovakian'
- 'Slovenian'
- 'Spanish'
- 'SpanishOld'
- 'Swahili'
- 'Swedish'
- 'Tagalog'
- 'Tamil'
- 'Telugu'
- 'Thai'
- 'Turkish'
- 'Ukrainian'

### **See Also**

ocr | visionSupportPackages

### **More About**

- “Install Computer Vision System Toolbox Support Packages”

## OpenCV Interface

### Install OpenCV Interface Files

The OpenCV Support package helps you integrate your OpenCV C++ code into MATLAB. It lets you build MEX files that calls OpenCV functions. Use the `visionSupportPackages` function to launch the Support Package Installer. Follow the steps in the “Install Computer Vision System Toolbox Support Packages” directions.

### Support Package Contents

The Computer Vision System Toolbox OpenCV Interface support package installs all the files you need in the `visionopencv` folder. To find the path to this folder, type the following command:

```
which mexOpenCV.m
```

The `visionopencv` folder contains:

**example** folder: Template Matching, Foreground Detector, and Oriented FAST and Rotated BRIEF (ORB) examples. Each subfolder contains a `README.txt` file with step-by-step instructions.

**opencv** folder: OpenCV header files, library files (for Windows® only), and OpenCV license file.

**registry** folder: Registration files.

**mexOpenCV.m** file: Function to build MEX files.

**README.txt** file: Help file.

### Create an OpenCV MEX file

Call the `mexOpenCV` function with your source file.

```
>> mexOpenCV yourfile.cpp
```

For help creating MEX files, type the following at the MATLAB command prompt:

```
help mexOpenCV
```

### OpenCV Examples

The OpenCV Interface support package includes three examples. Each example subfolder contains all the files you need to run the example. To run an example, you must call the

mexOpenCV function with one of the supplied source files. Each example subfolder also contains a README.txt file with specific instructions.

### Template Matching

To run the Template Matching example, follow these steps:

- 1 Change your current working folder to the `example/TemplateMatching` folder.
- 2 Create the MEX-file from the source file:  
`mexOpenCV matchTemplateOCV.cpp`
- 3 Run the test script, which uses the generated MEX-file:  
`testMatchTemplate.m`

### Foreground Detector

To run the Foreground Detector example, follow these steps:

- 1 Change your current working folder to the `example/ForegroundDetector` folder.
- 2 Create the MEX-file from the source file:  
`mexOpenCV backgroundSubtractorOCV.cpp`
- 3 Run the test script, which uses the generated MEX-file:  
`testBackgroundSubtractor.m`

### Detect ORB Features

To run the Oriented FAST and Rotated BRIEF (ORB) Detector example, follow these steps:

- 1 Change your current working folder to the `example/ORB` folder.
- 2 Create the MEX-file for the detector from the source file:  
`mexOpenCV detectORBFeaturesOCV.cpp`
- 3 Create the MEX-file for the extractor from the source file:  
`mexOpenCV extractORBFeaturesOCV.cpp`
- 4 Run the test script, which uses the generated MEX-files:  
`testORBFeaturesOCV.m`

## **See Also**

visionSupportPackages

## **More About**

- “Install Computer Vision System Toolbox Support Packages”

## **External Web Sites**

- Using OpenCV with MATLAB



# Input, Output, and Conversions

---

Learn how to import and export videos, and perform color space and video image conversions.

- “Export to Video Files” on page 2-2
- “Import from Video Files” on page 2-4
- “Batch Process Image Files” on page 2-6
- “Display a Sequence of Images” on page 2-8
- “Partition Video Frames to Multiple Image Files” on page 2-11
- “Combine Video and Audio Streams” on page 2-15
- “Import MATLAB Workspace Variables” on page 2-17
- “Transmit Audio and Video Content Over Network” on page 2-19
- “Resample Image Chroma” on page 2-21
- “Convert Intensity to Binary Images” on page 2-25
- “Convert R'G'B' to Intensity Images” on page 2-35
- “Process Multidimensional Color Video Signals” on page 2-39
- “Video Formats” on page 2-44
- “Image Formats” on page 2-46

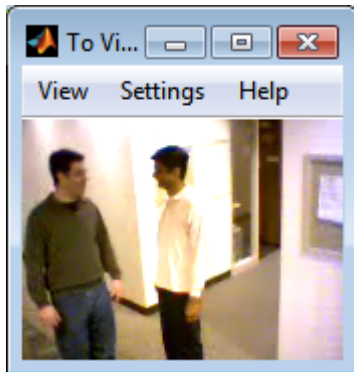
### Export to Video Files

The Computer Vision System Toolbox blocks enable you to export video data from your Simulink® model. In this example, you use the To Multimedia File block to export a multimedia file from your model. This example also uses Gain blocks from the **Math Operations** Simulink library.

You can open the example model by typing

```
ex_export_to_mmf  
at the MATLAB command line.
```

- 1 Run your model.
- 2 You can view your video in the To Video Display window.



By increasing the red, green, and blue color values, you increase the contrast of the video. The To Multimedia File block exports the video data from the Simulink model to a multimedia file that it creates in your current folder.

This example manipulated the video stream and exported it from a Simulink model to a multimedia file. For more information, see the To Multimedia File block reference page.

### Setting Block Parameters for this Example

The block parameters in this example were modified from default values as follows:

Block	Parameter
<b>Gain</b>	<p>The Gain blocks are used to increase the red, green, and blue values of the video stream. This increases the contrast of the video:</p> <ul style="list-style-type: none"> <li>• <b>Main</b> pane, <b>Gain</b> = 1.2</li> <li>• <b>Signal Attributes</b> pane, <b>Output data type</b> = Inherit: Same as input</li> </ul>
<b>To Multimedia File</b>	<p>The To Multimedia File block exports the video to a multimedia file:</p> <ul style="list-style-type: none"> <li>• <b>Output file name</b> = my_output.avi</li> <li>• <b>Write</b> = Video only</li> <li>• <b>Image signal</b> = Separate color signals</li> </ul>

## Configuration Parameters

You can locate the **Model Configuration Parameters** by selecting **Model Configuration Parameters** from the **Simulation** menu. For this example, the parameters on the **Solver** pane, are set as follows:

- **Stop time** = 20
- **Type** = Fixed-step
- **Solver** = Discrete (no continuous states)

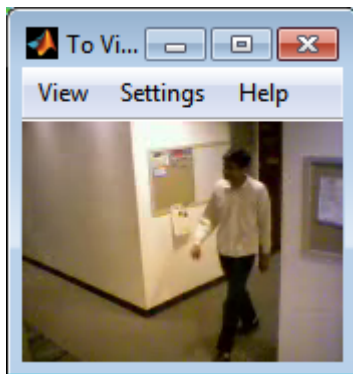
### Import from Video Files

In this example, you use the From Multimedia File source block to import a video stream into a Simulink model and the To Video Display sink block to view it. This procedure assumes you are working on a Windows platform.

You can open the example model by typing

`ex_import_mmf`  
at the MATLAB command line.

- 1 Run your model.
- 2 View your video in the To Video Display window that automatically appears when you start your simulation.



---

**Note:** The video that is displayed in the To Video Display window runs at the frame rate that corresponds to the input sample time. To run the video as fast as Simulink processes the video frames, use the Video Viewer block.

---

You have now imported and displayed a multimedia file in the Simulink model. In the “Export to Video Files” on page 2-2 example you can manipulate your video stream and export it to a multimedia file.

For more information on the blocks used in this example, see the From Multimedia File and To Video Display block reference pages.

## Setting Block Parameters for this Example

The block parameters in this example were modified from default values as follows:

Block	Parameter
<b>From Multimedia File</b>	<p>Use the From Multimedia File block to import the multimedia file into the model:</p> <ul style="list-style-type: none"> <li>• If you do not have your own multimedia file, use the default <code>vipmen.avi</code> file, for the <b>File name</b> parameter.</li> <li>• If the multimedia file is on your MATLAB path, enter the filename for the <b>File name</b> parameter.</li> <li>• If the file is not on your MATLAB path, use the <b>Browse</b> button to locate the multimedia file.</li> <li>• Set the <b>Image signal</b> parameter to <code>Separate color signals</code>.</li> </ul> <p>By default, the <b>Number of times to play file</b> parameter is set to <code>inf</code>. The model continues to play the file until the simulation stops.</p>
<b>To Video Display</b>	<p>Use the To Video Display block to view the multimedia file.</p> <ul style="list-style-type: none"> <li>• <b>Image signal:</b> <code>Separate color signals</code></li> </ul> <p>Set this parameter from the <b>Settings</b> menu of the display viewer.</p>

## Configuration Parameters

You can locate the **Model Configuration Parameters** by selecting **Model Configuration Parameters** from the **Simulation** menu. For this example, the parameters on the **Solver** pane, are set as follows:

- **Stop time** = 20
- **Type** = Fixed-step
- **Solver** = Discrete (no continuous states)

### Batch Process Image Files

A common image processing task is to apply an image processing algorithm to a series of files. In this example, you import a sequence of images from a folder into the MATLAB workspace.

---

**Note:** In this example, the image files are a set of 10 microscope images of rat prostate cancer cells. These files are only the first 10 of 100 images acquired.

---

- 1 Specify the folder containing the images, and use this information to create a list of the file names, as follows:

```
fileFolder = fullfile(matlabroot, 'toolbox', 'images', 'imdemos');  
dirOutput = dir(fullfile(fileFolder, 'AT3_1m4_*.tif'));  
fileNames = {dirOutput.name}'
```

- 2 View one of the images, using the following command sequence:

```
I = imread(fileNames{1});  
imshow(I);  
text(size(I,2),size(I,1)+15, ...  
      'Image files courtesy of Alan Partin', ...  
      'FontSize',7,'HorizontalAlignment','right');  
text(size(I,2),size(I,1)+25, ...  
      'Johns Hopkins University', ...  
      'FontSize',7,'HorizontalAlignment','right');
```

- 3 Use a for loop to create a variable that stores the entire image sequence. You can use this variable to import the sequence into Simulink.

```
for i = 1:length(fileNames)  
    my_video(:,:,i) = imread(fileNames{i});  
end
```

For additional information about batch processing, see the “Batch Processing Image Files in Parallel” example in the Image Processing Toolbox™.

## Configuration Parameters

You can locate the **Model Configuration Parameters** by selecting **Model Configuration Parameters** from the **Simulation** menu. For this example, the parameters on the **Solver** pane, are set as follows:

- **Stop time** = 10
- **Type** = Fixed-step
- **Solver** = Discrete (no continuous states)

### Display a Sequence of Images

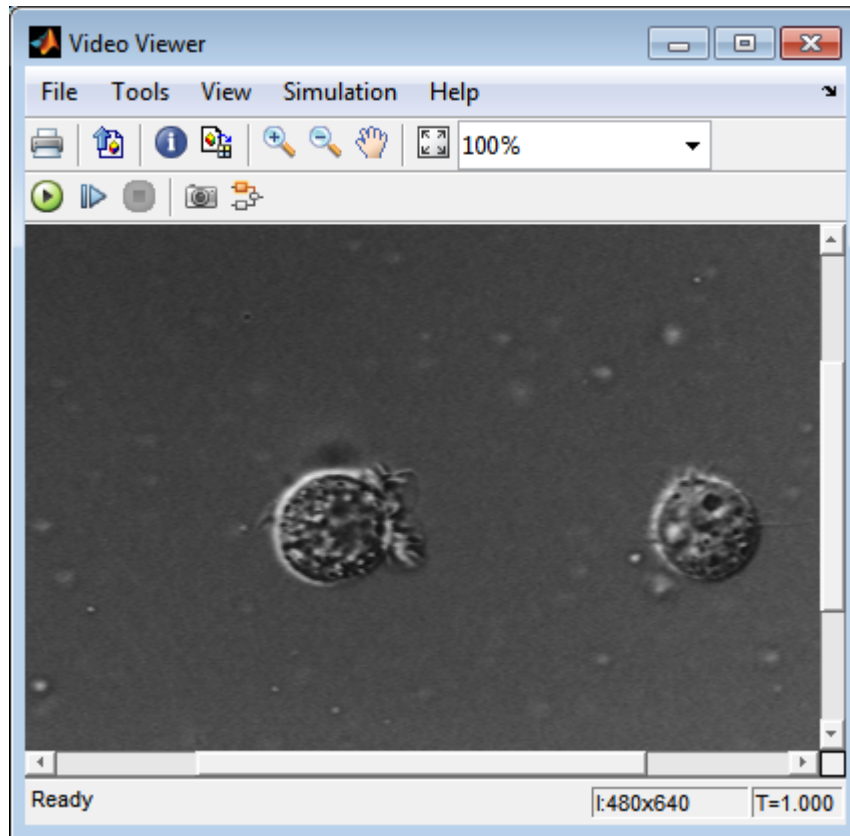
This example displays a sequence of images, which were saved in a folder, and then stored in a variable in the MATLAB workspace. At load time, this model executes the code from the “Batch Process Image Files” on page 2-6 example, which stores images in a workspace variable.

You can open the example model by typing

```
ex_display_sequence_of_images  
at the MATLAB command line.
```

- 1 The Video From Workspace block reads the files from the MATLAB workspace. The **Signal** parameter is set to the name of the variable for the stored images. For this example, it is set to `my_video`.
- 2 The Video Viewer block displays the sequence of images.
- 3 Run your model. You can view the image sequence in the Video Viewer window.





- 4 Because the Video From Workspace block's **Sample time** parameter is set to 1 and the **Stop time** parameter in the configuration parameters, is set to 10, the Video Viewer block displays 10 images before the simulation stops.

## Pre-loading Code

To find or modify the pre-loaded code, select **File > Model Properties > Model Properties**. Then select the **Callbacks** tab. For more details on how to set-up callbacks, see “Callbacks for Customized Model Behavior”.

### Configuration Parameters

You can locate the **Model Configuration Parameters** by selecting **Model Configuration Parameters** from the **Simulation** menu. For this example, the parameters on the **Solver** pane, are set as follows:

- **Stop time** = 10
- **Type** = Fixed-step
- **Solver** = Discrete (no continuous states)

## Partition Video Frames to Multiple Image Files

In this example, you use the To Multimedia File block, the Enabled Subsystem block, and a trigger signal, to save portions of one AVI file to three separate AVI files.

You can open the example model with the link below or by typing

`ex_vision_partition_video_frames_to_multiple_files`  
at the MATLAB command line.

- 1 Run your model.
- 2 The model saves the three output AVI files in your current folder.
- 3 View the resulting files by typing the following commands at the MATLAB command prompt:

```
implay output1.avi
implay output2.avi
implay output3.avi
```

- 4 Press the **Play** button.

For more information on the blocks used in this example, see the From Multimedia File, Insert Text, Enabled Subsystem, and To Multimedia File block reference pages.

### Setting Block Parameters for this Example

The block parameters in this example were modified from default values as follows:

Block	Parameter
<b>From Multimedia File</b>	<p>The From Multimedia File block imports an AVI file into the model.</p> <ul style="list-style-type: none"> <li>• Cleared <b>Inherit sample time from file</b> checkbox.</li> </ul>
<b>Insert Text</b>	<p>The example uses the Insert Text block to annotate the video stream with frame numbers. The block writes the frame number in green, in the upper-left corner of the output video stream.</p> <ul style="list-style-type: none"> <li>• <b>Text:</b> 'Frame %d'</li> <li>• <b>Color:</b> [0 1 0]</li> <li>• <b>Location:</b> [10 10]</li> </ul>

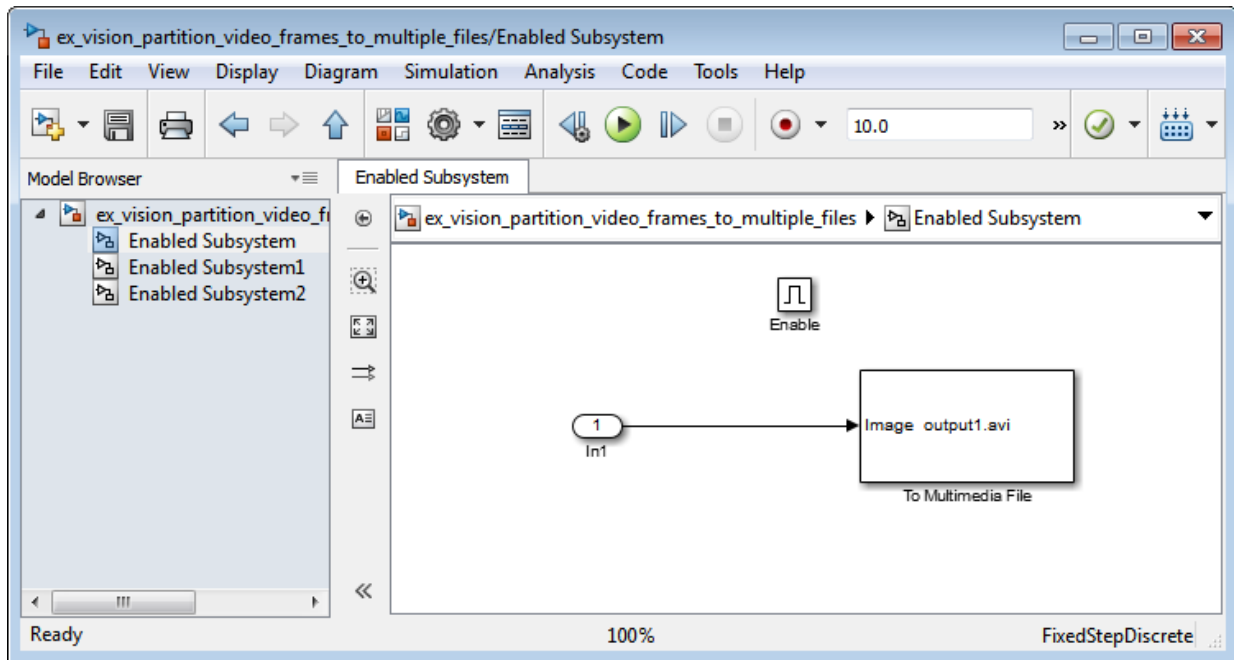
Block	Parameter
<b>To Multimedia File</b>	<p>The To Multimedia File blocks send the video stream to three separate AVI files. These block parameters were modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Output file name:</b> output1.avi, output2.avi, and output3.avi, respectively</li> <li>• <b>Write:</b> Video only</li> </ul>
<b>Counter</b>	<p>The Counter block counts the number of video frames. The example uses this information to specify which frames are sent to which file. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Number of bits:</b> 8</li> <li>• <b>Sample time:</b> 1/30</li> </ul>
<b>Bias</b>	<p>The bias block adds a bias to the input. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Bias:</b> 1</li> </ul>
<b>Compare to Constant</b>	<p>The Compare to Constant block sends frames 1 to 9 to the first AVI file. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Operator:</b> &lt;</li> <li>• <b>Constant value:</b> 10</li> </ul>
<b>Compare to Constant1</b> <b>Compare to Constant2</b>	<p>The Compare to Constant1 and Compare to Constant2 blocks send frames 10 to 19 to the second AVI file. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Operator:</b> &gt;=</li> <li>• <b>Constant value:</b> 10</li> </ul> <p>The Compare to Constant2 block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Operator:</b> &lt;</li> <li>• <b>Constant value:</b> 20</li> </ul>

Block	Parameter
<b>Compare to Constant3</b>	<p>The Compare to Constant3 block send frames 20 to 30 to the third AVI file. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Operator:</b> &gt;=</li> <li>• <b>Constant value:</b> 20</li> </ul>
<b>Compare to Constant4</b>	<p>The Compare to Constant4 block stopa the simulation when the video reaches frame 30. The block parameters are modified as follows:</p> <ul style="list-style-type: none"> <li>• <b>Operator:</b> ==</li> <li>• <b>Constant value:</b> 30</li> <li>• <b>Output data type mode:</b> boolean</li> </ul>

## Using the Enabled Subsystem Block

Each To Multimedia File block gets inserted into one Enabled Subsystem block, and connected to it's input. You can do this, by double-clicking the Enabled Subsystem blocks, then click-and-drag a To Multimedia File block into it.

Each enabled subsystem should look similar to the subsystem shown in the following figure.



### Configuration Parameters

You can locate the **Model Configuration Parameters** by selecting **Model Configuration Parameters** from the **Simulation** menu. For this example, the parameters on the **Solver** pane, are set as follows:

- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

## Combine Video and Audio Streams

In this example, you use the From Multimedia File blocks to import video and audio streams into a Simulink model. You then write the audio and video to a single file using the To Multimedia File block.

You can open the example model by typing

```
ex_combine_video_and_audio_streams  
on the MATLAB command line.
```

- 1 Run your model. The model creates a multimedia file called `output.avi` in your current folder.
- 2 Play the multimedia file using a media player. The original video file now has an audio component to it.

### Setting Up the Video Input Block

The From Multimedia File block imports a video file into the model. During import, the **Inherit sample time from file** check box is deselected, which enables the **Desired sample time** parameter. The other default parameters are accepted.

The From Multimedia File block used for the input video file inherits its sample time from the `vipmen.avi` file. For video signals, the sample time equals the frame period. The frame period is defined as  $1/(\text{frame rate})$ . Because the input video frame rate is 30 frames per second (fps), the block sets the frame period to  $1/30$  or `0.0333` seconds per frame.

### Setting Up the Audio Input Block

The From Multimedia File1 block imports an audio file into the model.

The **Samples per audio frame** parameter is set to `735`. This output audio frame size is calculated by dividing the frequency of the audio signal (22050 samples per second) by the frame rate (approximately 30 frames per second).

You must adjust the audio signal frame period to match the frame period of the video signal. The video frame period is `0.0333` seconds per frame. Because the frame period is also defined as the frame size divided by frequency, you can calculate the frame period of

the audio signal by dividing the frame size of the audio signal (735 samples per frame) by the frequency (22050 samples per second) to get 0.0333 seconds per frame.

$frame\ period = (frame\ size)/(frequency)$

$frame\ period = (735\ samples\ per\ frame)/(22050\ samples\ per\ second)$

$frame\ period = 0.0333\ seconds\ per\ frame$

Alternatively, you can verify that the frame period of the audio and video signals is the same using a Simulink Probe block.

### Setting Up the Output Block

The To Multimedia File block is used to output the audio and video signals to a single multimedia file. The **Video** and **audio** option is selected for the **Write** parameter and **One multidimensional signal** for the **Image signal** parameter. The other default parameters are accepted.

### Configuration Parameters

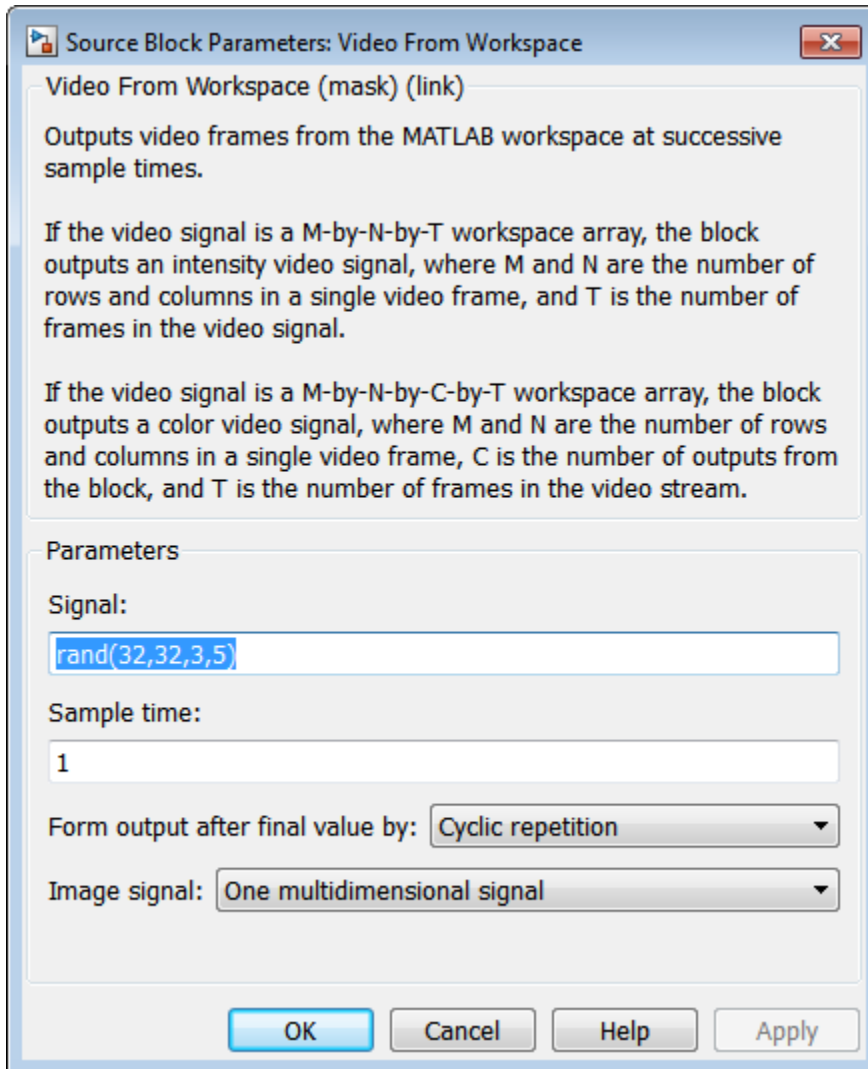
You can locate the Configuration Parameters by selecting **Model Configuration Parameters** from the **Simulation** menu. The parameters, on the **Solver** pane, are set as follows:

- **Stop time** = 10
- **Type** = Fixed-step
- **Solver** = Discrete (no continuous states)



## Import MATLAB Workspace Variables

You can import data from the MATLAB workspace using the Video From Workspace block, which is created specifically for this task.



Use the **Signal** parameter to specify the MATLAB workspace variable from which to read. For more information about how to use this block, see the Video From Workspace block reference page.

## Transmit Audio and Video Content Over Network

MATLAB and Simulink support network streaming via the Microsoft® MMS protocol (which is also known as the ASF, or advanced streaming format, protocol). This ability is supported on Windows operating systems. If you are using other operating systems, you can use UDP to transport your media streams. If you are using Simulink, use the To Multimedia File and From Multimedia File blocks. If you are using MATLAB, use the `VideoFileWriter` and the `VideoFileReader` System objects. It is possible to encode and view these streams with other applications.

In order to view an MMS stream generated by MATLAB, you should use Internet Explorer®, and provide the URL (e.g. "mms://127.0.0.1:81") to the stream which you wish to read. If you wish to create an MMS stream which can be viewed by MATLAB, download the Windows Media® Encoder or Microsoft Expression Encoder application, and configure it to produce a stream on a particular port (e.g. 81). Then, specify that URL in the **Filename** field of the From Multimedia File block or `VideoFileReader` System object™.

You cannot send and receive MMS streams from the same process. If you wish to send and receive, the sender or the receiver must be run in rapid accelerator mode or compiled as a separate application using Simulink Coder™.

If you run the “Transmit Audio and Video Over a Network” on page 2-19 example with `sendReceive` set to 'send', you can open up Internet Explorer and view the URL on which you have set up a server. By default, you should go to the following URL: `mms://127.0.0.1:80`. If you run this example with `sendReceive` set to 'receive', you will be able to view a MMS stream on the local computer on port 81. This implies that you will need to set up a stream on this port using software such as the Windows Media Encoder (which may be downloaded free of charge from Microsoft).

## Transmit Audio and Video Over a Network

This example shows how to specify parameters to transmit audio and video over a network.

Specify the `sendReceive` parameter to either 'send' to write the stream to the network or 'receive' to read the stream from the network.

```
sendReceive = 'send';  
url = 'mms://127.0.0.1:81';
```

```
filename = 'vipmen.avi';
```

Either send or receive the stream, as specified.

```
if strcmpi(sendReceive, 'send')
    % Create objects
    hSrc = vision.VideoFileReader(filename);
    hSnk = vision.VideoFileWriter;

    % Set parameters
    hSnk.FileFormat = 'WMV';
    hSnk.AudioInputPort = false;
    hSnk.Filename = url;

    % Run loop. Ctrl-C to exit
    while true
        data = step(hSrc);
        step(hSnk, data);
    end
else
    % Create objects
    hSrc = vision.VideoFileReader;
    hSnk = vision.DeployableVideoPlayer;

    % Set parameters
    hSrc.Filename = url;

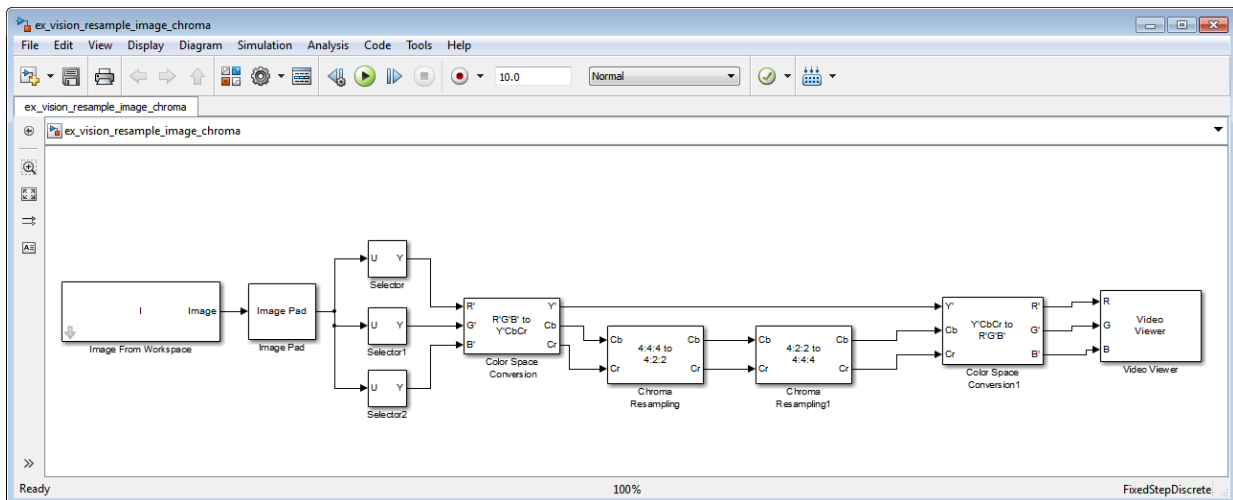
    % Run loop. Ctrl-C to exit
    while true
        data = step(hSrc);
        step(hSnk, data);
    end
end
```

## Resample Image Chroma

In this example, you use the Chroma Resampling block to downsample the Cb and Cr components of an image. The Y'CbCr color space separates the luma (Y') component of an image from the chroma (Cb and Cr) components. Luma and chroma, which are calculated using gamma corrected R, G, and B (R', G', B') signals, are different quantities than the CIE chrominance and luminance. The human eye is more sensitive to changes in luma than to changes in chroma. Therefore, you can reduce the bandwidth required for transmission or storage of a signal by removing some of the color information. For this reason, this color space is often used for digital encoding and transmission applications.

You can open the example model by typing

```
ex_vision_resample_image_chroma
on the MATLAB command line.
```



- 1 Define an RGB image in the MATLAB workspace. To do so, at the MATLAB command prompt, type:

```
I= imread('autumn.tif');
```

This command reads in an RGB image from a TIF file. The image I is a 206-by-345-by-3 array of 8-bit unsigned integer values. Each plane of this array represents the red, green, or blue color values of the image.

- 2 To view the image this array represents, at the MATLAB command prompt, type:

```
imshow(I)
```

- 3 Configure Simulink to display signal dimensions next to each signal line. Select **Display > Signals & Ports > Signal Dimensions**.
- 4 Run your model. The recovered image appears in the Video Viewer window. The Chroma Resampling block has downsampled the Cb and Cr components of an image.
- 5 Examine the signal dimensions in your model. The Chroma Resampling block downsamples the Cb and Cr components of the image from 206-by-346 matrices to 206-by-173 matrices. These matrices require less bandwidth for transmission while still communicating the information necessary to recover the image after it is transmitted.

## Setting Block Parameters for This Example

The block parameters in this example are modified from default values as follows:

Block	Parameter
Image from Workspace	Import your image from the MATLAB workspace. Set the <b>Value</b> parameter to I.
Image Pad	<p>Change dimensions of the input I array from 206-by-345-by-3 to 206-by-346-by-3. You are changing these dimensions because the Chroma Resampling block requires that the dimensions of the input be divisible by 2. Set the block parameters as follows:</p> <ul style="list-style-type: none"> <li>• <b>Method</b> = Symmetric</li> <li>• <b>Add columns to</b> = Right</li> <li>• <b>Number of added columns</b> = 1</li> <li>• <b>Add row to</b> = No padding</li> </ul> <p>The Image Pad block adds one column to the right of each plane of the array by repeating its border values. This padding minimizes the effect of the pixels outside the image on the processing of the image.</p> <hr/> <p><b>Note</b> When you process video streams, be aware that it is computationally expensive to pad every video frame. You should</p>

Block	Parameter
	change the dimensions of the video stream before you process it with Computer Vision System Toolbox blocks.
Selector, Selector1, Selector2	<p>Separate the individual color planes from the main signal. Such separation simplifies the color space conversion section of the model. Set the Selector block parameters as follows:</p> <p><b>Selector1</b></p> <ul style="list-style-type: none"> <li>• <b>Number of input dimensions</b> = 3</li> <li>• <b>Index 1</b> = Select all</li> <li>• <b>Index 2</b> = Select all</li> <li>• <b>Index 3</b> = Index vector (dialog) and <b>Index</b> = 1</li> </ul> <p><b>Selector2</b></p> <ul style="list-style-type: none"> <li>• <b>Number of input dimensions</b> = 3</li> <li>• <b>Index 1</b> = Select all</li> <li>• <b>Index 2</b> = Select all</li> <li>• <b>Index 3</b> = Index vector (dialog) and <b>Index</b> = 2</li> </ul> <p><b>Selector2</b></p> <ul style="list-style-type: none"> <li>• <b>Number of input dimensions</b> = 3</li> <li>• <b>Index 1</b> = Select all</li> <li>• <b>Index 2</b> = Select all</li> <li>• <b>Index 3</b> = Index vector (dialog) and <b>Index</b> = 3</li> </ul>
Color Space Conversion	Convert the input values from the R'G'B' color space to the Y'CbCr color space. The prime symbol indicates a gamma corrected signal. Set the <b>Image signal</b> parameter to <b>Separate color signals</b> .
Chroma Resampling	Downsample the chroma components of the image from the 4:4:4 format to the 4:2:2 format. Use the default parameters. The dimensions of the output of the Chroma Resampling block are smaller than the dimensions of the input. Therefore, the output signal requires less bandwidth for transmission.

Block	Parameter
Chroma Resampling1	Upsample the chroma components of the image from the 4:2:2 format to the 4:4:4 format. Set the <b>Resampling</b> parameter to 4:2:2 to 4:4:4.
Color Space Conversion1	Convert the input values from the Y'CbCr color space to the R'G'B' color space. Set the block parameters as follows: <ul style="list-style-type: none"><li>• <b>Conversion</b> = Y'CbCr to R'G'B'</li><li>• <b>Image signal</b> = Separate color signals</li></ul>
Video Viewer	Display the recovered image. Select <b>File&gt;Image signal</b> to set <b>Image signal</b> to Separate color signals.

### Configuration Parameters

Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)



## Convert Intensity to Binary Images

Binary images contain Boolean pixel values that are either 0 or 1. Pixels with the value 0 are displayed as black; pixels with the value 1 are displayed as white. Intensity images contain pixel values that range between the minimum and maximum values supported by their data type. Binary images can contain only 0s and 1s, but they are not binary images unless their data type is Boolean. “Thresholding Intensity Images Using Relational Operators” on page 2-25

### Thresholding Intensity Images Using Relational Operators

You can use the Relational Operator block to perform a thresholding operation that converts your intensity image to a binary image. This example shows you how to accomplish this task.

You can open the example model by typing

```
ex_vision_thresholding_intensity
```

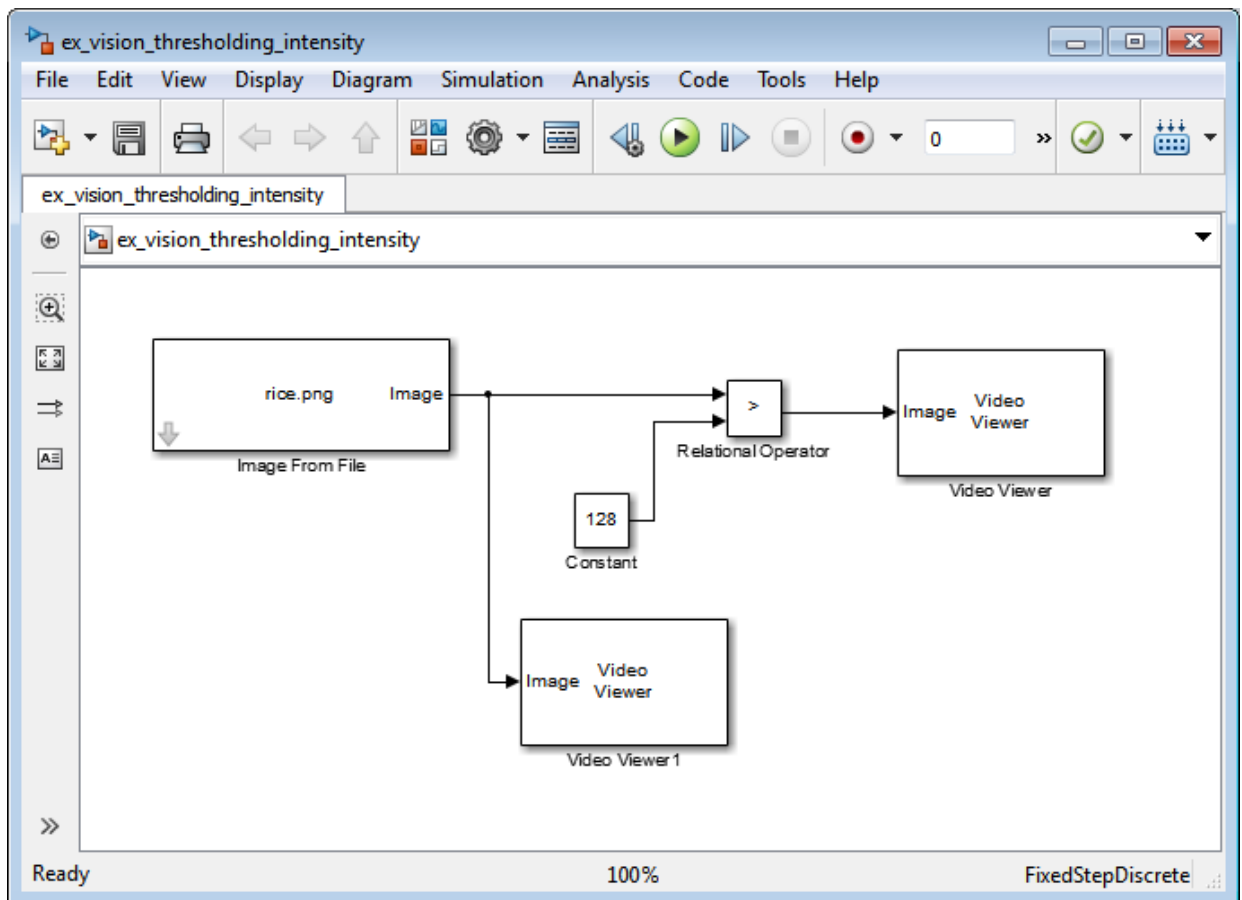
on the MATLAB command line.

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Video Viewer	Computer Vision System Toolbox > Sinks	2
Relational Operator	Simulink > Logic and Bit Operations	1
Constant	Simulink > Sources	1

- 2 Use the Image from File block to import your image. In this example the image file is a 256-by-256 matrix of 8-bit unsigned integer values that range from 0 to 255. Set the **File name** parameter to `rice.png`
- 3 Use the Video Viewer1 block to view the original intensity image. Accept the default parameters.
- 4 Use the Constant block to define a threshold value for the Relational Operator block. Since the pixel values range from 0 to 255, set the **Constant value** parameter to 128. This value is image dependent.

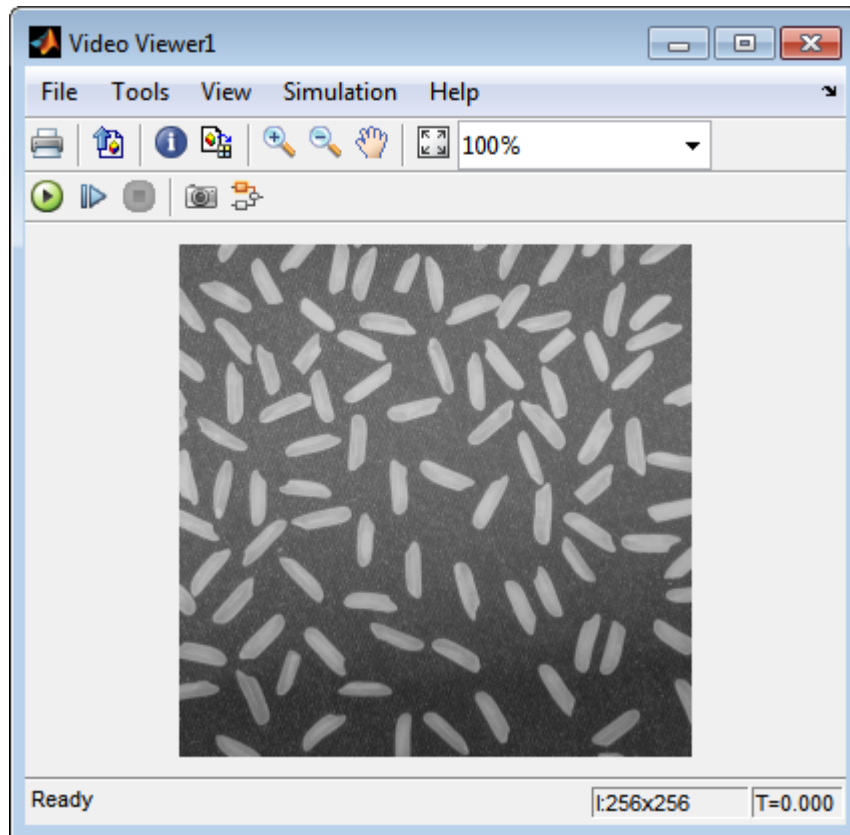
- 5 Use the Relational Operator block to perform a thresholding operation that converts your intensity image to a binary image. Set the **Relational Operator** parameter to  $>$ . If the input to the Relational Operator block is greater than 128, its output is a Boolean 1; otherwise, its output is a Boolean 0.
- 6 Use the Video Viewer block to view the binary image. Accept the default parameters.
- 7 Connect the blocks as shown in the following figure.



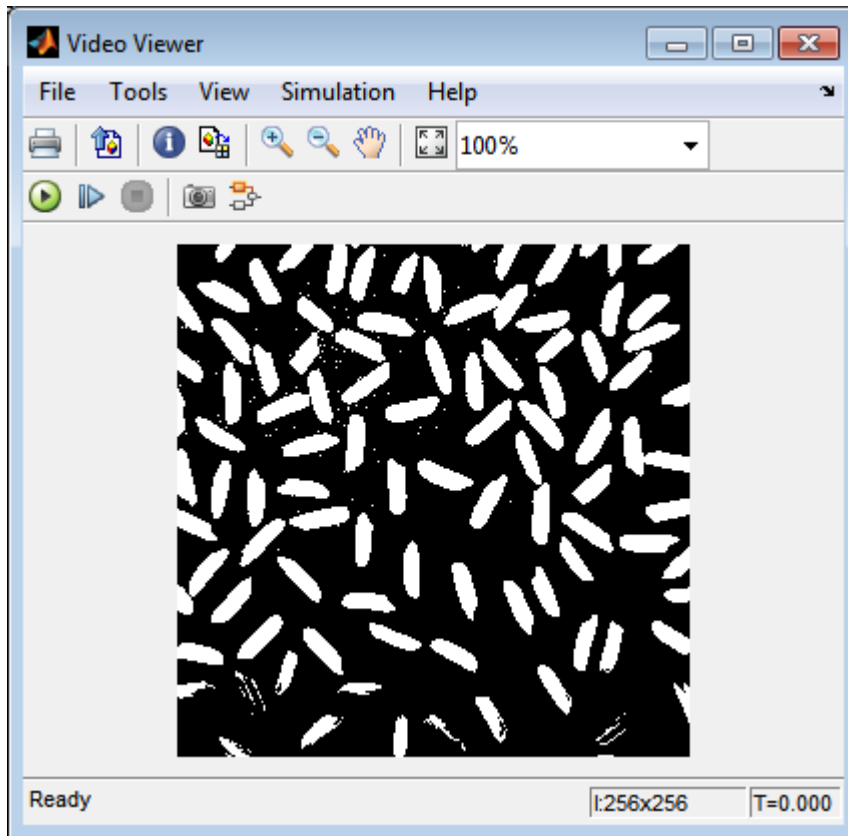
- 8 Set the configuration parameters. Open the Configuration dialog box by selecting **Simulation > Model Configuration Parameters** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 9 Run your model.

The original intensity image appears in the Video Viewer1 window.



The binary image appears in the Video Viewer window.



---

**Note:** A single threshold value was unable to effectively threshold this image due to its uneven lighting. For information on how to address this problem, see “Correct Nonuniform Illumination”.

---

You have used the Relational Operator block to convert an intensity image to a binary image. For more information about this block, see the Relational Operator block reference page in the Simulink documentation. For additional information, see “Converting Between Image Types” in the Image Processing Toolbox documentation.

## Thresholding Intensity Images Using the Autothreshold Block

In the previous topic, you used the Relational Operator block to convert an intensity image into a binary image. In this topic, you use the Autothreshold block to accomplish the same task. Use the Autothreshold block when lighting conditions vary and the threshold needs to change for each video frame.

---

**Note:** Running this example requires a DSP System Toolbox™ license.

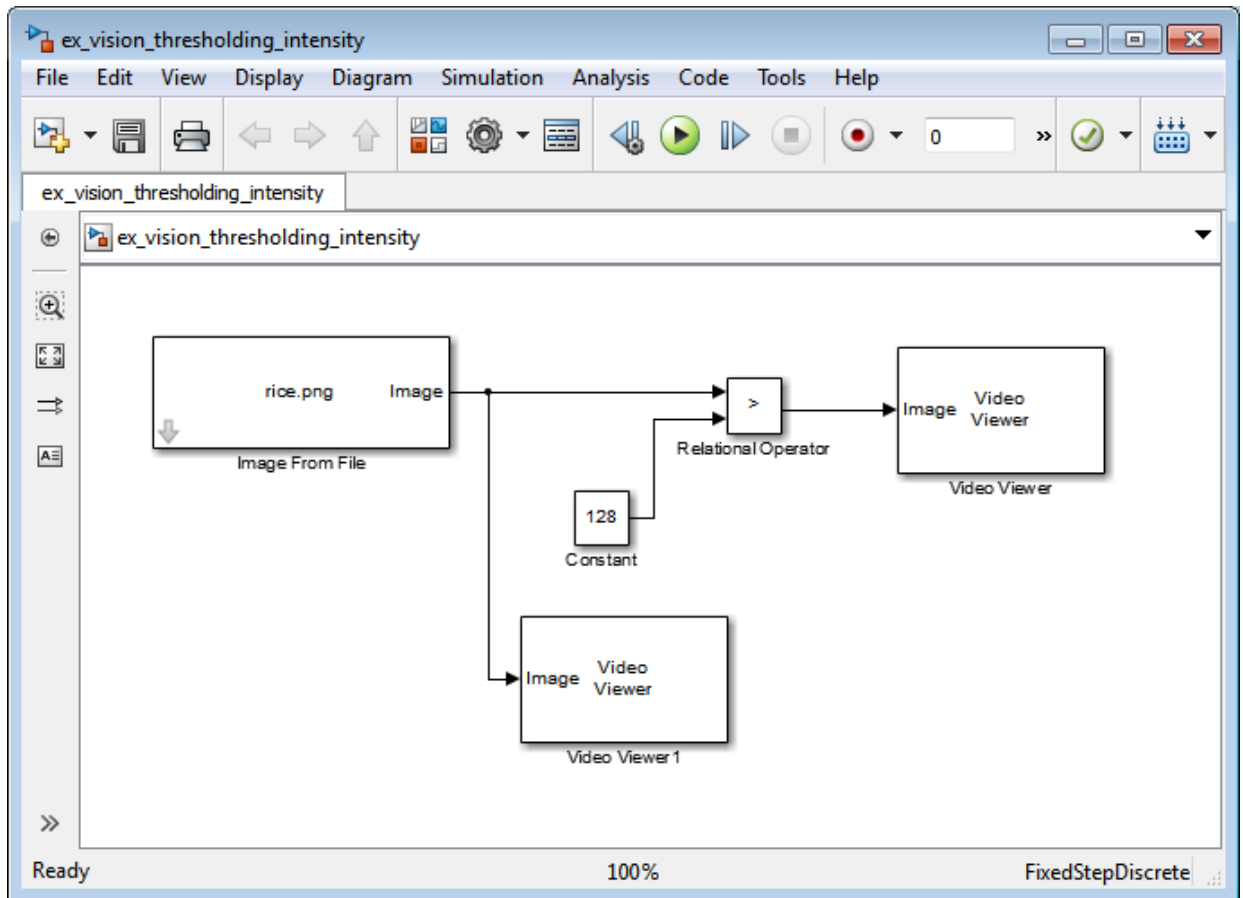
---

`ex_vision_autothreshold`

- 1 If the model you created in “Thresholding Intensity Images Using Relational Operators” on page 2-25 is not open on your desktop, you can open the model by typing

`ex_vision_thresholding_intensity`

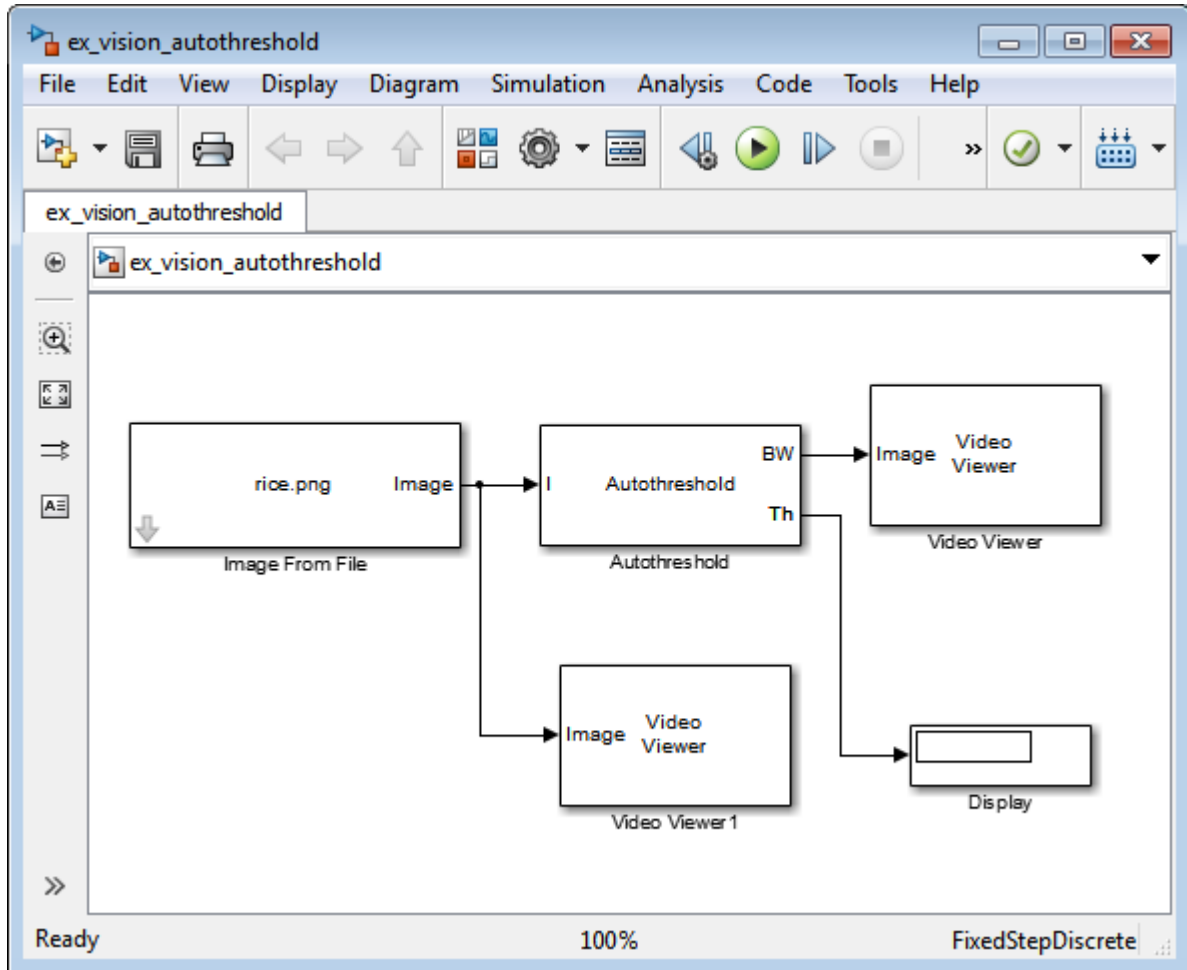
at the MATLAB command prompt.



- 2 Use the Image from File block to import your image. In this example the image file is a 256-by-256 matrix of 8-bit unsigned integer values that range from 0 to 255. Set the **File name** parameter to `rice.png`
- 3 Delete the Constant and the Relational Operator blocks in this model.
- 4 Add an Autothreshold block from the Conversions library of the Computer Vision System Toolbox into your model.
- 5 Use the Autothreshold block to perform a thresholding operation that converts your intensity image to a binary image. Select the **Output threshold** check box. This block outputs the calculated threshold value at the **Th** port.

- 6 Add a Display block from the Sinks library of the DSP System Toolbox library. Connect the Display block to the **Th** output port of the Autothreshold block.

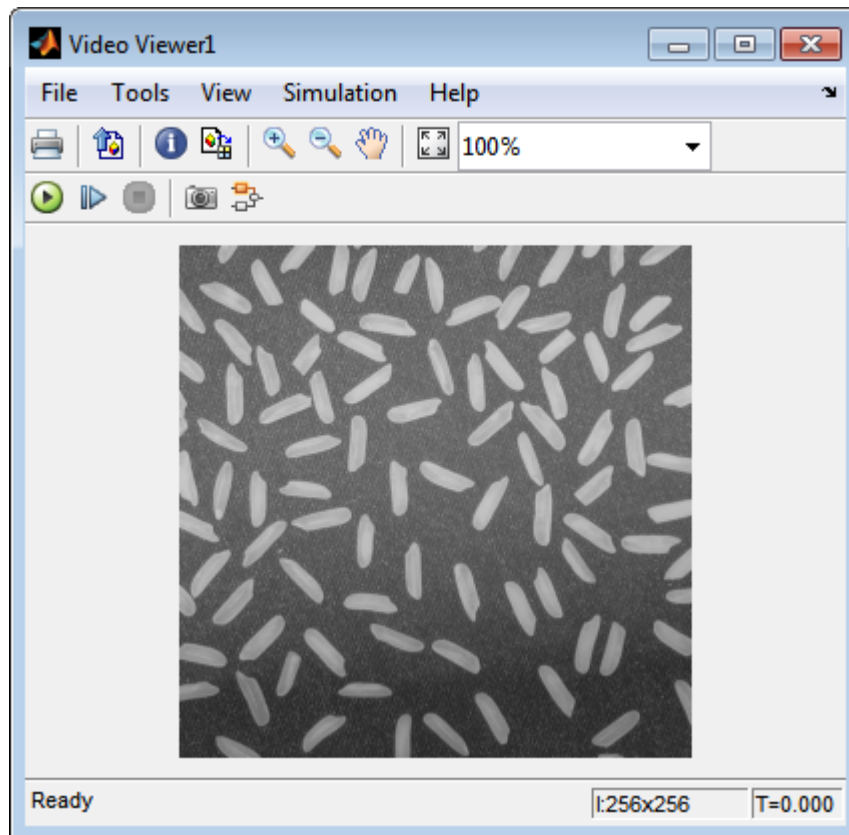
Your model should look similar to the following figure:



- 7 Double-click the Image From File block. On the **Data Types** pane, set the **Output data type** parameter to double.

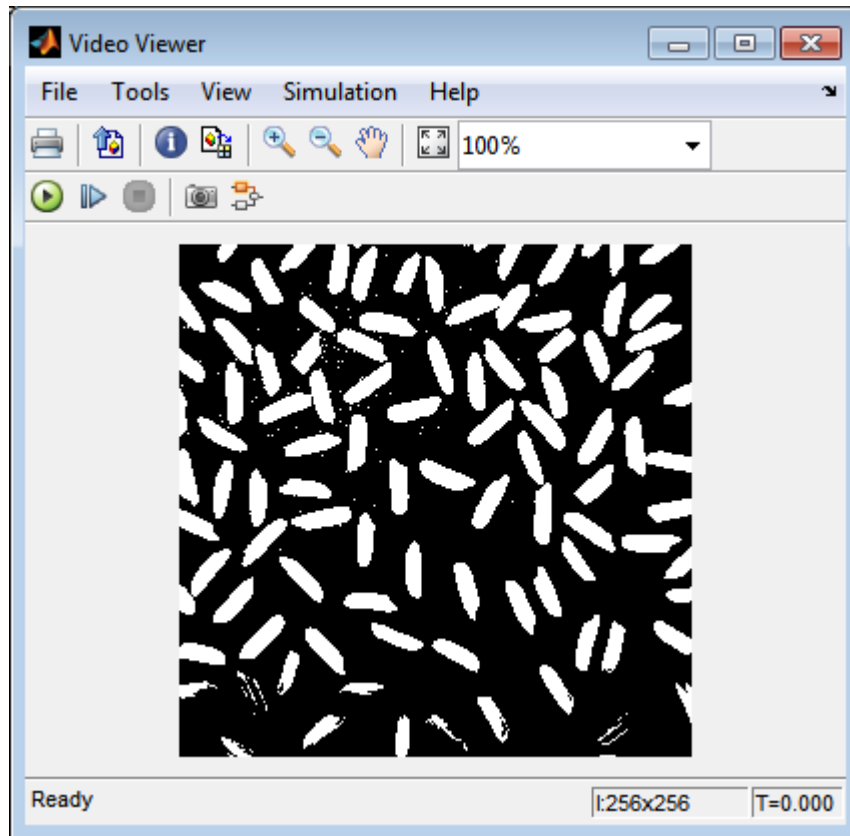
- 8 If you have not already done so, set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 9 Run the model.

The original intensity image appears in the Video Viewer1 window.

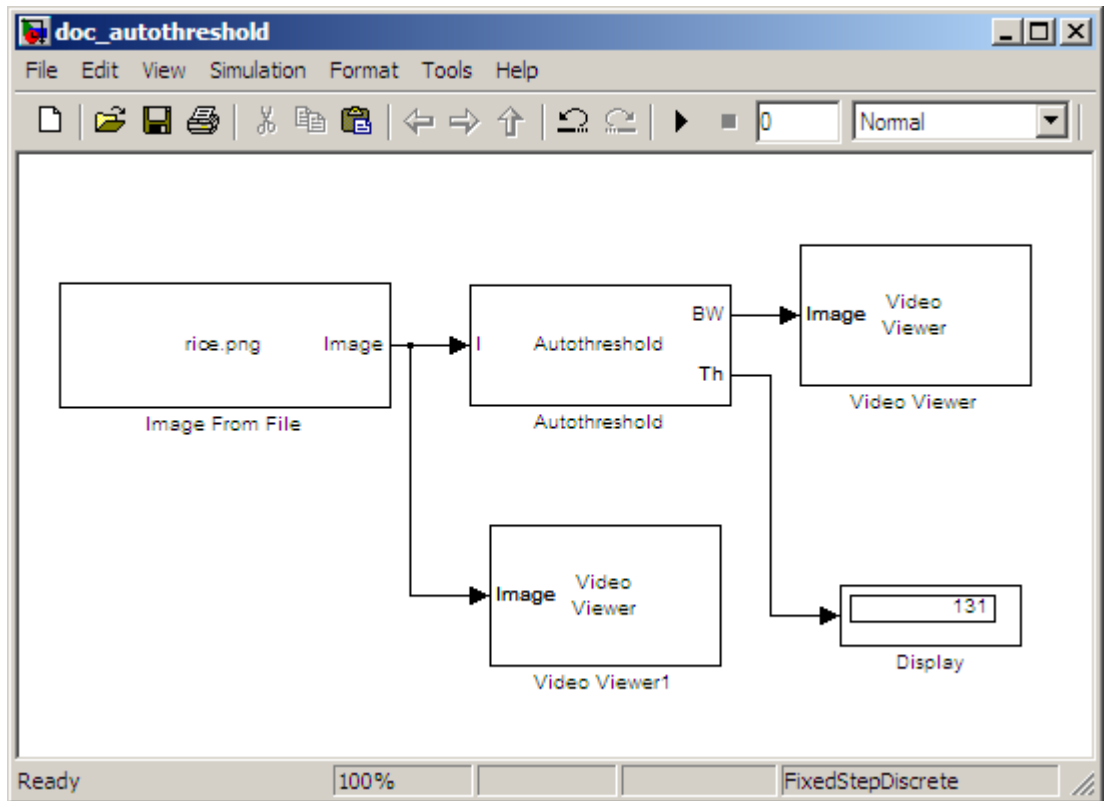


The binary image appears in the Video Viewer window.





In the model window, the Display block shows the threshold value, calculated by the Autothreshold block, that separated the rice grains from the background.



You have used the Autothreshold block to convert an intensity image to a binary image. For more information about this block, see the Autothreshold block reference page in the *Computer Vision System Toolbox Reference*. To open an example model that uses this block, type `vipstaples` at the MATLAB command prompt.

## Convert R'G'B' to Intensity Images

The Color Space Conversion block enables you to convert color information from the R'G'B' color space to the Y'CbCr color space and from the Y'CbCr color space to the R'G'B' color space as specified by Recommendation ITU-R BT.601-5. This block can also be used to convert from the R'G'B' color space to intensity. The prime notation indicates that the signals are gamma corrected.

Some image processing algorithms are customized for intensity images. If you want to use one of these algorithms, you must first convert your image to intensity. In this topic, you learn how to use the Color Space Conversion block to accomplish this task. You can use this procedure to convert any R'G'B' image to an intensity image:

`ex_vision_convert_rgb`

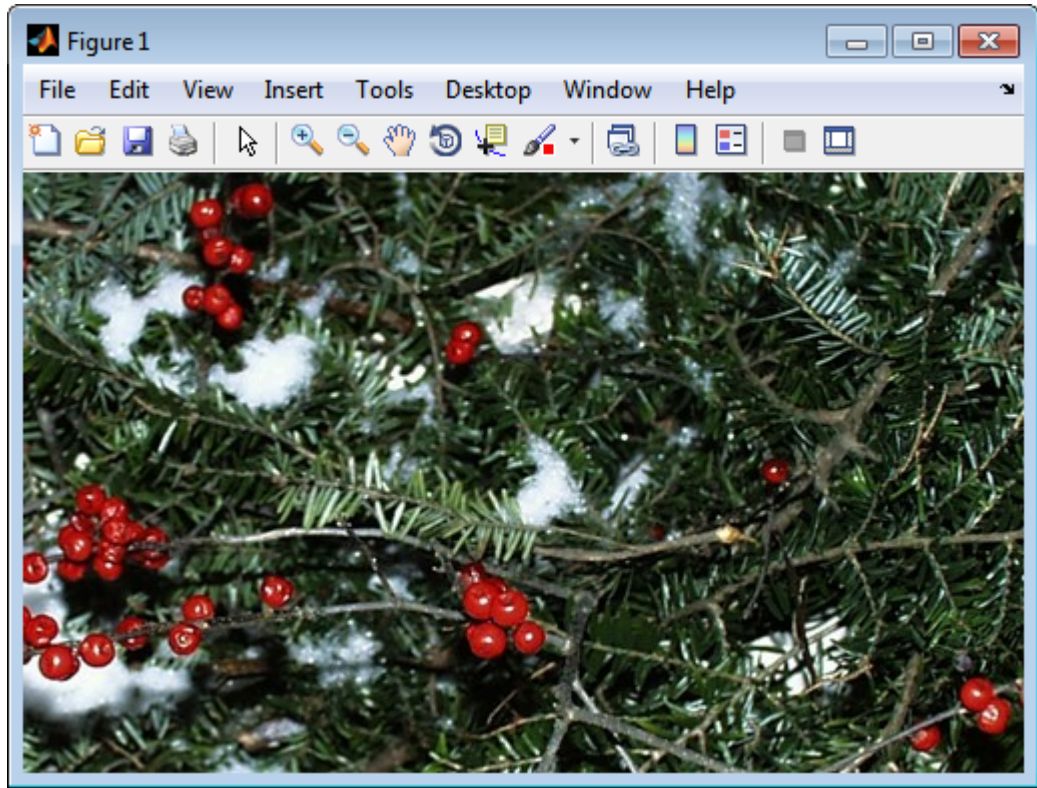
- 1 Define an R'G'B' image in the MATLAB workspace. To read in an R'G'B' image from a JPG file, at the MATLAB command prompt, type

```
I= imread('greens.jpg');
```

I is a 300-by-500-by-3 array of 8-bit unsigned integer values. Each plane of this array represents the red, green, or blue color values of the image.

- 2 To view the image this matrix represents, at the MATLAB command prompt, type

```
imshow(I)
```

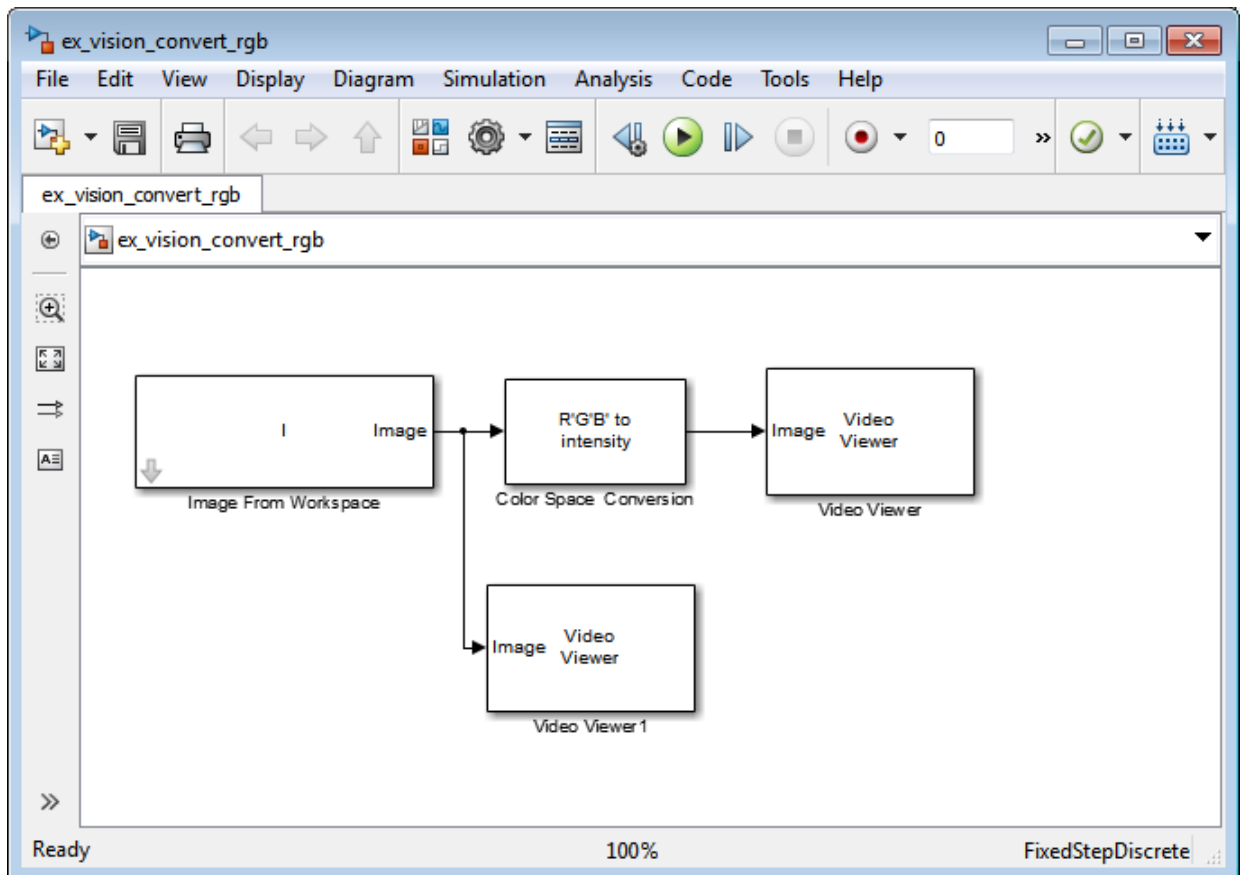


- 3 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From Workspace	Computer Vision System Toolbox > Sources	1
Color Space Conversion	Computer Vision System Toolbox > Conversions	1
Video Viewer	Computer Vision System Toolbox > Sinks	2

- 4 Use the Image from Workspace block to import your image from the MATLAB workspace. Set the **Value** parameter to **I**.

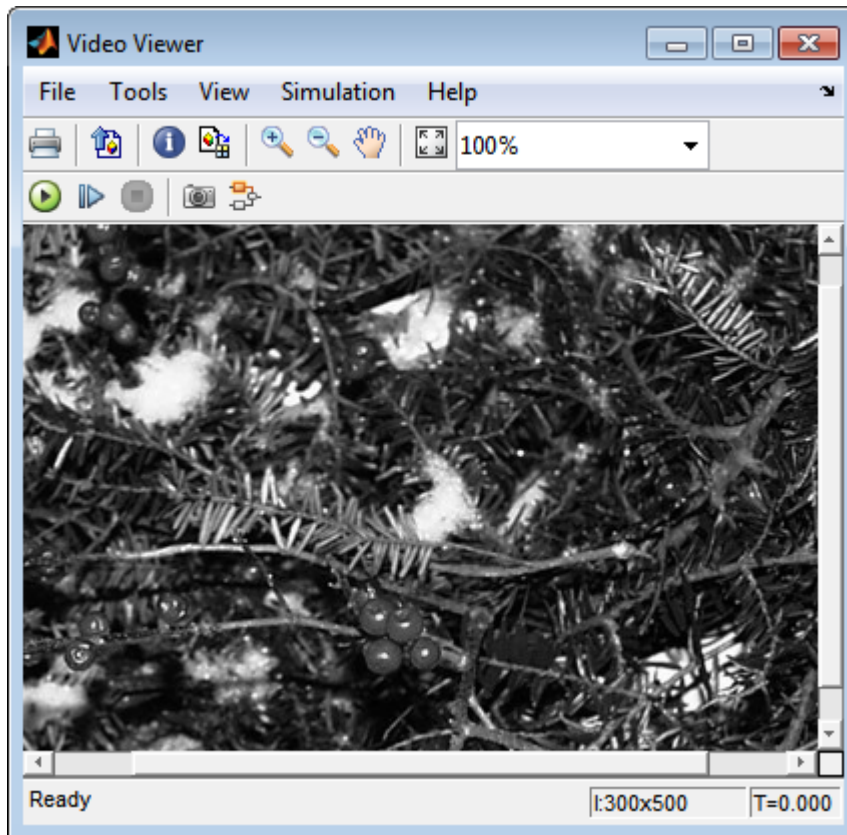
- 5 Use the Color Space Conversion block to convert the input values from the R'G'B' color space to intensity. Set the **Conversion** parameter to R'G'B' to intensity.
- 6 View the modified image using the Video Viewer block. View the original image using the Video Viewer1 block. Accept the default parameters.
- 7 Connect the blocks so that your model is similar to the following figure.



- 8 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0

- **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 9 Run your model.

The image displayed in the Video Viewer window is the intensity version of the greens .jpg image.

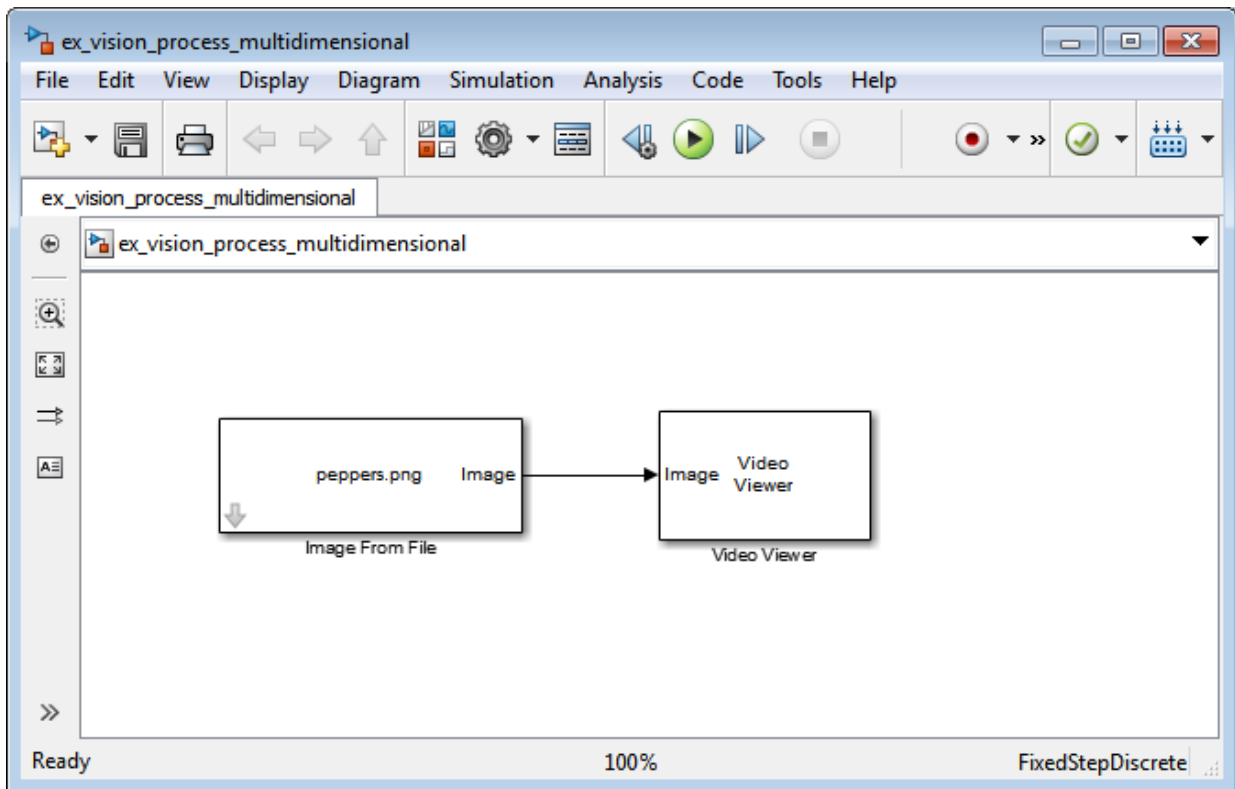


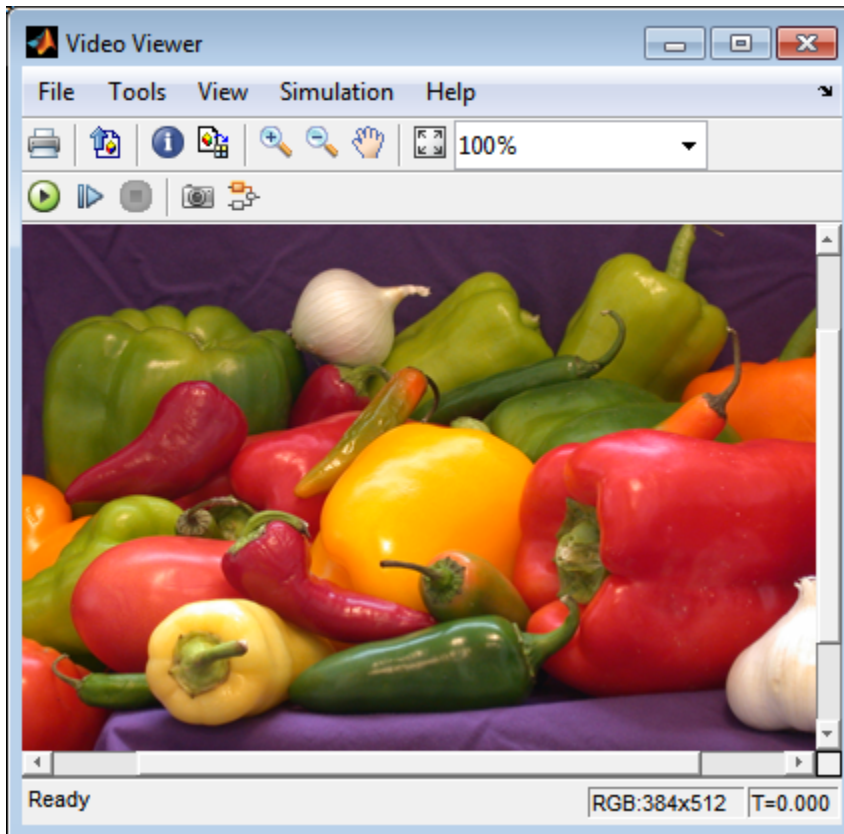
In this topic, you used the Color Space Conversion block to convert color information from the R'G'B' color space to intensity. For more information on this block, see the Color Space Conversion block reference page.

## Process Multidimensional Color Video Signals

The Computer Vision System Toolbox software enables you to work with color images and video signals as multidimensional arrays. For example, the following model passes a color image from a source block to a sink block using a 384-by-512-by-3 array.

`ex_vision_process_multidimensional`





You can choose to process the image as a multidimensional array by setting the **Image signal** parameter to One multidimensional signal in the Image From File block dialog box.

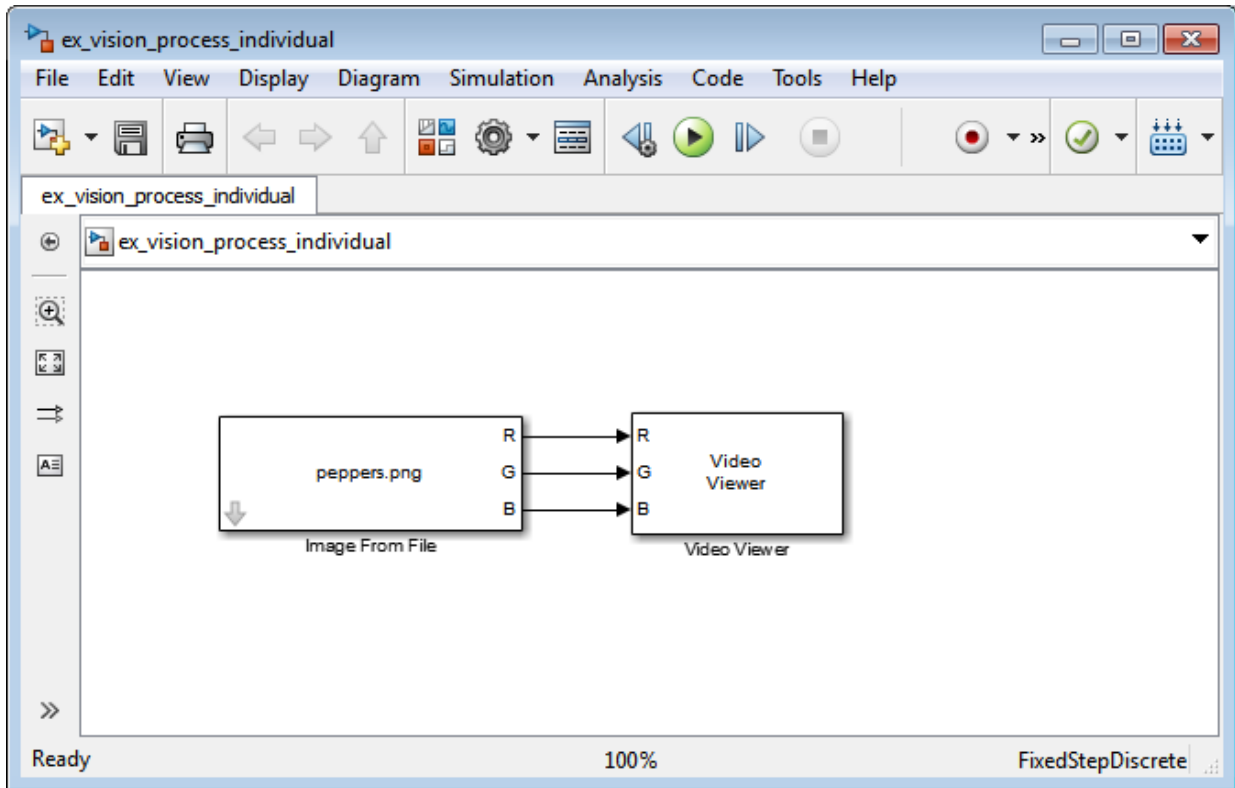
The blocks that support multidimensional arrays meet at least one of the following criteria:

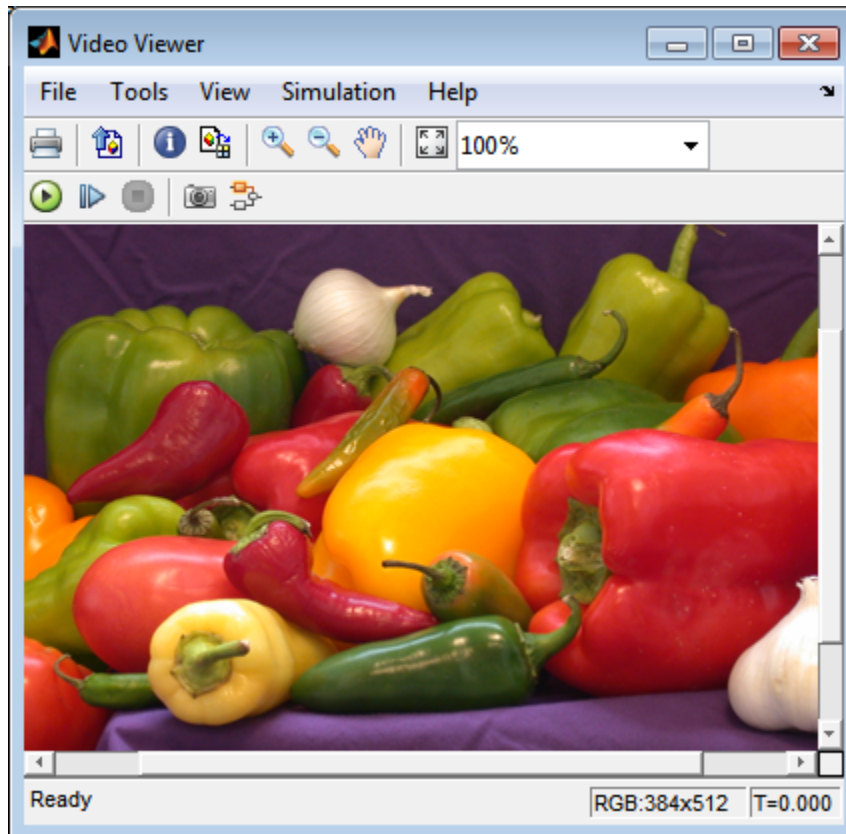
- They have the **Image signal** parameter on their block mask.
- They have a note in their block reference pages that says, “This block supports intensity and color images on its ports.”
- Their input and output ports are labeled “Image”.



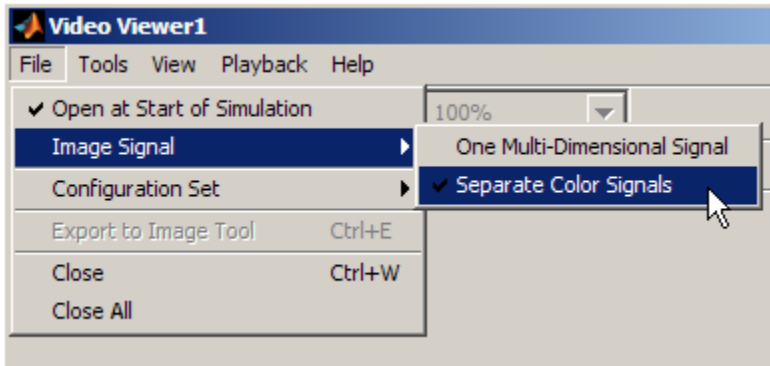
You can also choose to work with the individual color planes of images or video signals. For example, the following model passes a color image from a source block to a sink block using three separate color planes.

```
ex_vision_process_individual
```





To process the individual color planes of an image or video signal, set the **Image signal** parameter to **Separate color signals** in both the Image From File and Video Viewer block dialog boxes.



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**Note:** The ability to output separate color signals is a legacy option. It is recommend that you use multidimensional signals to represent color data.

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If you are working with a block that only outputs multidimensional arrays, you can use the Selector block to separate the color planes. For an example of this process, see Measure an Angle Between Lines. If you are working with a block that only accepts multidimensional arrays, you can use the Matrix Concatenation block to create a multidimensional array. For an example of this process, see Find the Histogram of an Image.

## Video Formats

Video data is a series of images over time. Video in binary or intensity format is a series of single images. Video in RGB format is a series of matrices grouped into sets of three, where each matrix represents an R, G, or B plane.

### Defining Intensity and Color

Video data is a series of images over time. Video in binary or intensity format is a series of single images. Video in RGB format is a series of matrices grouped into sets of three, where each matrix represents an R, G, or B plane.

The values in a binary, intensity, or RGB image can be different data types. The data type of the image values determines which values correspond to black and white as well as the absence or saturation of color. The following table summarizes the interpretation of the upper and lower bound of each data type. To view the data types of the signals at each port, from the **Display** menu, point to **Signals & Ports**, and select **Port Data Types**.

Data Type	Black or Absence of Color	White or Saturation of Color
Fixed point	Minimum data type value	Maximum data type value
Floating point	0	1

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**Note** The Computer Vision System Toolbox software considers any data type other than double-precision floating point and single-precision floating point to be fixed point.

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For example, for an intensity image whose image values are 8-bit unsigned integers, 0 is black and 255 is white. For an intensity image whose image values are double-precision floating point, 0 is black and 1 is white. For an intensity image whose image values are 16-bit signed integers, -32768 is black and 32767 is white.

For an RGB image whose image values are 8-bit unsigned integers, 0 0 0 is black, 255 255 255 is white, 255 0 0 is red, 0 255 0 is green, and 0 0 255 is blue. For an RGB image whose image values are double-precision floating point, 0 0 0 is black, 1 1 1 is white, 1 0 0 is red, 0 1 0 is green, and 0 0 1 is blue. For an RGB image whose image values are 16-bit signed integers, -32768 -32768 -32768 is black, 32767 32767 32767 is white, 32767 -32768 -32768 is red, -32768 32767 -32768 is green, and -32768 -32768 32767 is blue.

## Video Data Stored in Column-Major Format

The MATLAB technical computing software and Computer Vision System Toolbox blocks use column-major data organization. The blocks' data buffers store data elements from the first column first, then data elements from the second column second, and so on through the last column.

If you have imported an image or a video stream into the MATLAB workspace using a function from the MATLAB environment or the Image Processing Toolbox, the Computer Vision System Toolbox blocks will display this image or video stream correctly. If you have written your own function or code to import images into the MATLAB environment, you must take the column-major convention into account.

# Image Formats

In the Computer Vision System Toolbox software, images are real-valued ordered sets of color or intensity data. The blocks interpret input matrices as images, where each element of the matrix corresponds to a single pixel in the displayed image. Images can be binary, intensity (grayscale), or RGB. This section explains how to represent these types of images.

## Binary Images

Binary images are represented by a Boolean matrix of 0s and 1s, which correspond to black and white pixels, respectively.

For more information, see “Binary Images” in the Image Processing Toolbox documentation.

## Intensity Images

Intensity images are represented by a matrix of intensity values. While intensity images are not stored with colormaps, you can use a gray colormap to display them.

For more information, see “Grayscale Images” in the Image Processing Toolbox documentation.

## RGB Images

RGB images are also known as a true-color images. With Computer Vision System Toolbox blocks, these images are represented by an array, where the first plane represents the red pixel intensities, the second plane represents the green pixel intensities, and the third plane represents the blue pixel intensities. In the Computer Vision System Toolbox software, you can pass RGB images between blocks as three separate color planes or as one multidimensional array.

For more information, see “Truecolor Images” in the Image Processing Toolbox documentation.

# Display and Graphics

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- “Display, Stream, and Preview Videos” on page 3-2
- “Annotate Video Files with Frame Numbers” on page 3-4
- “Draw Shapes and Lines” on page 3-7

# Display, Stream, and Preview Videos

### In this section...

“View Streaming Video in MATLAB” on page 3-2

“Preview Video in MATLAB” on page 3-2

“View Video in Simulink” on page 3-2

## View Streaming Video in MATLAB

### Basic Video Streaming

Use the video player `vision.VideoPlayer` System object when you require a simple video display in MATLAB for streaming video.

### Code Generation Supported Video Streaming Object

Use the deployable video player `vision.DeployableVideoPlayer` System object as a basic display viewer designed for optimal performance. This object supports code generation on all platforms.

## Preview Video in MATLAB

Use the Image Processing Toolbox `implay` function to view and represent videos as variables in the MATLAB workspace. It is a full featured video player with toolbar controls. The `implay` player enables you to view videos directly from files without having to load all the video data into memory at once.

You can open several instances of the `implay` function simultaneously to view multiple video data sources at once. You can also dock these `implay` players in the MATLAB desktop. Use the figure arrangement buttons in the upper-right corner of the Sinks window to control the placement of the docked players.

## View Video in Simulink

### Code Generation Supported Video Streaming Block

Use the To Video Display block in your Simulink model as a simple display viewer designed for optimal performance. This block supports code generation for the Windows platform.



### Simulation Control and Video Analysis Block


Use the Video Viewer block when you require a wired-in video display with simulation controls in your Simulink model. The Video Viewer block provides simulation control buttons directly from the player interface. The block integrates play, pause, and step features while running the model and also provides video analysis tools such as pixel region viewer.

### View Video Signals Without Adding Blocks

The `implay` function enables you to view video signals in Simulink models without adding blocks to your model. You can open several instances of the `implay` player simultaneously to view multiple video data sources at once. You can also dock these players in the MATLAB desktop. Use the figure arrangement buttons in the upper-right corner of the Sinks window to control the placement of the docked players.

Set Simulink simulation mode to `Normal` to use `implay`. `implay` does not work when you use “Accelerating Simulink Models”.

#### Use `implay` to view a Simulink signal:

- 1 Open a Simulink model.
- 2 Open an `implay` player by typing `implay` on the MATLAB command line.
- 3 Run the Simulink model.
- 4 Select the signal line you want to view.
- 5 On the `implay` toolbar, select **File > Connect to Simulink Signal** or click the  icon.

The video appears in the player window.

- 6 You can use multiple `implay` players to display different Simulink signals.

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**Note:** During code generation, the Simulink Coder does not generate code for the `implay` player.

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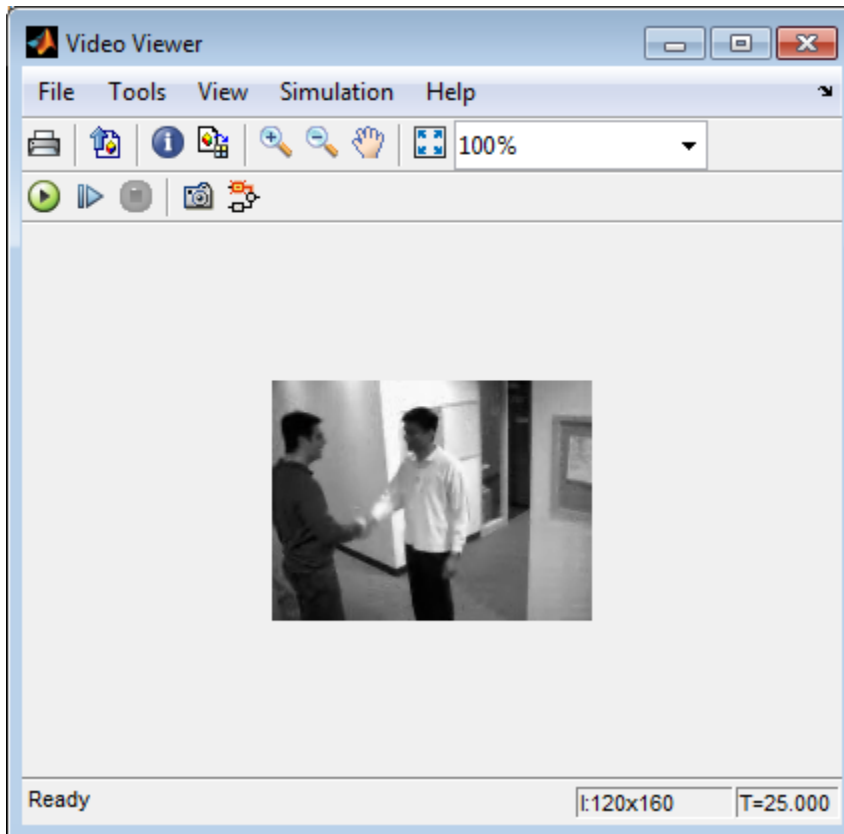
# Annotate Video Files with Frame Numbers

You can use the `vision.TextInserter` System object in MATLAB, or the Insert Text block in a Simulink model, to overlay text on video streams. In this Simulink model example, you add a running count of the number of video frames to a video using the Insert Text block. The model contains the From Multimedia File block to import the video into the Simulink model, a Frame Counter block to count the number of frames in the input video, and two Video Viewer blocks to view the original and annotated videos.

You can open the example model by typing

`ex_vision_annotate_video_file_with_frame_numbers`  
on the MATLAB command line.

- 1 Run your model.
- 2 The model displays the original and annotated videos.



## Color Formatting

For this example, the color format for the video was set to *Intensity*, and therefore the color value for the text was set to a scaled value. If instead, you set the color format to *RGB*, then the text value must satisfy this format, and requires a 3-element vector.

## Inserting Text

Use the Insert Text block to annotate the video stream with a running frame count. Set the block parameters as follows:

- **Main** pane, **Text** = ['Frame count' sprintf('\n') 'Source frame: %d']

- **Main** pane, **Color value** = 1
- **Main** pane, **Location [x y]** = [2 85]
- **Font** pane, **Font face** = LucindaTypewriterRegular

By setting the **Text** parameter to [ 'Frame count' sprintf('\n') 'Source frame: %d' ], you are asking the block to print **Frame count** on one line and the **Source frame**: on a new line. Because you specified %d, an ANSI C printf-style format specification, the **Variables** port appears on the block. The block takes the port input in decimal form and substitutes this input for the %d in the string. You used the **Location [x y]** parameter to specify where to print the text. In this case, the location is 85 rows down and 2 columns over from the top-left corner of the image.

## Configuration Parameters

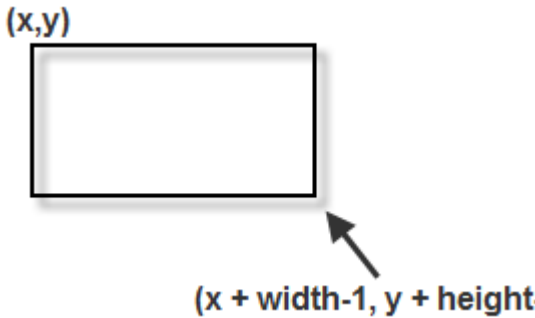
Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

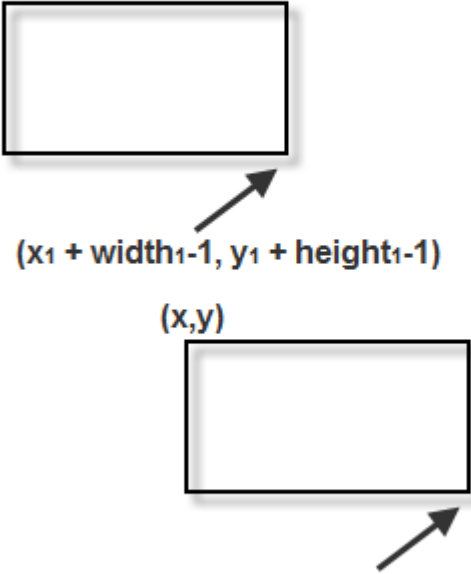
- **Solver** pane, **Stop time** = inf
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

## Draw Shapes and Lines

When you specify the type of shape to draw, you must also specify its location on the image. The table shows the format for the points input for the different shapes.

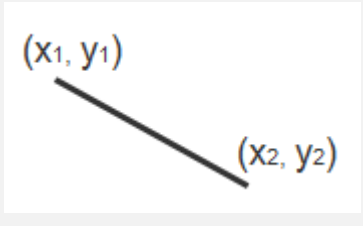
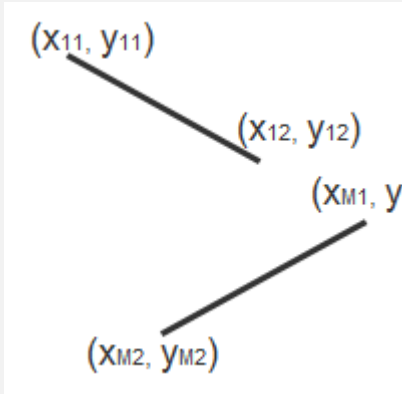
### Rectangle

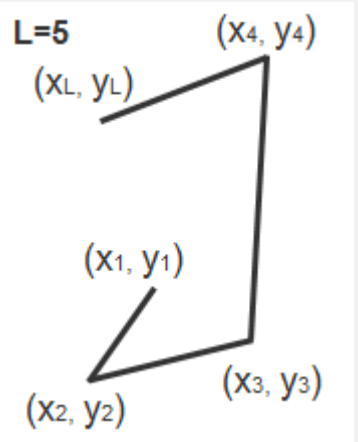
Shape	PTS input	Drawn Shape
Single Rectangle	<p>Four-element row vector  <code>[x y width height]</code> where</p> <ul style="list-style-type: none"> <li>• <code>x</code> and <code>y</code> are the one-based coordinates of the upper-left corner of the rectangle.</li> <li>• <code>width</code> and <code>height</code> are the width, in pixels, and height, in pixels, of the rectangle. The values of <code>width</code> and <code>height</code> must be greater than 0.</li> </ul>	 <p>The diagram shows a rectangle with a black border. The top-left corner is labeled <code>(x,y)</code>. The bottom-right corner is labeled <code>(x + width-1, y + height)</code> with an arrow pointing to it.</p>

Shape	PTS input	Drawn Shape
<p><math>M</math> Rectangles</p>	<p><math>M</math>-by-4 matrix</p> $\begin{bmatrix} x_1 & y_1 & width_1 & height_1 \\ x_2 & y_2 & width_2 & height_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_M & y_M & width_M & height_M \end{bmatrix}$ <p>where each row of the matrix corresponds to a different rectangle and is of the same form as the vector for a single rectangle.</p>	<p><b>M=2</b></p> <p><math>(x_1, y_1)</math></p>  <p><math>(x_1 + width_1 - 1, y_1 + height_1 - 1)</math></p> <p><math>(x, y)</math></p> <p><math>(x_2 + width_2 - 1, y_2 + height_2 - 1)</math></p>

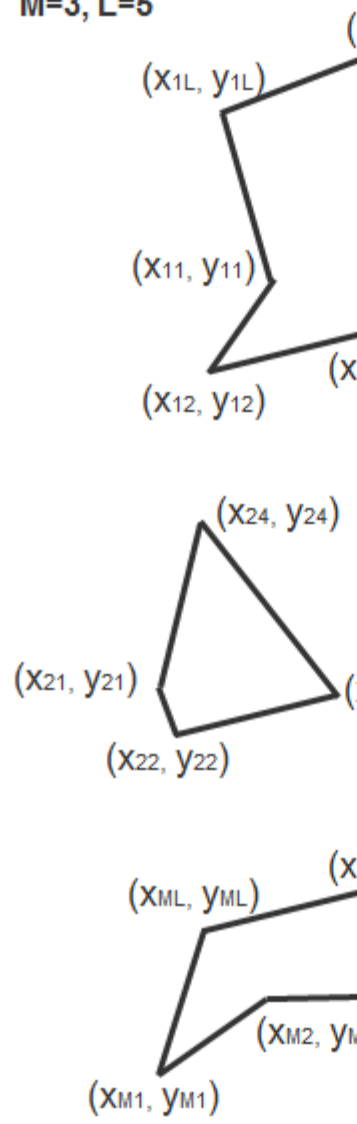
## Line and Polyline

You can draw one or more lines, and one or more polylines. A polyline contains a series of connected line segments.

Shape	PTS input	Drawn Shape
Single Line	<p>Four-element row vector <math>[x_1 \ y_1 \ x_2 \ y_2]</math> where</p> <ul style="list-style-type: none"> <li><math>x_1</math> and <math>y_1</math> are the coordinates of the beginning of the line.</li> <li><math>x_2</math> and <math>y_2</math> are the coordinates of the end of the line.</li> </ul>	 <p>A diagram showing a single line segment. The starting point is labeled <math>(x_1, y_1)</math> and the ending point is labeled <math>(x_2, y_2)</math>. The line slopes downwards from left to right.</p>
$M$ Lines	<p><math>M</math>-by-4 matrix</p> $\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} \\ x_{21} & y_{21} & x_{22} & y_{22} \\ \vdots & \vdots & \vdots & \vdots \\ x_{M1} & y_{M1} & x_{M2} & y_{M2} \end{bmatrix}$ <p>where each row of the matrix corresponds to a different line and is of the same form as the vector for a single line.</p>	 <p>A diagram showing three separate line segments. The first segment starts at <math>(x_{11}, y_{11})</math> and ends at <math>(x_{12}, y_{12})</math>. The second segment starts at <math>(x_{M1}, y_{M1})</math> and ends at <math>(x_{M2}, y_{M2})</math>. The third segment starts at <math>(x_{M2}, y_{M2})</math> and ends at <math>(x_{M1}, y_{M1})</math>, representing a line with a positive slope.</p>

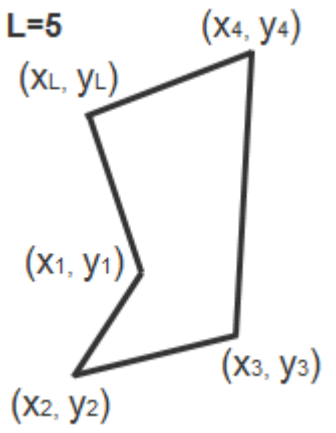
Shape	PTS input	Drawn Shape
<p>Single Polyline with <math>(L-1)</math> Segments</p>	<p>Vector of size <math>2L</math>, where <math>L</math> is the number of vertices, with format, <math>[x_1, y_1, x_2, y_2, \dots, x_L, y_L]</math>.</p> <ul style="list-style-type: none"> <li><math>x_1</math> and <math>y_1</math> are the coordinates of the beginning of the first line segment.</li> <li><math>x_2</math> and <math>y_2</math> are the coordinates of the end of the first line segment and the beginning of the second line segment.</li> <li><math>x_L</math> and <math>y_L</math> are the coordinates of the end of the <math>(L-1)^{\text{th}}</math> line segment.</li> </ul> <p>The polyline always contains <math>(L-1)</math> number of segments because the first and last vertex points do not connect. The block produces an error message when the number of rows is less than two or not a multiple of two.</p>	 <p>The diagram shows a single polyline with <math>L=5</math> segments. The vertices are labeled as <math>(x_1, y_1)</math>, <math>(x_2, y_2)</math>, <math>(x_3, y_3)</math>, <math>(x_4, y_4)</math>, and <math>(x_L, y_L)</math>. The segments connect <math>(x_1, y_1)</math> to <math>(x_2, y_2)</math>, <math>(x_2, y_2)</math> to <math>(x_3, y_3)</math>, <math>(x_3, y_3)</math> to <math>(x_4, y_4)</math>, and <math>(x_4, y_4)</math> to <math>(x_L, y_L)</math>. The first and last vertices are not connected.</p>



Shape	PTS input	Drawn Shape
<p><math>M</math> Polylines with <math>(L-1)</math> Segments</p>	<p><math>2L</math>-by-<math>N</math> matrix</p> $\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} & \cdots & x_{1L} & y_{1L} \\ x_{21} & y_{21} & x_{22} & y_{22} & \cdots & x_{2L} & y_{2L} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ x_{M1} & y_{M1} & x_{M2} & y_{M2} & \cdots & x_{ML} & y_{ML} \end{bmatrix}$ <p>where each row of the matrix corresponds to a different polyline and is of the same form as the vector for a single polyline. When you require one polyline to contain less than <math>(L-1)</math> number of segments, fill the matrix by repeating the coordinates of the last vertex.</p> <p>The block produces an error message if the number of rows is less than two or not a multiple of two.</p>	<p><b>M=3, L=5</b></p> 

## Polygon

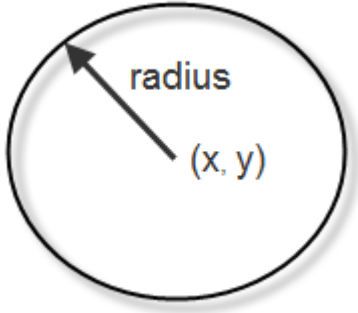
You can draw one or more polygons.

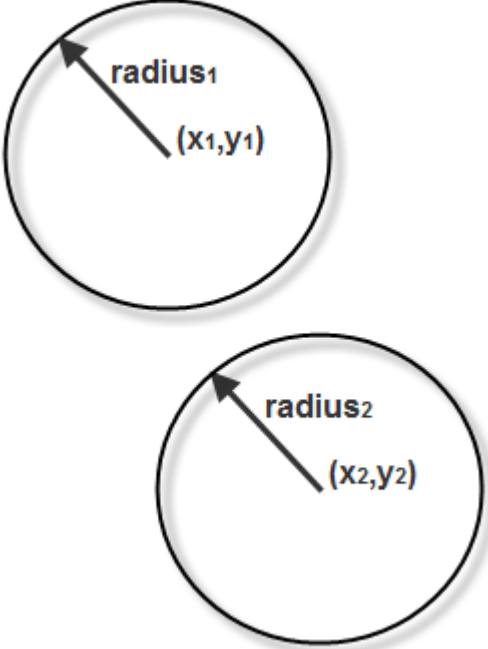
Shape	PTS input	Drawn Shape
<p>Single Polygon with <math>L</math> line segments</p>	<p>Row vector of size <math>2L</math>, where <math>L</math> is the number of vertices, with format, <math>[x_1 \ y_1 \ x_2 \ y_2 \ \dots \ x_L \ y_L]</math> where</p> <ul style="list-style-type: none"> <li><math>x_1</math> and <math>y_1</math> are the coordinates of the beginning of the first line segment.</li> <li><math>x_2</math> and <math>y_2</math> are the coordinates of the end of the first line segment and the beginning of the second line segment.</li> <li><math>x_L</math> and <math>y_L</math> are the coordinates of the end of the <math>(L-1)^{\text{th}}</math> line segment and the beginning of the <math>L^{\text{th}}</math> line segment.</li> </ul> <p>The block connects <math>[x_1 \ y_1]</math> to <math>[x_L \ y_L]</math> to complete the polygon. The block produces an error if the number of rows is negative or not a multiple of two.</p>	 <p>The diagram shows a closed polygon with five vertices. The vertices are labeled with their respective coordinates: <math>(x_1, y_1)</math>, <math>(x_2, y_2)</math>, <math>(x_3, y_3)</math>, <math>(x_4, y_4)</math>, and <math>(x_L, y_L)</math>. The text <math>L=5</math> is displayed in the upper left corner of the diagram area.</p>

Shape	PTS input	Drawn Shape
<p><math>M</math> Polygons with the largest number of line segments in any line being <math>L</math></p>	<p><math>M</math>-by-<math>2L</math> matrix</p> $\begin{bmatrix} x_{11} & y_{11} & x_{12} & y_{12} & \cdots & x_{1L} & y_{1L} \\ x_{21} & y_{21} & x_{22} & y_{22} & \cdots & x_{2L} & y_{2L} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ x_{M1} & y_{M1} & x_{M2} & y_{M2} & \cdots & x_{ML} & y_{ML} \end{bmatrix}$ <p>where each row of the matrix corresponds to a different polygon and is of the same form as the vector for a single polygon. If some polygons are shorter than others, repeat the ending coordinates to fill the polygon matrix.</p> <p>The block produces an error message if the number of rows is less than two or is not a multiple of two.</p>	<p><b>M=3, L=5</b></p>

## Circle

You can draw one or more circles.

Shape	PTS input	Drawn Shape
Single Circle	<p>Three-element row vector [x y radius] where</p> <ul style="list-style-type: none"><li>• x and y are coordinates for the center of the circle.</li><li>• radius is the radius of the circle, which must be greater than 0.</li></ul>	 A diagram of a circle with a black outline and a light gray drop shadow. The center of the circle is marked with the coordinates (x, y). A line segment with an arrowhead pointing to the circumference is labeled "radius".

Shape	PTS input	Drawn Shape
$M$ Circles	<p><math>M</math>-by-3 matrix</p> $\begin{bmatrix} x_1 & y_1 & radius_1 \\ x_2 & y_2 & radius_2 \\ \vdots & \vdots & \vdots \\ x_M & y_M & radius_M \end{bmatrix}$ <p>where each row of the matrix corresponds to a different circle and is of the same form as the vector for a single circle.</p>	<p><math>M=2</math></p>  <p>The diagram illustrates the drawing of two circles. The top circle is labeled with its center coordinates <math>(x_1, y_1)</math> and its radius <math>radius_1</math>. The bottom circle is labeled with its center coordinates <math>(x_2, y_2)</math> and its radius <math>radius_2</math>. The text <math>M=2</math> is positioned above the circles.</p>



# Registration and Stereo Vision

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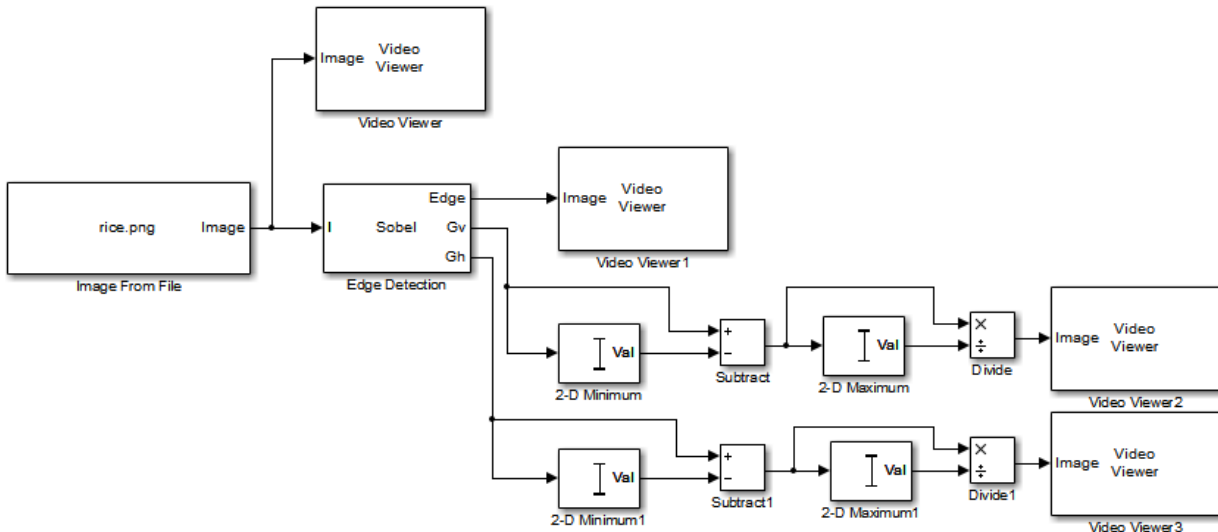
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## Detect Edges in Images

This example shows how to find the edges of rice grains in an intensity image. It finds the pixel locations where the magnitude of the gradient of intensity exceeds a threshold value. These locations typically occur at the boundaries of objects.

Open the Simulink model.

`ex_vision_detect_edges_in_image`



Set block parameters.

Block	Parameter setting
<b>Image From File</b>	<ul style="list-style-type: none"> <li>• <b>File name</b> to <code>rice.png</code>.</li> <li>• <b>Output data type</b> to <code>single</code>.</li> </ul>
<b>Edge Detection</b>	<p>Use the Edge Detection block to find the edges in the image.</p> <ul style="list-style-type: none"> <li>• <b>Output type</b> = <code>Binary image and gradient components</code></li> </ul>



Block	Parameter setting
	<ul style="list-style-type: none"> <li>Select the <b>Edge thinning</b> check box.</li> </ul>
<b>Video Viewer</b> and <b>Video Viewer1</b>	View the original and binary images. Accept the default parameters for both viewers.
<b>2-D Minimum</b> and <b>2-D Minimum1</b>	Find the minimum value of Gv and Gh matrices. Set the <b>Mode</b> parameters to <b>Value</b> for both of these blocks.
<b>Subtract</b> and <b>Subtract1</b>	Subtract the minimum values from each element of the Gv and Gh matrices. This process ensures that the minimum value of these matrices is 0. Accept the default parameters.
<b>2-D Maximum</b> and <b>2-D Maximum1</b>	Find the maximum value of the new Gv and Gh matrices. Set the <b>Mode</b> parameters to <b>Value</b> for both of these blocks.
<b>Divide</b> and <b>Divide1</b>	Divide each element of the Gv and Gh matrices by their maximum value. This normalization process ensures that these matrices range between 0 and 1. Accept the default parameters.
<b>Video Viewer2</b> and <b>Video Viewer3</b>	View the gradient components of the image. Accept the default parameters.

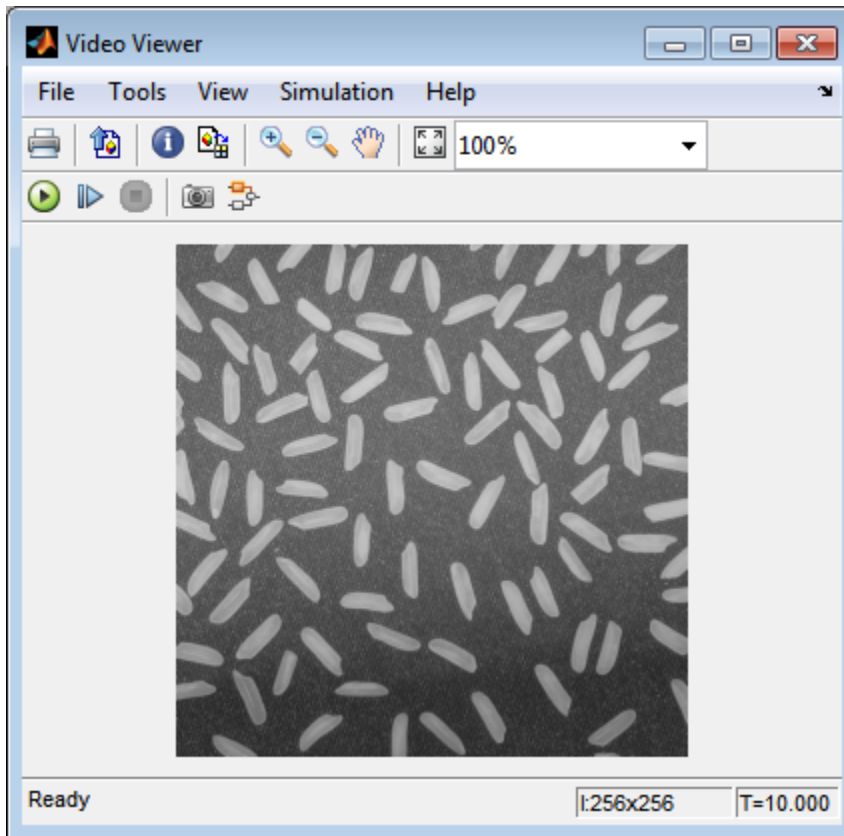
Set configuration parameters.

Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. The parameters are set as follows:

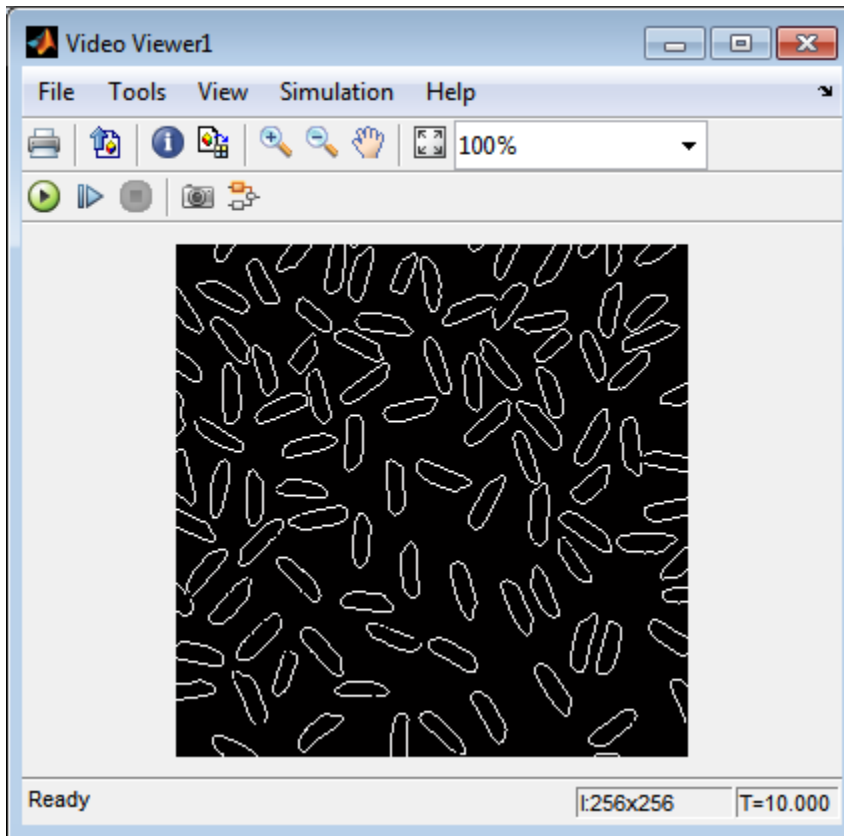
- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)
- **Diagnostics** pane, **Automatic solver parameter selection:** = none

Run your model and view edge detection results.

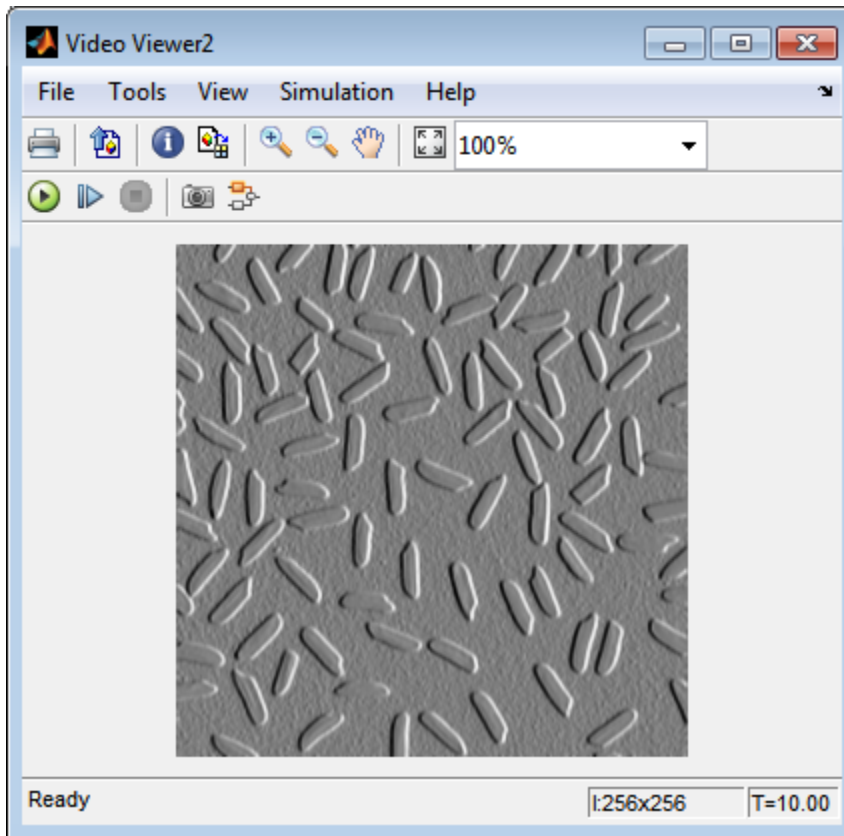
The Video Viewer window displays the original image.



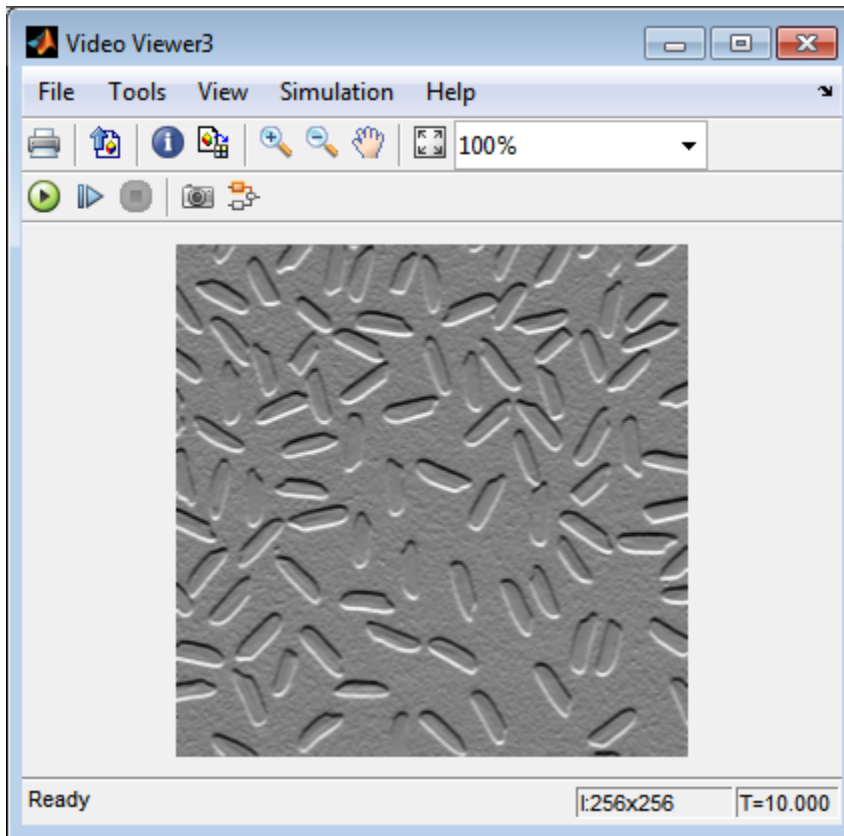
The Video Viewer1 window displays the edges of the rice grains in white and the background in black.



The Video Viewer2 window displays the intensity image of the vertical gradient components of the image. You can see that the vertical edges of the rice grains are darker and more well defined than the horizontal edges.



The Video Viewer3 window displays the intensity image of the horizontal gradient components of the image. In this image, the horizontal edges of the rice grains are more well defined.

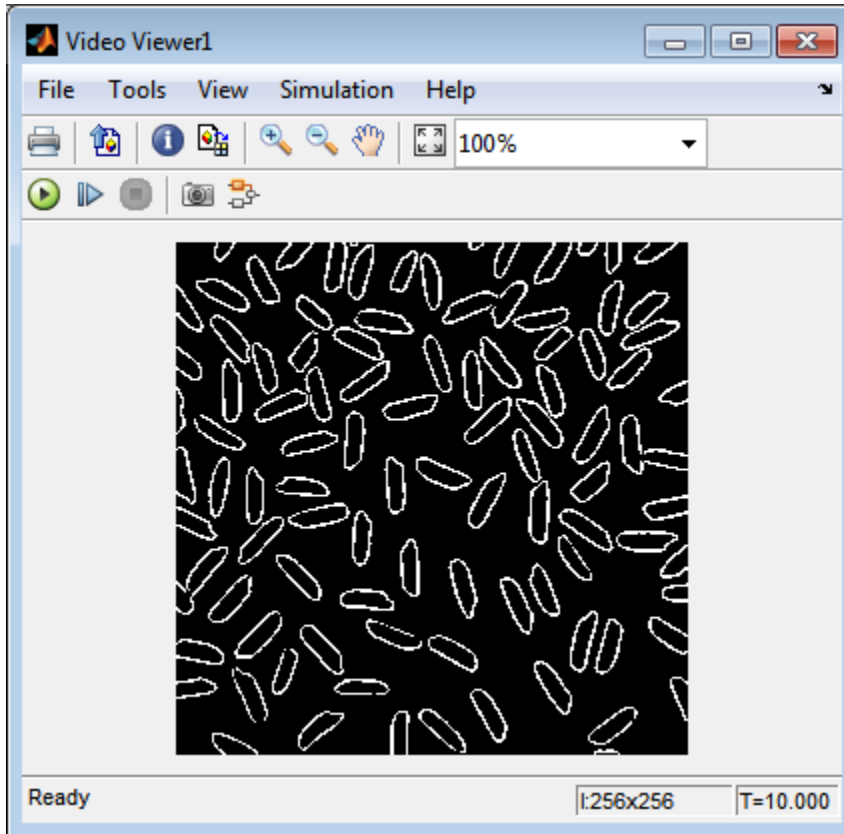


The Edge Detection block convolves the input matrix with the Sobel kernel. This calculates the gradient components of the image that correspond to the horizontal and vertical edge responses. The block outputs these components at the **G<sub>h</sub>** and **G<sub>v</sub>** ports, respectively. Then the block performs a thresholding operation on the gradient components to find the binary image. The binary image is a matrix filled with 1s and 0s. The nonzero elements of this matrix correspond to the edge pixels and the zero elements correspond to the background pixels. The block outputs the binary image at the **Edge** port.

The matrix values at the **G<sub>v</sub>** and **G<sub>h</sub>** output ports of the Edge Detection block are double-precision floating-point. These matrix values need to be scaled between 0 and 1 in order to display them using the Video Viewer blocks. This is done with the Statistics and Math Operation blocks.

Run the model faster by double-clicking the Edge Detection block and clear the **Edge thinning** check box.

Your model runs faster because the Edge Detection block is more efficient when you clear the **Edge thinning** check box. However, the edges of rice grains in the Video Viewer window are wider.



Close the model.

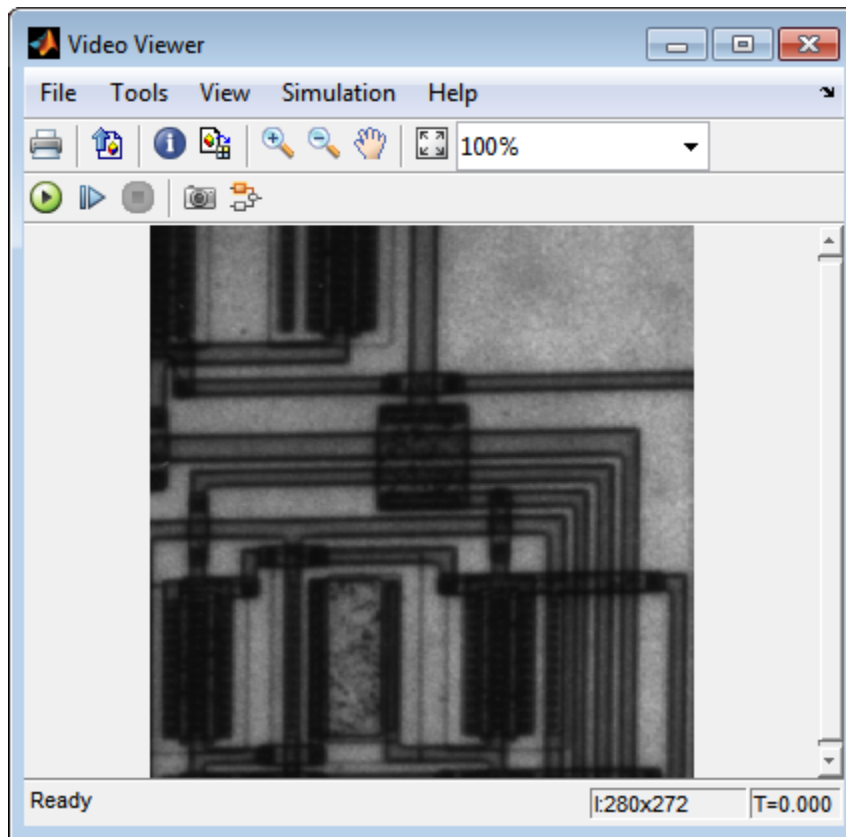
```
bdclose('ex_vision_detect_edges_in_image');
```

## Detect Lines in Images

This example shows you how to find lines within images and enables you to detect, measure, and recognize objects. You use the Hough Transform, Find Local Maxima, Edge Detection and Hough Lines blocks to find the longest line in an image.

You can open the model for this example by typing

```
ex_vision_detect_lines  
at the MATLAB command line.
```



The Video Viewer blocks display the original image, the image with all edges found, and the image with the longest line annotated.

The Edge Detection block finds the edges in the intensity image. This process improves the efficiency of the Hough Lines block by reducing the image area over which the block searches for lines. The block also converts the image to a binary image, which is the required input for the Hough Transform block.

For additional examples of the techniques used in this section, see the following list of examples. You can open these examples by typing the title at the MATLAB command prompt:

Example	MATLAB	Simulink model-based
Lane Departure Warning System	videoldws	vipldws
Rotation Correction	videorotationcorrection	viphough

### Setting Block Parameters

Block	Parameter setting
<b>Hough Transform</b>	<p>The Hough Transform block computes the Hough matrix by transforming the input image into the rho-theta parameter space. The block also outputs the rho and theta values associated with the Hough matrix. The parameters are set as follows:</p> <ul style="list-style-type: none"> <li>• <b>Theta resolution (radians) = <math>\pi/360</math></b></li> <li>• Select the <b>Output theta and rho values</b> check box.</li> </ul>
<b>Find Local Maxima</b>	<p>The Find Local Maxima block finds the location of the maximum value in the Hough matrix. The block parameters are set as follows:</p> <ul style="list-style-type: none"> <li>• <b>Maximum number of local maxima = 1</b></li> <li>• <b>Input is Hough matrix spanning full theta range</b></li> </ul>
<b>Selector</b>	<p>The Selector blocks separate the indices of the rho and theta values, which the Find</p>



Block	Parameter setting
	<p>Local Maxima block outputs at the <b>Idx</b> port. The rho and theta values correspond to the maximum value in the Hough matrix. The Selector blocks parameters are set as follows:</p> <ul style="list-style-type: none"> <li>• <b>Number of input dimensions:</b> 1</li> <li>• <b>Index mode</b> = One-based</li> <li>• <b>Index Option</b> = Index vector (port)</li> <li>• <b>Input port size</b> = 2</li> </ul>
<b>Variable Selector</b>	<p>The Variable Selector blocks index into the rho and theta vectors and determine the rho and theta values that correspond to the longest line in the original image. The parameters of the Variable Selector blocks are set as follows:</p> <ul style="list-style-type: none"> <li>• <b>Select</b> = Columns</li> <li>• <b>Index mode</b> = One-based</li> </ul>
<b>Hough Lines</b>	<p>The Hough Lines block determines where the longest line intersects the edges of the original image.</p> <ul style="list-style-type: none"> <li>• <b>Sine value computation method</b> = Trigonometric function</li> </ul>
<b>Draw Shapes</b>	<p>The Draw Shapes block draws a white line over the longest line on the original image. The coordinates are set to superimpose a line on the original image. The block parameters are set as follows:</p> <ul style="list-style-type: none"> <li>• <b>Shape</b> = Lines</li> <li>• <b>Border color</b> = White</li> </ul>

### Configuration Parameters

Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = discrete (no continuous states)
- **Solver** pane, **Fixed-step size (fundamental sample time)**: = 0.2

## Measure Angle Between Lines

The Hough Transform, Find Local Maxima, and Hough Lines blocks enable you to find lines in images. With the Draw Shapes block, you can annotate images. In the following example, you use these capabilities to draw lines on the edges of two beams and measure the angle between them.

Running this example requires a DSP System Toolbox license.

`ex_vision_measure_angle_btwn_lines`

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Color Space Conversion	Computer Vision System Toolbox > Conversions	1
Edge Detection	Computer Vision System Toolbox > Analysis & Enhancement	1
Hough Transform	Computer Vision System Toolbox > Transforms	1
Hough Lines	Computer Vision System Toolbox > Transforms	1
Find Local Maxima	Computer Vision System Toolbox > Statistics	1
Draw Shapes	Computer Vision System Toolbox > Text & Graphics	1
Video Viewer	Computer Vision System Toolbox > Sinks	3
Submatrix	DSP System Toolbox > Math Functions > Matrices and Linear Algebra > Matrix Operations	4
Selector	Simulink > Signal Routing	4
MATLAB Function	Simulink > User-Defined Functions	1
Terminator	Simulink > Sinks	1
Display	Simulink > Sinks	1

- 2 Use the Image From File block to import an image into the Simulink model. Set the parameters as follows:

- **File name** = gantrycrane.png
  - **Sample time** = 1
- 3 Use the Color Space Conversion block to convert the RGB image into the YCbCr color space. You perform this conversion to separate the luma information from the color information. Accept the default parameters.

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**Note:** In this example, you segment the image using a thresholding operation that performs best on the Cb channel of the YCbCr color space.

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- 4 Use the Selector and Selector1 blocks to separate the Y' (luminance) and Cb (chrominance) components from the main signal.

The Selector block separates the Y' component from the entire signal. Set its block parameters as follows:

- **Number of input dimensions** = 3
- **Index mode** = One-based
- **1 Index Option** = Select all
- **2 Index Option** = Select all
- **3 Index Option** = Index vector (dialog), **Index** = 1

The Selector1 block separates the Cb component from the entire signal. Set its block parameters as follows:

- **Number of input dimensions** = 3
  - **Index mode** = One-based
  - **1 Index Option** = Select all
  - **2 Index Option** = Select all
  - **3 Index Option** = Index vector (dialog), **Index** = 2
- 5 Use the Submatrix and Submatrix1 blocks to crop the Y' and Cb matrices to a particular region of interest (ROI). This ROI contains two beams that are at an angle to each other. Set the parameters as follows:
- **Starting row** = Index
  - **Starting row index** = 66
  - **Ending row** = Index

- **Ending row index** = 150
  - **Starting column** = Index
  - **Starting column index** = 325
  - **Ending column** = Index
  - **Ending column index** = 400
- 6 Use the Edge Detection block to find the edges in the Cb portion of the image. This block outputs a binary image. Set the **Threshold scale factor** parameter to 1.
  - 7 Use the Hough Transform block to calculate the Hough matrix, which gives you an indication of the presence of lines in an image. Select the **Output theta and rho values** checkbox.

---

**Note:** In step 11, you find the theta and rho values that correspond to the peaks in the Hough matrix.

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- 8 Use the Find Local Maxima block to find the peak values in the Hough matrix. These values represent potential lines in the input image. Set the parameters as follows:
  - **Neighborhood size** = [ 11 11 ]
  - Select the **Input is Hough matrix spanning full theta range** checkbox.
  - Uncheck the **Output variable size signal** checkbox.

Because you are expecting two lines, leave the **Maximum number of local maxima (N)** parameter set to 2.

- 9 Use the Submatrix2 block to find the indices that correspond to the theta values of the two peak values in the Hough matrix. Set the parameters as follows:
  - **Starting row** = Index
  - **Starting row index** = 2
  - **Ending row** = Index
  - **Ending row index** = 2

The Idx port of the Find Local Maxima block outputs a matrix whose second row represents the One-based indices of the theta values that correspond to the peaks in the Hough matrix. Now that you have these indices, you can use a Selector block to extract the corresponding theta values from the vector output of the Hough Transform block.

**10** Use the Submatrix3 block to find the indices that correspond to the rho values of the two peak values in the Hough matrix. Set the parameters as follows:

- **Ending row** = Index
- **Ending row index** = 1

The Idx port of the Find Local Maxima block outputs a matrix whose first row represents the One-based indices of the rho values that correspond to the peaks in the Hough matrix. Now that you have these indices, you can use a Selector block to extract the corresponding rho values from the vector output of the Hough Transform block.

**11** Use the Selector2 and Selector3 blocks to find the theta and rho values that correspond to the peaks in the Hough matrix. These values, output by the Hough Transform block, are located at the indices output by the Submatrix2 and Submatrix3 blocks. Set both block parameters as follows:

- **Index mode** = One-based
- **1 Index Option** = Index vector (port)
- **Input port size** = -1

You set the **Index mode** to One-based because the Find Local Maxima block outputs One-based indices at the Idx port.

**12** Use the Hough Lines block to find the Cartesian coordinates of lines that are described by rho and theta pairs. Set the **Sine value computation method** parameter to `Trigonometric function`.

**13** Use the Draw Shapes block to draw the lines on the luminance portion of the ROI. Set the parameters as follows:

- **Shape** = Lines
- **Border color** = White

**14** Use the MATLAB Function block to calculate the angle between the two lines. Copy and paste the following code into the block:

```
function angle = compute_angle(theta)

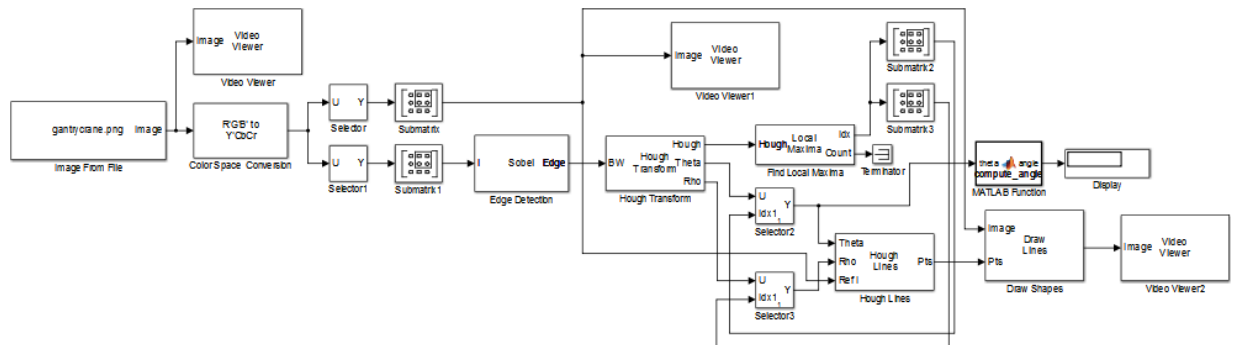
% Compute the angle value in degrees
angle = abs(theta(1)-theta(2))*180/pi;
% Always return an angle value less than 90 degrees
if (angle>90)
```

```

    angle = 180-angle;
end

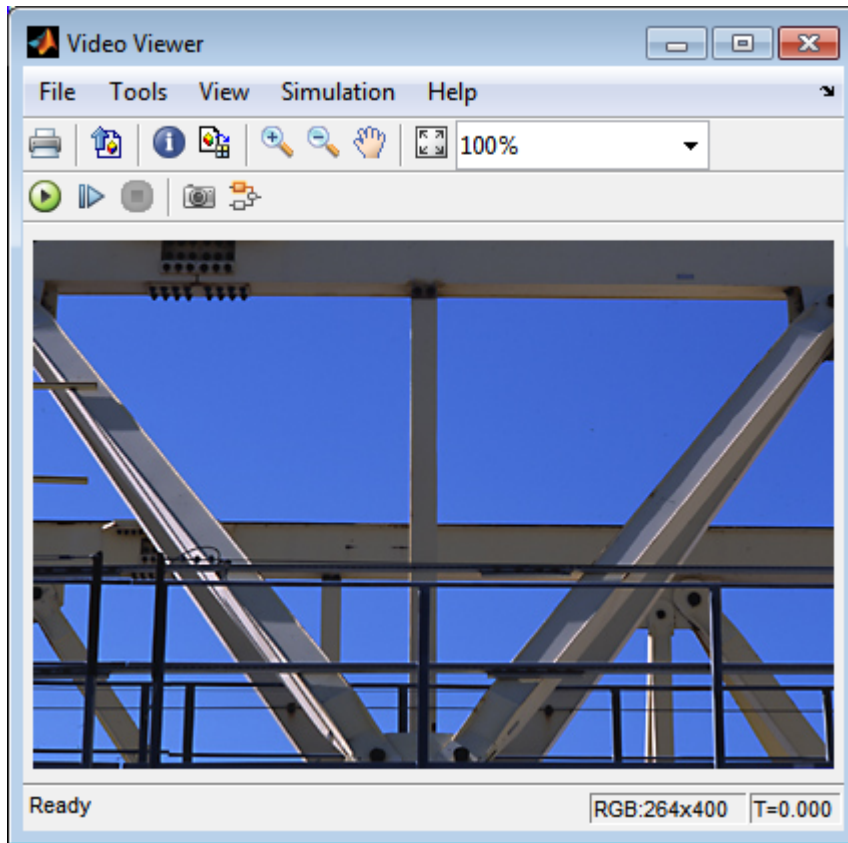
```

- 15 Use the Display block to view the angle between the two lines. Accept the default parameters.
- 16 Use the Video Viewer blocks to view the original image, the ROI, and the annotated ROI. Accept the default parameters.
- 17 Connect the blocks as shown in the following figure.



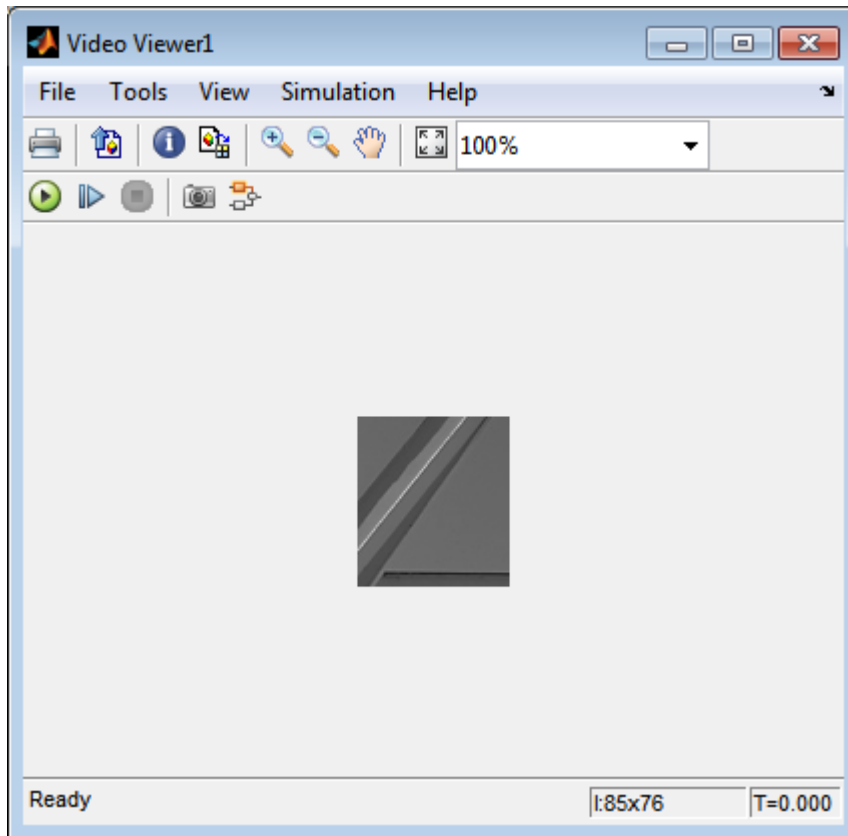
- 18 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 19 Run the model.

The Video Viewer window displays the original image.

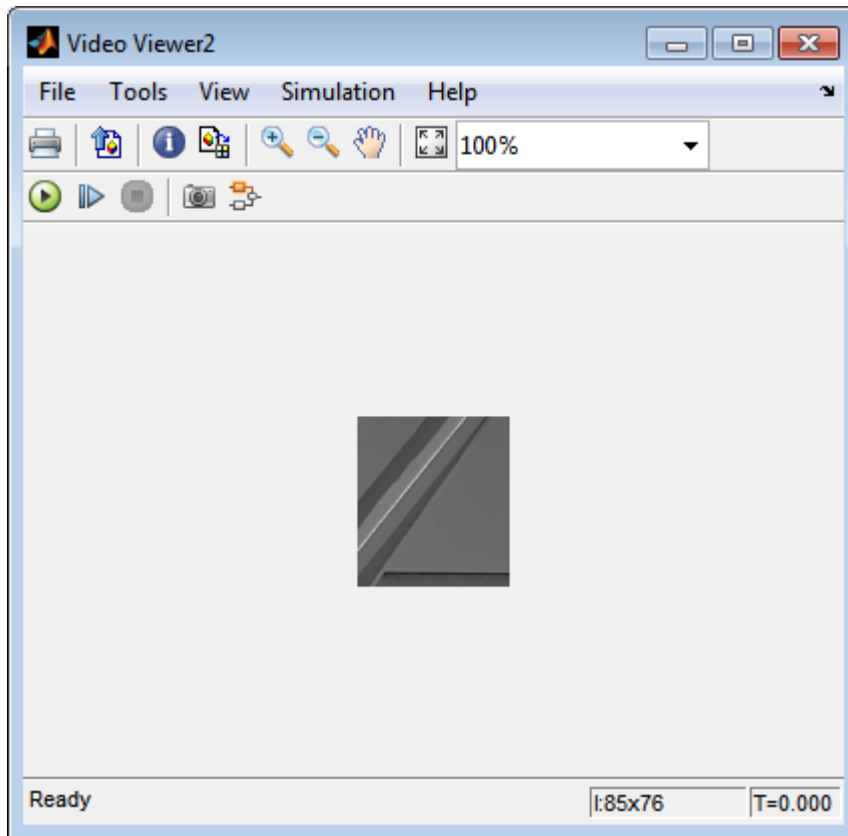


The Video Viewer1 window displays the ROI where two beams intersect.





The Video Viewer2 window displays the ROI that has been annotated with two white lines.



The Display block shows a value of 58, which is the angle in degrees between the two lines on the annotated ROI.

You have now annotated an image with two lines and measured the angle between them. For additional information, see the Hough Transform, Find Local Maxima, Hough Lines, and Draw Shapes block reference pages.

# Single Camera Calibration App

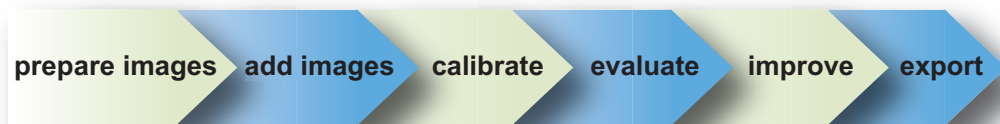
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## Camera Calibrator Overview

You can use the camera calibrator to estimate camera intrinsics, extrinsics, and lens distortion parameters. You can use these camera parameters for various computer vision applications. These applications include removing the effects of lens distortion from an image, measuring planar objects, or reconstructing 3-D scenes from multiple cameras.

### Single Camera Calibration Workflow



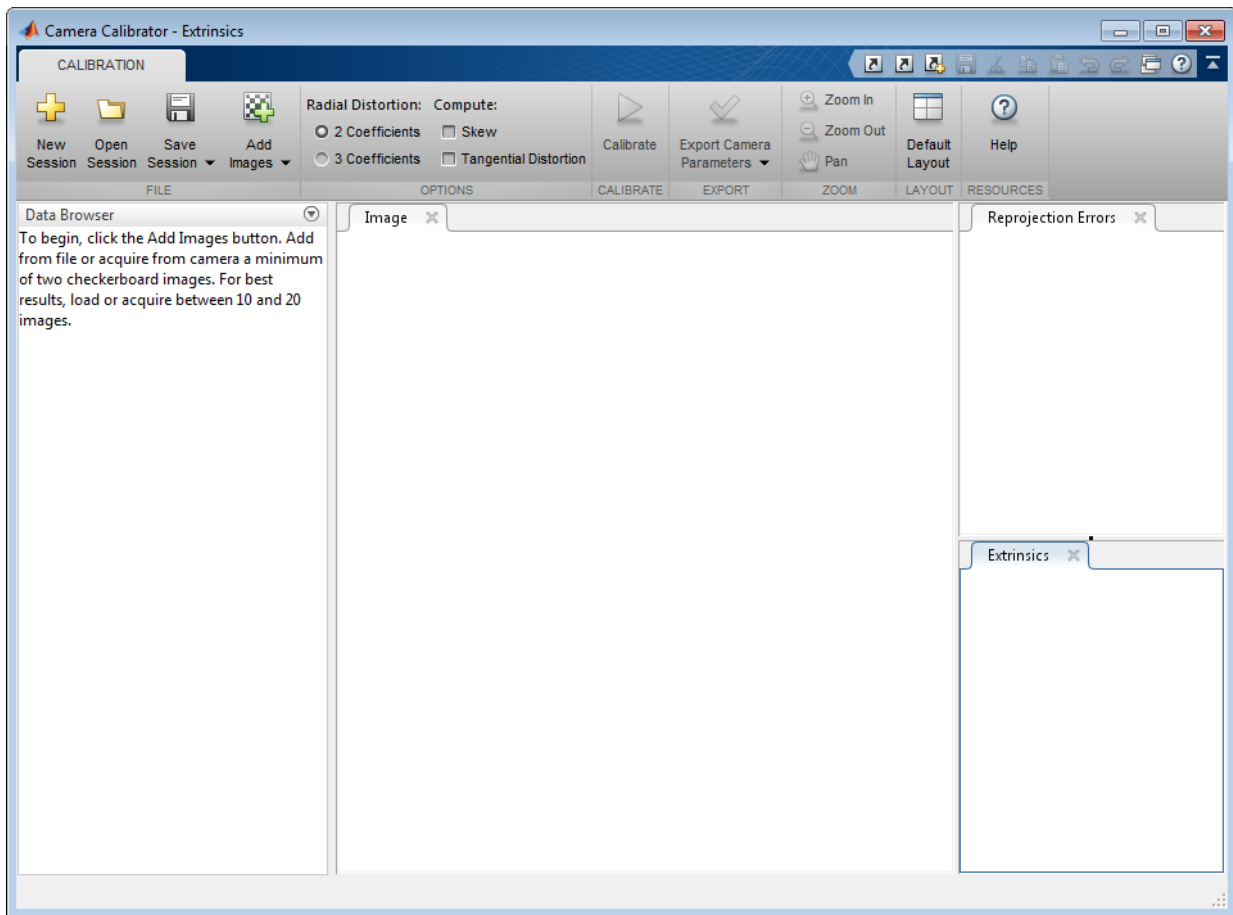
Follow this workflow to calibrate your camera using the app:

- 1 Prepare images, camera, and calibration pattern.
- 2 Load images.
- 3 Calibrate the camera.
- 4 Evaluate calibration accuracy.
- 5 Adjust parameters to improve accuracy (if necessary).
- 6 Export the parameters object.

In some cases, the default values work well, and you do not need to make any improvements before exporting parameters. If you do need to make improvements, you can use the camera calibration functions in MATLAB. For a list of functions, see “Geometric Camera Calibration”.

### Open the Camera Calibrator

- MATLAB Toolstrip: Open the Apps tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `cameraCalibrator`



## Prepare the Pattern, Camera, and Images

For best results, use between 10 and 20 images of the calibration pattern. The calibrator requires at least three images. Use uncompressed images or lossless compression formats such as PNG. The calibration pattern and the camera setup must satisfy a set of requirements to work with the calibrator. For greater calibration accuracy, follow these instructions for preparing the pattern, setting up the camera, and capturing the images.

### Prepare the Checkerboard Pattern

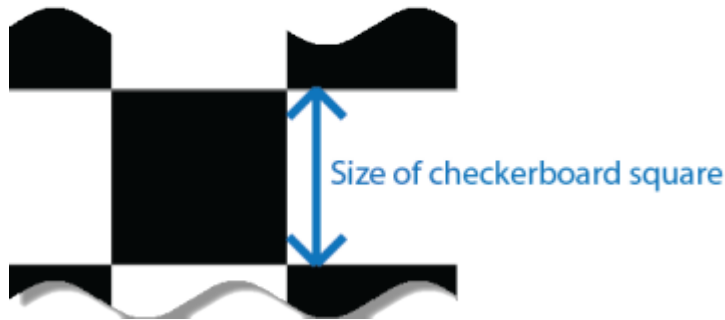
The Camera Calibrator app uses a checkerboard pattern. A checkerboard pattern is a convenient calibration target. If you want to use a different pattern to extract key points, you can use the camera calibration MATLAB functions directly. See “Geometric Camera Calibration” for the list of functions.

You can print (from MATLAB) and use the checkerboard pattern provided. The checkerboard pattern you use must not be square. One side must contain an even number of squares and the other side must contain an odd number of squares. Therefore, the pattern contains two black corners along one side and two white corners on the opposite side. This criteria enables the app to determine the orientation of the pattern. The calibrator assigns the longer side to be the  $x$ -direction.



To prepare the checkerboard pattern:

- 1 Attach the checkerboard printout to a flat surface. Imperfections on the surface can affect the accuracy of the calibration.
- 2 Measure one side of the checkerboard square. You need this measurement for calibration. The size of the squares can vary depending on printer settings.



- 3 To improve the detection speed, set up the pattern with as little background clutter as possible.

### Camera Setup

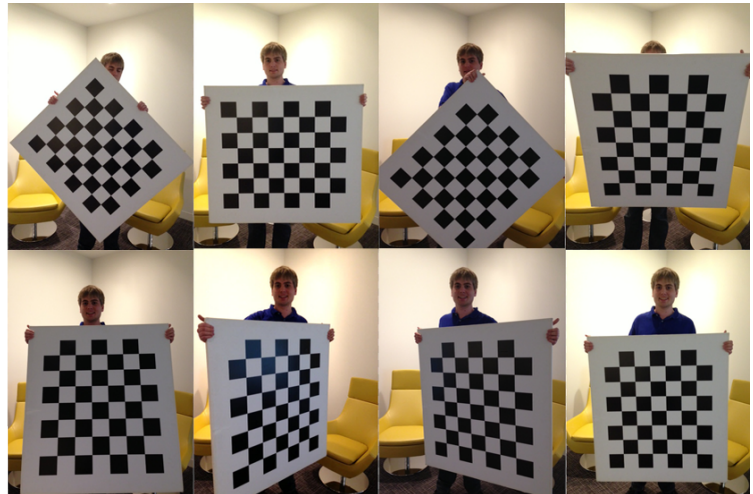
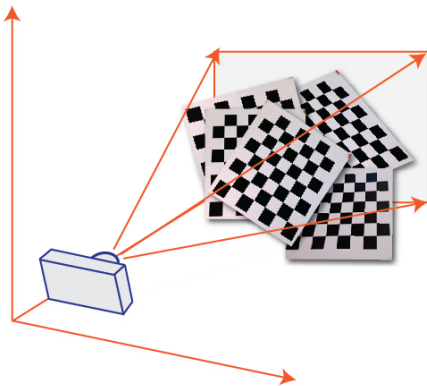
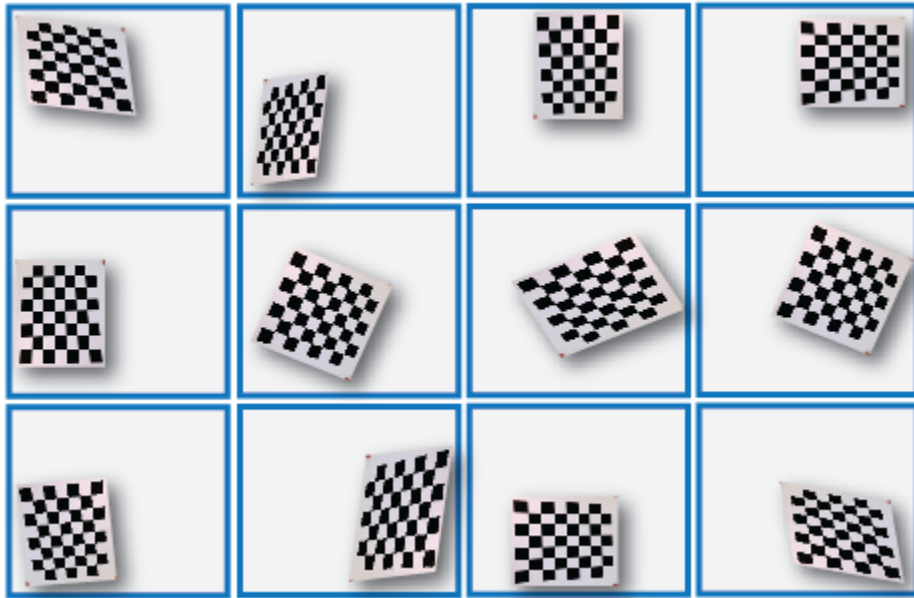
To properly calibrate your camera, follow these rules:

- Keep the pattern in focus, but do not use autofocus.
- Do not change zoom settings between images. Otherwise the focal length changes.

### Capture Images

For best results, use at least 10 to 20 images of the calibration pattern. The calibrator requires at least three images. Use uncompressed images or images in lossless compression formats such as PNG. For greater calibration accuracy:

- Capture the images of the pattern at a distance roughly equal to the distance from your camera to the objects of interest. For example, if you plan to measure objects from 2 meters, keep your pattern approximately 2 meters from the camera.
- Place the checkerboard at an angle less than 45 degrees relative to the camera plane.
- Do not modify the images. For example, do not crop them.
- Do not use autofocus or change the zoom between images.
- Capture the images of a checkerboard pattern at different orientations relative to the camera.
- Capture enough different images of the pattern so that you have covered as much of the image frame as possible. Lens distortion increases radially from the center of the image and sometimes is not uniform across the image frame. To capture this lens distortion, the pattern must appear close to the edges.



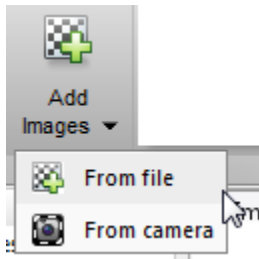
The Calibrator works with a range of checkerboard square sizes. As a general rule, your checkerboard should fill at least 20% of the captured image. For example, the preceding images were taken with a checkerboard square size of 108 mm.

### Add Images

To begin calibration, you must add images. You can add saved images from a folder or add images directly from a camera. The calibrator analyzes the images to ensure they meet the calibrator requirements and then detects the points.

#### Add Images from File

Click the Add images, button, and select **From file**. You can add images from multiple folders by clicking Add images for each folder.

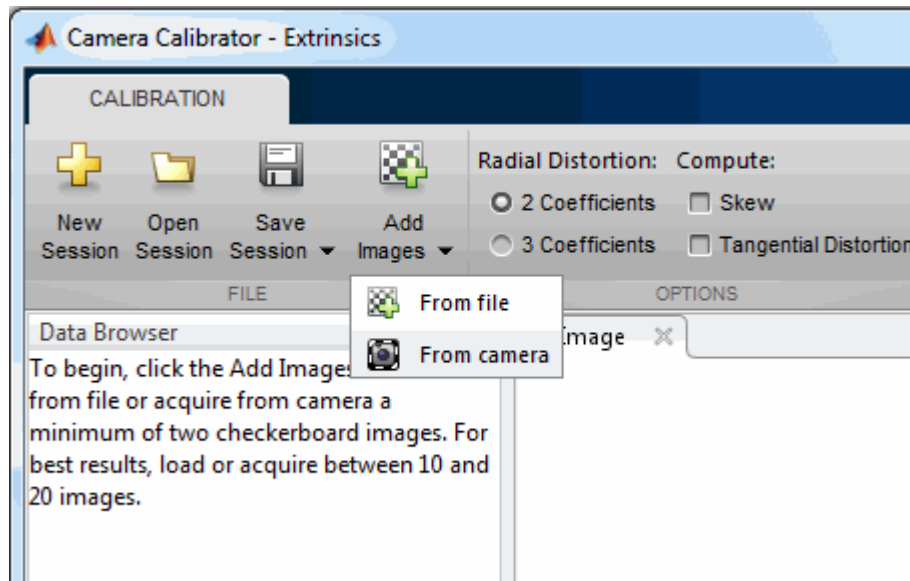


#### Acquire Live Images

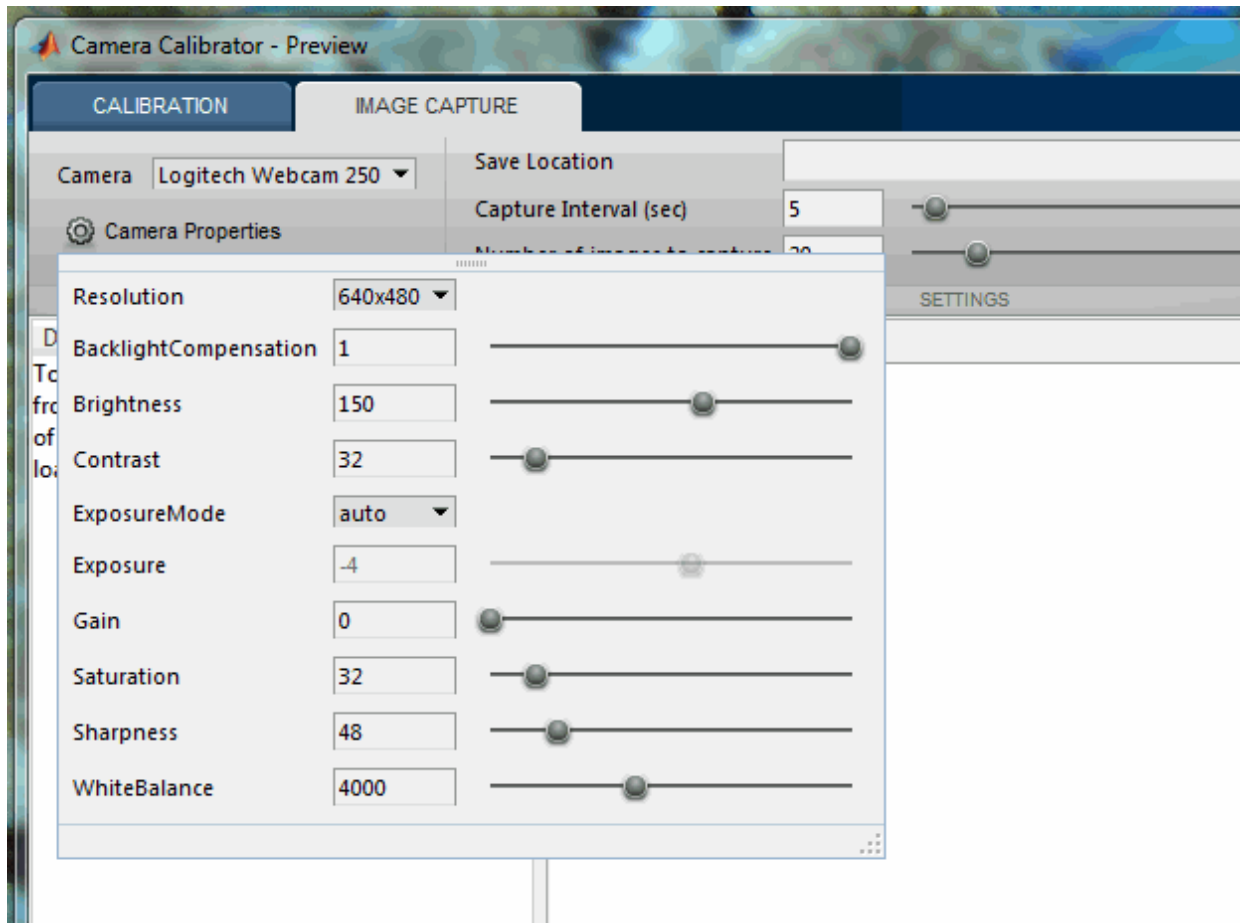
To begin calibration, you must add images. You can acquire images live from a Webcam using the MATLAB Webcam support. You must have the MATLAB Support Package for USB Webcams installed to use this feature. See “Install the Webcam Support Package” for information on installing the support package.

- 1 To add live images, click the **Add Images** arrow and select **From camera**.



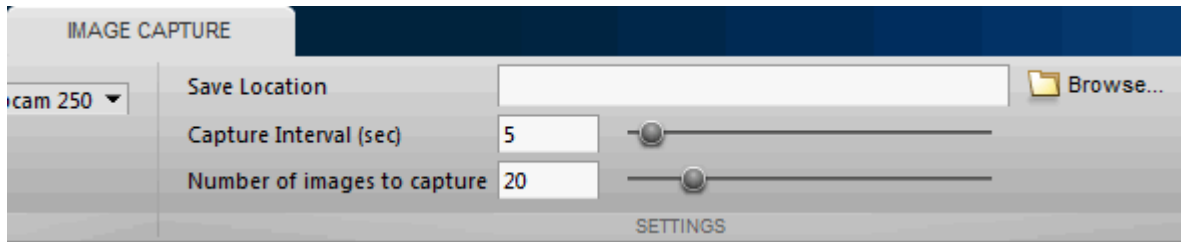


- 2 The **Image Capture** tab opens. If you have only one Webcam connected to your system, it is selected by default and a live preview window opens. If you have multiple cameras connected and want to use a different one, select the camera in the **Camera** list.
- 3 You can set properties for the camera to control the image. Click the **Camera Properties** field to open a list of your camera's properties. This list varies, depending on your device.



Use the sliders or drop-downs to change any available property settings. The **Preview** window updates dynamically when you change a setting. When you are done setting properties, click outside of the box to dismiss the properties list.

- 4 Enter a location for the acquired image files in the **Save Location** field by typing the path to the folder or using the **Browse** button. You must have permission to write to the folder you select.
- 5 Set your capture parameters.

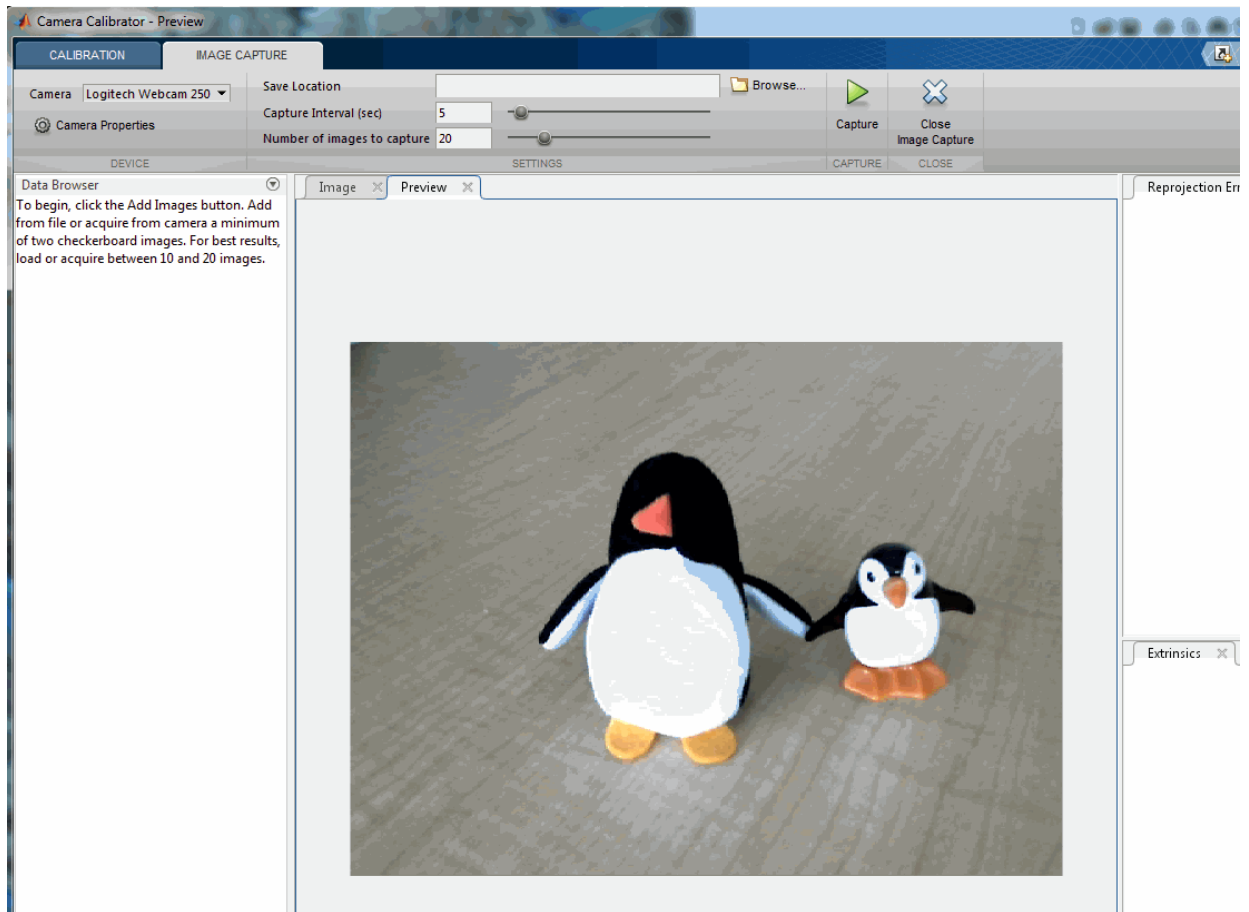


In the **Capture Interval** field, use the text box or slider to set the number of seconds between image captures. The default is 5 seconds, the minimum is 1 second, and the maximum is 60 seconds.

In the **Number of images to capture** field, use the text box or slider to set the number of image captures. The default is 20 images, the minimum is 2 images, and the maximum is 100 images.

In the default configuration, a total of 20 images are captured, one every 5 seconds.

- 6 It is helpful to dock the **Preview** window in the center of the tool. Move it from the right panel into the middle panel by dragging the banner. It then docks in the middle as shown here.

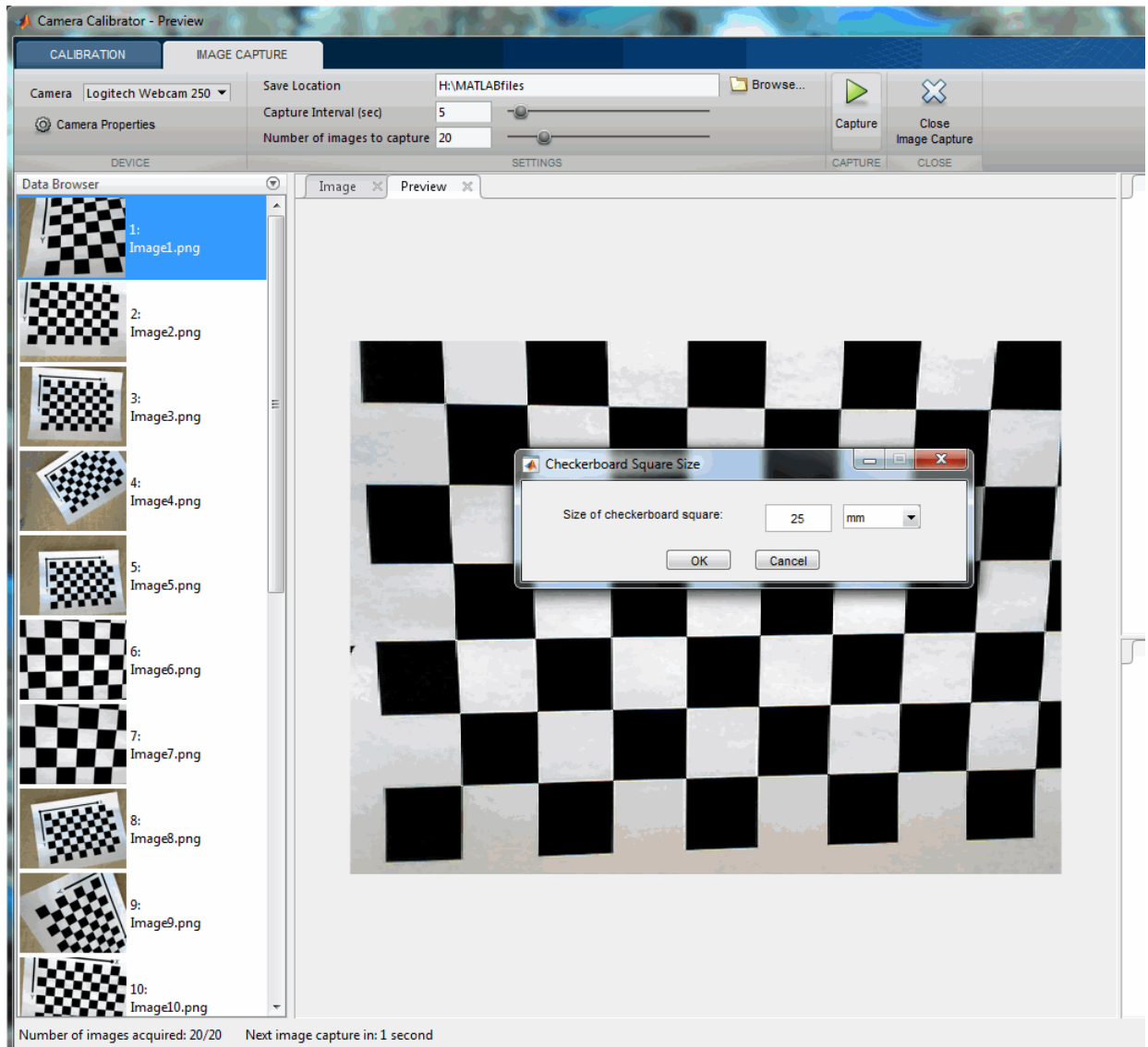


- 7 The **Preview** window shows the live images streamed as RGB data. After you adjust any device properties and capture settings, use the **Preview** window as a guide to line up the camera to acquire the checkerboard pattern image you wish to capture.
- 8 Click the **Capture** button. The number of images you set are captured and the thumbnails of the snapshots appear in the **Data Browser** panel. They are automatically named incrementally and are captured as **.png** files.

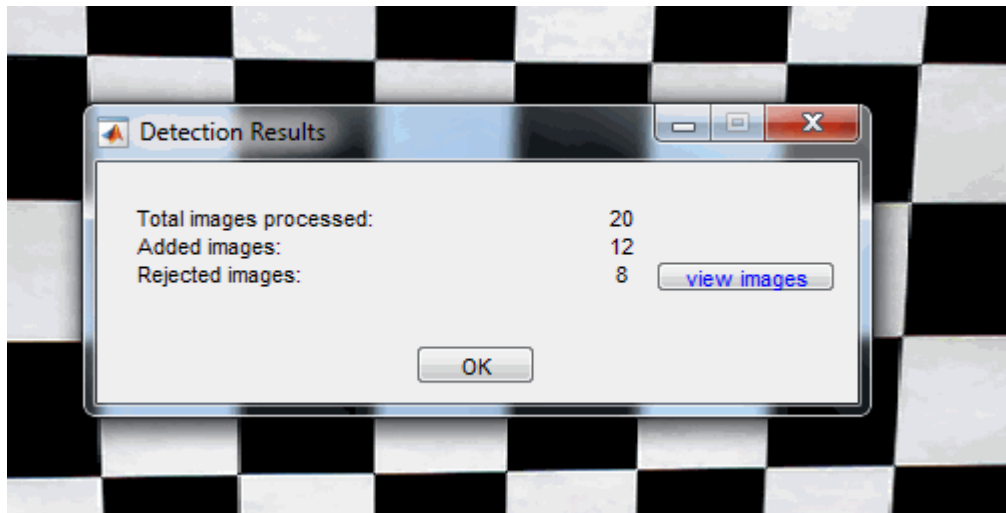
You can optionally stop the image capture before the designated number of images are captured by clicking **Stop Capture**.

When you are capturing images of a checkerboard, after the designated number of images are captured, a message displays with the size of the checkerboard square. Click **OK**.

## 4 Registration and Stereo Vision



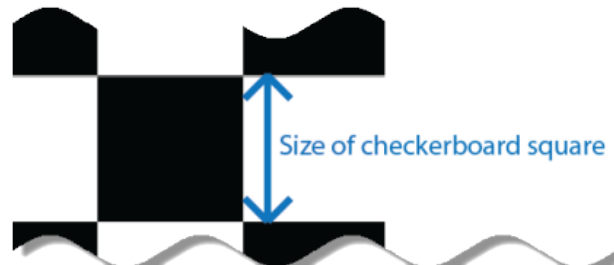
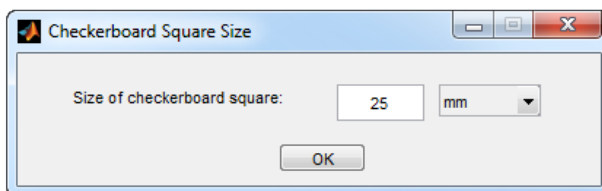
The Detection Results are then calculated and displayed. For example:



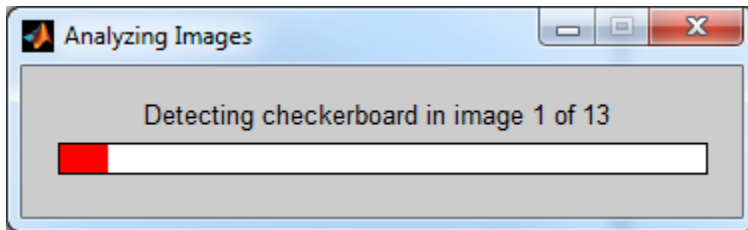
- 9 Click **OK** in the **Detection Results** dialog box.
- 10 When you have finished acquiring live images, you can click **Close Image Capture** to close the **Image Capture** tab and return to the **Calibration** tab.

### Analyze Images

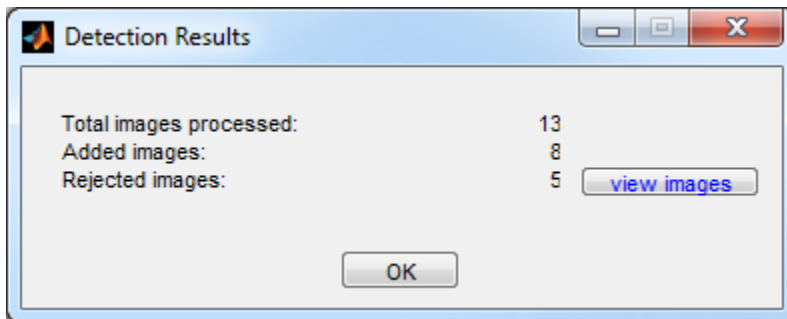
After you select the images, in the Checkerboard Square Size dialog box, enter the length of one side of a square from the checkerboard pattern.



The calibrator attempts to detect a checkerboard in each of the added images. An Analyzing Images progress bar window appears, indicating detection progress.



If any of the images are rejected, the Detection Results window appears, which contains diagnostic information. The results indicate how many total images were processed, and how many were accepted, rejected, or skipped. The calibrator skips duplicate images.

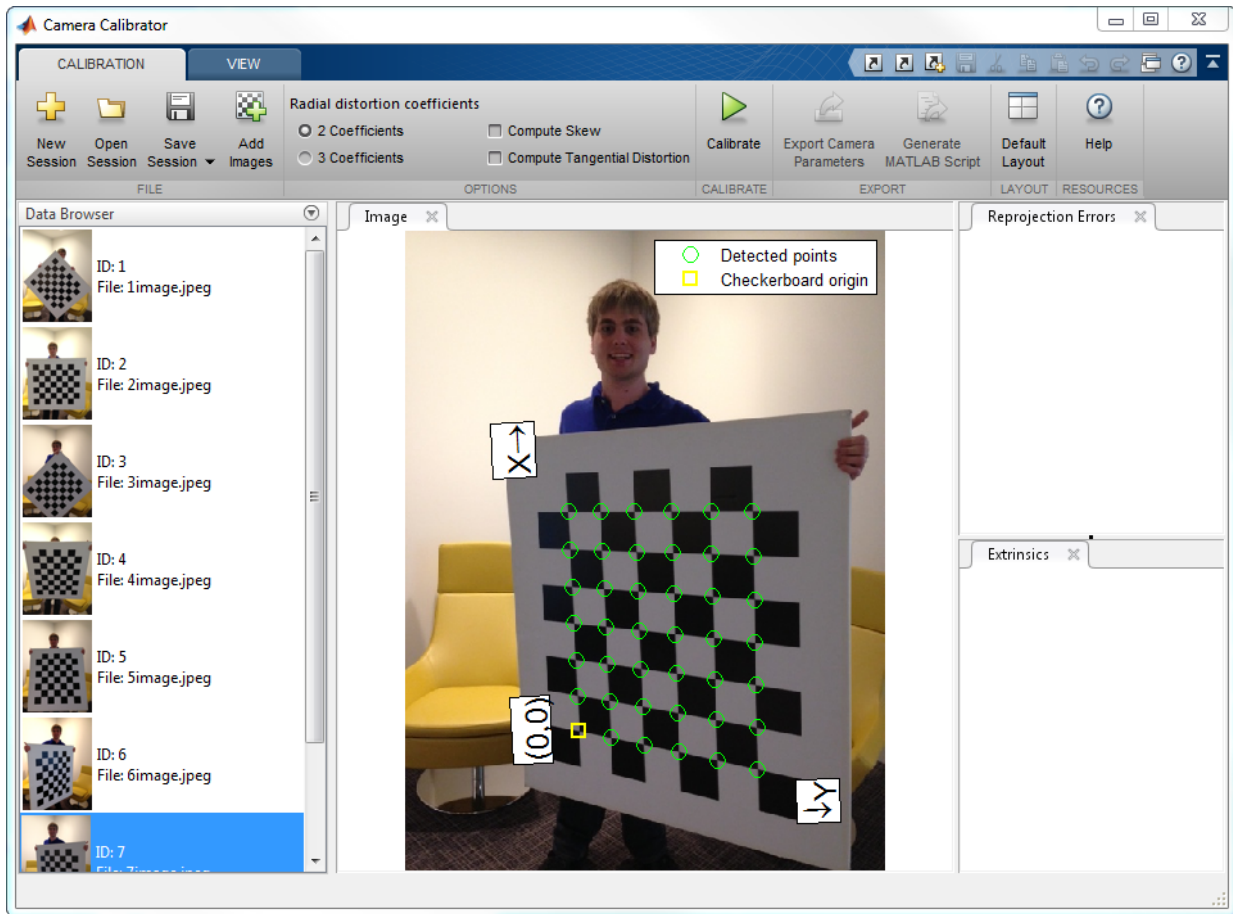


To view the rejected images, click **view images**. The calibrator rejects duplicate images. It also rejects images where the entire checkerboard could not be detected. Possible reasons for no detection are a blurry image or an extreme angle of the pattern. Detection takes longer with larger images and with patterns that contain a large number of squares.

### View Images and Detected Points

The Data Browser pane displays a list of images with IDs. These images contain a detected pattern. To view an image, select it from the **Data Browser** pane.





The **Image** pane displays the checkerboard image with green circles to indicate detected points. You can verify the corners were detected correctly using the zoom controls on the **View** tab. The yellow square indicates the (0,0) origin. The X and Y arrows indicate the checkerboard axes orientation.

## Calibrate

Once you are satisfied with the accepted images, click Calibrate. The default calibration settings assume the minimum set of camera parameters. Start by running the calibration with the default settings. After evaluating the results, you can try to improve calibration

accuracy by adjusting the settings and adding or removing images, and then calibrate again.

### Calibration Algorithm

The calibration algorithm assumes a pinhole camera model:

$$w[x \ y \ 1] = [X \ Y \ Z \ 1] \begin{bmatrix} R \\ t \end{bmatrix} K$$

.

- $(X, Y, Z)$ : world coordinates of a point
- $(x, y)$ : image coordinates of the corresponding image point in pixels
- $w$ : arbitrary homogeneous coordinates scale factor
- $K$ : camera intrinsic matrix, defined as:

$$\begin{bmatrix} f_x & 0 & 0 \\ s & f_y & 0 \\ c_x & c_y & 1 \end{bmatrix}$$

The coordinates  $[c_x \ c_y]$  represent the optical center (the principal point), in pixels. When the  $x$  and  $y$  axis are exactly perpendicular, the skew parameter,  $s$ , equals 0.

$$f_x = F^* s_x$$

$$f_y = F^* s_y$$

$F$ , is the focal length in world units, typically expressed in millimeters.

$[s_x, s_y]$  are the number of pixels per world unit in the  $x$  and  $y$  direction respectively.

$f_x$  and  $f_y$  are expressed in pixels.

- $R$ : matrix representing the 3-D rotation of the camera
- $t$ : translation of the camera relative to the world coordinate system

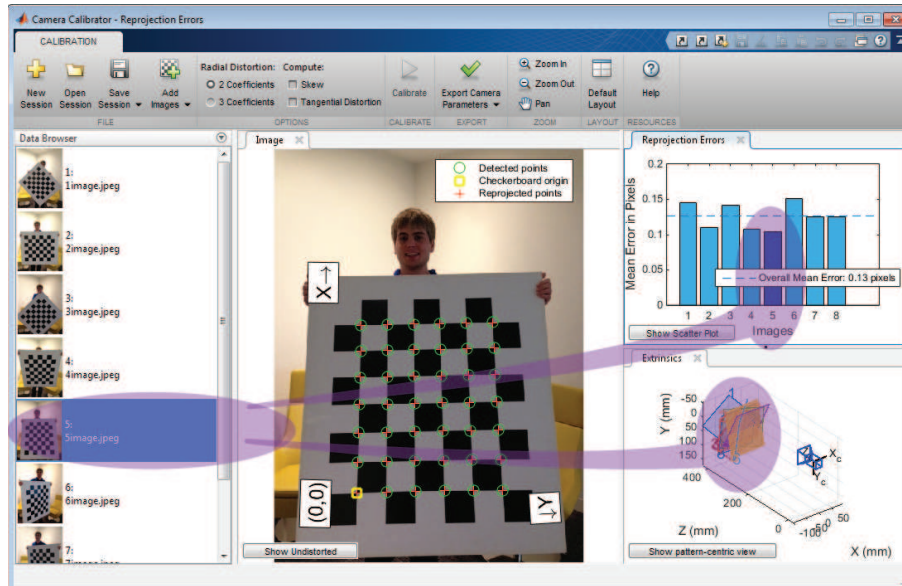
The camera calibration algorithm estimates the values of the intrinsic parameters, the extrinsic parameters, and the distortion coefficients. Camera calibration involves these steps:

- 1 Solve for the intrinsics and extrinsics in closed form, assuming that lens distortion is zero. [1]

- Estimate all parameters simultaneously, including the distortion coefficients, using nonlinear least-squares minimization (Levenberg–Marquardt algorithm). Use the closed-form solution from the preceding step as the initial estimate of the intrinsics and extrinsics. Set the initial estimate of the distortion coefficients to zero. [1][2]

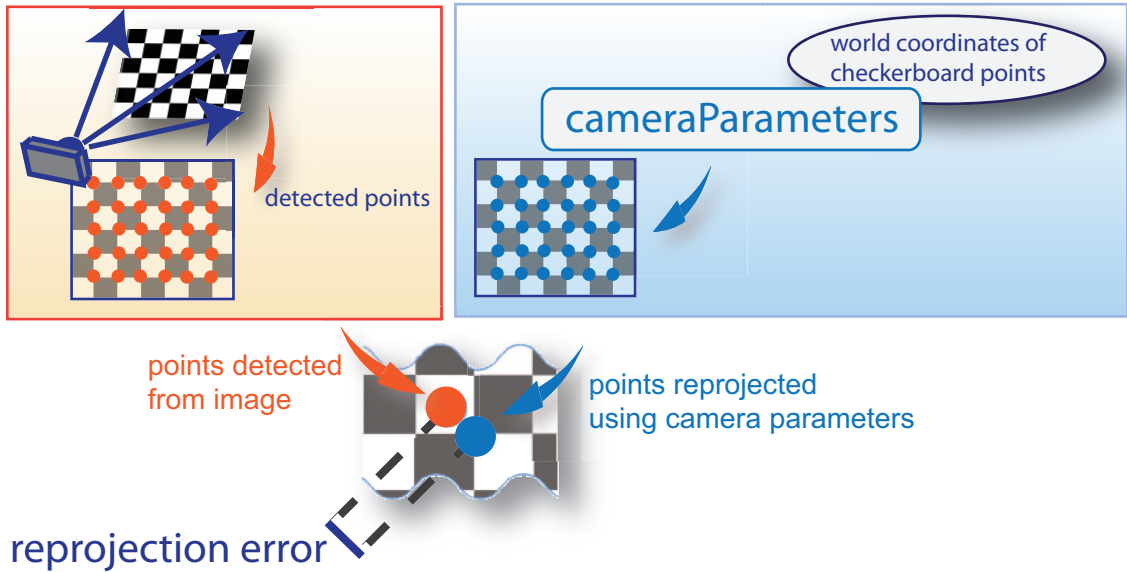
## Evaluate Calibration Results

You can evaluate calibration accuracy by examining the reprojection errors and the camera extrinsics, and by viewing the undistorted image. For best calibration results, use all three methods of evaluation.



### Examine Reprojection Errors

The *reprojection errors* are the distances in pixels between the detected and the reprojected points. The Camera Calibrator app calculates reprojection errors by projecting the checkerboard points from world coordinates, defined by the checkerboard, into image coordinates. The app then compares the reprojected points to the corresponding detected points. As a general rule, reprojection errors of less than one pixel are acceptable.



The Camera Calibrator app displays, in pixels, the reprojection errors as a bar graph and as a scatter plot. You can toggle between them using the button on the display. You can identify the images that adversely contribute to the calibration from either one of the graphs. You can then select and remove those images from the list in the **Data Browser** pane.

### Bar Graph

The bar graph displays the mean reprojection error per image, along with the overall mean error. The bar labels correspond to the image IDs. The highlighted bar corresponds to the selected image.

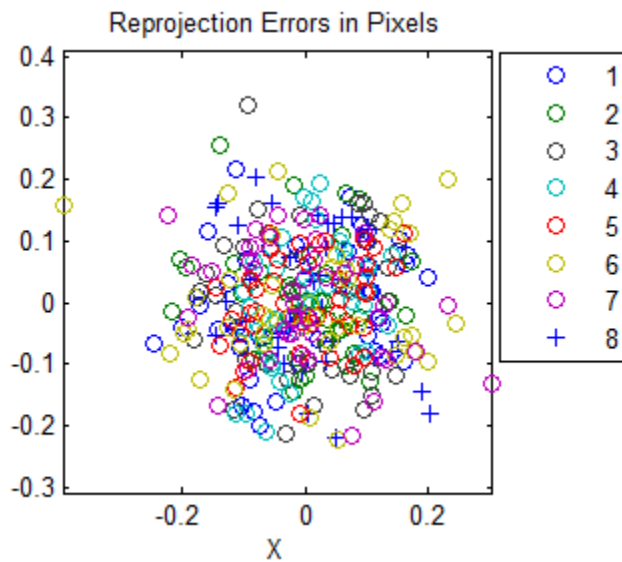


Select an image in one of these ways:

- Clicking the corresponding bar in the graph.
- Select the image from the list in the **Data Browser** pane.

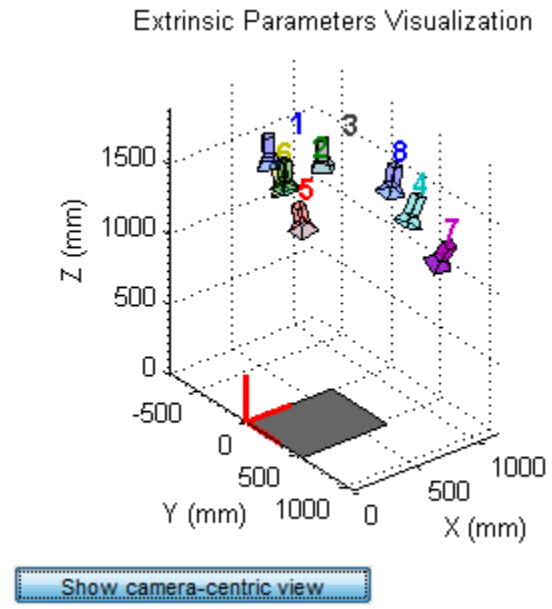
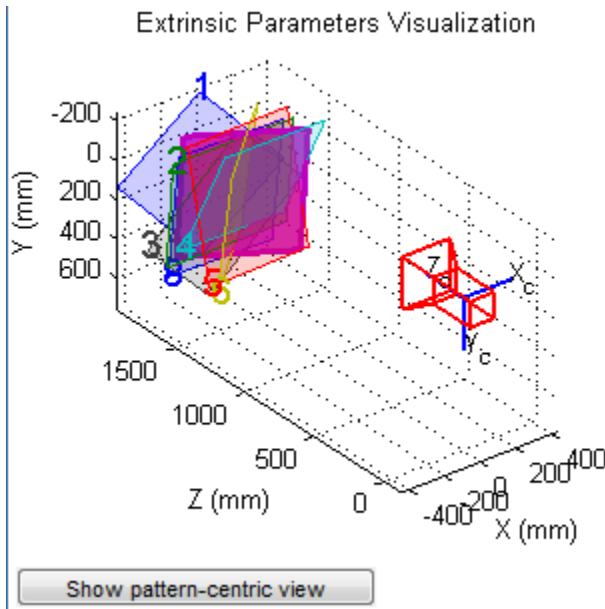
### Scatter Plot

The scatter plot displays the reprojection errors for each point. The plus markers correspond to the points in the selected image. An accurate calibration typically results in a compact cloud of points. Outliers indicate potential issues with the corresponding images. To improve accuracy, consider removing those images.



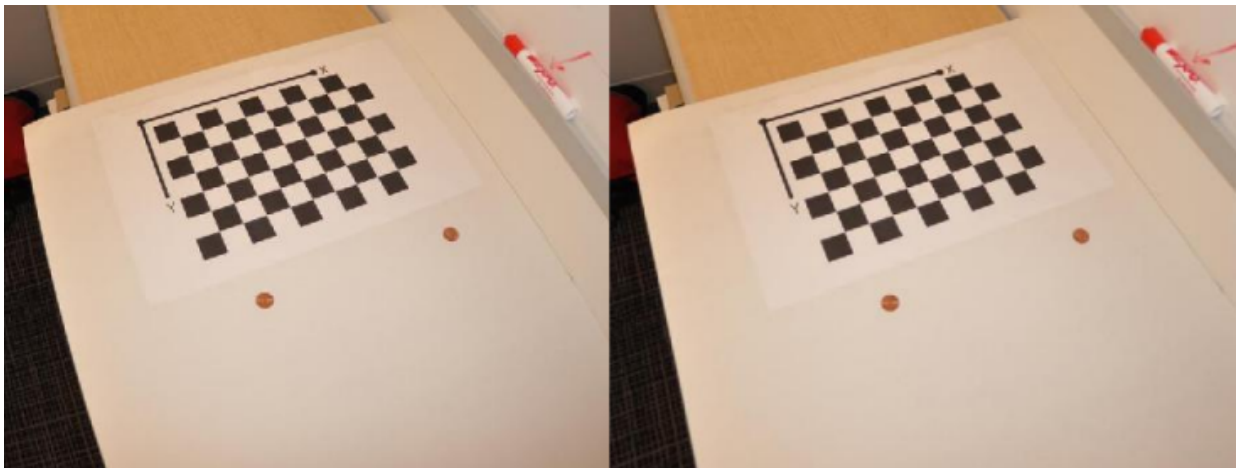
### Examine Extrinsic Parameter Visualization

The 3-D extrinsic parameters plot provides a camera-centric view of the patterns and a pattern-centric view of the camera. The camera-centric view is helpful if the camera was stationary when the images were captured. The pattern-centric view is helpful if the pattern was stationary. Click the button on the display to toggle between the two visuals. Click and drag a graph to rotate it. Click a checkerboard or a camera to select it. The highlighted data in the visualizations correspond to the selected image in the list. Examine the relative positions of the pattern and the camera to see if they match what you expect. For example, a pattern that appears behind the camera indicates a calibration error.



### View Undistorted Image

To view the effects of removing lens distortion, in the **Image** pane, click the **Show Undistorted**. If the calibration was accurate, the distorted lines in the image become straight.



It is important to check the undistorted images even if the reprojection errors are low. If the pattern covers only a small percentage of the image, the distortion estimation might be incorrect, even though the calibration resulted in few reprojection errors.



### Improve Calibration

To improve the calibration, you can remove high-error images, add more images, or modify the calibrator settings.

#### Add or Remove Images

Consider adding more images if:

- You have less than 10 images.
- The patterns do not cover enough of the image frame.
- The patterns do not have enough variation in orientation with respect to the camera.

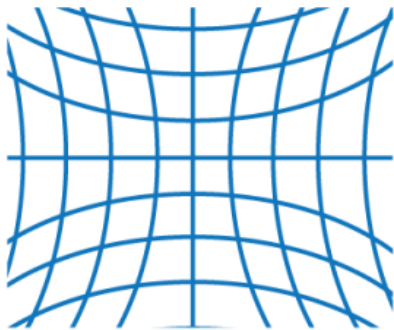
Consider removing images if the images:

- Have a high mean reprojection error
- Are blurry
- Contain a checkerboard at an angle greater than 45 degrees relative to the camera plane
- Contain incorrectly detected checkerboard points

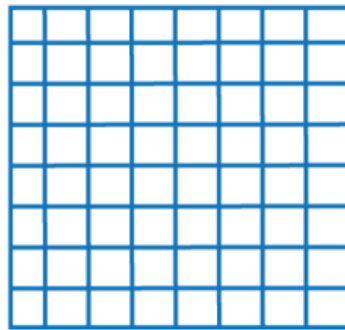


### Change the Number of Radial Distortion Coefficients

You can specify 2 or 3 radial distortion coefficients by selecting the corresponding radio button from the **Options** section. *Radial distortion* occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.



negative radial distortion  
"pincushion"



no distortion



positive radial distortion  
"barrel"

The radial distortion coefficients model this type of distortion. The distorted points are denoted as  $(x_{\text{distorted}}, y_{\text{distorted}})$ :

$$x_{\text{distorted}} = x(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

$$y_{\text{distorted}} = y(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

.

- $x, y$ : undistorted pixel locations
- $k_1, k_2,$  and  $k_3$ : radial distortion coefficients of the lens
- $r^2: x^2 + y^2$

Typically, two coefficients are sufficient for calibration. For severe distortion, such as in wide-angle lenses, select **3 Coefficients** to include  $k_3$ .

The undistorted pixel locations are in normalized image coordinates, with the origin at the optical center. The coordinates are expressed in world units.

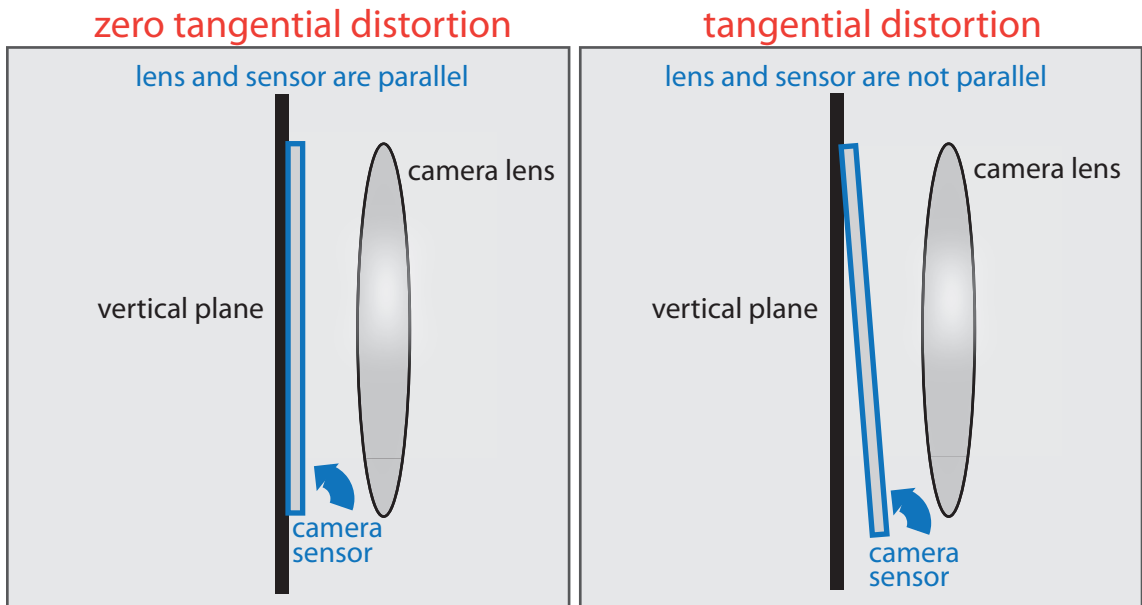
### Compute Skew

When you select the **Compute Skew** check box, the calibrator estimates the image axes skew. Some camera sensors contain imperfections that cause the  $x$ - and  $y$ -axis of the

image to not be perpendicular. You can model this defect using a skew parameter. If you do not select the check box, the image axes are assumed to be perpendicular, which is the case for most modern cameras.

### Compute Tangential Distortion

Tangential distortion occurs when the lens and the image plane are not parallel. The tangential distortion coefficients model this type of distortion.



The distorted points are denoted as  $(x_{\text{distorted}}, y_{\text{distorted}})$ :

$$x_{\text{distorted}} = x + [2 * p_1 * y + p_2 * (r^2 + 2 * x^2)]$$

$$y_{\text{distorted}} = y + [p_1 * (r^2 + 2 * y^2) + 2 * p_2 * x]$$

.

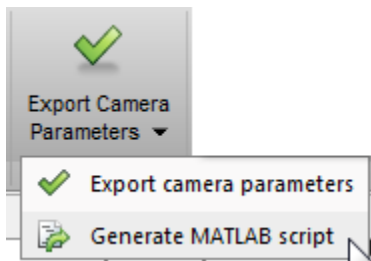
- $x, y$ : undistorted pixel locations
- $p_1$  and  $p_2$ : tangential distortion coefficients of the lens
- $r^2 = x^2 + y^2$

The undistorted pixel locations are in normalized image coordinates, with the origin at the optical center. The coordinates are in world units.

When you select the **Compute Tangential Distortion** check box, the calibrator estimates the tangential distortion coefficients. Otherwise, the calibrator sets the tangential distortion coefficients to zero.

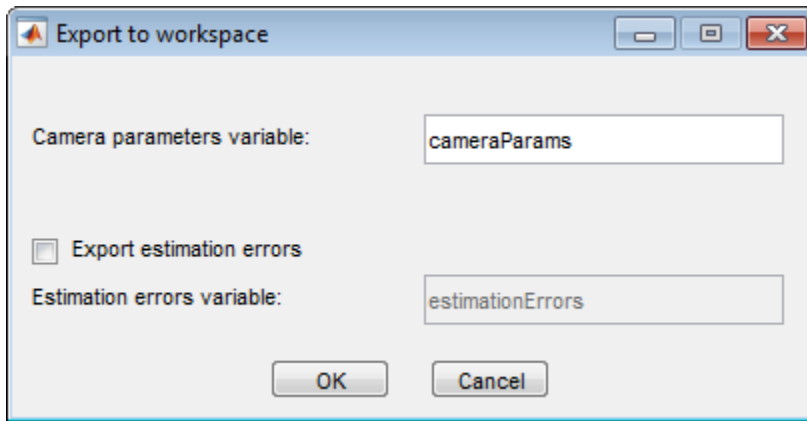
## Export Camera Parameters

When you are satisfied with calibration accuracy, click **Export Camera Parameters**. You can save and export the camera parameters to an object or generate the camera parameters as a MATLAB script.



### Export Camera Parameters

Click **Export Camera Parameters** to create a `cameraParameters` object in your workspace. The object contains the intrinsic and extrinsic parameters of the camera, and the distortion coefficients. You can use this object for various computer vision tasks, such as image undistortion, measuring planar objects, and 3-D reconstruction. See “Measuring Planar Objects with a Calibrated Camera”. You can optionally export the `cameraCalibrationErrors` object, which contains the standard errors of estimated camera parameters.



### Generate MATLAB Script

Click **Generate MATLAB script** to save your camera parameters to a MATLAB script, enabling you to reproduce the steps from your calibration session.

### References

- [1] Zhang, Z. “A Flexible New Technique for Camera Calibration”. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 22, No. 11, 2000, pp. 1330–1334.
- [2] Heikkila, J, and O. Silven. “A Four-step Camera Calibration Procedure with Implicit Image Correction.” *IEEE International Conference on Computer Vision and Pattern Recognition*. 1997.

### See Also

[cameraParameters](#) | [stereoParameters](#) | [Camera Calibrator](#) | [detectCheckerboardPoints](#) | [estimateCameraParameters](#) | [generateCheckerboardPoints](#) | [showExtrinsics](#) | [showReprojectionErrors](#) | [Stereo Camera Calibrator](#) | [undistortImage](#)

### Related Examples

- “Evaluating the Accuracy of Single Camera Calibration”
- “Measuring Planar Objects with a Calibrated Camera”
- “Stereo Calibration and Scene Reconstruction”

- “Depth Estimation From Stereo Video”
- “Sparse 3-D Reconstruction From Two Views”
- “Uncalibrated Stereo Image Rectification”
- Checkerboard pattern

### **More About**

- “Stereo Calibration App”

### **External Web Sites**

- Camera Calibration with MATLAB

## Stereo Calibration App

### In this section...

- “Stereo Camera Calibrator Overview” on page 4-48
- “Stereo Camera Calibration Workflow” on page 4-48
- “Open the Stereo Camera Calibrator” on page 4-49
- “Image, Camera, and Pattern Preparation” on page 4-50
- “Add Image Pairs” on page 4-54
- “Calibrate” on page 4-57
- “Evaluate Calibration Results” on page 4-58
- “Improve Calibration” on page 4-62
- “Export Camera Parameters” on page 4-65

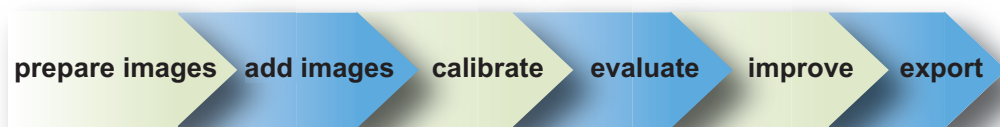
### Stereo Camera Calibrator Overview

You can use the Stereo Camera Calibrator app to calibrate a stereo camera, which you can then use to recover depth from images. A stereo system consists of two cameras: camera 1 and camera 2. The app estimates the parameters of each of the two cameras. It also calculates the position and orientation of camera 2 relative to camera 1.

The app produces an object containing the stereo camera parameters. You can use this object to rectify stereo images using the `rectifyStereoImages` function, reconstruct the 3-*D* scene using the `reconstructScene` function, or compute 3-*D* locations corresponding to matching pairs of image points using the `triangulate` function.

The suite of calibration functions used by the Stereo Camera Calibrator app provide the workflow for stereo system calibration. You can use them directly in the MATLAB workspace. For a list of functions, see “Geometric Camera Calibration”.

### Stereo Camera Calibration Workflow



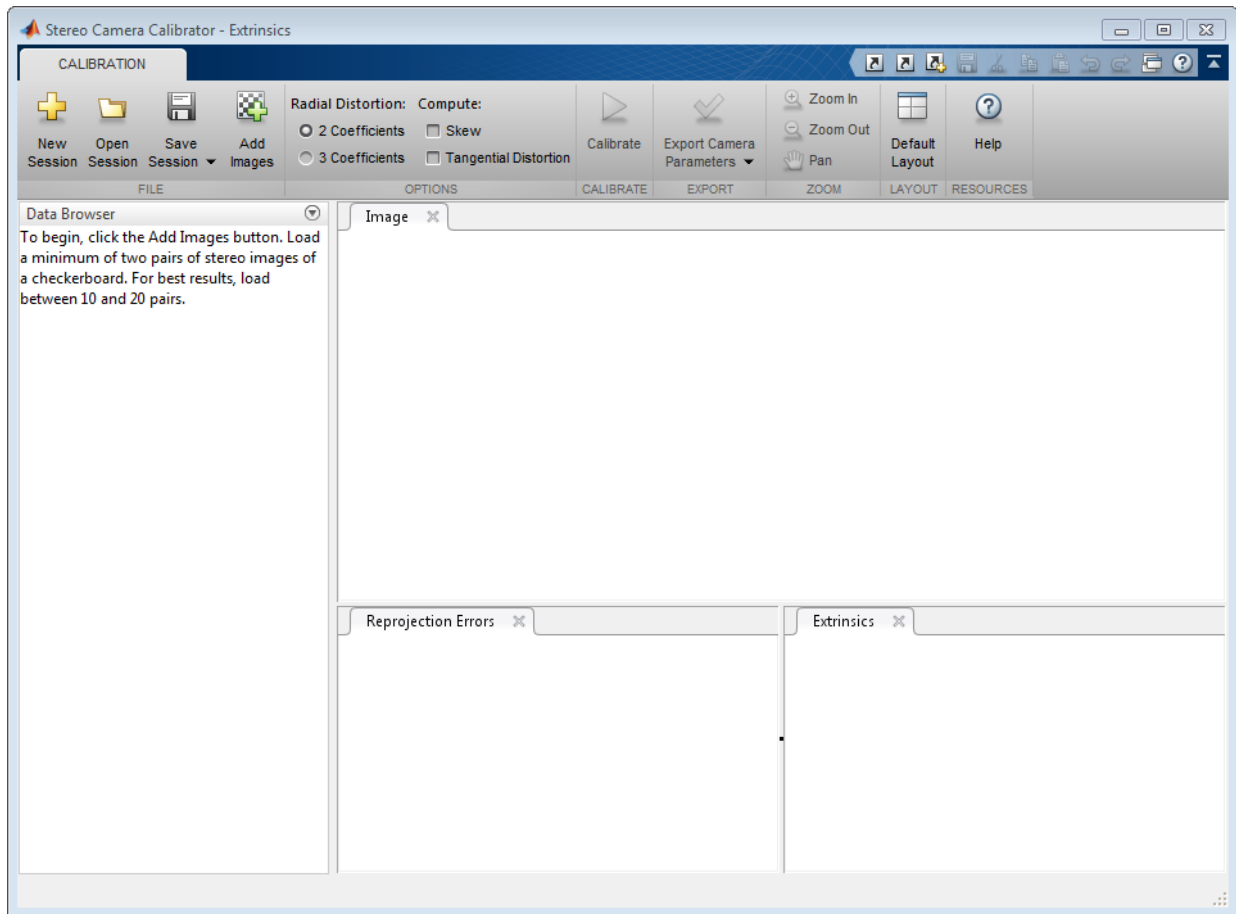
Follow this workflow to calibrate your stereo camera using the app:

- 1 Prepare images, camera, and calibration pattern.
- 2 Load image pairs.
- 3 Calibrate the stereo camera.
- 4 Evaluate calibration accuracy.
- 5 Adjust parameters to improve accuracy (if necessary).
- 6 Export the parameters object.

In some cases, the default values work well, and you do not need to make any improvements before exporting parameters. If you do need to make improvements, you can use the camera calibration functions in MATLAB. For a list of functions, see “Geometric Camera Calibration”.

## Open the Stereo Camera Calibrator

- MATLAB Toolstrip: Open the Apps tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `stereoCameraCalibrator`



### Image, Camera, and Pattern Preparation

For best results, use between 10 and 20 images of the calibration pattern. The calibrator requires at least three images. Use uncompressed images or lossless compression formats such as PNG. The calibration pattern and the camera setup must satisfy a set of requirements to work with the calibrator. For greater calibration accuracy, follow these instructions for preparing the pattern, setting up the camera, and capturing the images.



## Prepare the Checkerboard Pattern

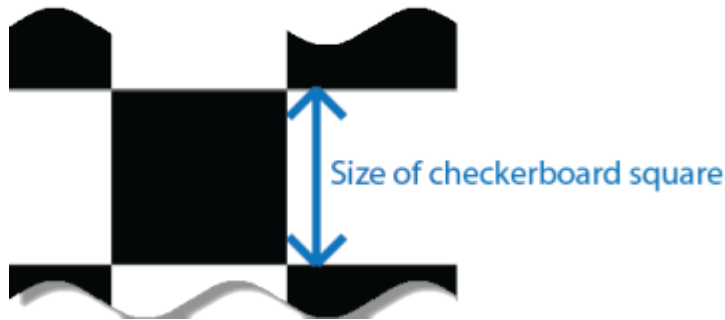
The Camera Calibrator app uses a checkerboard pattern, which is a convenient calibration target. If you want to use a different pattern to extract key points, you can use the camera calibration MATLAB functions directly. See “Geometric Camera Calibration” for the list of functions.

You can print (from MATLAB) and use the checkerboard pattern provided. The checkerboard pattern you use must not be square. One side must contain an even number of squares and the other side must contain an odd number of squares. Therefore, the pattern contains two black corners along one side and two white corners on the opposite side. This criteria enables the app to determine the orientation of the pattern. The calibrator assigns the longer side to be the  $x$ -direction.



To prepare the checkerboard pattern:

- 1 Attach the checkerboard printout to a flat surface. Imperfections on the surface can affect the accuracy of the calibration.
- 2 Measure one side of the checkerboard square. You need this measurement for calibration. The size of the squares can vary depending on printer settings.



- 3 To improve the detection speed, set up the pattern with as little background clutter as possible.

### Camera Setup

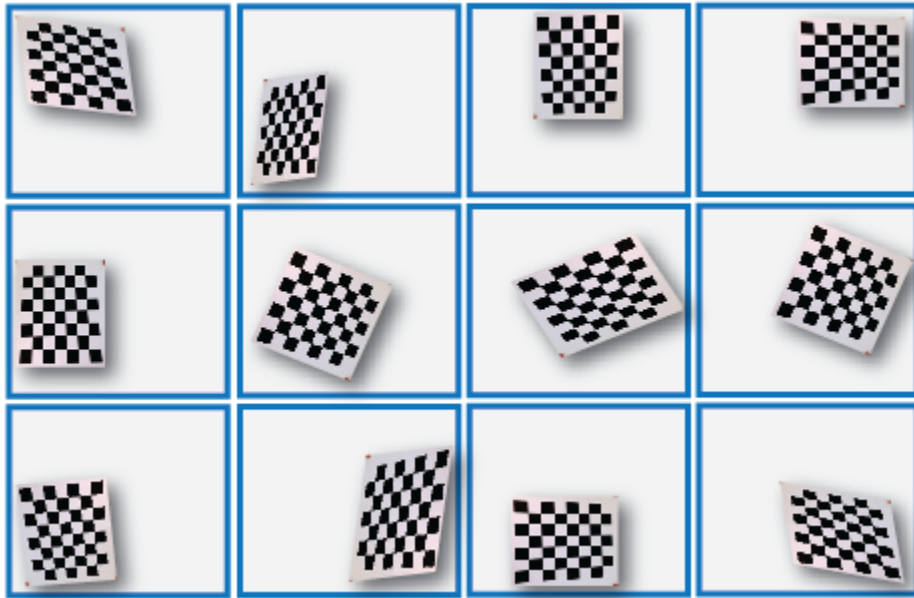
To properly calibrate your camera, follow these rules:

- Keep the pattern in focus, but do not use auto-focus.
- Do not change zoom settings between images, otherwise the focal length changes.

### Capture Images

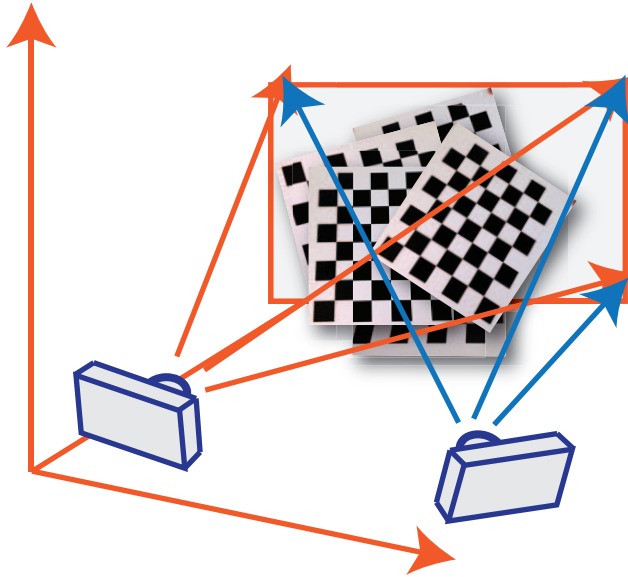
For best results, use at least 10 to 20 images of the calibration pattern. The calibrator requires at least three images. Use uncompressed images or images in lossless compression formats such as PNG. For greater calibration accuracy:

- Capture the images of the pattern at a distance roughly equal to the distance from your camera to the objects of interest. For example, if you plan to measure objects from 2 meters, keep your pattern approximately 2 meters from the camera.
- Place the checkerboard at an angle less than 45 degrees relative to the camera plane.
- Do not modify the images. For example, do not crop them.
- Do not use autofocus or change the zoom between images.
- Capture the images of a checkerboard pattern at different orientations relative to the camera.
- Capture enough different images of the pattern so that you have covered as much of the image frame as possible. Lens distortion increases radially from the center of the image and sometimes is not uniform across the image frame. To capture this lens distortion, the pattern must appear close to the edges.



Specific to stereo camera calibration:

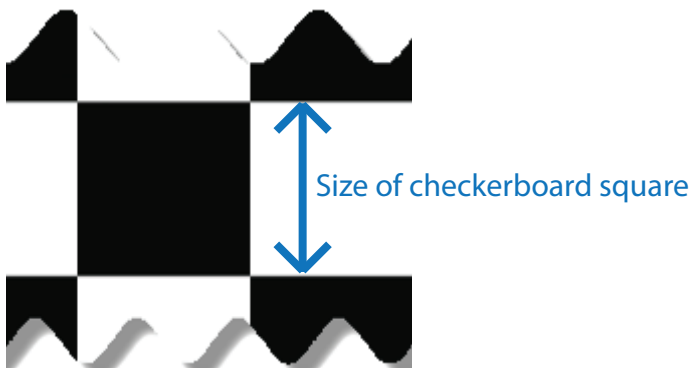
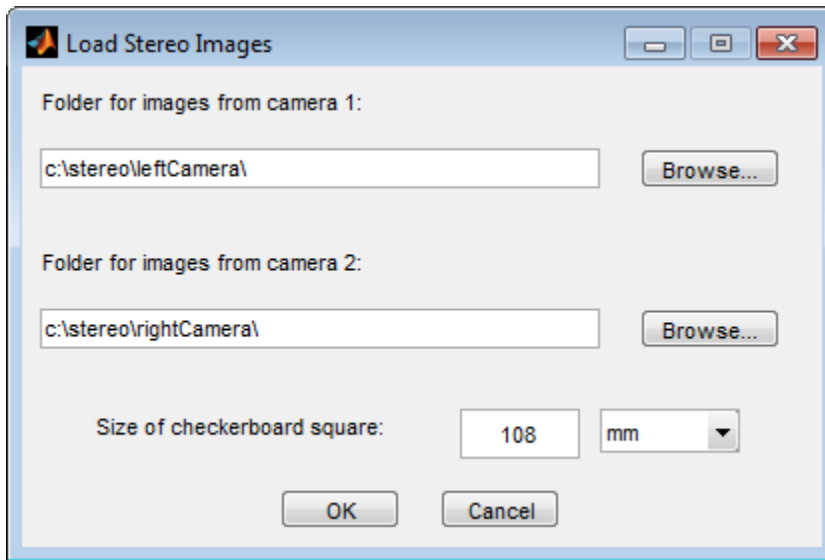
- Make sure the checkerboard pattern is fully visible in both images of each stereo pair.



- Keep the pattern stationary for each image pair. Any motion of the pattern between taking image 1 and image 2 of the pair negatively affects the calibration.
- To create a stereo display, or anaglyph, position the two cameras approximately 55 mm apart. This distance represents the average distance between human eyes.
- For greater reconstruction accuracy at longer distances, position your cameras farther apart.

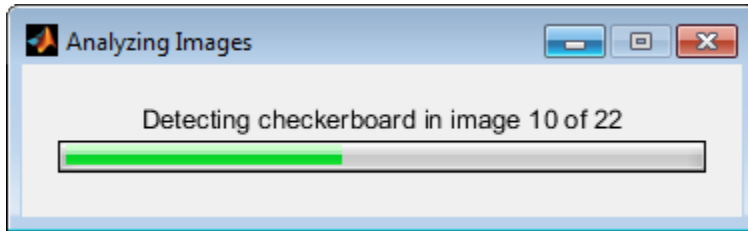
### Add Image Pairs

To begin calibration, click Add images to add two sets of stereo images of the checkerboard. You can add images from multiple folders by clicking Add images. Select the locations for the images corresponding to camera 1 and camera 2. Enter the length of one side of a square from the checkerboard pattern.

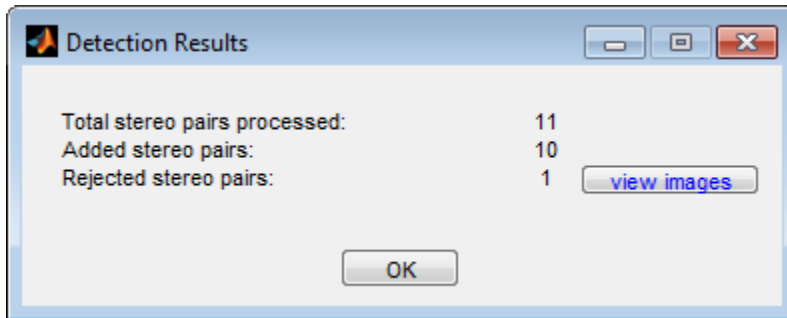


### Analyze Images

The calibrator attempts to detect a checkerboard in each of the added images. An Analyzing Images progress bar window appears, indicating detection progress.



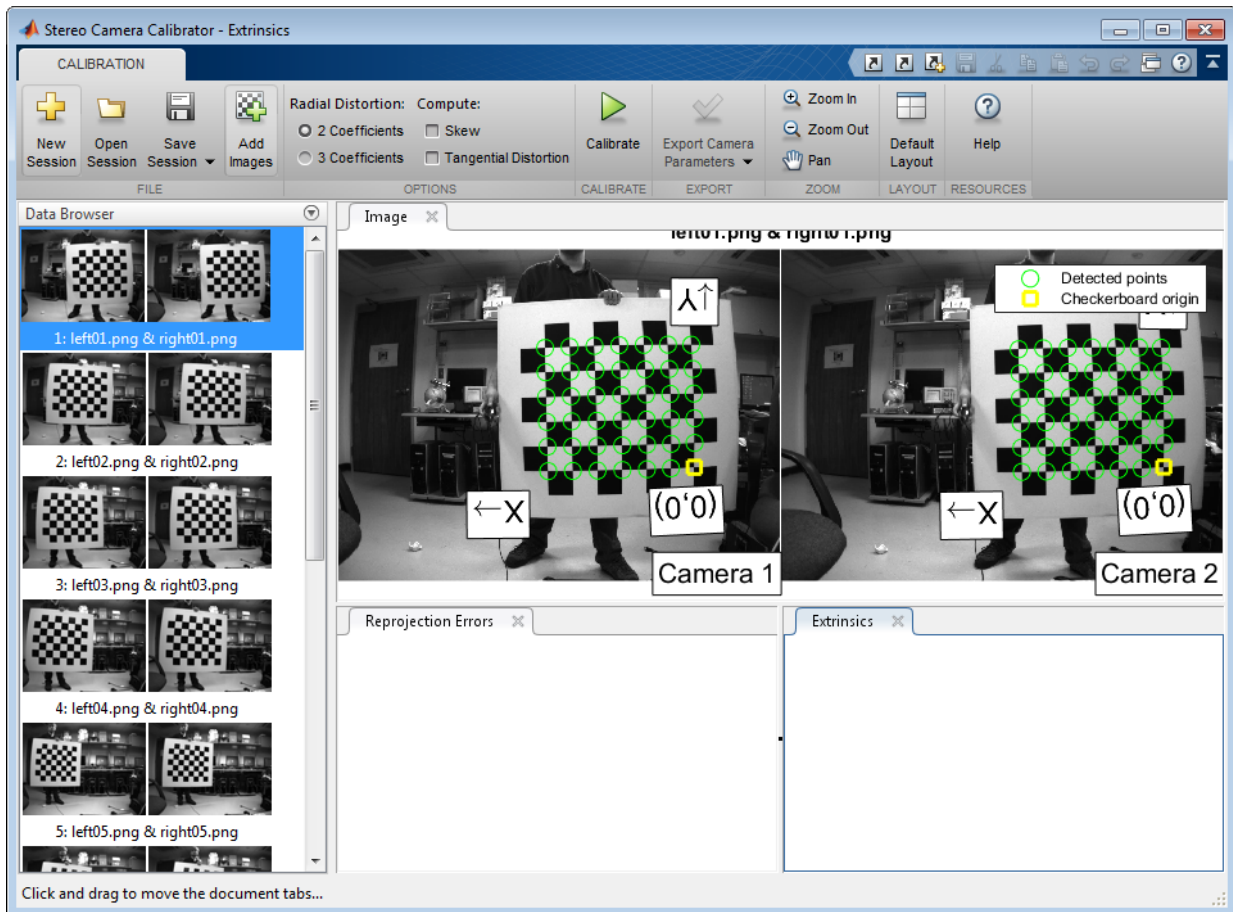
If any of the image pairs are rejected, the Detection Results window appears, which contains diagnostic information. The results indicate how many total image pairs were processed, and how many were accepted, rejected, or skipped. The calibrator skips duplicate images.



To view the rejected images, click **view images**. The calibrator rejects duplicate images. It also rejects images where the entire checkerboard could not be detected. Possible reasons for no detection are a blurry image or an extreme angle of the pattern. Detection takes longer with larger images and with patterns that contain a large number of squares.

### View Images and Detected Points

The Data Browser pane displays a list of image pairs with IDs. These image pairs contain a detected pattern. To view an image, select it from the **Data Browser** pane.



The **Image** pane displays the checkerboard image pair with green circles to indicate detected points. You can verify the corners were detected correctly using the zoom controls on the **View** tab. The yellow square indicates the (0,0) origin. The X and Y arrows indicate the checkerboard axes orientation.

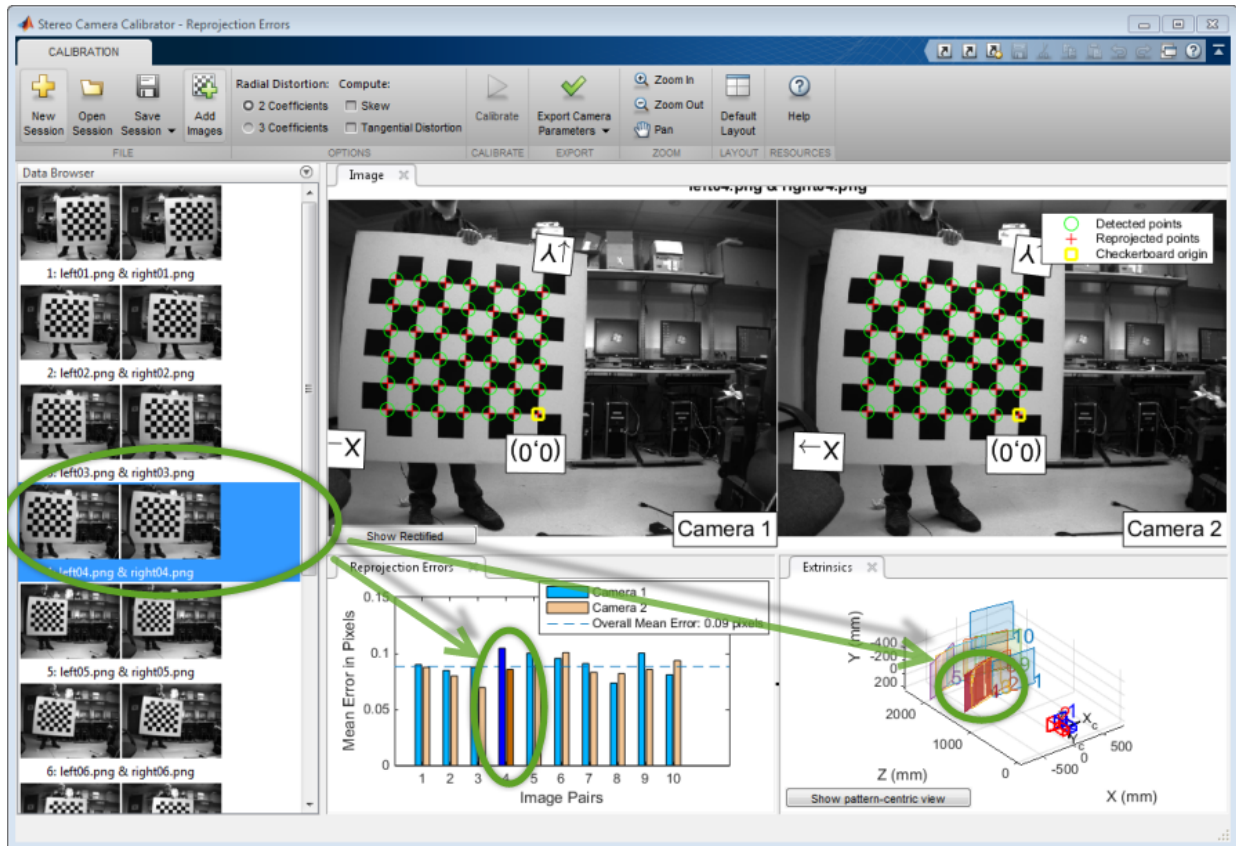
## Calibrate

Once you are satisfied with the accepted image pairs, click Calibrate. The default calibration settings assume the minimum set of camera parameters. Start by running the calibration with the default settings. After evaluating the results, you can try to improve

calibration accuracy by adjusting the settings and adding or removing images, and then calibrate again.

### Evaluate Calibration Results

You can evaluate calibration accuracy by examining the reprojection errors and the camera extrinsics, and by viewing the undistorted image. For best calibration results, use all three methods of evaluation.

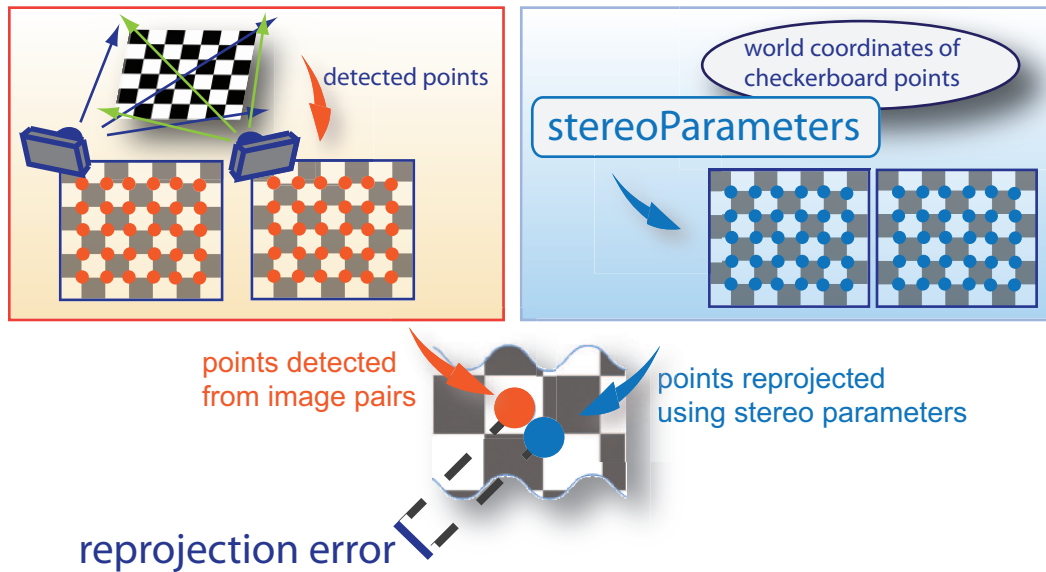


### Examine Reprojection Errors

The *reprojection errors* are the distances in pixels between the detected and the reprojected points. The Stereo Camera Calibrator app calculates reprojection



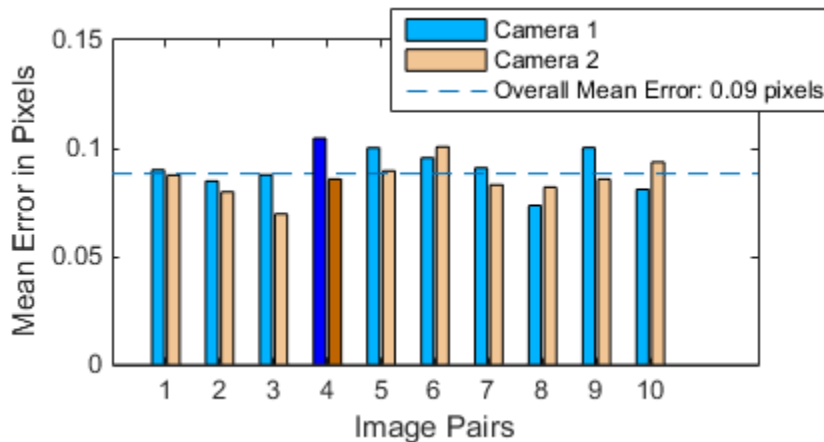
errors by projecting the checkerboard points from world coordinates, defined by the checkerboard, into image coordinates. The app then compares the reprojected points to the corresponding detected points. As a general rule, reprojection errors of less than one pixel are acceptable.



The Stereo Camera Calibrator app displays, in pixels, the reprojection errors as a bar graph and as a scatter plot. You can toggle between them using the button on the display. You can identify the image pairs that adversely contribute to the calibration from either one of the graphs. You can then select and remove those images from the list in the **Data Browser** pane.

### Bar Graph

The bar graph displays the mean reprojection error per image, along with the overall mean error. The bar labels correspond to the image pair IDs. The highlighted pair of bars corresponds to the selected image pair.

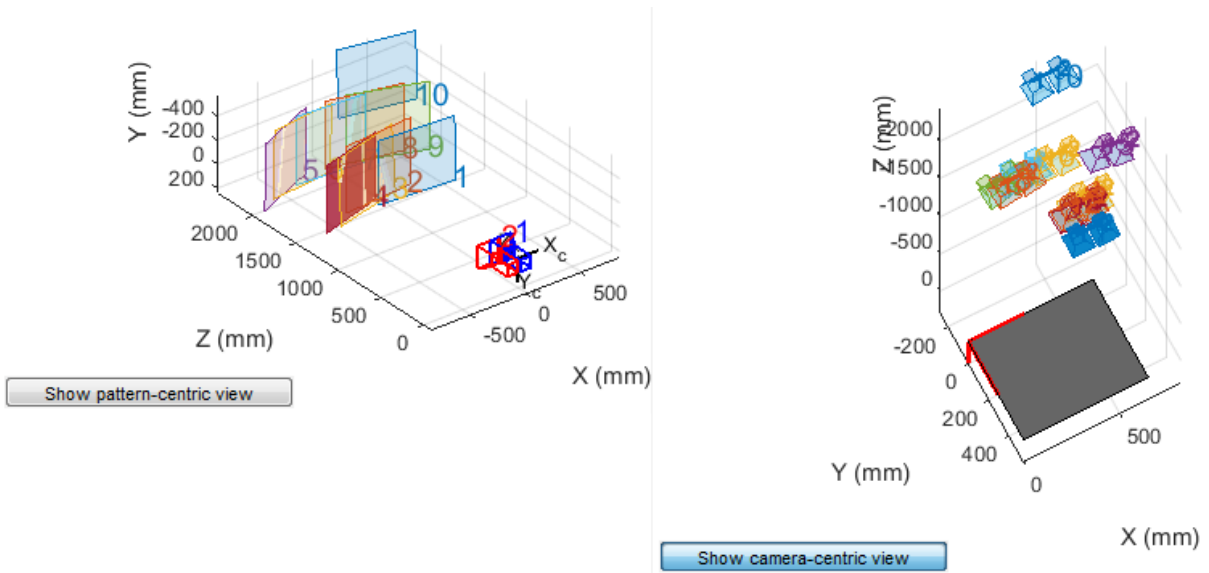


Select an image pair in one of these ways:

- Clicking the corresponding bar in the graph.
- Select the image pair from the list in the **Data Browser** pane.

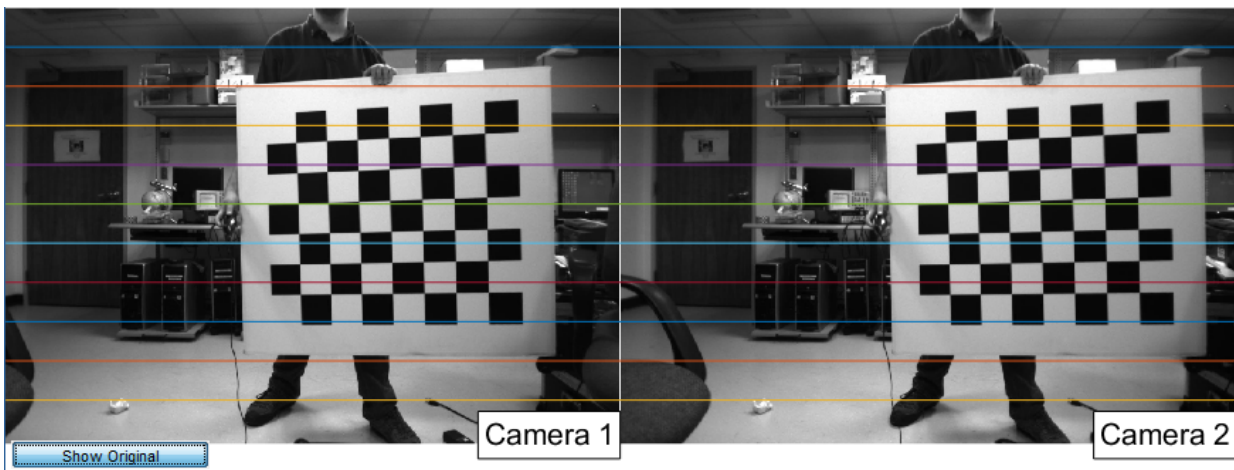
### Examine Extrinsic Parameter Visualization

The 3-D extrinsic parameters plot provides a camera-centric view of the patterns and a pattern-centric view of the camera. The camera-centric view is helpful if the camera was stationary when the images were captured. The pattern-centric view is helpful if the pattern was stationary. Click the button on the display to toggle between the two visuals. Click and drag a graph to rotate it. Click a checkerboard or a camera to select it. The highlighted data in the visualizations correspond to the selected image in the list. Examine the relative positions of the pattern and the camera to see if they match what you expect. For example, a pattern that appears behind the camera indicates a calibration error.

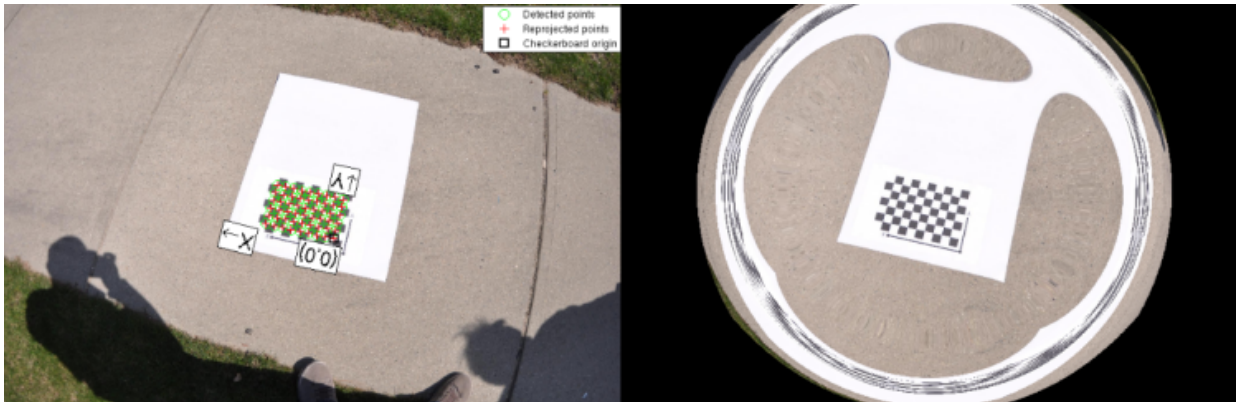


### Show Rectified Images

To view the effects of stereo rectification, in the **Image** pane, click **Show Rectified**. If the calibration was accurate, the images become undistorted and row-aligned.



It is important to check the rectified images even if the reprojection errors are low. Sometimes, if the pattern only covers a small percentage of the image, the calibration achieves low reprojection errors, but the distortion estimation is incorrect. An example of this type of incorrect estimation for single camera calibration is shown below.



### Improve Calibration

To improve the calibration, you can remove high-error image pairs, add more image pairs, or modify the calibrator settings.

#### Add and Remove Image Pairs

Consider adding more image pairs if:

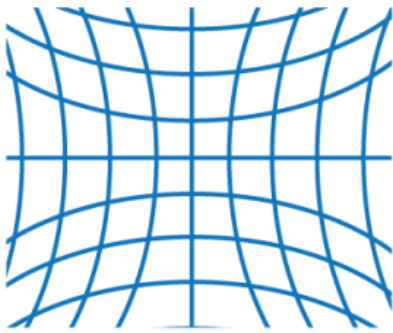
- You have less than 10 image pairs.
- The patterns do not cover enough of the image frame.
- The patterns in your image pairs do not have enough variation in orientation with respect to the camera.

YConsider removing image pairs if the images:

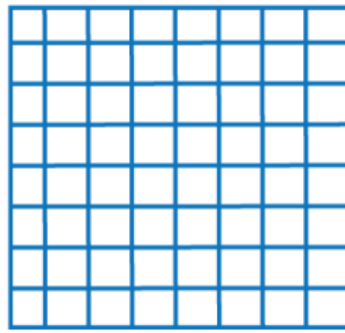
- Have a high mean reprojection error.
- Are blurry.
- Contain a checkerboard at an angle greater than 45 degrees relative to the camera plane.
- Contain incorrectly detected checkerboard points.

### Change the Number of Radial Distortion Coefficients

You can specify 2 or 3 radial distortion coefficients by selecting the corresponding radio button from the **Options** section. *Radial distortion* occurs when light rays bend more near the edges of a lens than they do at its optical center. The smaller the lens, the greater the distortion.



negative radial distortion  
"pincushion"



no distortion



positive radial distortion  
"barrel"

The radial distortion coefficients model this type of distortion. The distorted points are denoted as  $(x_{\text{distorted}}, y_{\text{distorted}})$ :

$$x_{\text{distorted}} = x(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

$$y_{\text{distorted}} = y(1 + k_1 * r^2 + k_2 * r^4 + k_3 * r^6)$$

.

- $x, y$ : undistorted pixel locations
- $k_1, k_2$ , and  $k_3$ : radial distortion coefficients of the lens
- $r^2: x^2 + y^2$

Typically, two coefficients are sufficient for calibration. For severe distortion, such as in wide-angle lenses, select **3 Coefficients** to include  $k_3$ .

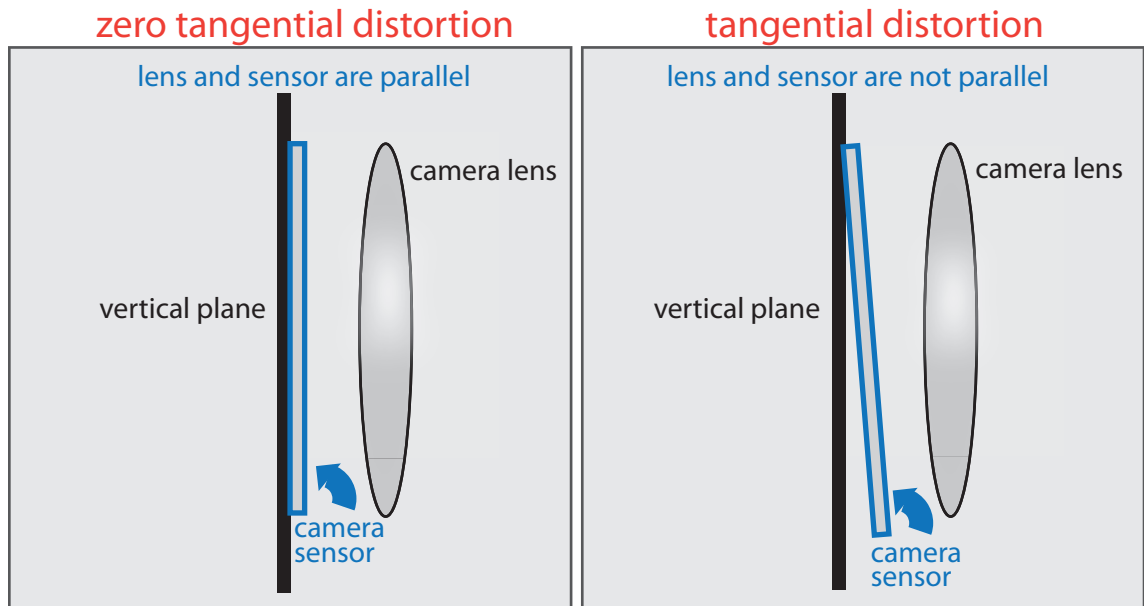
### Compute Skew

When you select the **Compute Skew** check box, the calibrator estimates the image axes skew. Some camera sensors contain imperfections that cause the  $x$ - and  $y$ -axis of the image to not be perpendicular. You can model this defect using a skew parameter. If you

do not select the check box, the image axes are assumed to be perpendicular, which is the case for most modern cameras.

### Compute Tangential Distortion

Tangential distortion occurs when the lens and the image plane are not parallel. The tangential distortion coefficients model this type of distortion.



The distorted points are denoted as  $(x_{\text{distorted}}, y_{\text{distorted}})$ :

$$x_{\text{distorted}} = x + [2 * p_1 * y + p_2 * (r^2 + 2 * x^2)]$$

$$y_{\text{distorted}} = y + [p_1 * (r^2 + 2 * y^2) + 2 * p_2 * x]$$

.

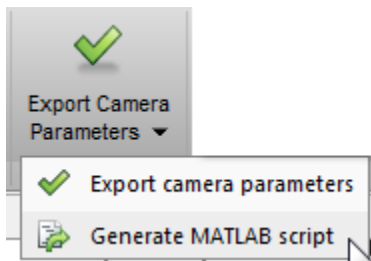
- $x, y$ : undistorted pixel locations
- $p_1$  and  $p_2$ : tangential distortion coefficients of the lens
- $r^2 = x^2 + y^2$

The undistorted pixel locations are in normalized image coordinates, with the origin at the optical center. The coordinates are in world units.

When you select the **Compute Tangential Distortion** check box, the calibrator estimates the tangential distortion coefficients. Otherwise, the calibrator sets the tangential distortion coefficients to zero.

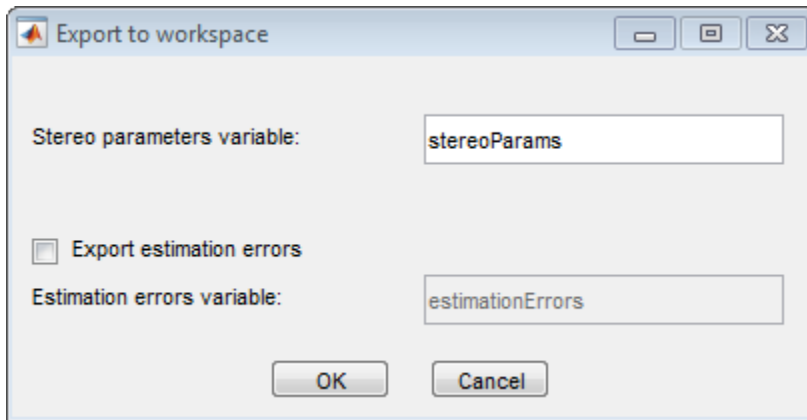
## Export Camera Parameters

When you are satisfied with calibration accuracy, click **Export Camera Parameters**. You can save and export the camera parameters to an object or generate the camera parameters as a MATLAB script.



### Export Camera Parameters

Click **Export Camera Parameters** to create a `stereoParameters` object in your workspace. The object contains the intrinsic and extrinsic parameters of the camera, and the distortion coefficients. You can use this object for various computer vision tasks, such as image undistortion, measuring planar objects, and 3-D reconstruction. See “Stereo Calibration and Scene Reconstruction”. You can optionally export the `stereoCalibrationErrors` object, which contains the standard errors of estimated stereo parameters.



### Generate MATLAB Script

You can also generate a MATLAB script which allows you save and reproduce the steps from your calibration session.

### References

- [1] Zhang, Z. “A Flexible New Technique for Camera Calibration”. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 22, No. 11, 2000, pp. 1330–1334.
- [2] Heikkila, J, and O. Silven. “A Four-step Camera Calibration Procedure with Implicit Image Correction.” *IEEE International Conference on Computer Vision and Pattern Recognition*. 1997.

### See Also

[cameraParameters](#) | [stereoParameters](#) | [Camera Calibrator](#) | [detectCheckerboardPoints](#) | [estimateCameraParameters](#) | [generateCheckerboardPoints](#) | [showExtrinsics](#) | [showReprojectionErrors](#) | [Stereo Camera Calibrator](#) | [undistortImage](#)

### Related Examples

- “Evaluating the Accuracy of Single Camera Calibration”
- “Measuring Planar Objects with a Calibrated Camera”
- “Stereo Calibration and Scene Reconstruction”



- “Depth Estimation From Stereo Video”
- “Sparse 3-D Reconstruction From Two Views”
- “Uncalibrated Stereo Image Rectification”
- Checkerboard pattern

### **More About**

- “Single Camera Calibration App”

### **External Web Sites**

- Camera Calibration with MATLAB



# Object Detection

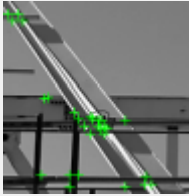

---

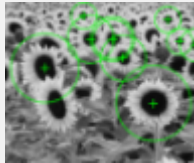

- “Point Feature Types” on page 5-2
- “Local Feature Detection and Extraction” on page 5-7
- “Label Images for Classification Model Training” on page 5-28
- “Train a Cascade Object Detector” on page 5-35
- “Troubleshoot ocr Function Results” on page 5-50
- “Create a Custom Feature Extractor” on page 5-51
- “Image Retrieval with Bag of Visual Words” on page 5-55
- “Image Classification with Bag of Visual Words” on page 5-59

## Point Feature Types

Image feature detection is a building block of many computer vision tasks, such as image registration, tracking, and object detection. The Computer Vision System Toolbox includes a variety of functions for image feature detection. These functions return points objects that store information specific to particular types of features, including (x,y) coordinates (in the Location property). You can pass a points object from a detection function to a variety of other functions that require feature points as inputs. The algorithm that a detection function uses determines the type of points object it returns.

### Functions That Return Points Objects

Points Object	Returned By	Type of Feature
cornerPoints	<b>detectFASTFeatures</b> Features from accelerated segment test (FAST) algorithm Uses an approximate metric to determine corners.[1]	 Corners Single-scale detection Point tracking, image registration with little or no scale change, corner detection in scenes of human origin, such as streets and indoor scenes.
	<b>detectMinEigenFeatures</b> Minimum eigenvalue algorithm Uses minimum eigenvalue metric to determine corner locations. [4]	
	<b>detectHARRISFeatures</b> Harris-Stephens algorithm More efficient than the minimum eigenvalue algorithm.[3]	
BRISKPoints	<b>detectBRISKFeatures</b> Binary Robust Invariant Scalable Keypoints (BRISK) algorithm [6]	

Points Object	Returned By	Type of Feature
		<p>Corners</p> <p>Multiscale detection</p> <p>Point tracking, image registration, handles changes in scale and rotation, corner detection in scenes of human origin, such as streets and indoor scenes</p>
SURFPoints	<p>detectSURFFeatures</p> <p>Speeded-up robust features (SURF) algorithm[11]</p>	 <p>Blobs</p> <p>Multiscale detection</p> <p>Object detection and image registration with scale and rotation changes</p>
MSERRegions	<p>detectMSERFeatures</p> <p>Maximally stable extremal regions (MSER) algorithm</p> <p>[7] [8] [9] [10]</p>	 <p>Regions of uniform intensity</p> <p>Multi-scale detection</p> <p>Registration, wide baseline stereo calibration, text detection, object detection. Handles changes to scale and rotation. More robust to affine transforms in contrast to other detectors.</p>

## Functions That Accept Points Objects

Function	Description	
extractFeatures	Extract interest point descriptors	
	Method	Feature Vector
	BRISK	The function sets the <b>Orientation</b> property of the validPoints output object to the orientation of the extracted features, in radians.
	FREAK	The function sets the <b>Orientation</b> property of the validPoints output object to the orientation of the extracted features, in radians.
	SURF	<p>The function sets the <b>Orientation</b> property of the validPoints output object to the orientation of the extracted features, in radians.</p> <p>When you use an <b>MSERRegions</b> object with the SURF method, the <b>Centroid</b> property of the object extracts SURF descriptors. The <b>Axes</b> property of the object selects the scale of the SURF descriptors such that the circle representing the feature has an area proportional to the MSER ellipse area. The scale is calculated as <math>1/4 * \text{sqrt}((\text{majorAxes}/2) * (\text{minorAxes}/2))</math> and saturated to 1.6, as required by the <b>SURFPnts</b> object.</p>
	Block	<p>Simple square neighborhood.</p> <p>The <b>Block</b> method extracts only the neighborhoods fully contained within the image boundary. Therefore, the output, <b>validPoints</b>, can contain fewer points than the input <b>POINTS</b>.</p>
Auto	The function selects the Method based on the class of the input points and implements: The <b>FREAK</b> method for a <b>cornerPoints</b> input object.	

Function	Description
	<p>The SURF method for a SURFPoints or MSERRegions input object.</p> <p>The FREAK method for a BRISKPoints input object.</p> <p>For an <math>M</math>-by-2 input matrix of <math>[x\ y]</math> coordinates, the function implements the BLOCK method.</p>
extractHOGFeature	Extract histogram of oriented gradients (HOG) features
estimateGeometric	Estimate geometric transform from matching point pairs
triangulate	3-D locations of undistorted matching points in stereo images
estimateFundament	Estimate fundamental matrix from corresponding points in stereo images
estimateUncalibra	Uncalibrated stereo rectification
insertMarker	Insert markers in image or video
showMatchedFeatur	Display corresponding feature points
undistortPoints	Correct point coordinates for lens distortion

## References

- [1] Rosten, E., and T. Drummond, “Machine Learning for High-Speed Corner Detection.” *9th European Conference on Computer Vision*. Vol. 1, 2006, pp. 430–443.
- [2] Mikolajczyk, K., and C. Schmid. “A performance evaluation of local descriptors.” *IEEE Transactions on Pattern Analysis and Machine Intelligence*. Vol. 27, Issue 10, 2005, pp. 1615–1630.
- [3] Harris, C., and M. J. Stephens. “A Combined Corner and Edge Detector.” *Proceedings of the 4th Alvey Vision Conference*. August 1988, pp. 147–152.
- [4] Shi, J., and C. Tomasi. “Good Features to Track.” *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. June 1994, pp. 593–600.
- [5] Tuytelaars, T., and K. Mikolajczyk. “Local Invariant Feature Detectors: A Survey.” *Foundations and Trends in Computer Graphics and Vision*. Vol. 3, Issue 3, 2007, pp. 177–280.

- [6] Leutenegger, S., M. Chli, and R. Siegwart. "BRISK: Binary Robust Invariant Scalable Keypoints." *Proceedings of the IEEE International Conference. ICCV*, 2011.
- [7] Nister, D., and H. Stewenius. "Linear Time Maximally Stable Extremal Regions." *Lecture Notes in Computer Science. 10th European Conference on Computer Vision*. Marseille, France: 2008, no. 5303, pp. 183–196.
- [8] Matas, J., O. Chum, M. Urba, and T. Pajdla. "Robust wide-baseline stereo from maximally stable extremal regions." *Proceedings of British Machine Vision Conference*. 2002, pp. 384–396.
- [9] Obdrzalek D., S. Basovnik, L. Mach, and A. Mikulik. "Detecting Scene Elements Using Maximally Stable Colour Regions." *Communications in Computer and Information Science*. La Ferte-Bernard, France: 2009, Vol. 82 CCIS (2010 12 01), pp 107–115.
- [10] Mikolajczyk, K., T. Tuytelaars, C. Schmid, A. Zisserman, T. Kadir, and L. Van Gool. "A Comparison of Affine Region Detectors." *International Journal of Computer Vision*. Vol. 65, No. 1–2, November, 2005, pp. 43–72 .
- [11] Bay, H., A. Ess, T. Tuytelaars, and L. Van Gool. "SURF:Speeded Up Robust Features." *Computer Vision and Image Understanding (CVIU)*.Vol. 110, No. 3, 2008, pp. 346–359.

### Related Examples

- "Detect BRISK Points in an Image and Mark Their Locations"
- "Find Corner Points in an Image Using the FAST Algorithm"
- "Find Corner Points Using the Harris-Stephens Algorithm"
- "Find Corner Points Using the Eigenvalue Algorithm"
- "Find MSER Regions in an Image"
- "Detect SURF Interest Points in a Grayscale Image"
- "Automatically Detect and Recognize Text in Natural Images"
- "Object Detection in a Cluttered Scene Using Point Feature Matching"
- "Image Search Using Point Features"



## Local Feature Detection and Extraction

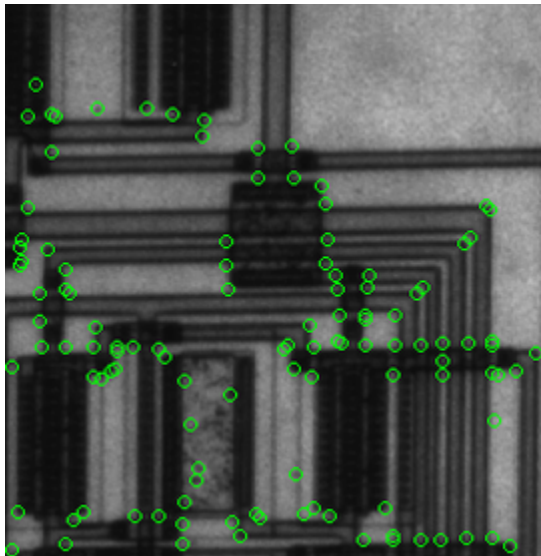
Local features and their descriptors, which are a compact vector representations of a local neighborhood, are the building blocks of many computer vision algorithms. Their applications include image registration, object detection and classification, tracking, and motion estimation. Using local features enables these algorithms to better handle scale changes, rotation, and occlusion. The Computer Vision System Toolbox™ provides the FAST, Harris, and Shi & Tomasi methods for detecting corner features, and the SURF and MSER methods for detecting blob features. The toolbox includes the SURF, FREAK, BRISK, and HOG descriptors. You can mix and match the detectors and the descriptors depending on the requirements of your application.

### What Are Local Features?

Local features refer to a pattern or distinct structure found in an image, such as a point, edge, or small image patch. They are usually associated with an image patch that differs from its immediate surroundings by texture, color, or intensity. What the feature actually represents does not matter, just that it is distinct from its surroundings. Examples of local features are blobs, corners, and edge pixels.

#### Example of Corner Detection

```
I = imread('circuit.tif');
corners = detectFASTFeatures(I,'MinContrast',0.1);
J = insertMarker(I,corners,'circle');
imshow(J);
```



## Benefits and Applications of Local Features

Local features let you find image correspondences regardless of occlusion, changes in viewing conditions, or the presence of clutter. In addition, the properties of local features make them suitable for image classification, such as in “Image Classification with Bag of Visual Words”.

Local features are used in two fundamental ways:

- To localize anchor points for use in image stitching or 3-D reconstruction.
- To represent image contents compactly for detection or classification, without requiring image segmentation.

Application	MATLAB Examples
Image registration and stitching	“Feature Based Panoramic Image Stitching”
Object detection	“Object Detection in a Cluttered Scene Using Point Feature Matching”
Object recognition	“Digit Classification Using HOG Features”
Object tracking	“Face Detection and Tracking Using the KLT Algorithm”

Application	MATLAB Examples
Image category recognition	“Image Category Classification Using Bag of Features”
Finding geometry of a stereo system	“Uncalibrated Stereo Image Rectification”
3-D reconstruction	“Sparse 3-D Reconstruction From Two Views”
Image retrieval	“Image Search Using Point Features”

## What Makes a Good Local Feature?

Detectors that rely on gradient-based and intensity variation approaches detect good local features. These features include edges, blobs, and regions. Good local features exhibit the following properties:

- **Repeatable detections:**  
When given two images of the same scene, most features that the detector finds in both images are the same. The features are robust to changes in viewing conditions and noise.
- **Distinctive:**  
The neighborhood around the feature center varies enough to allow for a reliable comparison between the features.
- **Localizable:**  
The feature has a unique location assigned to it. Changes in viewing conditions do not affect its location.

## Feature Detection and Feature Extraction

*Feature detection* selects regions of an image that have unique content, such as corners or blobs. Use feature detection to find points of interest that you can use for further processing. These points do not necessarily correspond to physical structures, such as the corners of a table. The key to feature detection is to find features that remain locally invariant so that you can detect them even in the presence of rotation or scale change.

*Feature extraction* involves computing a descriptor, which is typically done on regions centered around detected features. Descriptors rely on image processing to transform a local pixel neighborhood into a compact vector representation. This new representation permits comparison between neighborhoods regardless of changes in scale or orientation.

Descriptors, such as SIFT or SURF, rely on local gradient computations. Binary descriptors, such as BRISK or FREAK, rely on pairs of local intensity differences, which are then encoded into a binary vector.

## Choose a Feature Detector and Descriptor

Select the best feature detector and descriptor by considering the criteria of your application and the nature of your data. The first table helps you understand the general criteria to drive your selection. The next two tables provide details on the detectors and descriptors available in Computer Vision System Toolbox.

### Considerations for Selecting a Detector and Descriptor

Criteria	Suggestion
Type of features in your image	Use a detector appropriate for your data. For example, if your image contains an image of bacteria cells, use the blob detector rather than the corner detector. If your image is an aerial view of a city, you can use the corner detector to find man-made structures.
Context in which you are using the features: <ul style="list-style-type: none"> <li>• Matching key points</li> <li>• Classification</li> </ul>	The HOG and SURF descriptors are suitable for classification tasks. In contrast, binary descriptors, such as BRISK and FREAK, are typically used for finding point correspondences between images, which are used for registration.
Type of distortion present in your image	Choose a detector and descriptor that addresses the distortion in your data. For example, if there is no scale change present, consider a corner detector that does not handle scale. If your data contains a higher level of distortion, such as scale and rotation, then use the more computationally intensive SURF feature detector and descriptor.
Performance requirements: <ul style="list-style-type: none"> <li>• Real-time performance required</li> </ul>	Binary descriptors are generally faster but less accurate than gradient-based

Criteria	Suggestion
<ul style="list-style-type: none"> <li>Accuracy versus speed</li> </ul>	descriptors. For greater accuracy, use several detectors and descriptors at the same time.

### Choose a Detection Function Based on Feature Type

Detector	Feature Type	Function	Scale Independent
FAST [1]	Corner	detectFASTFeature	No
Minimum eigenvalue algorithm[4]	Corner	detectMinEigenFea	No
Corner detector [3]	Corner	detectHarrisFeatu	No
SURF [11]	Blob	detectSURFFeature	Yes
BRISK [6]	Corner	detectBRISKFeatur	Yes
MSER [8]	Region with uniform intensity	detectMSERFeature	Yes

**Note:** Detection functions return objects that contain information about the features. The `extractHOGFeatures` and `extractFeatures` functions use these objects to create descriptors.

### Choose a Descriptor Method

Descriptor	Binary	Function and Method	Invariance		Typical Use	
			Scale	Rotation	Finding Point Correspondence	Classification
HOG	No	<code>extractHOGFeatures</code>	No	No	No	Yes
SURF	No	<code>extractFeatures</code> 'Method','SURF'	Yes	Yes	Yes	Yes
FREAK	Yes	<code>extractFeatures</code> 'Method','FREAK'	Yes	Yes	Yes	No
BRISK	Yes	<code>extractFeatures</code> 'Method','BRISK'	Yes	Yes	Yes	No

Descriptor	Binary	Function and Method	Invariance		Typical Use	
			Scale	Rotation	Finding Point Correspondence	Classification
<ul style="list-style-type: none"> <li>Block</li> <li>Simple pixel neighborhood around a keypoint</li> </ul>	No	<code>extractFeatures</code> , 'Method', 'Block'	No	No	Yes	Yes

**Note:**

- The `extractFeatures` function provides different extraction methods to best match the requirements of your application. When you do not specify the 'Method' input for the `extractFeatures` function, the function automatically selects the method based on the type of input point class.
- Binary descriptors are fast but less precise in terms of localization. They are not suitable for classification tasks. The `extractFeatures` function returns a `binaryFeatures` object. This object enables the Hamming-distance-based matching metric used in the `matchFeatures` function.

## Use Local Features

Registering two images is a simple way to understand local features. This example finds a geometric transformation between two images. It uses local features to find well-localized anchor points.

### Display two images.

The first image is the original image.

```
original = imread('cameraman.tif');
figure;
imshow(original);
```



The second image, is the original image rotated and scaled.

```
scale = 1.3;  
J = imresize(original, scale);  
theta = 31;  
distorted = imrotate(J, theta);  
figure  
imshow(distorted)
```



**Detect matching features between the original and distorted image.**

Detecting the matching SURF features is the first step in determining the transform needed to correct the distorted image.

```
ptsOriginal = detectSURFFeatures(original);
```



```
ptsDistorted = detectSURFFeatures(distorted);
```

### **Extract features and compare the detected blobs between the two images.**

The detection step found several roughly corresponding blob structures in both images. Compare the detected blob features. This process is facilitated by feature extraction, which determines a local patch descriptor.

```
[featuresOriginal,validPtsOriginal] = extractFeatures(original,ptsOriginal);
[featuresDistorted,validPtsDistorted] = extractFeatures(distorted,ptsDistorted);
```

It is possible that not all of the original points were used to extract descriptors. Points might have been rejected if they were too close to the image border. Therefore, the valid points are returned in addition to the feature descriptors.

The patch size used to compute the descriptors is determined during the feature extraction step. The patch size corresponds to the scale at which the feature is detected. Regardless of the patch size, the two feature vectors, `featuresOriginal` and `featuresDistorted`, are computed in such a way that they are of equal length. The descriptors enable you to compare detected features, regardless of their size and rotation.

### **Find candidate matches.**

Obtain candidate matches between the features by inputting the descriptors to the `matchFeatures` function. Candidate matches imply that the results can contain some invalid matches. Two patches that match can indicate like features but might not be a correct match. A table corner can look like a chair corner, but the two features are obviously not a match.

```
indexPairs = matchFeatures(featuresOriginal,featuresDistorted);
```

### **Find point locations from both images.**

Each row of the returned `indexPairs` contains two indices of candidate feature matches between the images. Use the indices to collect the actual point locations from both images.

```
matchedOriginal = validPtsOriginal(indexPairs(:,1));
matchedDistorted = validPtsDistorted(indexPairs(:,2));
```

### **Display the candidate matches.**

```
figure
showMatchedFeatures(original,distorted,matchedOriginal,matchedDistorted)
```

```
title('Candidate matched points (including outliers)')
```

**Candidate matched points (including outliers)**



**Analyze the feature locations.**

If there are a sufficient number of valid matches, remove the false matches. An effective technique for this scenario is the RANSAC algorithm. The

`estimateGeometricTransform` function implements M-estimator sample consensus (MSAC), which is a variant of the RANSAC algorithm. MSAC finds a geometric transform and separates the inliers (correct matches) from the outliers (spurious matches).

```
[tform, inlierDistorted,inlierOriginal] = estimateGeometricTransform(matchedDistorted,r
```

**Display the matching points.**

```
figure  
showMatchedFeatures(original,distorted,inlierOriginal,inlierDistorted)  
title('Matching points (inliers only)')  
legend('ptsOriginal','ptsDistorted')
```



**Verify the computed geometric transform.**

Apply the computed geometric transform to the distorted image.

```
outputView = imref2d(size(original));  
recovered = imwarp(distorted,tform,'OutputView',outputView);
```

Display the recovered image and the original image.

```
figure
imshowpair(original, recovered, 'montage')
```



## Image Registration Using Multiple Features

This example builds on the results of the "Use Local Features" example. Using more than one detector and descriptor pair enables you to combine and reinforce your results. Multiple pairs are also useful for when you cannot obtain enough good matches (inliers) using a single feature detector.

Load the original image.

```
original = imread('cameraman.tif');
figure;
imshow(original);
text(size(original,2),size(original,1)+15, ...
     'Image courtesy of Massachusetts Institute of Technology', ...
     'FontSize',7,'HorizontalAlignment','right');
```



Image courtesy of Massachusetts Institute of Technology

Scale and rotate the original image to create the distorted image.

```
scale = 1.3;
J = imresize(original, scale);

theta = 31;
distorted = imrotate(J,theta);
figure
imshow(distorted)
```



Detect the features in both images. Use the BRISK detectors first, followed by the SURF detectors.

```
ptsOriginalBRISK = detectBRISKFeatures(original, 'MinContrast', 0.01);  
ptsDistortedBRISK = detectBRISKFeatures(distorted, 'MinContrast', 0.01);
```

```
ptsOriginalSURF = detectSURFFeatures(original);
ptsDistortedSURF = detectSURFFeatures(distorted);
```

Extract descriptors from the original and distorted images. The BRISK features use the FREAK descriptor by default.

```
[featuresOriginalFREAK, validPtsOriginalBRISK] = extractFeatures(original, ptsOriginal);
[featuresDistortedFREAK, validPtsDistortedBRISK] = extractFeatures(distorted, ptsDistorted);
```

```
[featuresOriginalSURF, validPtsOriginalSURF] = extractFeatures(original, ptsOriginal);
[featuresDistortedSURF, validPtsDistortedSURF] = extractFeatures(distorted, ptsDistorted);
```

Determine candidate matches by matching FREAK descriptors first, and then SURF descriptors. To obtain as many feature matches as possible, start with detector and matching thresholds that are lower than the default values. Once you get a working solution, you can gradually increase the thresholds to reduce the computational load required to extract and match features.

```
indexPairsBRISK = matchFeatures(featuresOriginalFREAK, featuresDistortedFREAK, 'MatchThreshold');
```

```
indexPairsSURF = matchFeatures(featuresOriginalSURF, featuresDistortedSURF);
```

Obtain candidate matched points for BRISK and SURF.

```
matchedOriginalBRISK = validPtsOriginalBRISK(indexPairsBRISK(:,1));
matchedDistortedBRISK = validPtsDistortedBRISK(indexPairsBRISK(:,2));
```

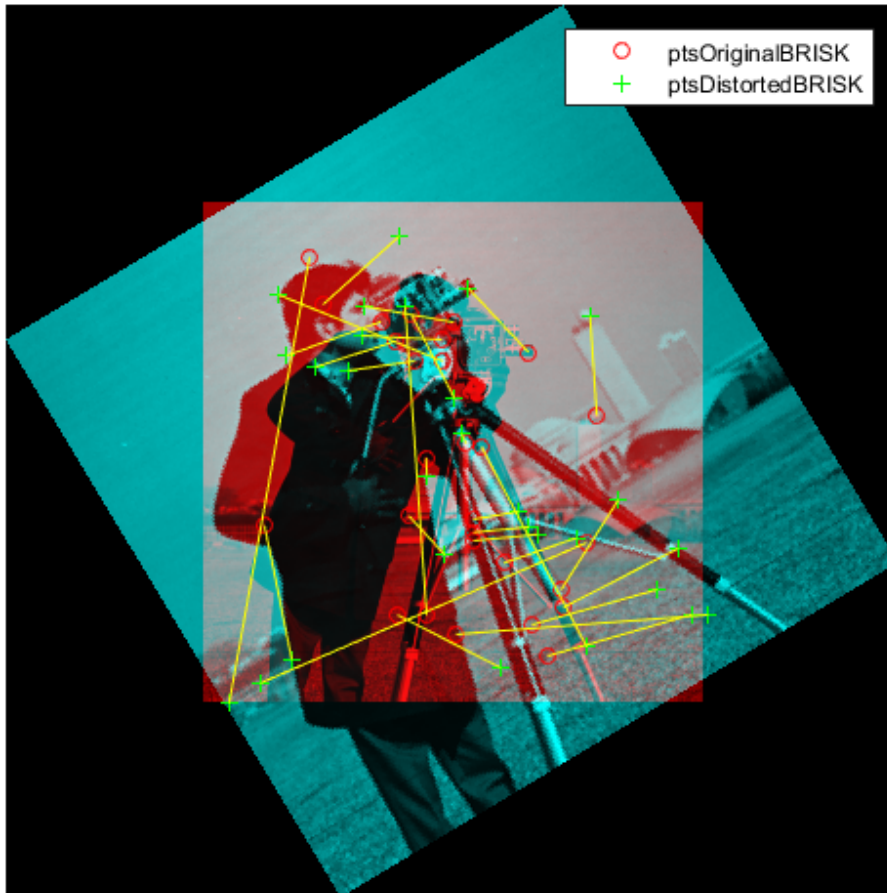
```
matchedOriginalSURF = validPtsOriginalSURF(indexPairsSURF(:,1));
matchedDistortedSURF = validPtsDistortedSURF(indexPairsSURF(:,2));
```

Visualize the BRISK putative matches.

```
figure
showMatchedFeatures(original, distorted, matchedOriginalBRISK, matchedDistortedBRISK)
title('Putative matches using BRISK & FREAK')
legend('ptsOriginalBRISK', 'ptsDistortedBRISK')
```



## Putative matches using BRISK &amp; FREAK



Combine the candidate matched BRISK and SURF local features. Use the `Location` property to combine the point locations from BRISK and SURF features.

```
matchedOriginalXY = [matchedOriginalSURF.Location; matchedOriginalBRISK.Location];  
matchedDistortedXY = [matchedDistortedSURF.Location; matchedDistortedBRISK.Location];
```

Determine the inlier points and the geometric transform of the BRISK and SURF features.

```
[tformTotal,inlierDistortedXY,inlierOriginalXY] = estimateGeometricTransform(matchedDi
```

Display the results. The result provides several more matches than the example that used a single feature detector.

```
figure  
showMatchedFeatures(original,distorted,inlierOriginalXY,inlierDistortedXY)  
title('Matching points using SURF and BRISK (inliers only)')  
legend('ptsOriginal','ptsDistorted')
```

## Matching points using SURF and BRISK (inliers only)



Compare the original and recovered image.

```
outputView = imref2d(size(original));  
recovered = imwarp(distorted,tformTotal, 'OutputView',outputView);  
  
figure;
```

```
imshowpair(original, recovered, 'montage')
```



### References

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## Related Examples

- "Detect BRISK Points in an Image and Mark Their Locations"
- "Find Corner Points in an Image Using the FAST Algorithm"
- "Find Corner Points Using the Harris-Stephens Algorithm"
- "Find Corner Points Using the Eigenvalue Algorithm"
- "Find MSER Regions in an Image"
- "Detect SURF Interest Points in a Grayscale Image"
- "Automatically Detect and Recognize Text in Natural Images"
- "Object Detection in a Cluttered Scene Using Point Feature Matching"
- "Image Search Using Point Features"

## Label Images for Classification Model Training

In this section...
“Description” on page 5-28
“Open the Training Image Labeler” on page 5-28
“App Controls” on page 5-28
“Example” on page 5-32

### Description

The Training Image Labeler provides an easy way to label positive samples that the `trainCascadeObjectDetector` function uses to create a cascade classifier. Using this app, you can:

- Interactively specify rectangular regions of interest (ROIs).
- Using the ROIs, you can detect objects of interest in target images with the `vision.CascadeObjectDetector` System object.
- You can load multiple images at one time, draw ROIs, and then export the ROI information in the appropriate format for the `trainCascadeObjectDetector`. The labeler app supports all image data formats that the `trainCascadeObjectDetector` function uses.

### Open the Training Image Labeler

- MATLAB Toolstrip: Open the Apps tab, under **Image Processing and Computer Vision**, click the app icon.
- MATLAB command prompt: Enter `trainingImageLabeler`

### App Controls

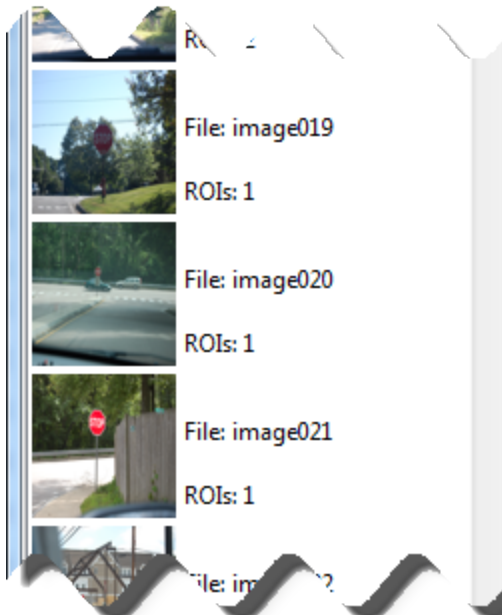
You can add an unlimited number of images to the **Data Browser**. You can then select, remove, and create ROIs, and save your session. When you are done, you can export the ROI information to an XML file.



### Add Images


Use the **Add Images** icon to select and add images to the **Data Browser**. You can add more images at any time during your editing session. The source images remain in the folder where they were originally located. The app does not make copies of the original images or move them. If you rotate the images in the **Data Browser**, the app overwrites the images in their original location with the modified orientation.

The app provides a list of image thumbnails that you loaded for the session. Next to each thumbnail, you see the file name and number of ROIs created in that image.



### Specify Regions of Interest

After you have loaded images, you can delineate ROIs. You can switch between images and continue creating ROIs. Drag the cursor over the object in the image that you want to identify for an ROI. You can modify the size of an ROI by clicking either the corner or side grips. To copy and paste an ROI, left-click within its border to select it. You can

select one or more ROIs to move or to copy and paste. To delete an ROI, click the red x-box, , in the upper-right corner.



Remove  
Rotate  
Sort

### Remove, Rotate, and Sort Images

You can remove, rotate, or sort the images. Right-click any image to access these options. To select multiple images, press **Ctrl**+click. To select consecutive images, press **Shift**+click. To sort images by the number of ROIs, from least amount of ROIs contained in each image, right-click any image and select **Sort list by number of ROIs**.



### New Session

When you start a new session, you can save the current session before clearing it.





### Open Session

You can open a new session to replace or add to the current session. The app loads the selected .MAT session file. To replace your current session, from the **Open Session** options, select **Open an existing session**. To combine multiple sessions, select **Add session to the current session**.



### Save Session

You can name and save your session to a .MAT file. The default name is `LabelingSession`. The saved session file contains all the required information to reload the session in the state that you saved it. It contains the paths to the original images, the coordinates for the ROI bounding boxes for each image, file names, and logical information to record the state of the files.



### Export ROIs

When you click the **Export ROIs** button, the app exports the ROI information to the MATLAB workspace in a 1-by- $M$  structure, where  $M$  represents the number of images. The structure contains two fields. One field stores the image file location and the other field stores the corresponding ROI information for each image. You are prompted to name the variable or to accept the default `positiveInstances` name. The first field, `imageFileName`, contains the full path and file name of the images. The app does not copy and resave images, so the stored path refers to the original image and folder that you loaded the images from. The second field, `objectBoundingBoxes`, contains the ROI [ $x$ ,  $y$ ,  $width$ ,  $height$ ] information.

Fields	ImageFileName	BoundingBoxes
1	'E:\jobarchive\Bvisio...	[1273,1063,225,229]
2	'E:\jobarchive\Bvisio...	[1317,916,104,134]
3	'E:\jobarchive\Bvisio...	[1308,592,186,238]

## Example

### Train a Five-Stage Stop-Sign Detector

This example shows how to set up and train a five-stage, stop-sign detector, using 86 positive samples. The default value for TruePositiveRate is 0.995.

Step 1: Load the positive samples data from a MAT file. File names and bounding boxes are contained in the array of structures labeled 'data'.

```
load('stopSigns.mat');
```

Step 2: Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages');
addpath(imDir);
```

Step 3: Specify folder with negative images.

```
negativeFolder = fullfile(matlabroot,'toolbox','vision','visiondata','non_stop_signs');
```

Step 4: Train the detector.

```
trainCascadeObjectDetector('stopSignDetector.xml',data,negativeFolder,'FalseAlarmRate');
```

Computer Vision software returns the following message:

```
Automatically setting ObjectTrainingSize to [ 33, 32 ]
Using at most 86 of 86 positive samples per stage
Using at most 172 negative samples per stage

Training stage 1 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 2 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 3 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 4 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 5 of 5
[.....]
Used 86 positive and 172 negative samples

Training complete
```

Notice that all 86 positive samples were used to train each stage. This is because the true-positive rate is very high relative to the number of positive samples.

## See Also

[vision.CascadeObjectDetector | imrect | insertObjectAnnotation | trainCascadeObjectDetector](#) | Training Image Labeler

## More About

- “Train a Cascade Object Detector”

## **External Web Sites**

- Cascade Training GUI

## Train a Cascade Object Detector

### In this section...

“Why Train a Detector?” on page 5-35

“What Kinds of Objects Can You Detect?” on page 5-35

“How Does the Cascade Classifier Work?” on page 5-36

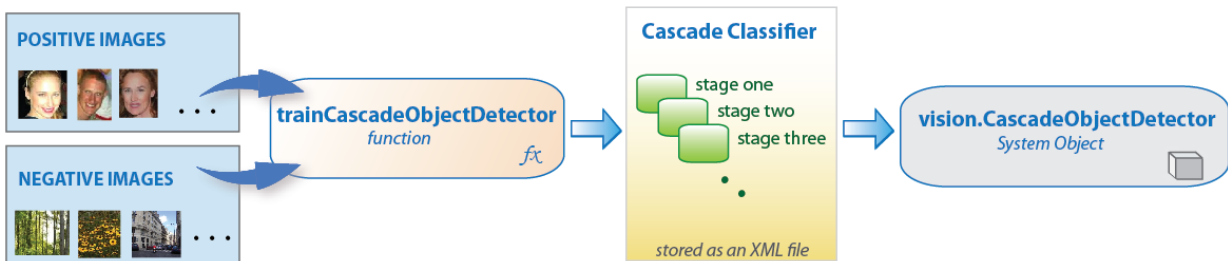
“Create a Cascade Classifier Using the `trainCascadeObjectDetector`” on page 5-37

“Troubleshooting” on page 5-41

“Examples” on page 5-42

### Why Train a Detector?

The `vision.CascadeObjectDetector` System object comes with several pretrained classifiers for detecting frontal faces, profile faces, noses, eyes, and the upper body. However, these classifiers are not always sufficient for a particular application. Computer Vision System Toolbox provides the `trainCascadeObjectDetector` function to train a custom classifier.



### What Kinds of Objects Can You Detect?

The Computer Vision System Toolbox cascade object detector can detect object categories whose aspect ratio does not vary significantly. Objects whose aspect ratio remains approximately fixed include faces, stop signs, and cars viewed from one side.

The `vision.CascadeObjectDetector` System object detects objects in images by sliding a window over the image. The detector then uses a cascade classifier to decide whether the window contains the object of interest. The size of the window varies to

detect objects at different scales, but its aspect ratio remains fixed. The detector is very sensitive to out-of-plane rotation, because the aspect ratio changes for most 3-D objects. Thus, you need to train a detector for each orientation of the object. Training a single detector to handle all orientations will not work.

## How Does the Cascade Classifier Work?

The cascade classifier consists of stages, where each stage is an ensemble of weak learners. The weak learners are simple classifiers called *decision stumps*. Each stage is trained using a technique called boosting. *Boosting* provides the ability to train a highly accurate classifier by taking a weighted average of the decisions made by the weak learners.

Each stage of the classifier labels the region defined by the current location of the sliding window as either positive or negative. *Positive* indicates that an object was found and *negative* indicates no objects were found. If the label is negative, the classification of this region is complete, and the detector slides the window to the next location. If the label is positive, the classifier passes the region to the next stage. The detector reports an object found at the current window location when the final stage classifies the region as positive.

The stages are designed to reject negative samples as fast as possible. The assumption is that the vast majority of windows do not contain the object of interest. Conversely, true positives are rare and worth taking the time to verify.

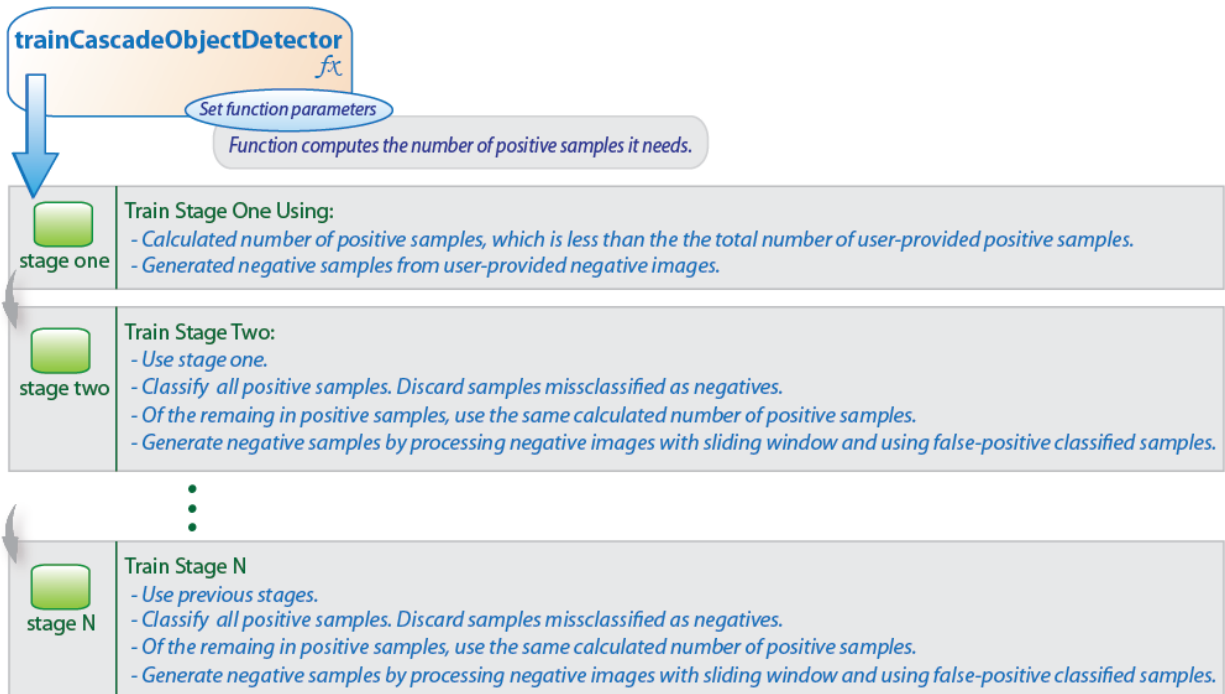
- A *true positive* occurs when a positive sample is correctly classified.
- A *false positive* occurs when a negative sample is mistakenly classified as positive.
- A *false negative* occurs when a positive sample is mistakenly classified as negative.

To work well, each stage in the cascade must have a low false negative rate. If a stage incorrectly labels an object as negative, the classification stops, and you cannot correct the mistake. However, each stage can have a high false positive rate. Even if the detector incorrectly labels a nonobject as positive, you can correct the mistake in subsequent stages.

The overall false positive rate of the cascade classifier is  $f^s$ , where  $f$  is the false positive rate per stage in the range (0 1), and  $s$  is the number of stages. Similarly, the overall true positive rate is  $t^s$ , where  $t$  is the true positive rate per stage in the range (0 1]. Thus, adding more stages reduces the overall false positive rate, but it also reduces the overall true positive rate.

## Create a Cascade Classifier Using the `trainCascadeObjectDetector`

Cascade classifier training requires a set of positive samples and a set of negative images. You must provide a set of positive images with regions of interest specified to be used as positive samples. You can use the Training Image Labeler to label objects of interest with bounding boxes. The Training Image Labeler outputs an array of structs to use for positive samples. You also must provide a set of negative images from which the function generates negative samples automatically. To achieve acceptable detector accuracy, set the number of stages, feature type, and other function parameters.



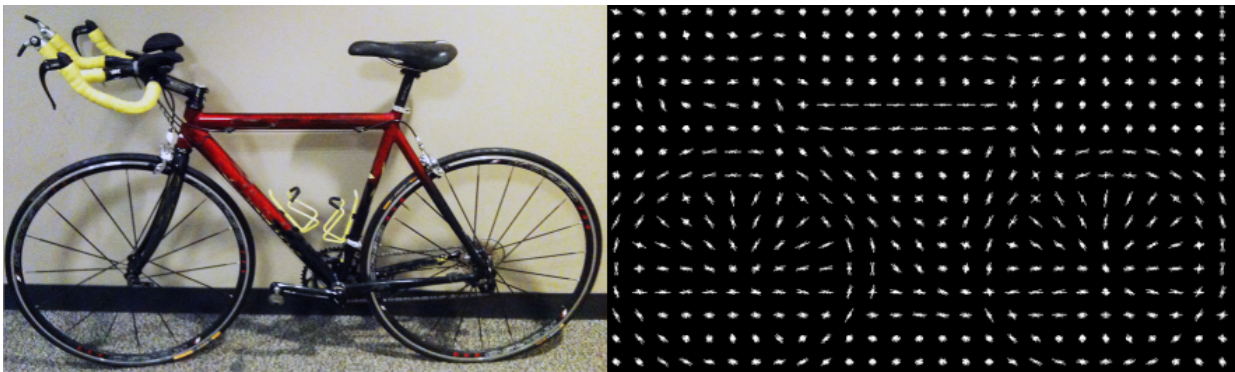
### Considerations when Setting Parameters

Select the function parameters to optimize the number of stages, the false positive rate, the true positive rate, and the type of features to use for training. When you set the parameters, consider these tradeoffs.

Condition	Consideration
A large training set (in the thousands).	Increase the number of stages and set a higher false positive rate for each stage.
A small training set.	Decrease the number of stages and set a lower false positive rate for each stage.
To reduce the probability of missing an object.	Increase the true positive rate. However, a high true positive rate can prevent you from achieving the desired false positive rate per stage, making the detector more likely to produce false detections.
To reduce the number of false detections.	Increase the number of stages or decrease the false alarm rate per stage.

### Feature Types Available for Training

Choose the feature that suits the type of object detection you need. The `trainCascadeObjectDetector` supports three types of features: Haar, local binary patterns (LBP), and histograms of oriented gradients (HOG). Haar and LBP features are often used to detect faces because they work well for representing fine-scale textures. The HOG features are often used to detect objects such as people and cars. They are useful for capturing the overall shape of an object. For example, in the following visualization of the HOG features, you can see the outline of the bicycle.



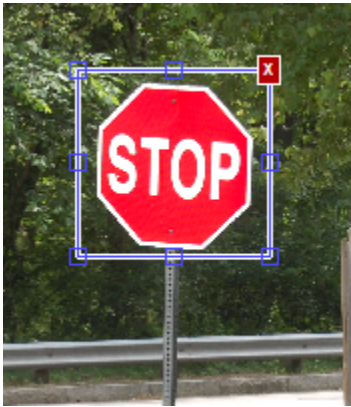
You might need to run the `trainCascadeObjectDetector` function multiple times to tune the parameters. To save time, you can use LBP or HOG features on a small subset



of your data. Training a detector using Haar features takes much longer. After that, you can run the Haar features to see if the accuracy improves.

### Supply Positive Samples

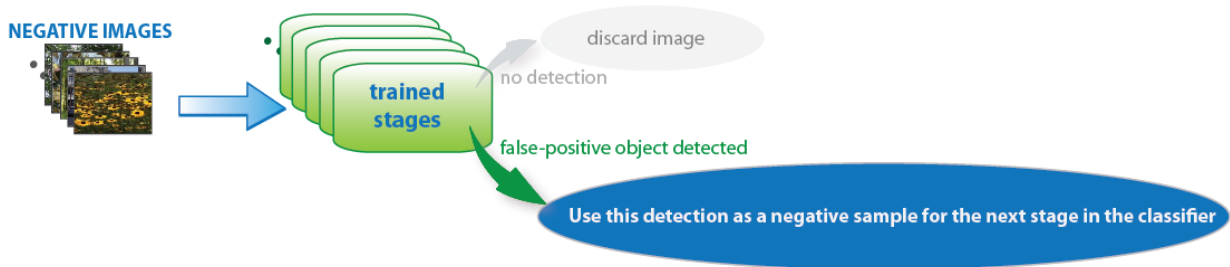
To create positive samples easily, you can use the Training Image Labeler app. The Training Image Labeler provides an easy way to label positive samples by interactively specifying rectangular regions of interest (ROIs).



You can also specify positive samples manually in one of two ways. One way is to specify rectangular regions in a larger image. The regions contain the objects of interest. The other approach is to crop out the object of interest from the image and save it as a separate image. Then, you can specify the region to be the entire image. You can also generate more positive samples from existing ones by adding rotation or noise, or by varying brightness or contrast.

### Supply Negative Images

Negative samples are not specified explicitly. Instead, the `trainCascadeObjectDetector` function automatically generates negative samples from user-supplied negative images that do not contain objects of interest. Before training each new stage, the function runs the detector consisting of the stages already trained on the negative images. Any objects detected from these image are false positives, which are used as negative samples. In this way, each new stage of the cascade is trained to correct mistakes made by previous stages.



As more stages are added, the detector's overall false positive rate decreases, causing generation of negative samples to be more difficult. For this reason, it is helpful to supply as many negative images as possible. To improve training accuracy, supply negative images that contain backgrounds typically associated with the objects of interest. Also, include negative images that contain nonobjects similar in appearance to the objects of interest. For example, if you are training a stop-sign detector, include negative images that contain road signs and shapes similar to a stop sign.

### Choose the Number of Stages

There is a trade-off between fewer stages with a lower false positive rate per stage or more stages with a higher false positive rate per stage. Stages with a lower false positive rate are more complex because they contain a greater number of weak learners. Stages with a higher false positive rate contain fewer weak learners. Generally, it is better to have a greater number of simple stages because at each stage the overall false positive rate decreases exponentially. For example, if the false positive rate at each stage is 50%, then the overall false positive rate of a cascade classifier with two stages is 25%. With three stages, it becomes 12.5%, and so on. However, the greater the number of stages, the greater the amount of training data the classifier requires. Also, increasing the number of stages increases the false negative rate. This increase results in a greater chance of rejecting a positive sample by mistake. Set the false positive rate (`FalseAlarmRate`) and the number of stages, (`NumCascadeStages`) to yield an acceptable overall false positive rate. Then you can tune these two parameters experimentally.

Training can sometimes terminate early. For example, suppose that training stops after seven stages, even though you set the number of stages parameter to 20. It is possible that the function cannot generate enough negative samples. If you run the function again and set the number of stages to seven, you do not get the same result. The results between stages differ because the number of positive and negative samples to use for each stage is recalculated for the new number of stages.

## Training Time of Detector

Training a good detector requires thousands of training samples. Large amounts of training data can take hours or even days to process. During training, the function displays the time it took to train each stage in the MATLAB Command Window. Training time depends on the type of feature you specify. Using Haar features takes much longer than using LBP or HOG features.

## Troubleshooting

### What if you run out of positive samples?

The `trainCascadeObjectDetector` function automatically determines the number of positive samples to use to train each stage. The number is based on the total number of positive samples supplied by the user and the values of the `TruePositiveRate` and `NumCascadeStages` parameters.

The number of available positive samples used to train each stage depends on the true positive rate. The rate specifies what percentage of positive samples the function can classify as negative. If a sample is classified as a negative by any stage, it never reaches subsequent stages. For example, suppose you set the `TruePositiveRate` to `0.9`, and all of the available samples are used to train the first stage. In this case, 10% of the positive samples are rejected as negatives, and only 90% of the total positive samples are available for training the second stage. If training continues, then each stage is trained with fewer and fewer samples. Each subsequent stage must solve an increasingly more difficult classification problem with fewer positive samples. With each stage getting fewer samples, the later stages are likely to overfit the data.

Ideally, use the same number of samples to train each stage. To do so, the number of positive samples used to train each stage must be less than the total number of available positive samples. The only exception is that when the value of `TruePositiveRate` times the total number of positive samples is less than 1, no positive samples are rejected as negatives.

The function calculates the number of positive samples to use at each stage using the following formula:

$$\text{number of positive samples} = \text{floor}(\text{totalPositiveSamples} / (1 + (\text{NumCascadeStages} - 1) * (1 - \text{TruePositiveRate})))$$

This calculation does not guarantee that the same number of positive samples are available for each stage. The reason is that it is impossible to predict with certainty how many positive samples will be rejected as negatives. The training continues as long

as the number of positive samples available to train a stage is greater than 10% of the number of samples the function determined automatically using the preceding formula. If there are not enough positive samples the training stops and the function issues a warning. The function also outputs a classifier consisting of the stages that it had trained up to that point. If the training stops, you can add more positive samples. Alternatively, you can increase `TruePositiveRate`. Reducing the number of stages can also work, but such reduction can also result in a higher overall false alarm rate.

### What to do if you run out of negative samples?

The function calculates the number of negative samples used at each stage. This calculation is done by multiplying the number of positive samples used at each stage by the value of `NegativeSamplesFactor`.

Just as with positive samples, there is no guarantee that the calculated number of negative samples are always available for a particular stage. The `trainCascadeObjectDetector` function generates negative samples from the negative images. However, with each new stage, the overall false alarm rate of the cascade classifier decreases, making it less likely to find the negative samples.

The training continues as long as the number of negative samples available to train a stage is greater than 10% of the calculated number of negative samples. If there are not enough negative samples, the training stops and the function issues a warning. It outputs a classifier consisting of the stages that it had trained up to that point. When the training stops, the best approach is to add more negative images. Alternatively, you can reduce the number of stages or increase the false positive rate.

## Examples

### Train a Five-Stage Stop-Sign Detector

This example shows you how to set up and train a five-stage, stop-sign detector, using 86 positive samples. The default value for `TruePositiveRate` is `0.995`.

Step 1: Load the positive samples data from a MAT-file. File names and bounding boxes are contained in the array of structures labeled `'data'`.

```
load('stopSigns.mat');
```

Step 2: Add the image directory to the MATLAB path.

```
imDir = fullfile(matlabroot,'toolbox','vision','visiondata','stopSignImages');
```

```
addpath(imDir);
```

Step 3: Specify the folder with negative images.

```
negativeFolder = fullfile(matlabroot,'toolbox','vision','visiondata','non_stop_signs');
```

Step 4: Train the detector.

```
trainCascadeObjectDetector('stopSignDetector.xml',data,negativeFolder,'FalseAlarmRate');
```

Computer Vision System Toolbox software returns the following message:

```
Automatically setting ObjectTrainingSize to [ 33, 32 ]
Using at most 86 of 86 positive samples per stage
Using at most 172 negative samples per stage

Training stage 1 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 2 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 3 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 4 of 5
[.....]
Used 86 positive and 172 negative samples

Training stage 5 of 5
[.....]
Used 86 positive and 172 negative samples

Training complete
```

All 86 positive samples were used to train each stage. This high rate occurs because the true positive rate is very high relative to the number of positive samples.

### Train a Five-Stage Stop-Sign Detector with a Decreased True Positive Rate

This example shows you how to train a stop-sign detector on the same data set as the first example, (steps 1–3), but with the TruePositiveRate decreased to 0.98.

Step 4: Train the detector.

```
trainCascadeObjectDetector('stopSignDetector_tpr0_98.xml',data,negativeFolder,'FalseAl
```

```
Automatically setting ObjectTrainingSize to [ 33, 32 ]
Using at most 79 of 86 positive samples per stage
Using at most 158 negative samples per stage

Training stage 1 of 5
[.....]
Used 79 positive and 158 negative samples

Training stage 2 of 5
[.....]
Used 79 positive and 158 negative samples

Training stage 3 of 5
[.....]
Used 79 positive and 158 negative samples

Training stage 4 of 5
[.....]
Used 79 positive and 158 negative samples

Training stage 5 of 5
[.....]
Used 79 positive and 85 negative samples

Training complete
```

Only 79 of the total 86 positive samples were used to train each stage. This lowered rate occurs because the true positive rate was low enough for the function to start rejecting some of the positive samples as false negatives.

### **Train a Ten-Stage Stop-Sign Detector**

This example shows you how to train a stop-sign detector on the same data set as the first example, (steps 1–3), but with the number of stages increased to 10.

Step 4: Train the detector.

```
trainCascadeObjectDetector('stopSignDetector_10stages.xml', data, negativeFolder, 'FalseA
```

```
Automatically setting ObjectTrainingSize to [ 33, 32 ]
Using at most 86 of 86 positive samples per stage
Using at most 172 negative samples per stage

Training stage 1 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 2 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 3 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 4 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 5 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 6 of 10
[.....]
Used 86 positive and 33 negative samples

Training stage 7 of 10
[.....Warning:
Unable to generate a sufficient number of negative samples for this stage.
Consider reducing the number of stages, reducing the false alarm rate
or adding more negative images.

Cannot find enough samples for training.
Training will halt and return cascade detector with 6 stages
Training complete
```



In this case, `NegativeSamplesFactor` was set to 2, therefore the number of negative samples used to train each stage was 172. Notice that the function generated only 33 negative samples for stage 6 and was not able to train stage 7 at all. This condition occurs because the number of negatives in stage 7 was less than 17, (roughly half of the previous number of negative samples). The function produced a stop-sign detector with 6 stages, instead of the 10 previously specified. The resulting overall false alarm rate is  $0.2^7=1.28e-05$ , while the expected false alarm rate is  $1.024e-07$ .

At this point, you can add more negative images, reduce the number of stages, or increase the false positive rate. For example, you can increase the false positive rate, `FalseAlarmRate`, to 0.5. The expected overall false-positive rate in this case is 0.0039.

Step 4: Train the detector.

```
trainCascadeObjectDetector('stopSignDetector_10stages_far0_5.xml',data,negativeFolder,
```

```
Automatically setting ObjectTrainingSize to [ 33, 32 ]
Using at most 86 of 86 positive samples per stage
Using at most 172 negative samples per stage

Training stage 1 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 2 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 3 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 4 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 5 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 6 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 7 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 8 of 10
[.....]
Used 86 positive and 172 negative samples

Training stage 9 of 10
[.....]
Very low false alarm rate 0.000587108 reached in stage.
  Training will halt and return cascade detector with 8 stages
Training complete
```

This time the function trains eight stages before the threshold reaches the overall false alarm rate of 0.000587108 and training stops.

### **More About**

- “Label Images for Classification Model Training”

### **External Web Sites**

- Cascade Training GUI

# Troubleshoot ocr Function Results

## Performance Options with the ocr Function

If your ocr results are not what you expect, try one or more of the following options:

- Increase image size 2-to-4 times larger.
- If the characters in the image are too close together or their edges are touching, use morphology to thin out the characters. Using morphology to thin out the characters separates the characters.
- Use binarization to check for non-uniform lighting issues. Use the `graythresh` and `im2bw` functions to binarize the image. If the characters are not visible in the results of the binarization, it indicates a potential non-uniform lighting issue. Try top hat, using the `imtophat` function, or other techniques that deal with removing non-uniform illumination.
- Use the region of interest `roi` option to isolate the text. Specify the `roi` manually or use text detection.
- If your image looks like a natural scene containing words, like a street scene, rather than a scanned document, try setting the `TextLayout` property to either 'Block' or 'Word'.

## See Also

`ocrText` | `graythresh` | `im2bw` | `imtophat` | `ocr` | `visionSupportPackages`

## More About

- “Install Computer Vision System Toolbox Support Packages”

## Create a Custom Feature Extractor

You can use the bag-of-features (BoF) framework with many different types of image features. To use a custom feature extractor instead of the default speeded-up robust features (SURF) feature extractor, use the `CustomExtractor` property of a `bagOfFeatures` object.

### Example of a Custom Feature Extractor

This example shows how to write a custom feature extractor function for `bagOfFeatures`. You can open this example function file and use it as a template by typing the following command at the MATLAB command prompt:

```
edit('exampleBagOfFeaturesExtractor.m')
```

- Step 1. Define the image sets.
- Step 2. Create a new extractor function file.
- Step 3. Preprocess the image.
- Step 4. Select a point location for feature extraction.
- Step 5. Extract features.
- Step 6. Compute the feature metric.

#### Define the image sets

You can use `imageSet` to define a collection of images. For example:

```
setDir = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imgSets = imageSet(setDir,'recursive');
```

#### Create a new extractor function file

The extractor function must be specified as a function handle:

```
extractorFcn = @exampleBagOfFeaturesExtractor;
bag = bagOfFeatures(imgSets,'CustomExtractor',extractorFcn)
exampleBagOfFeaturesExtractor is a MATLAB function. For example:
```

```
function [features,featureMetrics] = exampleBagOfFeaturesExtractor(img)
...

```

You can also specify the optional location output:

```
function [features,featureMetrics,location] = exampleBagOfFeaturesExtractor(img)
...
```

The function must be on the path or in the current working folder.

Argument	Input/Output	Description
img	Input	<ul style="list-style-type: none"> <li>• Binary, grayscale, or truecolor image.</li> <li>• The input image is from the image set that was originally passed into <code>bagOfFeatures</code>.</li> </ul>
features	Output	<ul style="list-style-type: none"> <li>• An <math>M</math>-by-<math>N</math> numeric matrix of image features, where <math>M</math> is the number of features and <math>N</math> is the length of each feature vector.</li> <li>• The feature length, <math>N</math>, must be greater than zero and be the same for all images processed during the <code>bagOfFeatures</code> creation process.</li> <li>• If you cannot extract features from an image, supply an empty feature matrix and an empty feature metrics vector. Use the empty matrix and vector if, for example, you did not find any keypoints for feature extraction.</li> <li>• Numeric, real, and nonsparse.</li> </ul>
featureMetrics	Output	<ul style="list-style-type: none"> <li>• An <math>M</math>-by-1 vector of feature metrics indicating the strength of each feature vector.</li> <li>• Used to apply the 'SelectStrongest' criteria in <code>bagOfFeatures</code> framework.</li> <li>• Numeric, real, and nonsparse.</li> </ul>
location	Output	<ul style="list-style-type: none"> <li>• An <math>M</math>-by-2 matrix of 1-based <math>[x\ y]</math> values.</li> <li>• The <math>[x\ y]</math> values can be fractional.</li> <li>• Numeric, real, and nonsparse.</li> </ul>

### Preprocess the image

Input images can require preprocessing before feature extraction. To extract SURF features and to use the `detectSURFFeatures` or `detectMSERFeatures` functions, the images must be grayscale. If the images are not grayscale, you can convert them using the `rgb2gray` function.

```
[height,width,numChannels] = size(I);
if numChannels > 1
    grayImage = rgb2gray(I);
else
    grayImage = I;
end
```

### Select a point location for feature extraction

Use a regular spaced grid of point locations. Using the grid over the image allows for dense SURF feature extraction. The grid step is in pixels.

```
gridStep = 8;
gridX = 1:gridStep:width;
gridY = 1:gridStep:height;

[x,y] = meshgrid(gridX,gridY);

gridLocations = [x(:) y(:)];
```

You can manually concatenate multiple `SURFPoints` objects at different scales to achieve multiscale feature extraction.

```
multiscaleGridPoints = [SURFPoints(gridLocations, 'Scale', 1.6);
    SURFPoints(gridLocations, 'Scale', 3.2);
    SURFPoints(gridLocations, 'Scale', 4.8);
    SURFPoints(gridLocations, 'Scale', 6.4)];
```

Alternatively, you can use a feature detector, such as `detectSURFFeatures` or `detectMSERFeatures`, to select point locations.

```
multiscaleSURFPoints = detectSURFFeatures(I);
```

### Extract features

Extract features from the selected point locations. By default, `bagOfFeatures` extracts upright SURF features.

```
features = extractFeatures(grayImage,multiscaleGridPoints,'Upright',true);
```

### Compute the feature metric

The feature metrics indicate the strength of each feature. Larger metric values are assigned to stronger features. Use feature metrics to identify and remove weak features before using `bagOfFeatures` to learn the visual vocabulary of an image set. Use the metric that is suitable for your feature vectors.

For example, you can use the variance of the SURF features as the feature metric.

```
featureMetrics = var(features,[],2);
```

If you used a feature detector for the point selection, then use the detection metric instead.

```
featureMetrics = multiscaleSURFPoints.Metric;
```

You can optionally return the feature location information. The feature location can be used for spatial or geometric verification image search applications. See the “Geometric Verification Using estimateGeometricTransform Function” example. The `retrieveImages` and `indexImages` functions are used for content-based image retrieval systems.

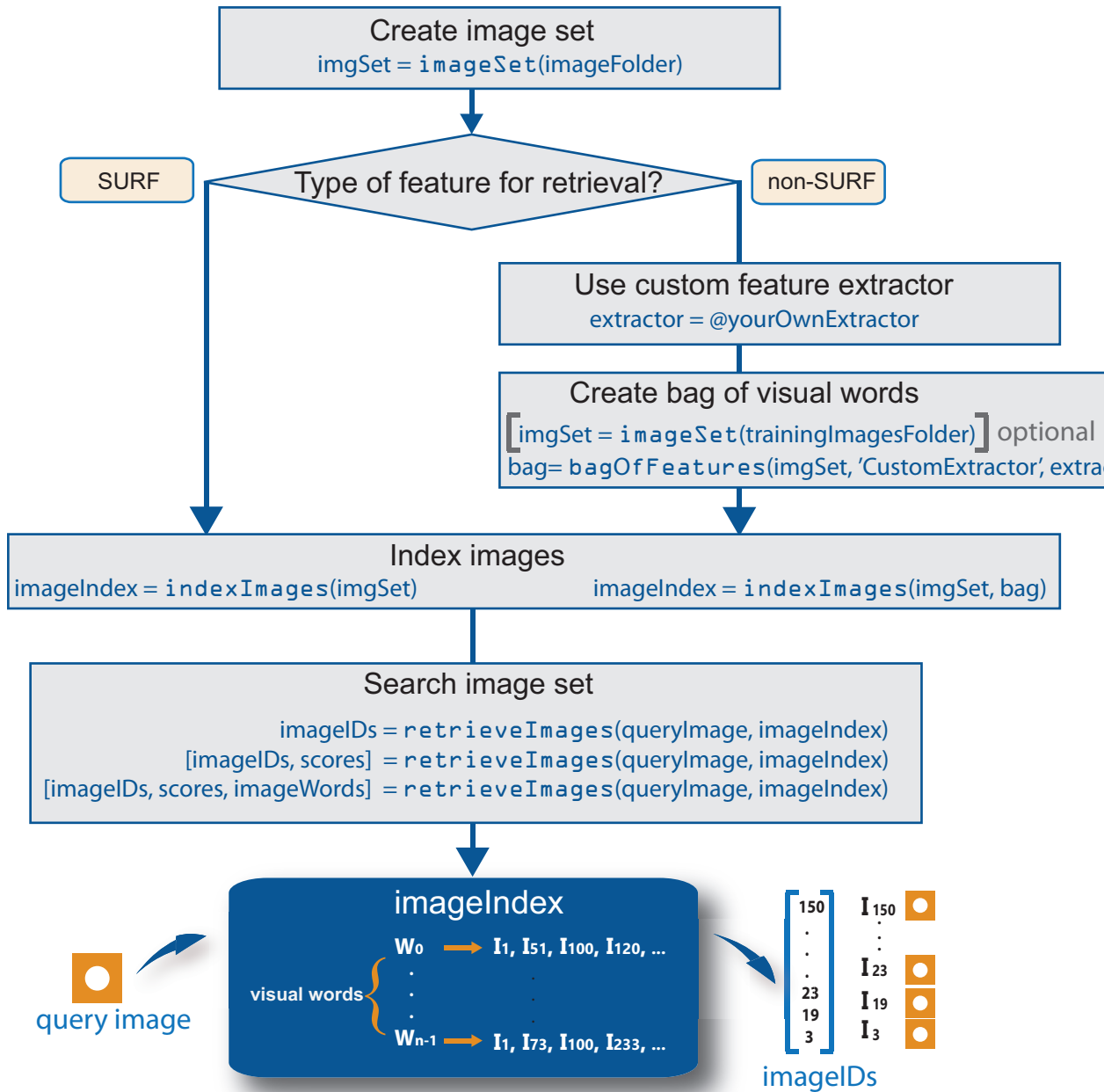
```
if nargout > 2  
    varargout{1} = multiscaleGridPoints.Location;  
end
```



## Image Retrieval with Bag of Visual Words

You can use the Computer Vision System Toolbox functions to search by image, also known as a content-based image retrieval (CBIR) system. CBIR systems are used to retrieve images from a collection of images that are similar to a query image. The application of these types of systems can be found in many areas such as a web-based product search, surveillance, and visual place identification. First the system searches a collection of images to find the ones that are visually similar to a query image.

The retrieval system uses a bag of visual words, a collection of image descriptors, to represent your data set of images. Images are indexed to create a mapping of visual words. The index maps each visual word to their occurrences in the image set. A comparison between the query image and the index provides the images most similar to the query image. By using the CBIR system workflow, you can evaluate the accuracy for a known set of image search results.



## Retrieval System Workflow

- 1 Create image set that represents image features for retrieval.** Use `imgSet` to store the image data. Use a large number of images that represent various viewpoints of the object. A large and diverse number of images helps train the bag of visual words and increases the accuracy of the image search.
- 2 Type of feature.** The `indexImages` function creates the bag of visual words using the speeded up robust features (SURF). For other types of features, you can use a custom extractor, and then use `bagOfFeatures` to create the bag of visual words. See the “Create Search Index Using Custom Bag of Features” example.

You can use the original `imgSet` or a different collection of images for the training set. To use a different collection, create the bag of visual words before creating the image index, using the `bagOfFeatures` function. The advantage of using the same set of images is that the visual vocabulary is tailored to the search set. The disadvantage of this approach is that the retrieval system must relearn the visual vocabulary to use on a drastically different set of images. With an independent set, the visual vocabulary is better able to handle the additions of new images into the search index.

- 3 Index the images.** The `indexImages` function creates a search index that maps visual words to their occurrences in the image collection. When you create the bag of visual words using an independent or subset collection, include the `bag` as an input argument to `indexImages`. If you do not create an independent bag of visual words, then the function creates the bag based on the entire `imgSet` input collection. You can add and remove images directly to and from the image index using the `addImages` and `removeImages` methods.
- 4 Search data set for similar images.** Use the `retrieveImages` function to search the image set for images which are similar to the query image. Use the `NumResults` property to control the number of results. For example, to return the top 10 similar images, set the `ROI` property to use a smaller region of a query image. A smaller region is useful for isolating a particular object in an image that you want to search for.

## Evaluate Image Retrieval

Use the `evaluateImageRetrieval` function to evaluate image retrieval by using a query image with a known set of results. If the results are not what you expect, you can modify or augment image features by the bag of visual words. Examine the type of the features retrieved. The type of feature used for retrieval depends on the type of images

within the collection. For example, if you are searching an image collection made up of scenes, such as beaches, cities, or highways, use a global image feature. A global image feature, such as a color histogram, captures the key elements of the entire scene. To find specific objects within the image collections, use local image features extracted around object keypoints instead.

### **Related Examples**

- “Image Search Using Point Features”
- “Image Retrieval Using Customized Bag of Features”

## Image Classification with Bag of Visual Words

You can use the Computer Vision System Toolbox functions for image category classification by creating a bag of visual words. The process generates a histogram of visual word occurrences that represent an image. These histograms are used to train an image category classifier. The steps below describe how to setup your images, create the bag of visual words, and then train and apply an image category classifier.

### Step 1: Set Up Image Category Sets

Organize and partition the images into training and test subsets. Use the `imageSet` function to organize categories of images to use for training an image classifier.

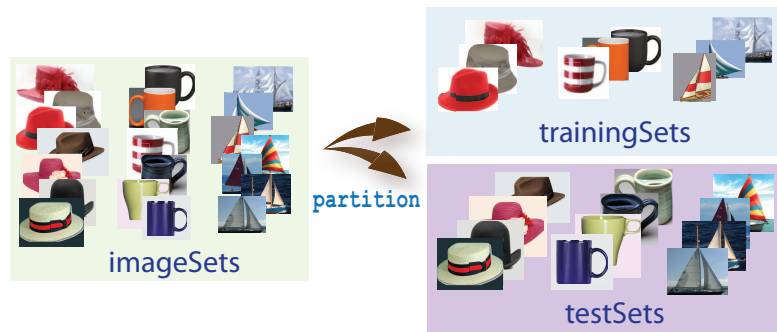
Organizing images into categories makes handling large sets of images much easier. You can use the `imageSet.partition` method to create subsets of representative images from each category.

Read the category images and create the image sets.

```
setDir = fullfile(toolboxdir('vision'),'visiondata','imageSets');
imgSets = imageSet(setDir,'recursive');
```

Separate the sets into training and test image subsets. In this example, 30% of the images are partitioned for training and the remainder for testing.

```
[trainingSets,testSets] = partition(imgSets,0.3,'randomize');
```

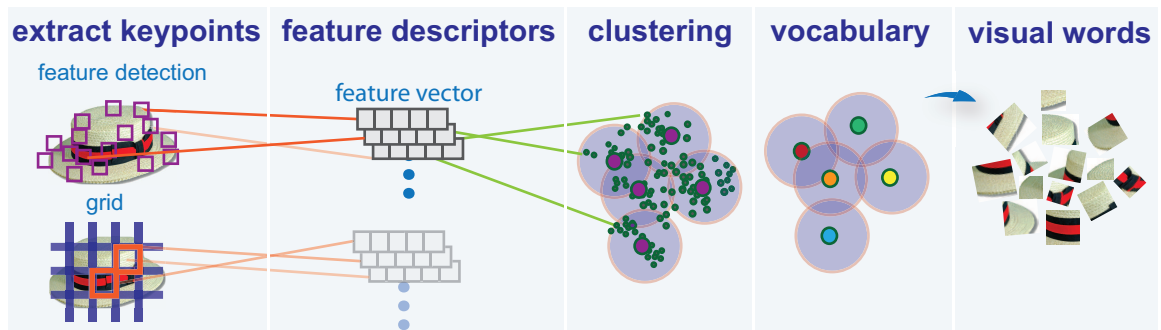


### Step 2: Create Bag of Features

Create a visual vocabulary, or bag of features, by extracting feature descriptors from representative images of each category.

The `bagOfFeatures` object defines the features, or visual words, by using the  $k$ -means clustering algorithm on the feature descriptors extracted from `trainingSets`. The algorithm iteratively groups the descriptors into  $k$  mutually exclusive clusters. The resulting clusters are compact and separated by similar characteristics. Each cluster center represents a feature, or visual word.

You can extract features based on a feature detector, or you can define a grid to extract feature descriptors. The grid method may lose fine-grained scale information. Therefore, use the grid for images that do not contain distinct features, such as an image containing scenery, like the beach. Using speeded up robust features (or SURF) detector provides greater scale invariance. By default, the algorithm runs the 'grid' method.

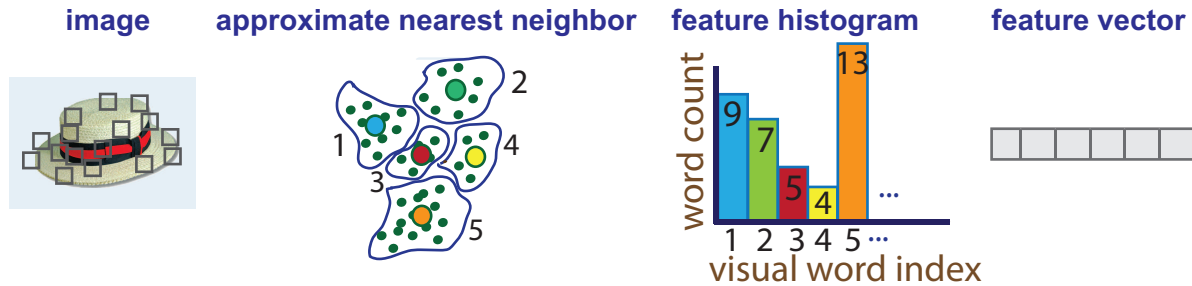


This algorithm workflow analyzes images in their entirety. Images must have appropriate labels describing the class that they represent. For example, a set of car images could be labeled cars. The workflow does not rely on spatial information nor on marking the particular objects in an image. The bag-of-visual-words technique relies on detection without localization.

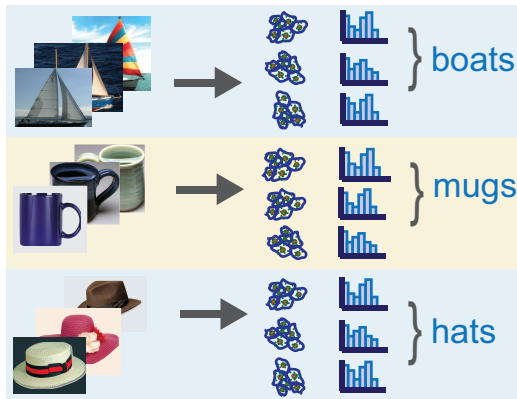
### Step 3: Train an Image Classifier With Bag of Visual Words

The `trainImageCategoryClassifier` function returns an image classifier. The function trains a multiclass classifier using the error-correcting output codes (ECOC) framework with binary support vector machine (SVM) classifiers. The `trainImageCategoryClassifier` function uses the bag of visual words returned by the `bagOfFeatures` object to encode images in the image set into the histogram of visual words. The histogram of visual words are then used as the positive and negative samples to train the classifier.

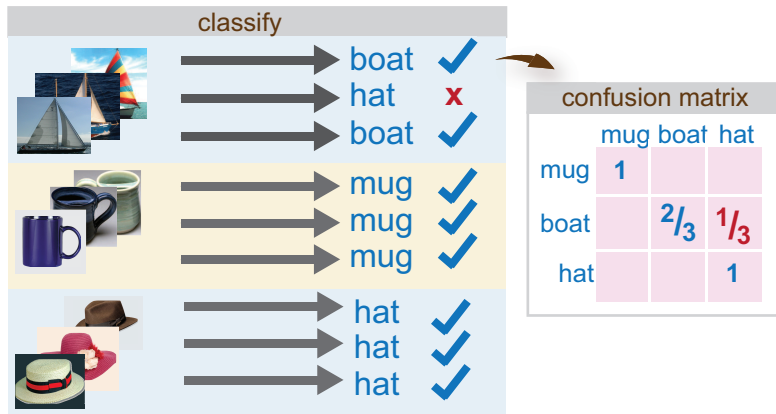
- 1 Use the `bagOfFeatures` encode method to encode each image from the training set. This function detects and extracts features from the image and then uses the approximate nearest neighbor algorithm to construct a feature histogram for each image. The function then increments histogram bins based on the proximity of the descriptor to a particular cluster center. The histogram length corresponds to the number of visual words that the `bagOfFeatures` object constructed. The histogram becomes a feature vector for the image.



- 2 Repeat step 1 for each image in the training set to create the training data.



- 3 Evaluate the quality of the classifier. Use the `imageCategoryClassifier` `evaluate` method to test the classifier against the validation image set. The output confusion matrix represents the analysis of the prediction. A perfect classification results in a normalized matrix containing 1s on the diagonal. An incorrect classification results fractional values.



## Step 4: Classify an Image or Image Set

Use the `imageCategoryClassifier predict` method on a new image to determine its category.

## References

- [1] Csurka, G., C. R. Dance, L. Fan, J. Willamowski, and C. Bray. *Visual Categorization with Bags of Keypoints*. Workshop on Statistical Learning in Computer Vision. ECCV 1 (1–22), 1–2.

## Related Examples

- “Image Category Classification Using Bag of Features”
- “Image Search Using Point Features”
- “Image Retrieval Using Customized Bag of Features”



# Motion Estimation and Tracking

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- “Multiple Object Tracking” on page 6-2
- “Video Mosaicking” on page 6-6
- “Pattern Matching” on page 6-13
- “Pattern Matching” on page 6-20
- “Track an Object Using Correlation” on page 6-24
- “Panorama Creation” on page 6-28

## Multiple Object Tracking

*Tracking* is the process of locating a moving object or multiple objects over time in a video stream. Tracking an object is not the same as object detection. Object detection is the process of locating an object of interest in a single frame. Tracking associates detections of an object across multiple frames.

Tracking multiple objects requires detection, prediction, and data association.

- **Detection:** Detect objects of interest in a video frame.
- **Prediction:** Predict the object locations in the next frame.
- **Data association:** Use the predicted locations to associate detections across frames to form *tracks*.

### Detection

Selecting the right approach for detecting objects of interest depends on what you want to track and whether the camera is stationary.

#### Detect Objects Using a Stationary Camera

To detect objects in motion with a stationary camera, you can perform background subtraction using the `vision.ForegroundDetectorSystem` object. The background subtraction approach works efficiently but requires the camera to be stationary.

#### Detect Objects Using a Moving Camera

To detect objects in motion with a moving camera, you can use a sliding-window detection approach. This approach typically works more slowly than the background subtraction approach. To detect and track a specific category of object, use the System objects or functions described in the table.

#### Select A Detection Algorithm

Type of Object to Track	Camera	Functionality
Anything that moves	Stationary	<code>vision.ForegroundDetectorSystem</code> object
Faces, eyes, nose, mouth, upper body	Stationary, Moving	<code>vision.CascadeObjectDetectorSystem</code> object

Type of Object to Track	Camera	Functionality
Pedestrians	Stationary, Moving	<code>vision.PeopleDetectorSystem</code> object
Custom object category	Stationary, Moving	<code>trainCascadeObjectDetector</code> function or custom sliding window detector using <code>extractHOGFeatures</code> and <code>selectStrongestBbox</code>

## Prediction

To track an object over time means that you must predict its location in the next frame. The simplest method of prediction is to assume that the object will be near its last known location. In other words, the previous detection serves as the next prediction. This method is especially effective for high frame rates. However, using this prediction method can fail when objects move at varying speeds, or when the frame rate is low relative to the speed of the object in motion.

A more sophisticated method of prediction is to use the previously observed motion of the object. The Kalman filter (`vision.KalmanFilter`) predicts the next location of an object, assuming that it moves according to a motion model, such as constant velocity or constant acceleration. The Kalman filter also takes into account process noise and measurement noise. *Process noise* is the deviation of the actual motion of the object from the motion model. *Measurement noise* is the detection error.

To make configuring a Kalman filter easier, use `configureKalmanFilter`. This function sets up the filter for tracking a physical object moving with constant velocity or constant acceleration within a Cartesian coordinate system. The statistics are the same along all dimensions. If you need to configure a Kalman filter with different assumptions, you need to construct the `vision.KalmanFilter` object directly.

## Data Association

*Data association* is the process of associating detections corresponding to the same physical object across frames. The temporal history of a particular object consists of multiple detections, and is called a *track*. A track representation can include the entire history of the previous locations of the object. Alternatively, it can consist only of the object's last known location and its current velocity.

### Detection to Track Cost Functions

To match a detection to a track, you must establish criteria for evaluating the matches. Typically, you establish this criteria by defining a cost function. The higher the cost of matching a detection to a track, the less likely that the detection belongs to the track. A simple cost function can be defined as the degree of overlap between the bounding boxes of the predicted and detected objects. The “Tracking Pedestrians from a Moving Car” example implements this cost function using the `bbboxOverlapRatio` function. You can implement a more sophisticated cost function, one that accounts for the uncertainty of the prediction, using the `distance` method of the `vision.KalmanFilter` object. You can also implement a custom cost function than can incorporate information about the object size and appearance.

### Elimination of Unlikely Matches

*Gating* is a method of eliminating highly unlikely matches from consideration, such as by imposing a threshold on the cost function. An observation cannot be matched to a track if the cost exceeds a certain threshold value. Using this threshold method effectively results in a circular *gating region* around each prediction, where a matching detection can be found. An alternative gating technique is to make the gating region large enough to include the  $k$ -nearest neighbors of the prediction.

### Assign Detections to Track

Data association reduces to a minimum weight bipartite matching problem, which is a well-studied area of graph theory. A bipartite graph represents tracks and detections as vertices. It also represents the cost of matching a detection and a track as a weighted edge between the corresponding vertices.

The `assignDetectionsToTracks` function implements the Munkres' variant of the Hungarian bipartite matching algorithm. Its input is the *cost matrix*, where the rows correspond to tracks and the columns correspond to detections. Each entry contains the cost of assigning a particular detection to a particular track. You can implement gating by setting the cost of impossible matches to infinity.

### Track Management

Data association must take into account the fact that new objects can appear in the field of view, or that an object being tracked can leave the field of view. In other words, in any given frame, some number of new tracks might need to be created, and some number of existing tracks might need to be discarded. The `assignDetectionsToTracks` function

returns the indices of unassigned tracks and unassigned detections in addition to the matched pairs.

One way of handling unmatched detections is to create a new track from each of them. Alternatively, you can create new tracks from unmatched detections greater than a certain size, or from detections that have certain locations or appearance. For example, if the scene has a single entry point, such as a doorway, then you can specify that only unmatched detections located near the entry point can begin new tracks, and that all other detections are considered noise.

Another way of handling unmatched tracks is to delete any track that remain unmatched for a certain number of frames. Alternatively, you can specify to delete an unmatched track when its last known location is near an exit point.

## See Also

`vision.KalmanFilter` | `vision.ForegroundDetector` |  
`vision.PeopleDetector` | `vision.CascadeObjectDetector` |  
`assignDetectionsToTracks` | `bboxOverlapRatio` | `configureKalmanFilter`  
| `extractHOGFeatures` | `vision.PointTracker` | `selectStrongestBbox` |  
`trainCascadeObjectDetector`

## Related Examples

- “Motion-Based Multiple Object Tracking”
- “Tracking Pedestrians from a Moving Car”
- “Using Kalman Filter for Object Tracking”

## More About

- “Train a Cascade Object Detector”

## External Web Sites

- Detect and Track Multiple Faces

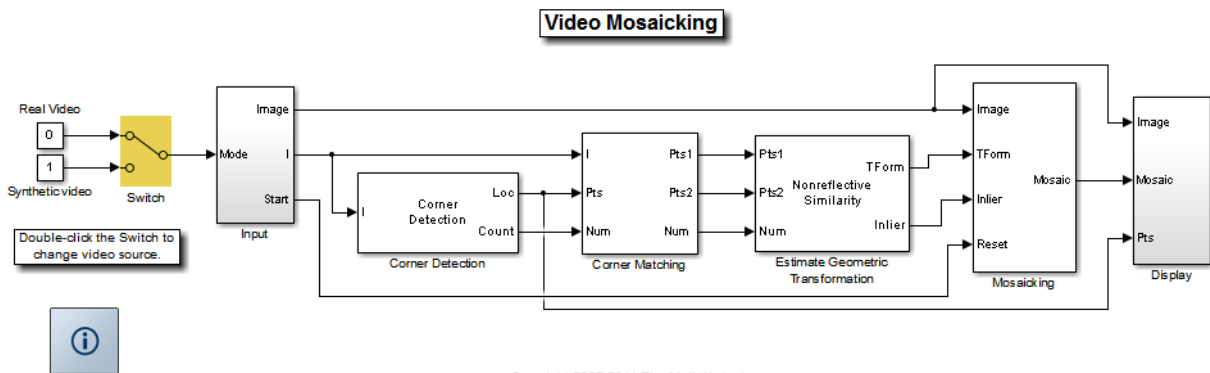
## Video Mosaicking

This example shows how to create a mosaic from a video sequence. Video mosaicking is the process of stitching video frames together to form a comprehensive view of the scene. The resulting mosaic image is a compact representation of the video data. The Video Mosaicking block is often used in video compression and surveillance applications.

This example illustrates how to use the Corner Detection block, the Estimate Geometric Transformation block, the Projective Transform block, and the Compositing block to create a mosaic image from a video sequence.

### Example Model

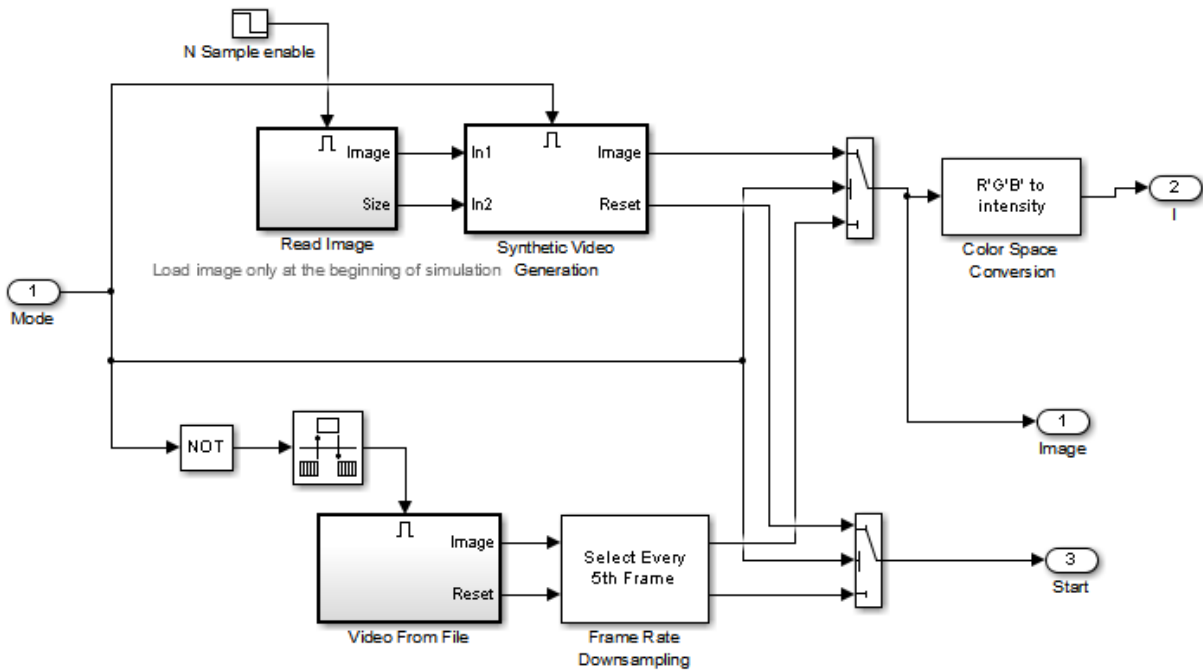
The following figure shows the Video Mosaicking model:



The Input subsystem loads a video sequence from either a file, or generates a synthetic video sequence. The choice is user defined. First, the Corner Detection block finds points that are matched between successive frames by the Corner Matching subsystem. Then the Estimate Geometric Transformation block computes an accurate estimate of the transformation matrix. This block uses the RANSAC algorithm to eliminate outlier input points, reducing error along the seams of the output mosaic image. Finally, the Mosaicking subsystem overlays the current video frame onto the output image to generate a mosaic.

### Input Subsystem

The Input subsystem can be configured to load a video sequence from a file, or to generate a synthetic video sequence.

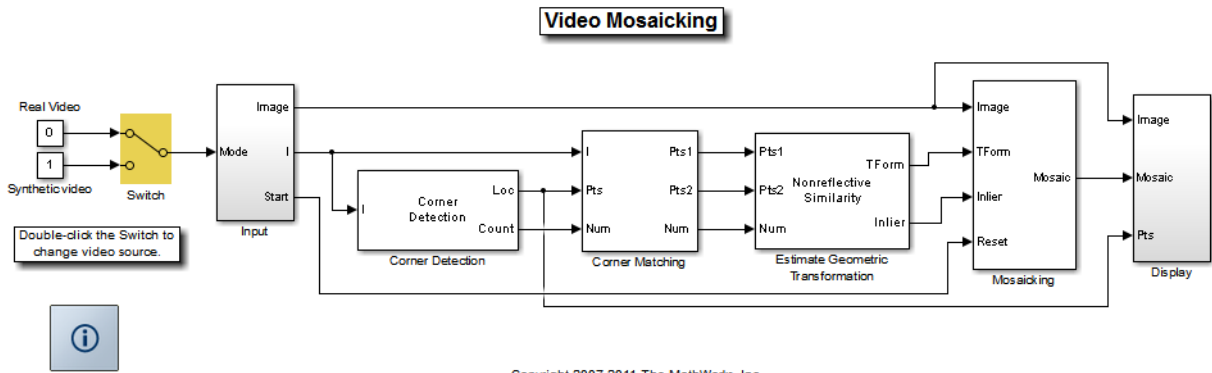


If you choose to use a video sequence from a file, you can reduce computation time by processing only some of the video frames. This is done by setting the downsampling rate in the Frame Rate Downsampling subsystem.

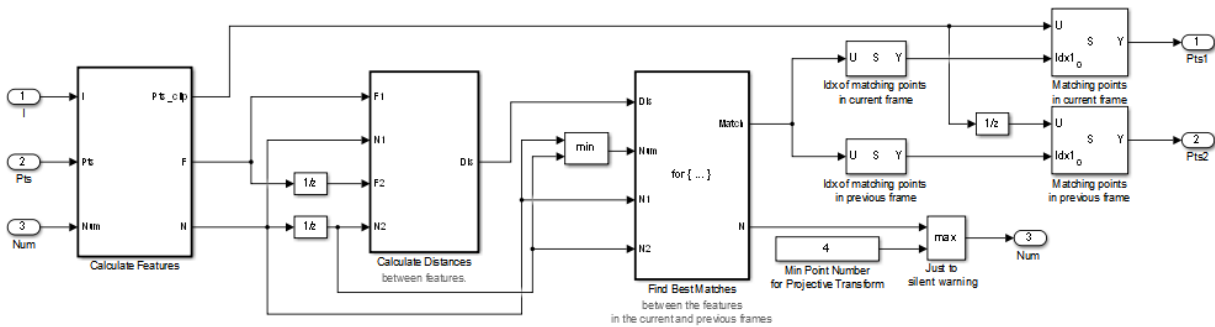
If you choose a synthetic video sequence, you can set the speed of translation and rotation, output image size and origin, and the level of noise. The output of the synthetic video sequence generator mimics the images captured by a perspective camera with arbitrary motion over a planar surface.

### Corner Matching Subsystem

The subsystem finds corner features in the current video frame in one of three methods. The example uses Local intensity comparison (Rosen & Drummond), which is the fastest method. The other methods available are the Harris corner detection (Harris & Stephens) and the Minimum Eigenvalue (Shi & Tomasi).



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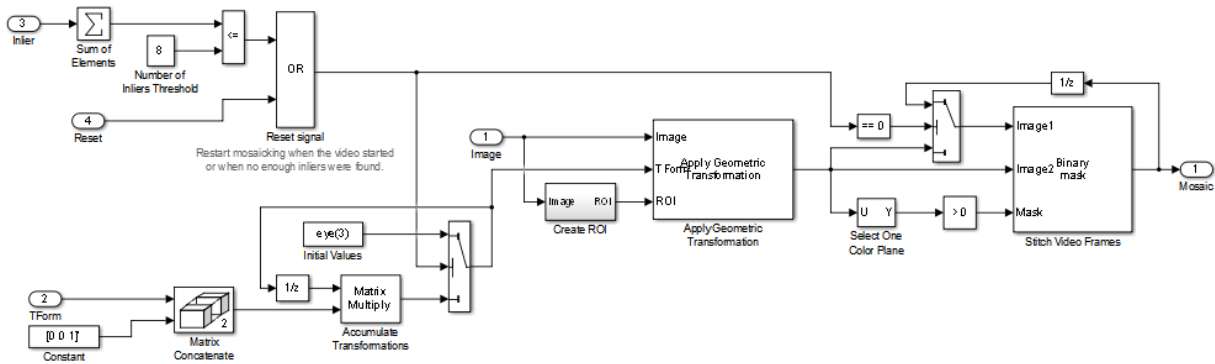


The Corner Matching Subsystem finds the number of corners, location, and their metric values. The subsystem then calculates the distances between all features in the current frame with those in the previous frame. By searching for the minimum distances, the subsystem finds the best matching features.

### Mosaicking Subsystem

By accumulating transformation matrices between consecutive video frames, the subsystem calculates the transformation matrix between the current and the first video frame. The subsystem then overlays the current video frame on to the output image. By repeating this process, the subsystem generates a mosaic image.





The subsystem is reset when the video sequence rewinds or when the Estimate Geometric Transformation block does not find enough inliers.

### Video Mosaicking Using Synthetic Video

The Corners window shows the corner locations in the current video frame.



The Mosaic window shows the resulting mosaic image.



### Video Mosaicking Using Captured Video

The Corners window shows the corner locations in the current video frame.



The Mosaic window shows the resulting mosaic image.



## Pattern Matching

This example shows how to use the 2-D normalized cross-correlation for pattern matching and target tracking. The example uses predefined or user specified target and number of similar targets to be tracked. The normalized cross correlation plot shows that when the value exceeds the set threshold, the target is identified.

### Introduction

In this example you use normalized cross correlation to track a target pattern in a video. The pattern matching algorithm involves the following steps:

- The input video frame and the template are reduced in size to minimize the amount of computation required by the matching algorithm.
- Normalized cross correlation, in the frequency domain, is used to find a template in the video frame.
- The location of the pattern is determined by finding the maximum cross correlation value.

### Initialization

Initialize required variables such as the threshold value for the cross correlation and the decomposition level for Gaussian Pyramid decomposition.

```
threshold = single(0.99);
level = 2;
```

Create System object™ to read a video file.

```
hVideoSrc = vision.VideoFileReader('vipboard.avi', ...
    'VideoOutputDataType', 'single', ...
    'ImageColorSpace', 'Intensity');
```

Create three gaussian pyramid System objects for decomposing the target template and decomposing the Image under Test(IUT). The decomposition is done so that the cross correlation can be computed over a small region instead of the entire original size of the image.

```
hGaussPynd1 = vision.Pyramid('PyramidLevel', level);
hGaussPynd2 = vision.Pyramid('PyramidLevel', level);
hGaussPynd3 = vision.Pyramid('PyramidLevel', level);
```

Create a System object to rotate the image by angle of pi before computing multiplication with the target in the frequency domain which is equivalent to correlation.

```
hRotate1 = vision.GeometricRotator('Angle', pi);
```

Create two 2-D FFT System objects one for the image under test and the other for the target.

```
hFFT2D1 = vision.FFT;  
hFFT2D2 = vision.FFT;
```

Create a System object to perform 2-D inverse FFT after performing correlation (equivalent to multiplication) in the frequency domain.

```
hIFFFT2D = vision.IFFT;
```

Create 2-D convolution System object to average the image energy in tiles of the same dimension of the target.

```
hConv2D = vision.Convolver('OutputSize', 'Valid');
```

Here you implement the following sequence of operations.

```
% Specify the target image and number of similar targets to be tracked. By  
% default, the example uses a predefined target and finds up to 2 similar  
% patterns. Set the variable useDefaultTarget to false to specify a new  
% target and the number of similar targets to match.
```

```
useDefaultTarget = true;  
[Img, numberOfTargets, target_image] = ...  
    videopattern_gettemplate(useDefaultTarget);
```

```
% Downsample the target image by a predefined factor using the  
% gaussian pyramid System object. You do this to reduce the amount of  
% computation for cross correlation.
```

```
target_image = single(target_image);  
target_dim_nopyramid = size(target_image);  
target_image_gp = step(hGaussPynd1, target_image);  
target_energy = sqrt(sum(target_image_gp(:).^2));
```

```
% Rotate the target image by 180 degrees, and perform zero padding so that  
% the dimensions of both the target and the input image are the same.
```

```
target_image_rot = step(hRotate1, target_image_gp);  
[rt, ct] = size(target_image_rot);  
Img = single(Img);  
Img = step(hGaussPynd2, Img);  
[ri, ci] = size(Img);  
r_mod = 2^nextpow2(rt + ri);  
c_mod = 2^nextpow2(ct + ci);  
target_image_p = [target_image_rot zeros(rt, c_mod-ct)];
```

```
target_image_p = [target_image_p; zeros(r_mod-rt, c_mod)];

% Compute the 2-D FFT of the target image
target_fft = step(hFFT2D1, target_image_p);

% Initialize constant variables used in the processing loop.
target_size = repmat(target_dim_nopyramid, [numberOfTargets, 1]);
gain = 2^(level);
Im_p = zeros(r_mod, c_mod, 'single'); % Used for zero padding
C_ones = ones(rt, ct, 'single'); % Used to calculate mean using conv
```

Create a System object to calculate the local maximum value for the normalized cross correlation.

```
hFindMax = vision.LocalMaximaFinder( ...
    'Threshold', single(-1), ...
    'MaximumNumLocalMaxima', numberOfTargets, ...
    'NeighborhoodSize', floor(size(target_image_gp)/2)*2 - 1);
```

Create a System object to display the tracking of the pattern.

```
sz = get(0, 'ScreenSize');
pos = [20 sz(4)-400 400 300];
hROIPlayer = vision.VideoPlayer('Name', 'Overlay the ROI on the target', ...
    'Position', pos);
```

Initialize figure window for plotting the normalized cross correlation value

```
hPlot = videopatternplots('setup', numberOfTargets, threshold);
```

## Video Processing Loop

Create a processing loop to perform pattern matching on the input video. This loop uses the System objects you instantiated above. The loop is stopped when you reach the end of the input file, which is detected by the VideoFileReader System object.

```
while ~isDone(hVideoSrc)
    Im = step(hVideoSrc);
    Im_gp = step(hGaussPyrd3, Im);

    % Frequency domain convolution.
    Im_p(1:ri, 1:ci) = Im_gp; % Zero-pad
    img_fft = step(hFFT2D2, Im_p);
    corr_freq = img_fft .* target_fft;
    corrOutput_f = step(hIFFFT2D, corr_freq);
    corrOutput_f = corrOutput_f(rt:ri, ct:ci);
```

```
% Calculate image energies and block run tiles that are size of
% target template.
IUT_energy = (Im_gp).^2;
IUT = step(hConv2D, IUT_energy, C_ones);
IUT = sqrt(IUT);

% Calculate normalized cross correlation.
norm_Corr_f = (corrOutput_f) ./ (IUT * target_energy);
xyLocation = step(hFindMax, norm_Corr_f);

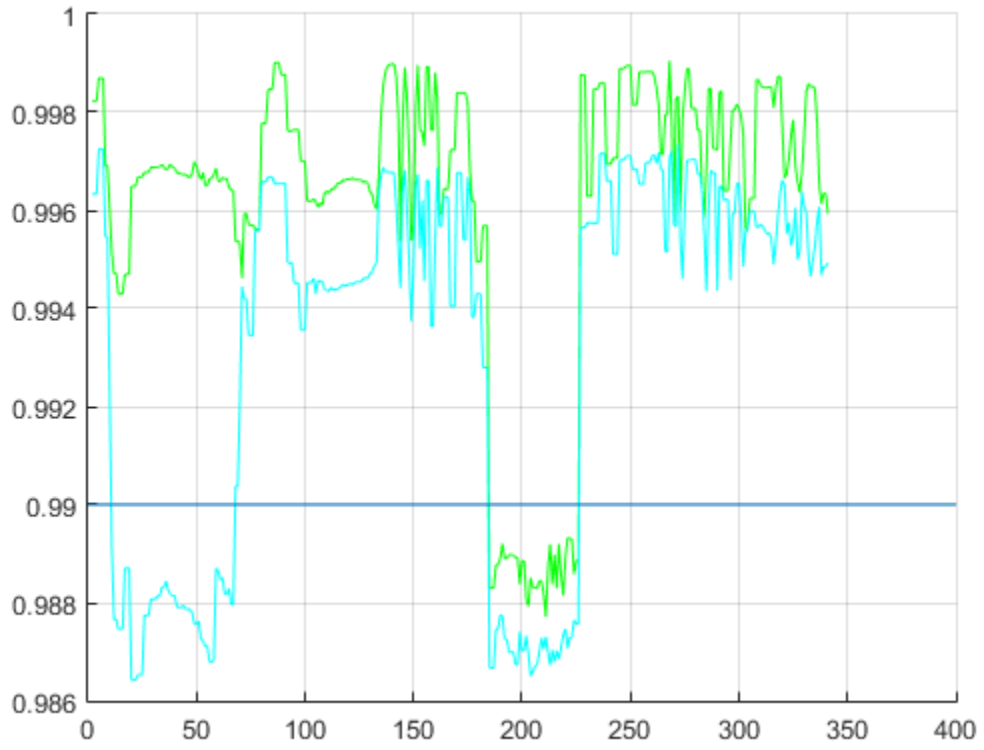
% Calculate linear indices.
linear_index = sub2ind([ri-rt, ci-ct]+1, xyLocation(:,2),...
    xyLocation(:,1)));

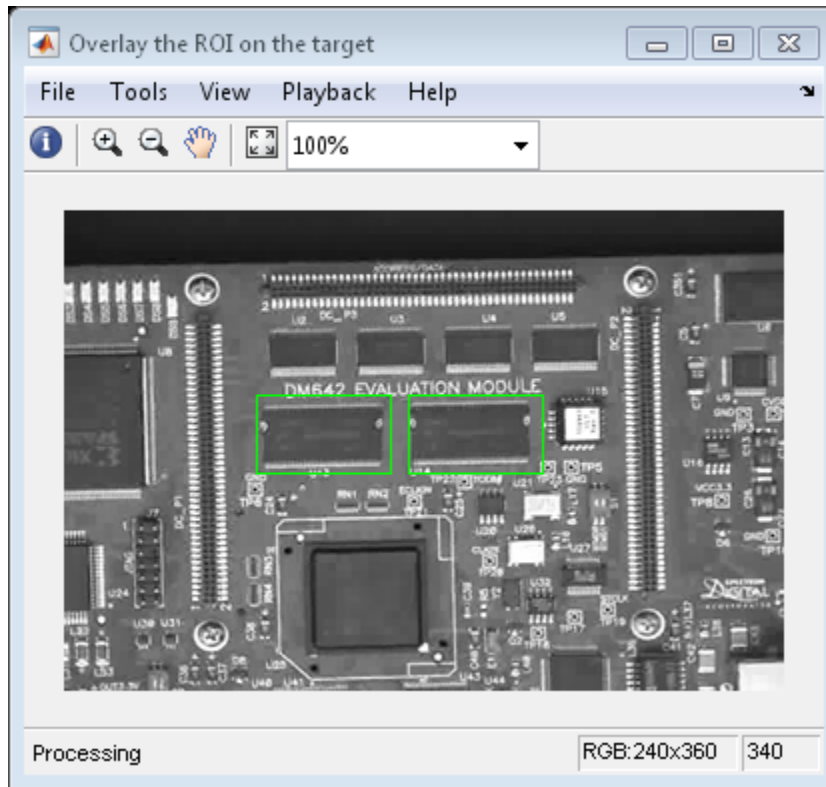
norm_Corr_f_linear = norm_Corr_f(:);
norm_Corr_value = norm_Corr_f_linear(linear_index);
detect = (norm_Corr_value > threshold);
target_roi = zeros(length(detect), 4);
ul_corner = (gain.*(xyLocation(detect, :)-1))+1;
target_roi(detect, :) = [ul_corner, fliplr(target_size(detect, :))];

% Draw bounding box.
Imf = insertShape(Im, 'Rectangle', target_roi, 'Color', 'green');
% Plot normalized cross correlation.
videopatternplots('update',hPlot,norm_Corr_value);
step(hROIPattern, Imf);
end

release(hVideoSrc);
```







### Summary

This example shows use of Computer Vision System Toolbox™ to find a user defined pattern in a video and track it. The algorithm is based on normalized frequency domain cross correlation between the target and the image under test. The video player window displays the input video with the identified target locations. Also a figure displays the normalized correlation between the target and the image which is used as a metric to match the target. As can be seen whenever the correlation value exceeds the threshold (indicated by the blue line), the target is identified in the input video and the location is marked by the green bounding box.

### Appendix

The following helper functions are used in this example.

- `videopattern_gettemplate.m`

- videopatternplots.m

## Pattern Matching

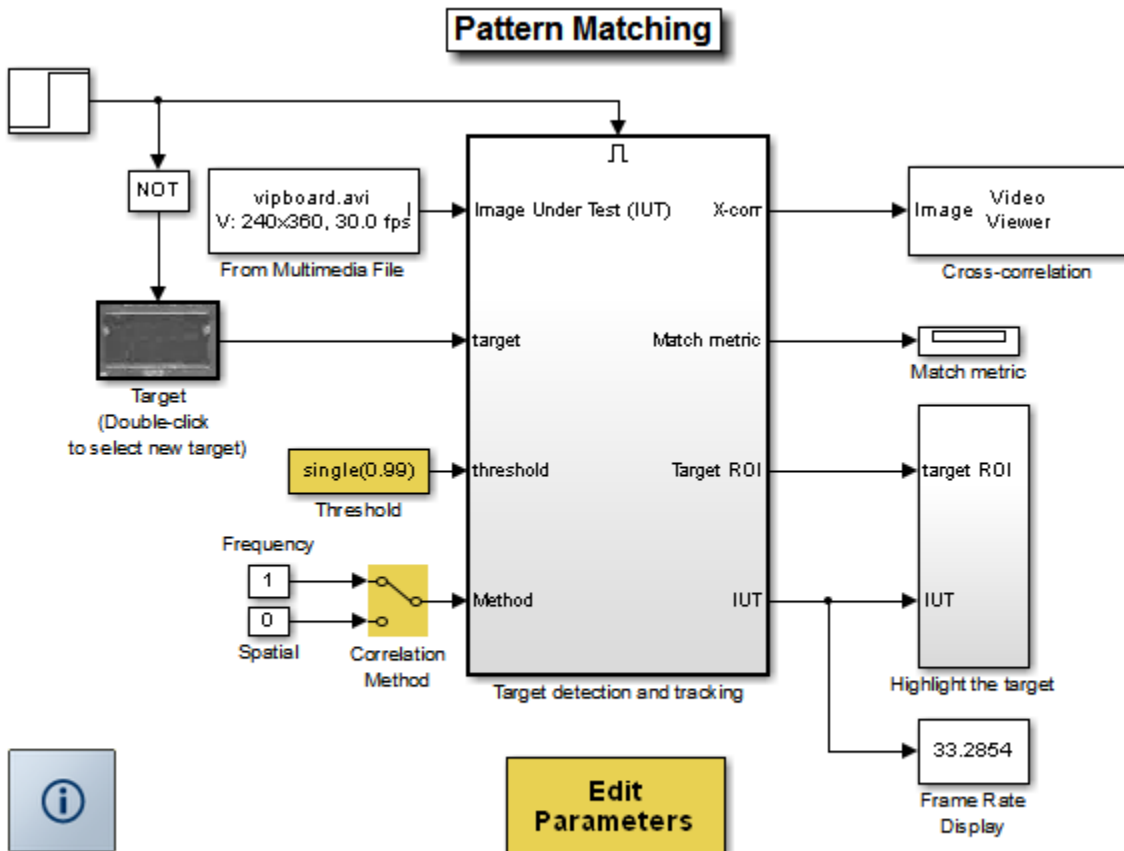
This example shows how to use the 2-D normalized cross-correlation for pattern matching and target tracking.

Double-click the Edit Parameters block to select the number of similar targets to detect. You can also change the pyramiding factor. By increasing it, you can match the target template to each video frame more quickly. Changing the pyramiding factor might require you to change the Threshold value.

Additionally, you can double-click the Correlation Method switch to specify the domain in which to perform the cross-correlation. The relative size of the target to the input video frame and the pyramiding factor determine which domain computation is faster.

### **Example Model**

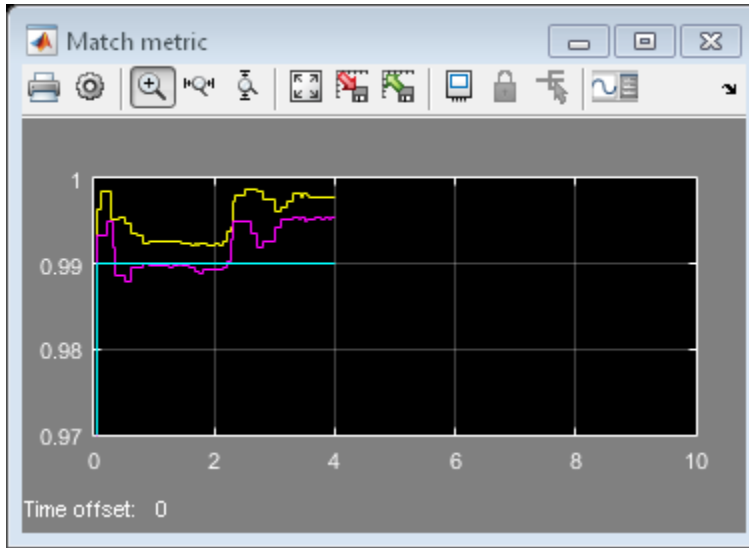
The following figure shows the Pattern Matching model:



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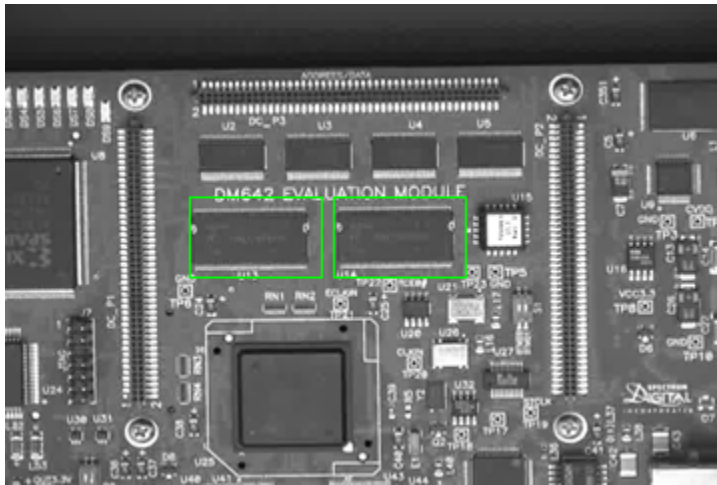
### Pattern Matching Results

The Match metric window shows the variation of the target match metrics. The model determines that the target template is present in a video frame when the match metric exceeds a threshold (cyan line).



The Cross-correlation window shows the result of cross-correlating the target template with a video frame. Large values in this window correspond to the locations of the targets in the input image.

The Overlay window shows the locations of the targets by highlighting them with rectangular regions of interest (ROIs). These ROIs are present only when the targets are detected in the video frame.



## Track an Object Using Correlation

You can open the example model by typing

```
ex_vision_track_object
```

on the MATLAB command line.

In this example, you use the 2-D Correlation, 2-D Maximum, and Draw Shapes blocks to find and indicate the location of a sculpture in each video frame:

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Read Binary File	Computer Vision System Toolbox > Sources	1
Image Data Type Conversion	Computer Vision System Toolbox > Conversions	1
Image From File	Computer Vision System Toolbox > Sources	1
2-D Correlation	Computer Vision System Toolbox > Statistics	1
2-D Maximum	Computer Vision System Toolbox > Statistics	1
Draw Shapes	Computer Vision System Toolbox > Text & Graphics	1
Video Viewer	Computer Vision System Toolbox > Sinks	1
Data Type Conversion	Simulink > Signal Attributes	1
Constant	Simulink > Sources	1
Mux	Simulink > Signal Routing	1

- 2 Use the Read Binary File block to import a binary file into the model. Set the block parameters as follows:
  - **File name** = `cat_video.bin`
  - **Four character code** = `GREY`
  - **Number of times to play file** = `inf`

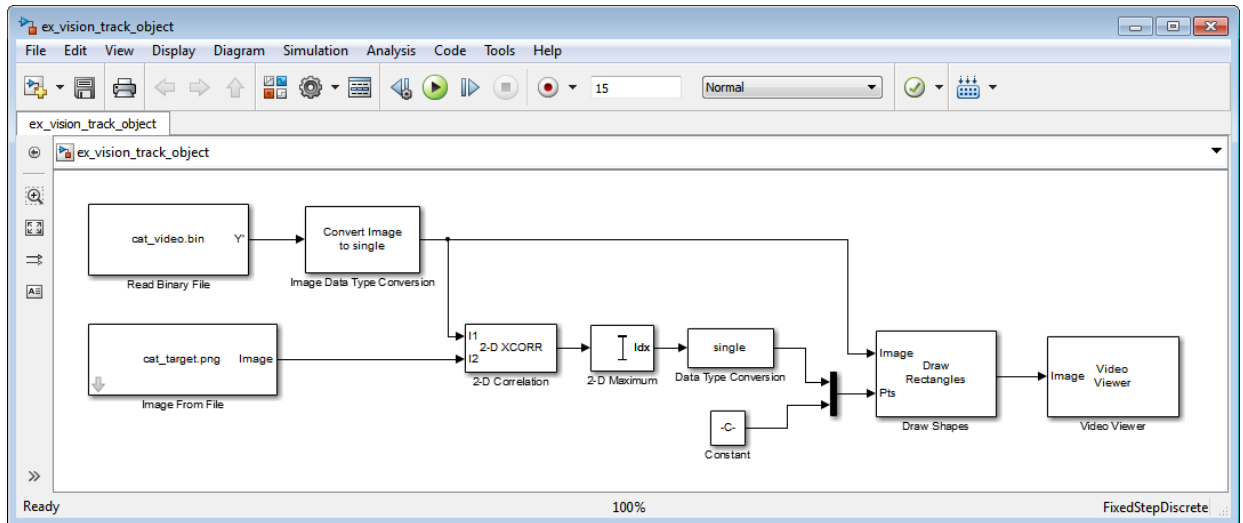


- **Sample time** = 1/30
- 3 Use the Image Data Type Conversion block to convert the data type of the video to single-precision floating point. Accept the default parameter.
  - 4 Use the Image From File block to import the image of the cat sculpture, which is the object you want to track. Set the block parameters as follows:
    - **Main** pane, **File name** = `cat_target.png`
    - **Data Types** pane, **Output data type** = `single`
  - 5 Use the 2-D Correlation block to determine the portion of each video frame that best matches the image of the cat sculpture. Set the block parameters as follows:
    - **Output size** = `Valid`
    - Select the **Normalized output** check box.

Because you chose `Valid` for the **Output size** parameter, the block outputs only those parts of the correlation that are computed without the zero-padded edges of any input.

- 6 Use the 2-D Maximum block to find the index of the maximum value in each input matrix. Set the **Mode** parameter to `Index`. This block outputs the zero-based location of the maximum value as a two-element vector of 32-bit unsigned integers at the **Idx** port.
- 7 Use the Data Type Conversion block to change the index values from 32-bit unsigned integers to single-precision floating-point values. Set the **Output data type** parameter to `single`.
- 8 Use the Constant block to define the size of the image of the cat sculpture. Set the **Constant value** parameter to `single([41 41])`.
- 9 Use the Mux block to concatenate the location of the maximum value and the size of the image of the cat sculpture into a single vector. You use this vector to define a rectangular region of interest (ROI) that you pass to the Draw Shapes block.
- 10 Use the Draw Shapes block to draw a rectangle around the portion of each video frame that best matches the image of the cat sculpture. Accept the default parameters.
- 11 Use the Video Viewer block to display the video stream with the ROI displayed on it. Accept the default parameters. This block automatically displays the video in the Video Viewer window when you run the model. Because the image is represented by single-precision floating-point values, a value of 0 corresponds to black and a value of 1 corresponds to white.

12 Connect the blocks as shown in the following figure.

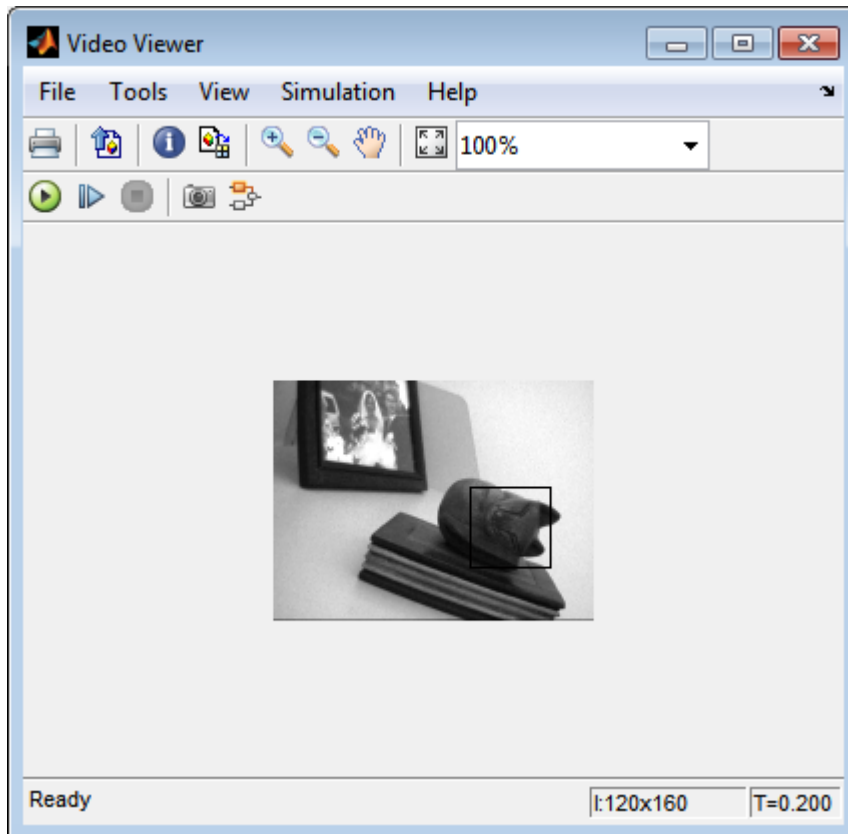


13 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = inf
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

14 Run the simulation.

The video is displayed in the Video Viewer window and a rectangular box appears around the cat sculpture. To view the video at its true size, right-click the window and select **Set Display To True Size**.



As the video plays, you can watch the rectangular ROI follow the sculpture as it moves.

In this example, you used the 2-D Correlation, 2-D Maximum, and Draw Shapes blocks to track the motion of an object in a video stream. For more information about these blocks, see the 2-D Correlation, 2-D Maximum, and Draw Shapes block reference pages.

---

**Note** This example model does not provide an indication of whether or not the sculpture is present in each video frame. For an example of this type of model, type `vippattern` at the MATLAB command prompt.

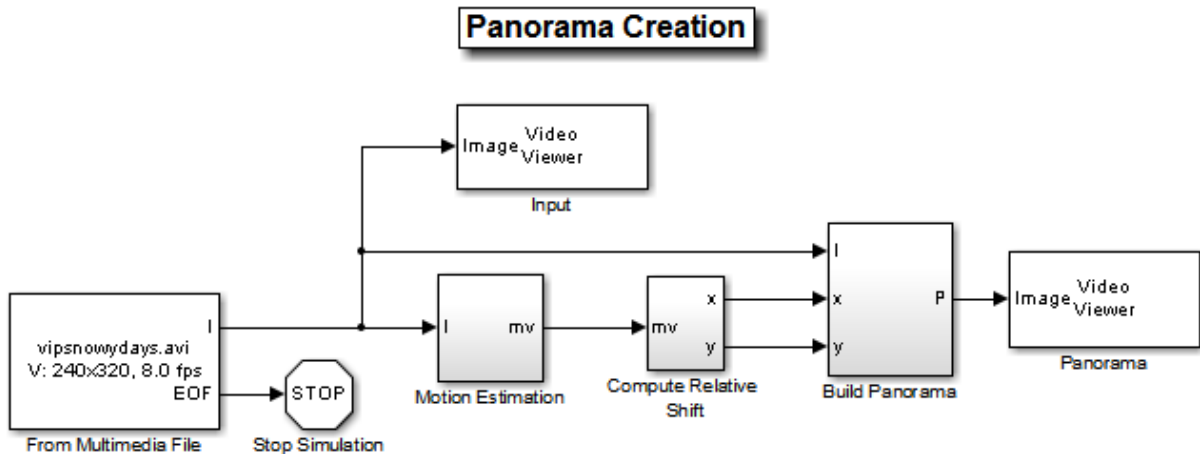
---

## Panorama Creation

This example shows how to create a panorama from a video sequence. The model calculates the motion vector between two adjacent video frames and uses it to find the portion of each frame that best matches the previous frame. Then it selects the matching portion and concatenates it with the previous frame. By repeating this process, it builds a panoramic image out of the video sequence.

### Example Model

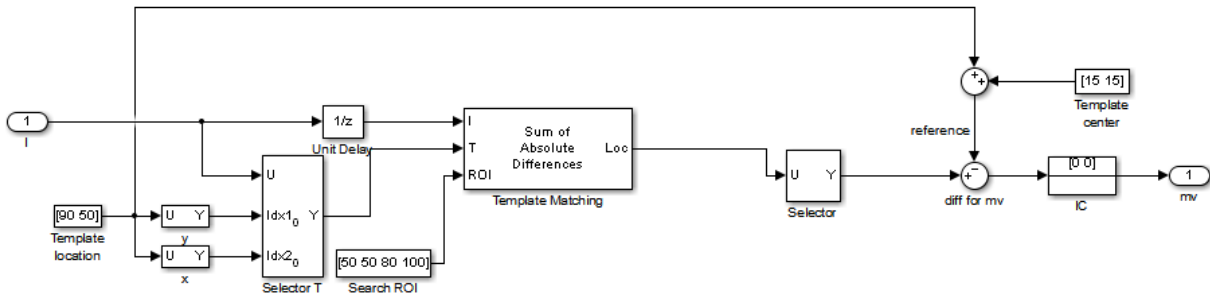
The following figure shows the Panorama Creation model:



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### Motion Estimation Subsystem

This model computes the Sum of Absolute Differences (SAD) using Template Matching block to estimate the motion between consecutive video frames. Then it computes the motion vector of a particular block in the current frame with respect to the previous frame. The model uses this motion vector to align consecutive frames of the video to form a panoramic picture.



### Panorama Creation Results

The model takes the video sequence in the Input window and creates a panorama, which it displays in the Panorama window. Note that this method of panoramic picture creation assumes there is no zooming or rotational variation in the video.





**Available Example Versions**

Windows® only: vippanorama\_win.slx

Platform independent: vippanorama\_all.slx

Some compressed multimedia files are only supported on Windows platforms. The examples that use these types of files can only be run on Windows.

# Geometric Transformations

---

- “Rotate an Image” on page 7-2
- “Resize an Image” on page 7-8
- “Crop an Image” on page 7-12
- “Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods” on page 7-16

## Rotate an Image

You can use the Rotate block to rotate your image or video stream by a specified angle. In this example, you learn how to use the Rotate block to continuously rotate an image.

---

**Note:** Running this example requires a DSP System Toolbox license.

---

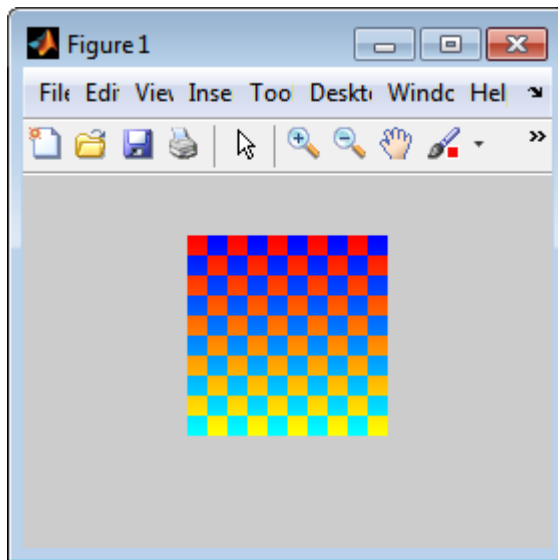
ex\_vision\_rotate\_image

- 1 Define an RGB image in the MATLAB workspace. At the MATLAB command prompt, type

```
I = checker_board;
```

I is a 100-by-100-by-3 array of double-precision values. Each plane of the array represents the red, green, or blue color values of the image.

- 2 To view the image this matrix represents, at the MATLAB command prompt, type  
`imshow(I)`



- 3 Create a new Simulink model, and add to it the blocks shown in the following table.



Block	Library	Quantity
Image From Workspace	Computer Vision System Toolbox > Sources	1
Rotate	Computer Vision System Toolbox > Geometric Transformations	1
Video Viewer	Computer Vision System Toolbox > Sinks	2
Gain	Simulink > Math Operations	1
Display	DSP System Toolbox > Sinks	1
Counter	DSP System Toolbox > Signal Management > Switches and Counters	1

- 4 Use the Image From Workspace block to import the RGB image from the MATLAB workspace. On the Main pane, set the **Value** parameter to **I**. Each plane of the array represents the red, green, or blue color values of the image.
- 5 Use the Video Viewer block to display the original image. Accept the default parameters.

The Video Viewer block automatically displays the original image in the Video Viewer window when you run the model. Because the image is represented by double-precision floating-point values, a value of 0 corresponds to black and a value of 1 corresponds to white.

- 6 Use the Rotate block to rotate the image. Set the block parameters as follows:
  - **Rotation angle source** = Input port
  - **Sine value computation method** = Trigonometric function

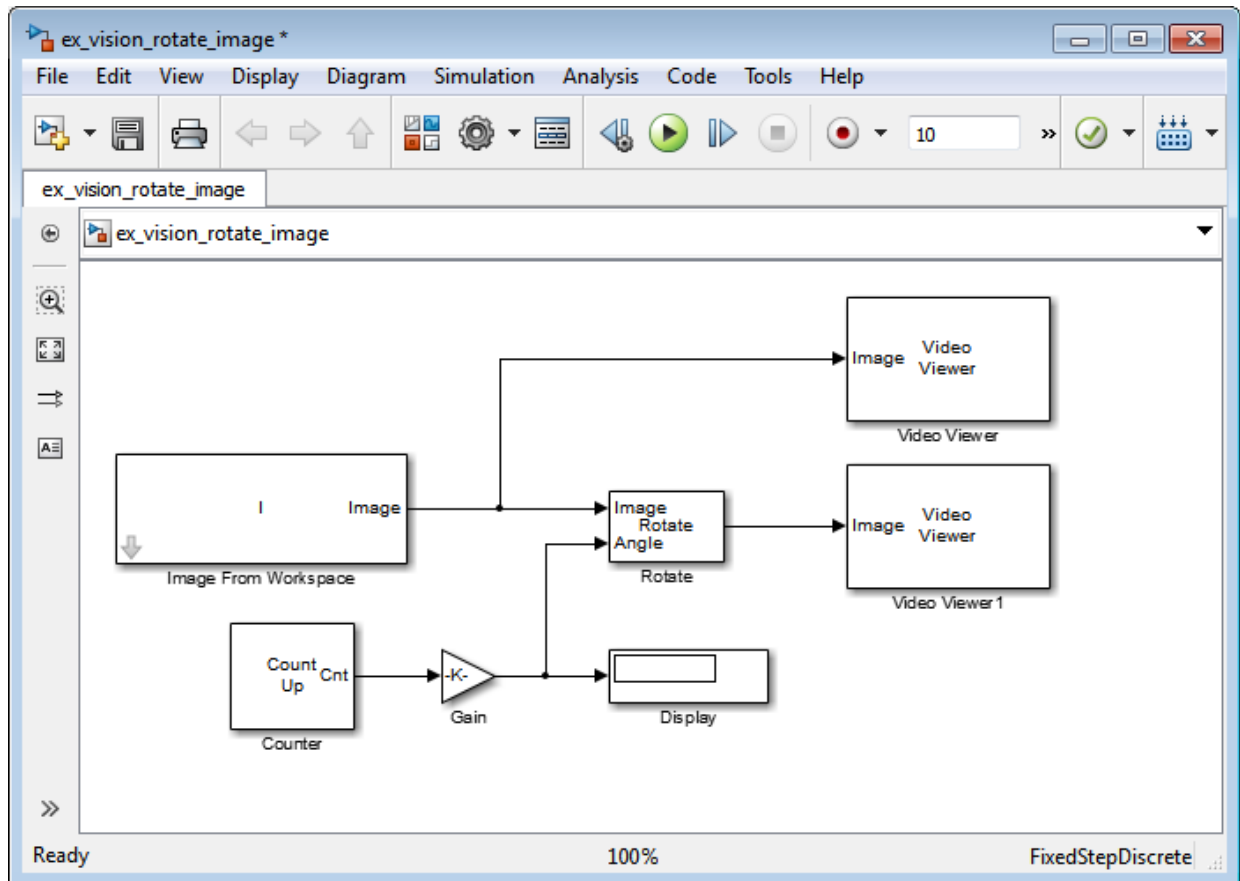
The Angle port appears on the block. You use this port to input a steadily increasing angle. Setting the **Output size** parameter to **Expanded to fit rotated input image** ensures that the block does not crop the output.

- 7 Use the Video Viewer1 block to display the rotating image. Accept the default parameters.
- 8 Use the Counter block to create a steadily increasing angle. Set the block parameters as follows:
  - **Count event** = Free running

- **Counter size** = 16 bits
- **Output** = Count
- Clear the **Reset input** check box.
- **Sample time** = 1/30

The Counter block counts upward until it reaches the maximum value that can be represented by 16 bits. Then, it starts again at zero. You can view its output value on the Display block while the simulation is running. The Counter block's **Count data type** parameter enables you to specify its output data type.

- 9 Use the Gain block to convert the output of the Counter block from degrees to radians. Set the **Gain** parameter to  $\pi/180$ .
- 10 Connect the blocks as shown in the following figure.

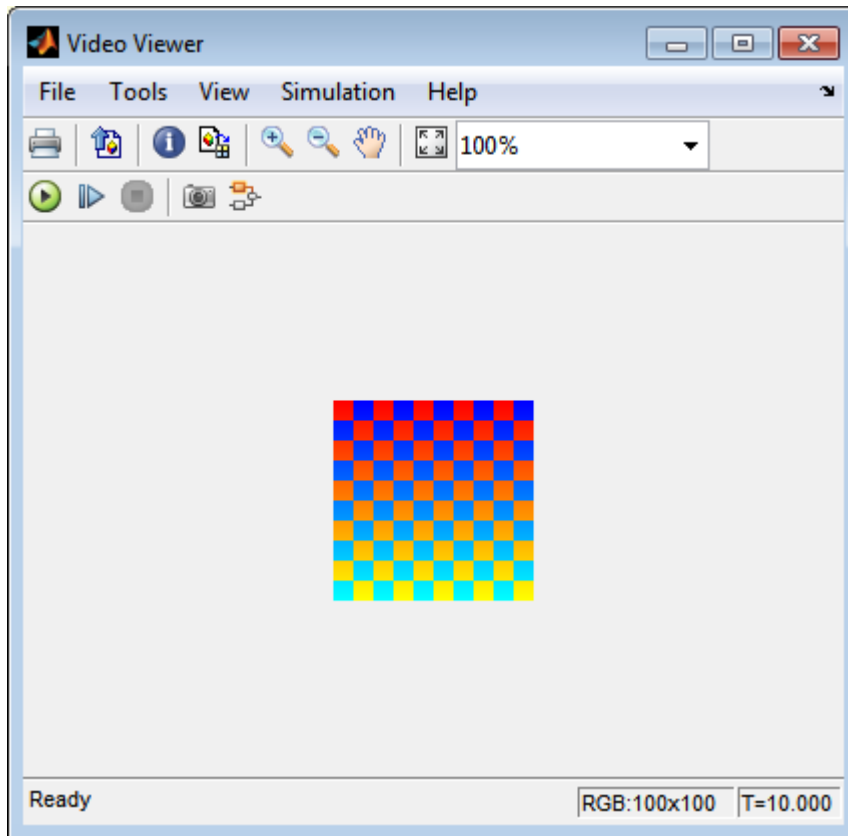


11 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

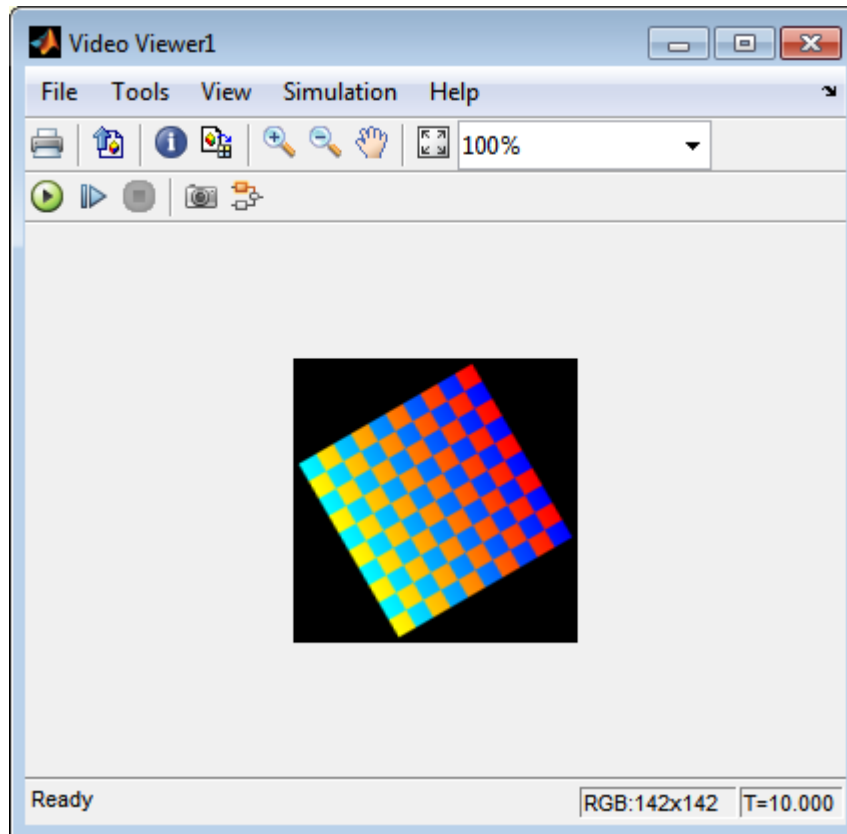
- **Solver** pane, **Stop time** = inf
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

12 Run the model.

The original image appears in the Video Viewer window.



The rotating image appears in the Video Viewer1 window.



In this example, you used the Rotate block to continuously rotate your image. For more information about this block, see the Rotate block reference page in the *Computer Vision System Toolbox Reference*. For more information about other geometric transformation blocks, see the Resize and Shear block reference pages.

---

**Note** If you are on a Windows operating system, you can replace the Video Viewer block with the To Video Display block, which supports code generation.

---

## Resize an Image

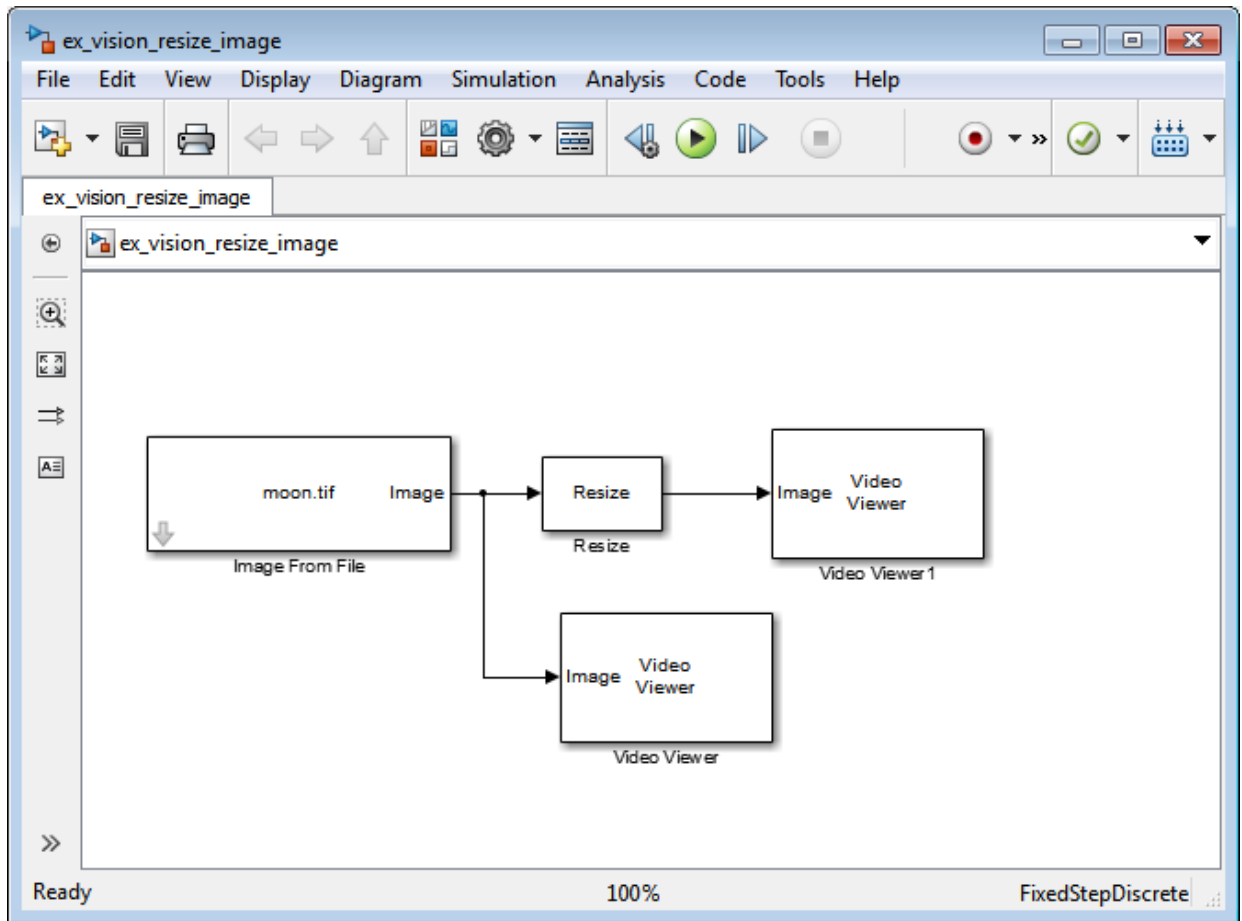
You can use the Resize block to change the size of your image or video stream. In this example, you learn how to use the Resize block to reduce the size of an image:

`ex_vision_resize_image`

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

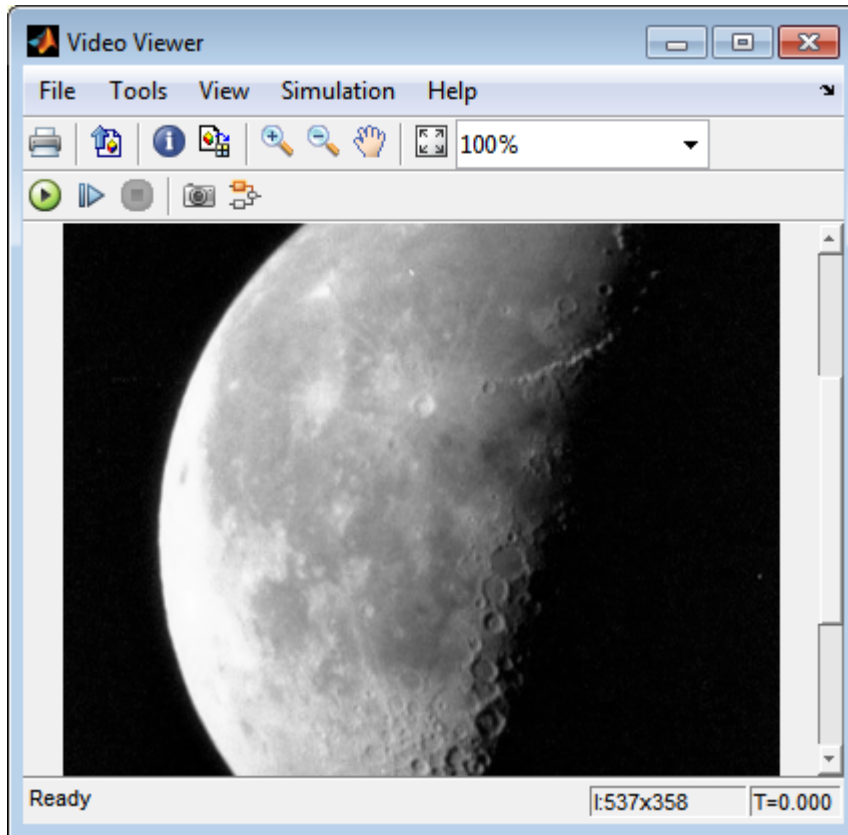
Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Resize	Computer Vision System Toolbox > Geometric Transformations	1
Video Viewer	Computer Vision System Toolbox > Sinks	2

- 2 Use the Image From File block to import the intensity image. Set the **File name** parameter to `moon.tif`. The tif file is a 537-by-358 matrix of 8-bit unsigned integer values.
- 3 Use the Video Viewer block to display the original image. Accept the default parameters. This block automatically displays the original image in the Video Viewer window when you run the model.
- 4 Use the Resize block to shrink the image. Set the **Resize factor in %** parameter to 50. This shrinks the image to half its original size.
- 5 Use the Video Viewer1 block to display the modified image. Accept the default parameters.
- 6 Connect the blocks as shown in the following figure.



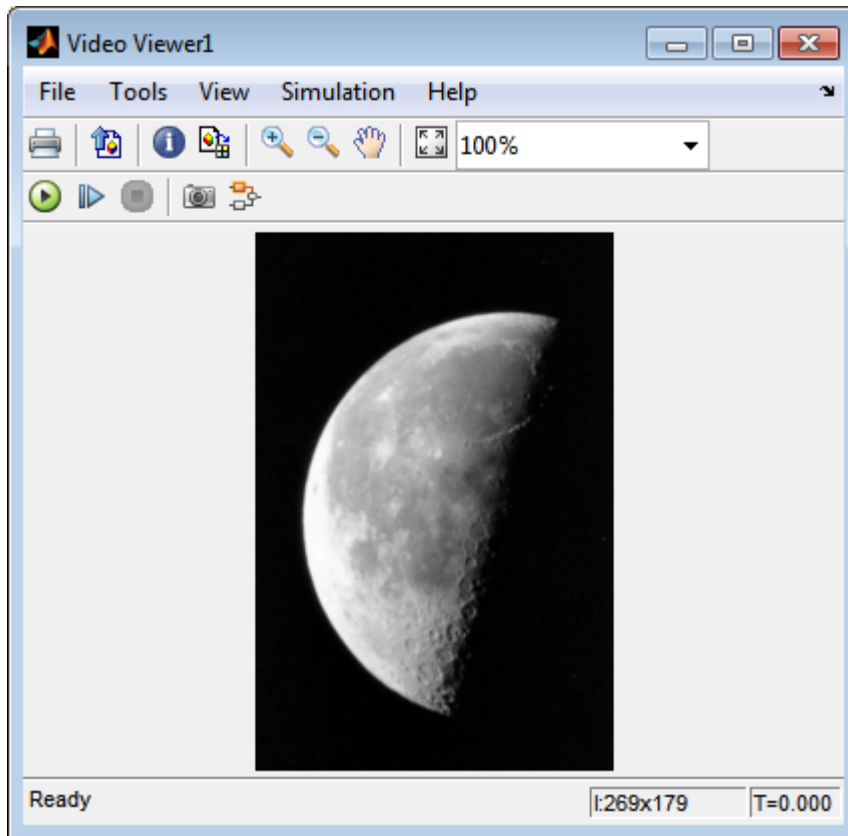
- 7 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 8 Run the model.

The original image appears in the Video Viewer window.



The reduced image appears in the Video Viewer1 window.





In this example, you used the Resize block to shrink an image. For more information about this block, see the [Resize block reference page](#). For more information about other geometric transformation blocks, see the [Rotate](#), [Apply Geometric Transformation](#), [Estimate Geometric Transformation](#), and [Translate](#) block reference pages.

## Crop an Image

You can use the Selector block to crop your image or video stream. In this example, you learn how to use the Selector block to trim an image down to a particular region of interest:

`ex_vision_crop_image`

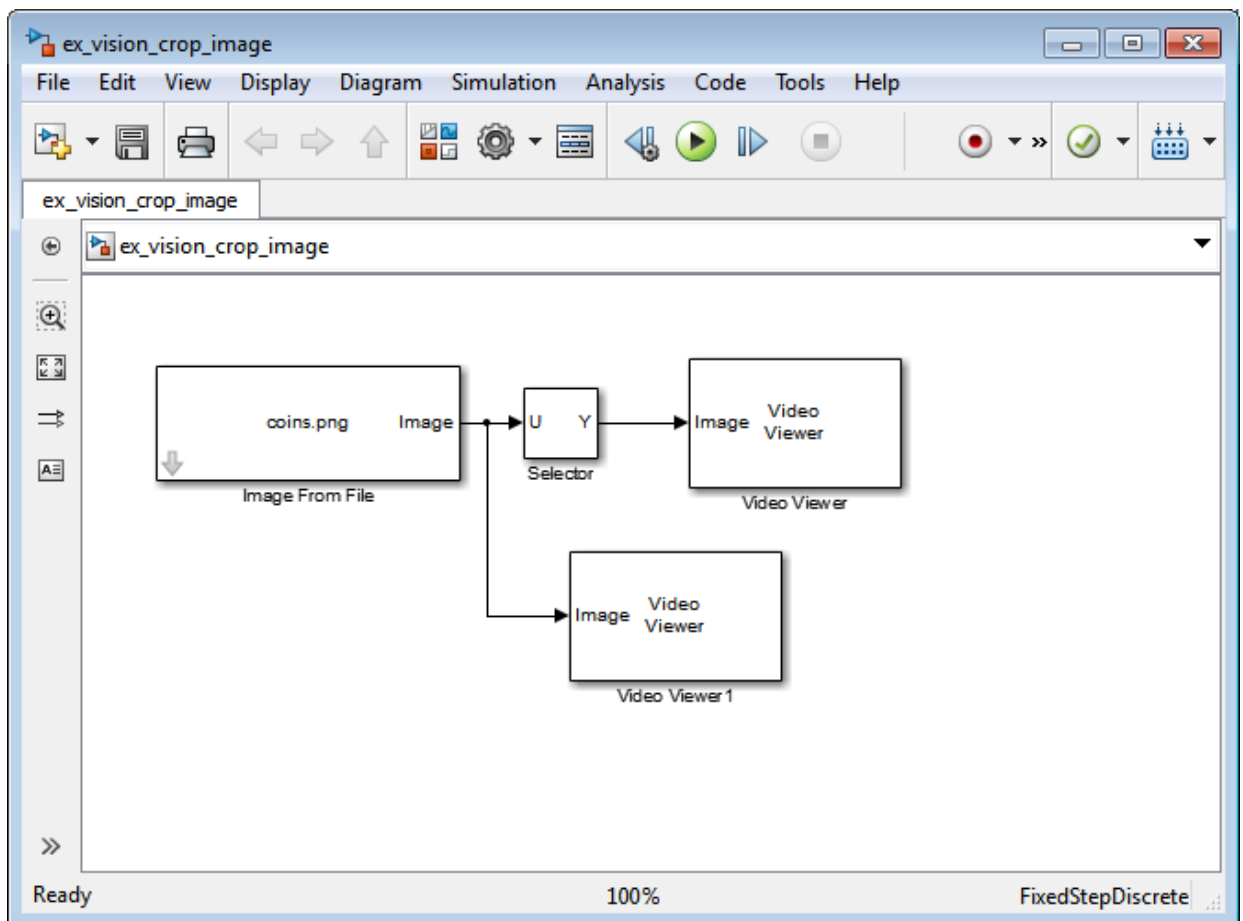
- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Video Viewer	Computer Vision System Toolbox > Sinks	2
Selector	Simulink > Signal Routing	1

- 2 Use the Image From File block to import the intensity image. Set the **File name** parameter to `coins.png`. The image is a 246-by-300 matrix of 8-bit unsigned integer values.
- 3 Use the Video Viewer block to display the original image. Accept the default parameters. This block automatically displays the original image in the Video Viewer window when you run the model.
- 4 Use the Selector block to crop the image. Set the block parameters as follows:
  - **Number of input dimensions** = 2
  - **1**
    - **Index Option** = Starting index (dialog)
    - **Index** = 140
    - **Output Size** = 70
  - **2**
    - **Index Option** = Starting index (dialog)
    - **Index** = 200
    - **Output Size** = 70

The Selector block starts at row 140 and column 200 of the image and outputs the next 70 rows and columns of the image.

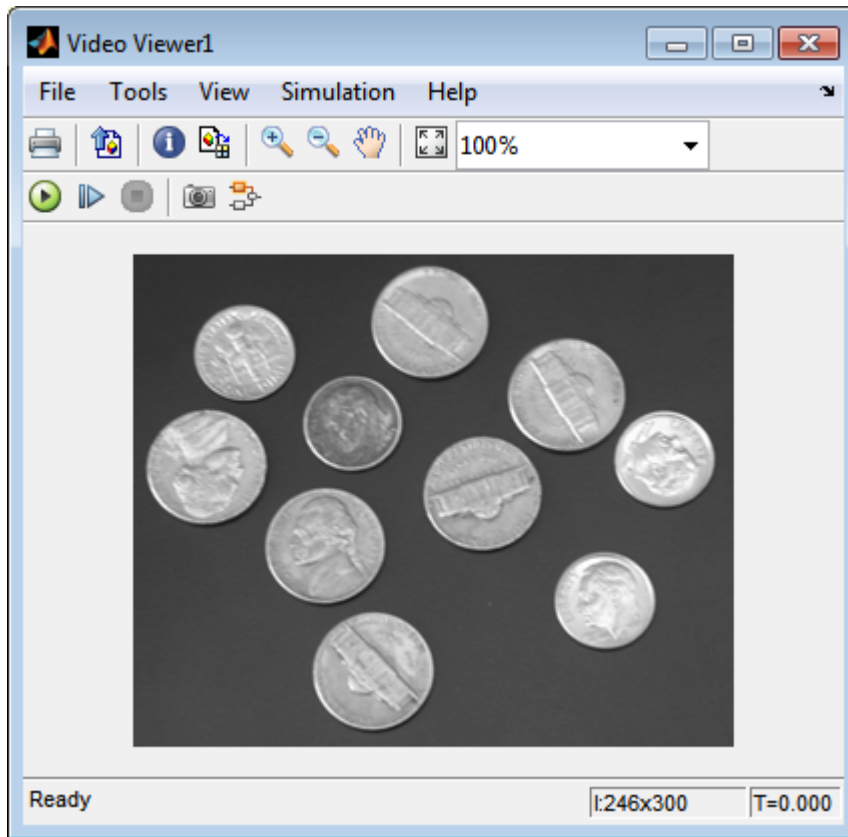
- 5 Use the Video Viewer1 block to display the cropped image. This block automatically displays the modified image in the Video Viewer window when you run the model.
- 6 Connect the blocks as shown in the following figure.



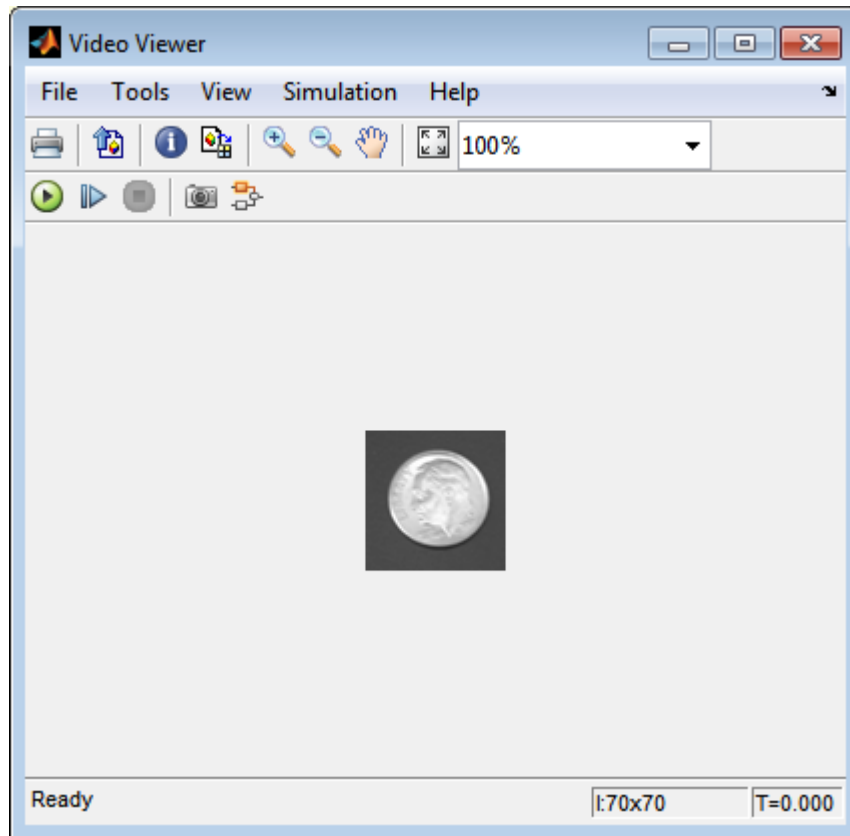
- 7 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 8 Run the model.

The original image appears in the Video Viewer window.



The cropped image appears in the Video Viewer1 window. The following image is shown at its true size.



In this example, you used the Selector block to crop an image. For more information about the Selector block, see the Simulink documentation. For information about the `imcrop` function, see the Image Processing Toolbox documentation.

## Nearest Neighbor, Bilinear, and Bicubic Interpolation Methods

### In this section...

“Nearest Neighbor Interpolation” on page 7-16

“Bilinear Interpolation” on page 7-17

“Bicubic Interpolation” on page 7-18

### Nearest Neighbor Interpolation

For nearest neighbor interpolation, the block uses the value of nearby translated pixel values for the output pixel values.

For example, suppose this matrix,

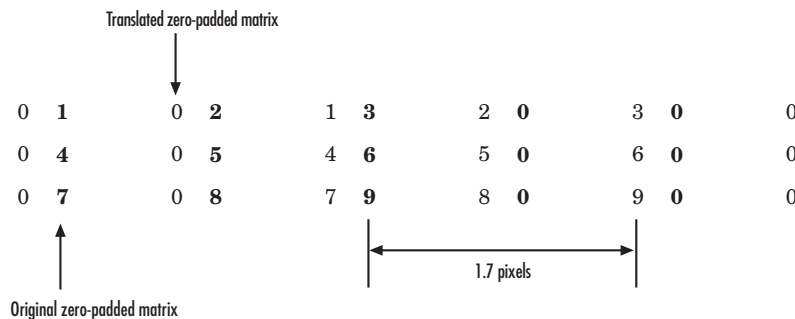
```

1  2  3
4  5  6
7  8  9

```

represents your input image. You want to translate this image 1.7 pixels in the positive horizontal direction using nearest neighbor interpolation. The Translate block's nearest neighbor interpolation algorithm is illustrated by the following steps:

- 1 Zero pad the input matrix and translate it by 1.7 pixels to the right.



- 2 Create the output matrix by replacing each input pixel value with the translated value nearest to it. The result is the following matrix:

```

0 0 1 2 3
0 0 4 5 6
0 0 7 8 9
    
```

---

**Note:** You wanted to translate the image by 1.7 pixels, but this method translated the image by 2 pixels. Nearest neighbor interpolation is computationally efficient but not as accurate as bilinear or bicubic interpolation.

---

## Bilinear Interpolation

For bilinear interpolation, the block uses the weighted average of two translated pixel values for each output pixel value.

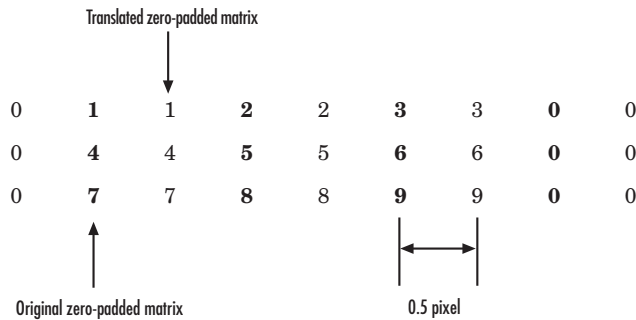
For example, suppose this matrix,

```

1 2 3
4 5 6
7 8 9
    
```

represents your input image. You want to translate this image 0.5 pixel in the positive horizontal direction using bilinear interpolation. The Translate block's bilinear interpolation algorithm is illustrated by the following steps:

- 1 Zero pad the input matrix and translate it by 0.5 pixel to the right.



- 2 Create the output matrix by replacing each input pixel value with the weighted average of the translated values on either side. The result is the following matrix where the output matrix has one more column than the input matrix:

```

0.5  1.5  2.5  1.5
  2   4.5  5.5   3
 3.5  7.5  8.5  4.5
    
```

### Bicubic Interpolation

For bicubic interpolation, the block uses the weighted average of four translated pixel values for each output pixel value.

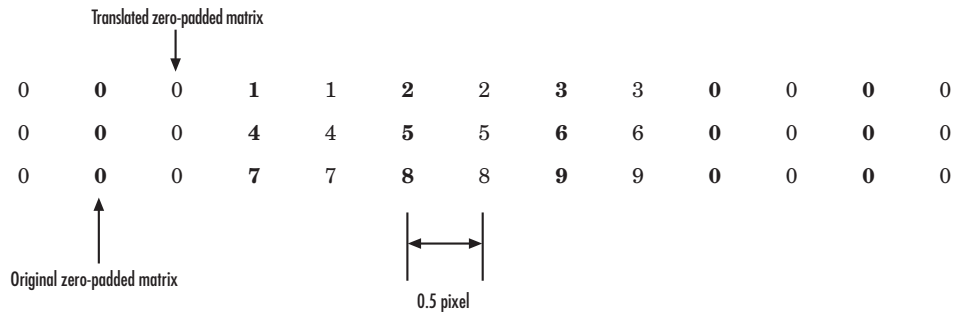
For example, suppose this matrix,

```

 1  2  3
 4  5  6
 7  8  9
    
```

represents your input image. You want to translate this image 0.5 pixel in the positive horizontal direction using bicubic interpolation. The Translate block's bicubic interpolation algorithm is illustrated by the following steps:

- 1 Zero pad the input matrix and translate it by 0.5 pixel to the right.



- 2 Create the output matrix by replacing each input pixel value with the weighted average of the two translated values on either side. The result is the following matrix where the output matrix has one more column than the input matrix:



0.375	1.5	3	1.625
1.875	4.875	6.375	3.125
3.375	8.25	9.75	4.625



# Filters, Transforms, and Enhancements

---

- “Adjust the Contrast of Intensity Images” on page 8-2
- “Adjust the Contrast of Color Images” on page 8-6
- “Remove Salt and Pepper Noise from Images” on page 8-11
- “Sharpen an Image” on page 8-16

## Adjust the Contrast of Intensity Images

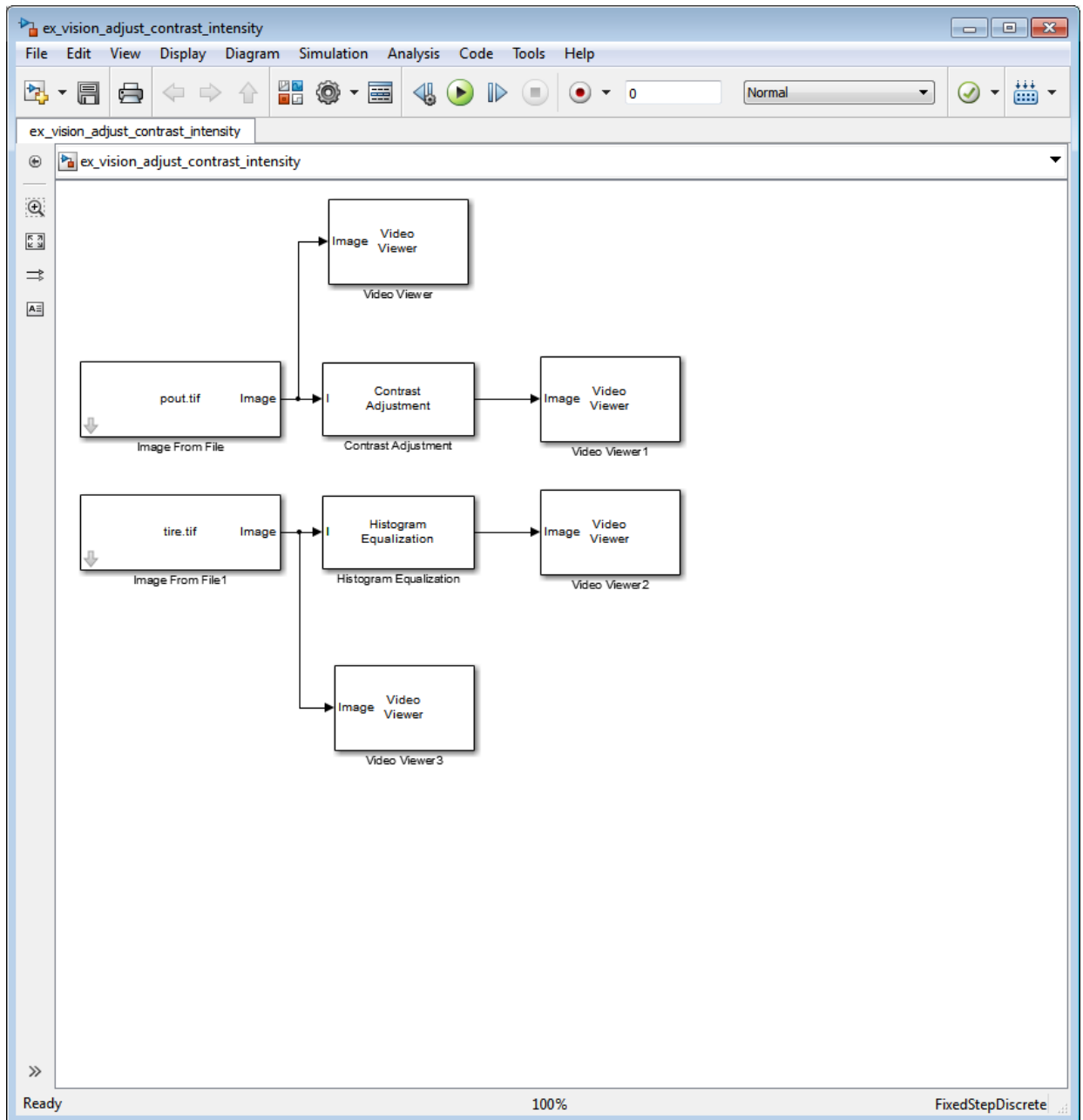
This example shows you how to modify the contrast in two intensity images using the Contrast Adjustment and Histogram Equalization blocks.

`ex_vision_adjust_contrast_intensity`

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

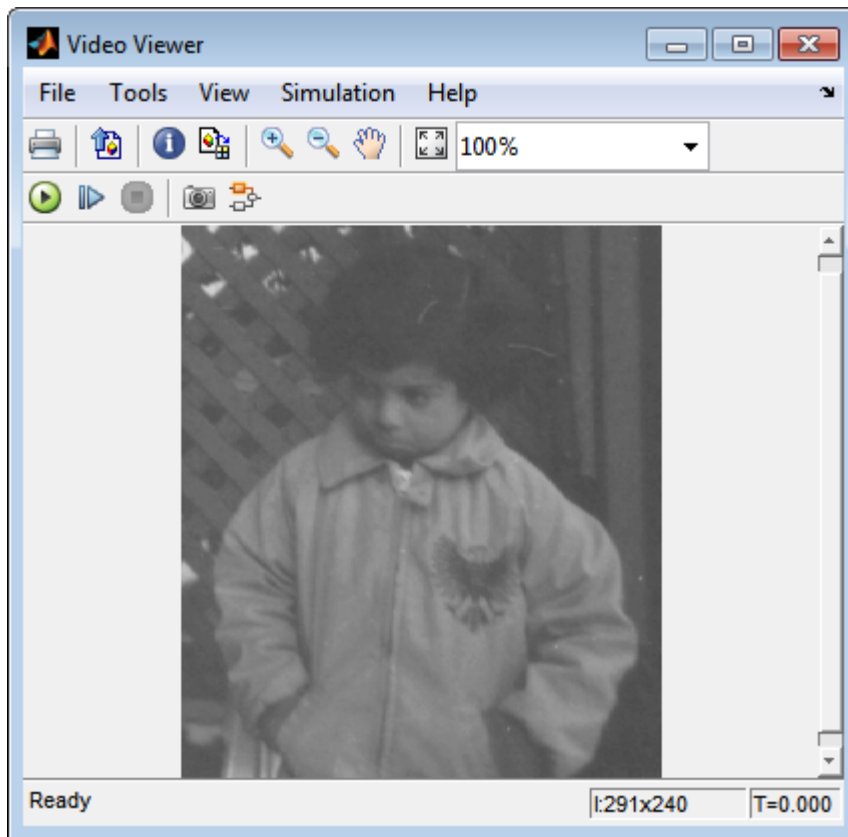
Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	2
Contrast Adjustment	Computer Vision System Toolbox > Analysis & Enhancement	1
Histogram Equalization	Computer Vision System Toolbox > Analysis & Enhancement	1
Video Viewer	Computer Vision System Toolbox > Sinks	4

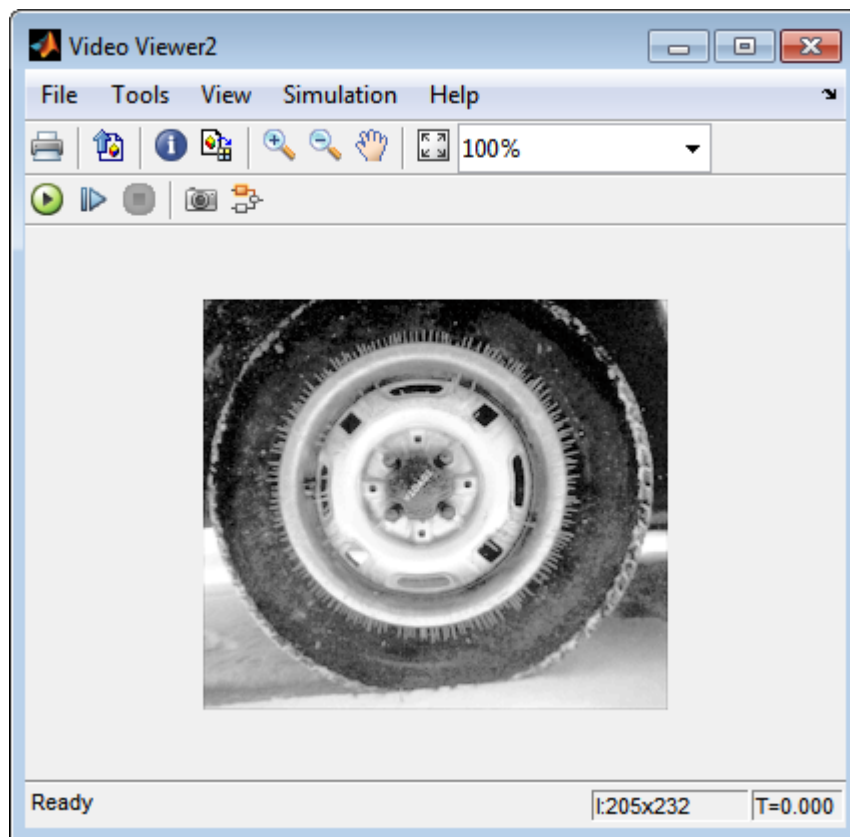
- 2 Place the blocks listed in the table above into your new model.
- 3 Use the Image From File block to import the first image into the Simulink model. Set the **File name** parameter to `pout.tif`.
- 4 Use the Image From File1 block to import the second image into the Simulink model. Set the **File name** parameter to `tire.tif`.
- 5 Use the Contrast Adjustment block to modify the contrast in `pout.tif`. Set the **Adjust pixel values from** parameter to **Range determined by saturating outlier pixels**. This block adjusts the contrast of the image by linearly scaling the pixel values between user-specified upper and lower limits.
- 6 Use the Histogram Equalization block to modify the contrast in `tire.tif`. Accept the default parameters. This block enhances the contrast of images by transforming the values in an intensity image so that the histogram of the output image approximately matches a specified histogram.
- 7 Use the Video Viewer blocks to view the original and modified images. Accept the default parameters.
- 8 Connect the blocks as shown in the following figure.



- 9 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 10 Run the model.

The results appear in the Video Viewer windows.





In this example, you used the Contrast Adjustment block to linearly scale the pixel values in `pout.tif` between new upper and lower limits. You used the Histogram Equalization block to transform the values in `tire.tif` so that the histogram of the output image approximately matches a uniform histogram. For more information, see the Contrast Adjustment and Histogram Equalization reference pages.

## Adjust the Contrast of Color Images

This example shows you how to modify the contrast in color images using the Histogram Equalization block.

ex\_vision\_adjust\_contrast\_color.mdl

- 1 Use the following code to read in an indexed RGB image, `shadow.tif`, and convert it to an RGB image. The model provided above already includes this code in `file > Model Properties > Model Properties > InitFcn`, and executes it prior to simulation.

```
[X map] = imread('shadow.tif');
shadow = ind2rgb(X,map);
```

- 2 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From Workspace	Computer Vision System Toolbox > Sources	1
Color Space Conversion	Computer Vision System Toolbox > Conversions	2
Histogram Equalization	Computer Vision System Toolbox > Analysis & Enhancement	1
Video Viewer	Computer Vision System Toolbox > Sinks	2
Constant	Simulink > Sources	1
Divide	Simulink > Math Operations	1
Product	Simulink > Math Operations	1

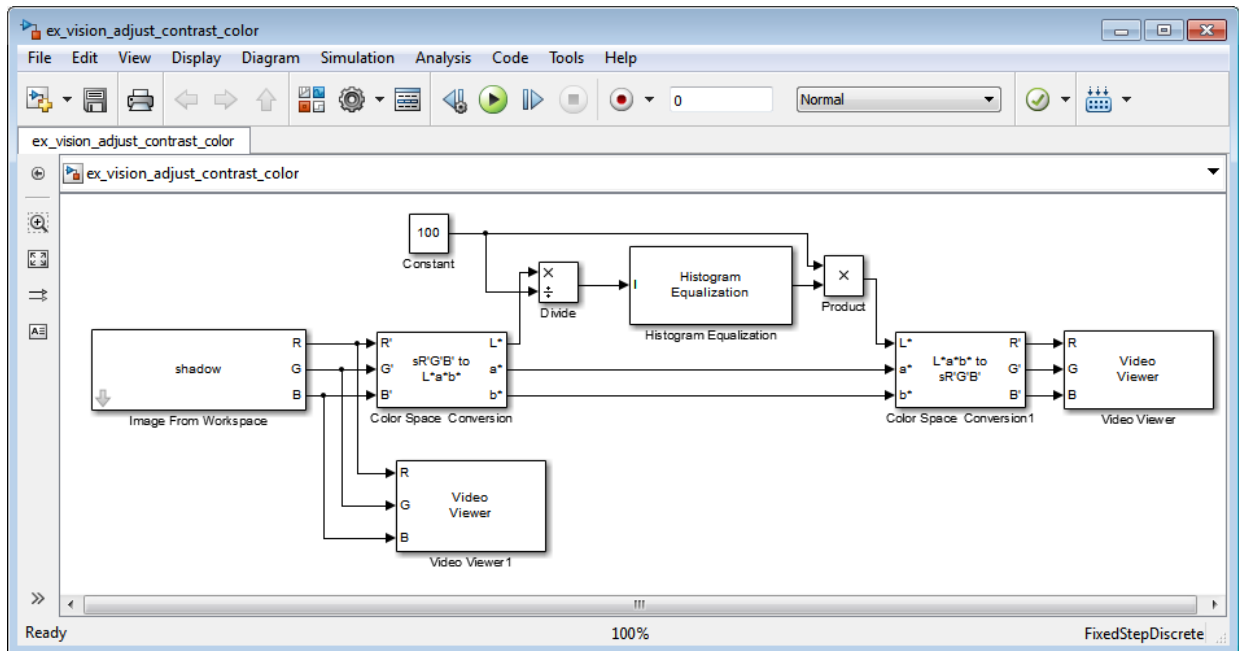
- 3 Place the blocks listed in the table above into your new model.
- 4 Use the Image From Workspace block to import the RGB image from the MATLAB workspace into the Simulink model. Set the block parameters as follows:
  - **Value** = `shadow`
  - **Image signal** = `Separate color signals`
- 5 Use the Color Space Conversion block to separate the luma information from the color information. Set the block parameters as follows:
  - **Conversion** = `sR'G'B'` to `L*a*b*`



- **Image signal** = Separate color signals

Because the range of the  $L^*$  values is between 0 and 100, you must normalize them to be between zero and one before you pass them to the Histogram Equalization block, which expects floating point input in this range.

- 6 Use the Constant block to define a normalization factor. Set the **Constant value** parameter to 100.
- 7 Use the Divide block to normalize the  $L^*$  values to be between 0 and 1. Accept the default parameters.
- 8 Use the Histogram Equalization block to modify the contrast in the image. This block enhances the contrast of images by transforming the luma values in the color image so that the histogram of the output image approximately matches a specified histogram. Accept the default parameters.
- 9 Use the Product block to scale the values back to be between the 0 to 100 range. Accept the default parameters.
- 10 Use the Color Space Conversion1 block to convert the values back to the sR'G'B' color space. Set the block parameters as follows:
  - **Conversion** =  $L^*a^*b^*$  to sR'G'B'
  - **Image signal** = Separate color signals
- 11 Use the Video Viewer blocks to view the original and modified images. For each block, set the **Image signal** parameter to **Separate color signals** from the file menu.
- 12 Connect the blocks as shown in the following figure.

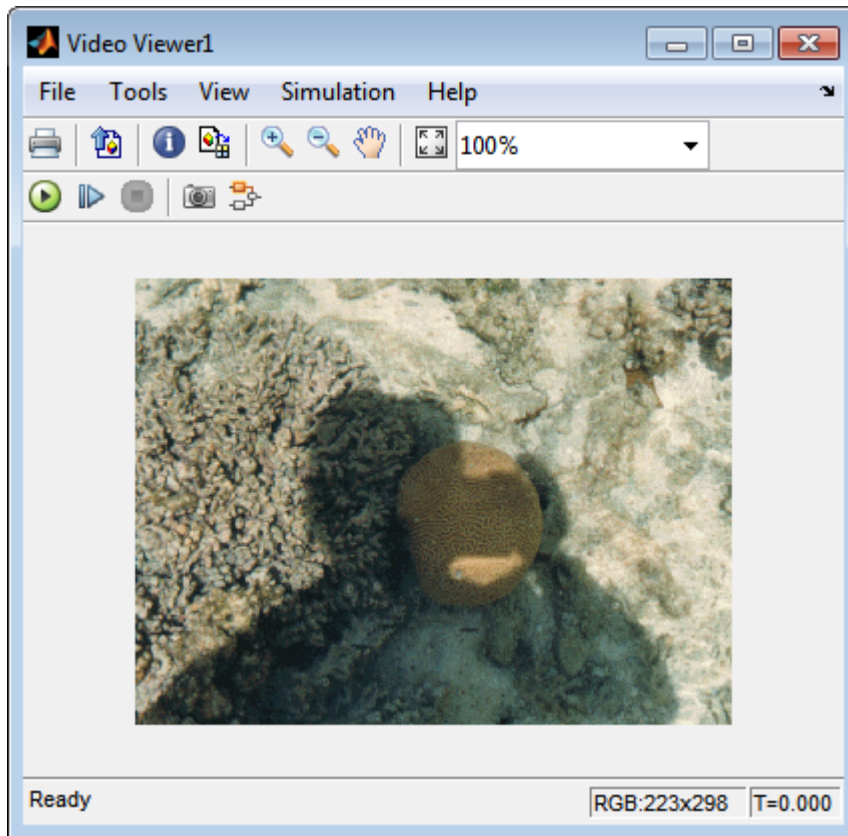


**13** Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

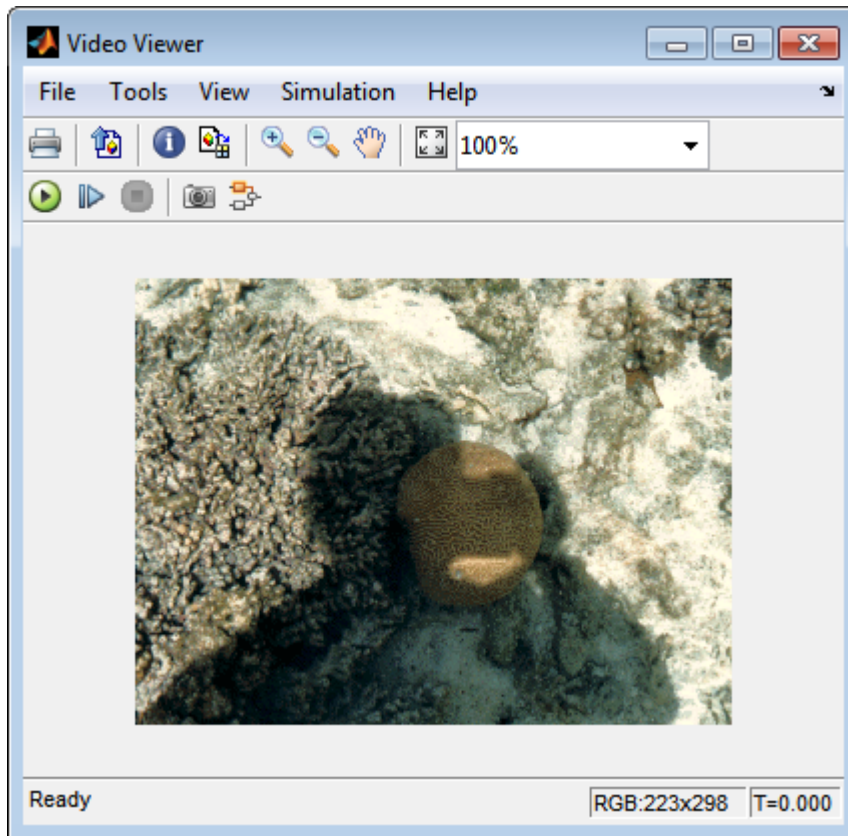
- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

**14** Run the model.

As shown in the following figure, the model displays the original image in the Video Viewer1 window.



As the next figure shows, the model displays the enhanced contrast image in the Video Viewer window.



In this example, you used the Histogram Equalization block to transform the values in a color image so that the histogram of the output image approximately matches a uniform histogram. For more information, see the Histogram Equalization reference page.

## Remove Salt and Pepper Noise from Images

Median filtering is a common image enhancement technique for removing salt and pepper noise. Because this filtering is less sensitive than linear techniques to extreme changes in pixel values, it can remove salt and pepper noise without significantly reducing the sharpness of an image. In this topic, you use the Median Filter block to remove salt and pepper noise from an intensity image:

`ex_vision_remove_noise`

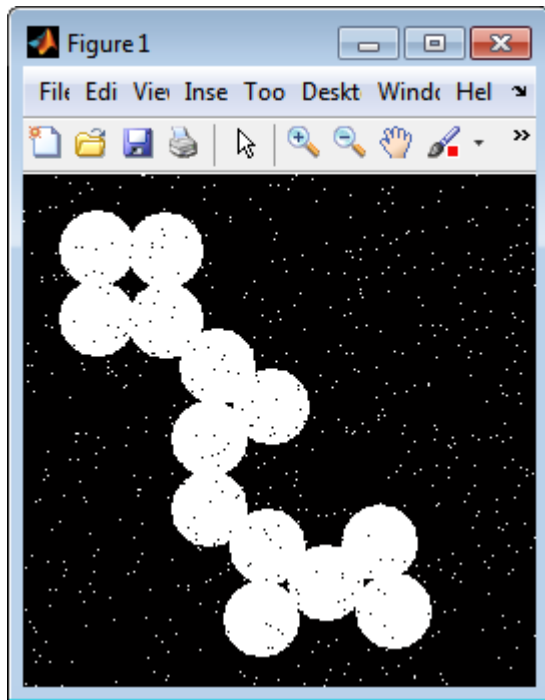
- 1 Define an intensity image in the MATLAB workspace and add noise to it by typing the following at the MATLAB command prompt:

```
I= double(imread('circles.png'));  
I= imnoise(I,'salt & pepper',0.02);
```

I is a 256-by-256 matrix of 8-bit unsigned integer values.

The model provided with this example already includes this code in `file>Model Properties>Model Properties>InitFcn`, and executes it prior to simulation.

- 2 To view the image this matrix represents, at the MATLAB command prompt, type  
`imshow(I)`



The intensity image contains noise that you want your model to eliminate.

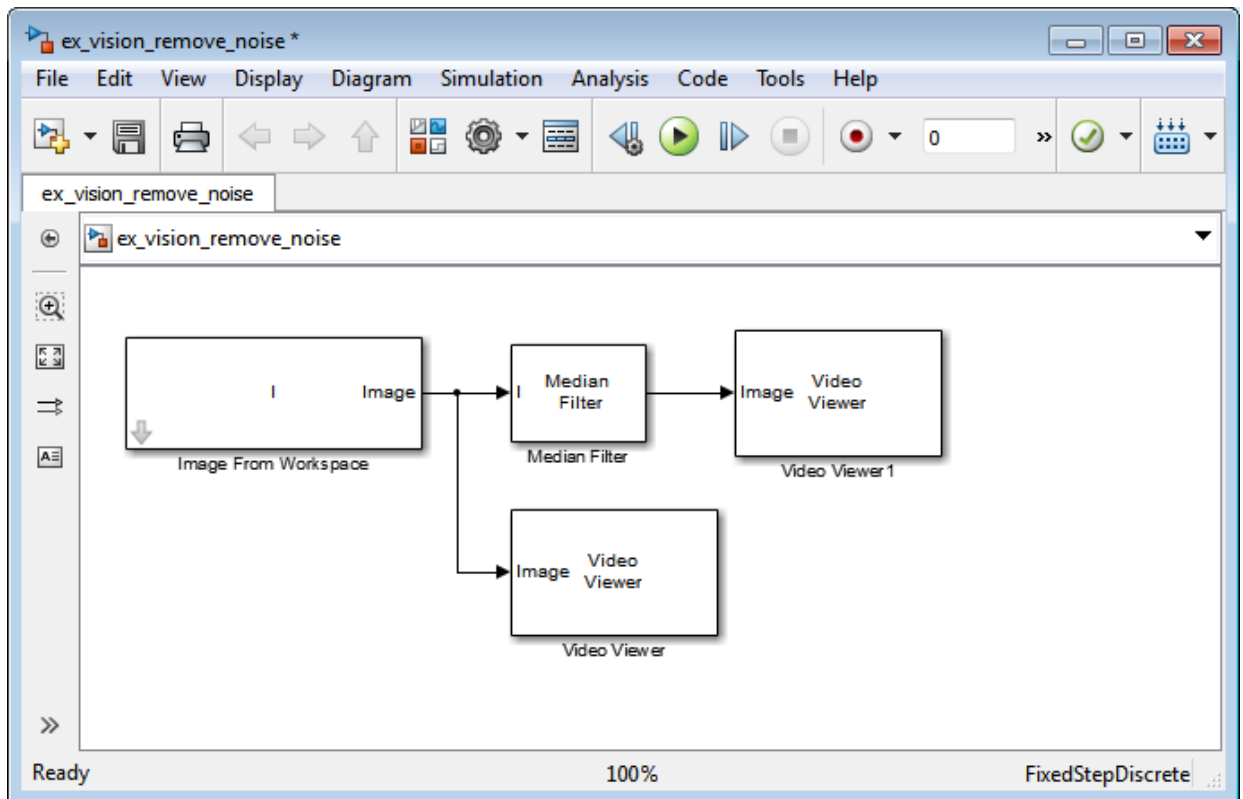
- 3 Create a Simulink model, and add the blocks shown in the following table.

Block	Library	Quantity
Image From Workspace	Computer Vision System Toolbox > Sources	1
Median Filter	Computer Vision System Toolbox > Filtering	1
Video Viewer	Computer Vision System Toolbox > Sinks	2

- 4 Use the Image From Workspace block to import the noisy image into your model. Set the **Value** parameter to **I**.
- 5 Use the Median Filter block to eliminate the black and white speckles in the image. Use the default parameters.

The Median Filter block replaces the central value of the 3-by-3 neighborhood with the median value of the neighborhood. This process removes the noise in the image.

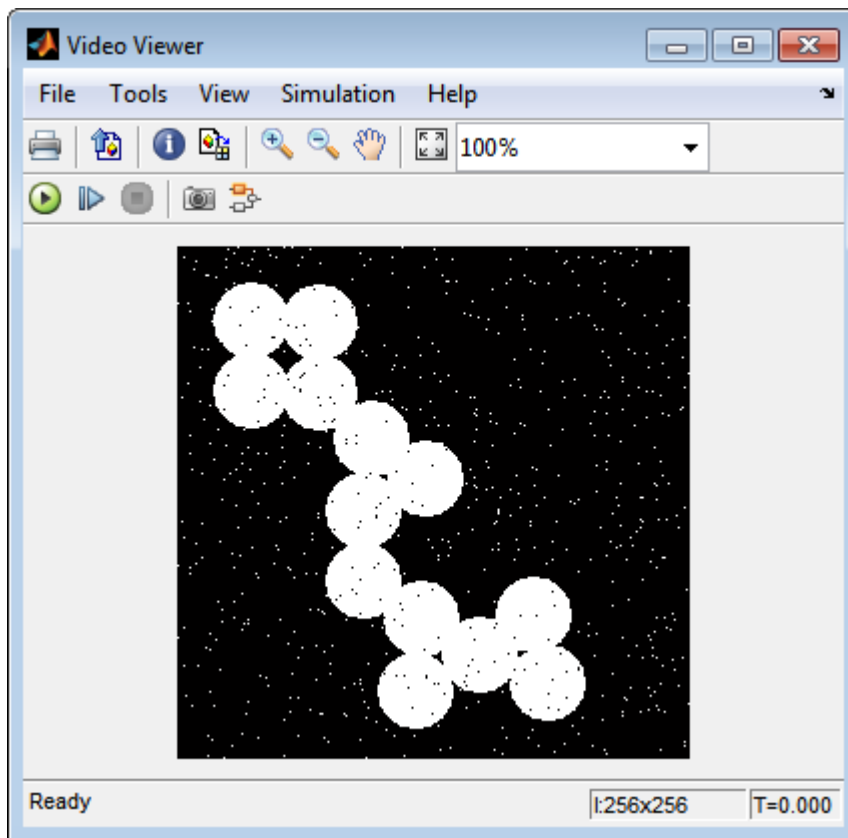
- 6 Use the Video Viewer blocks to display the original noisy image, and the modified image. Images are represented by 8-bit unsigned integers. Therefore, a value of 0 corresponds to black and a value of 255 corresponds to white. Accept the default parameters.
- 7 Connect the blocks as shown in the following figure.



- 8 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0

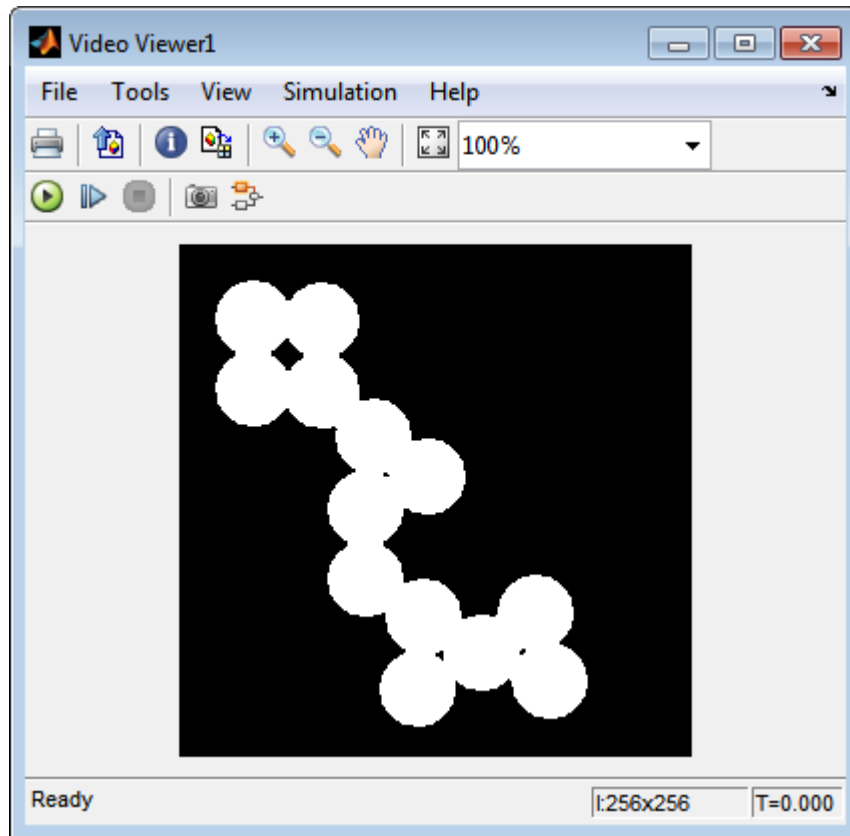
- **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 9 Run the model.

The original noisy image appears in the Video Viewer window. To view the image at its true size, right-click the window and select **Set Display To True Size**.



The cleaner image appears in the Video Viewer1 window. The following image is shown at its true size.





You have used the Median Filter block to remove noise from your image. For more information about this block, see the Median Filter block reference page in the *Computer Vision System Toolbox Reference*.

## Sharpen an Image

To sharpen a color image, you need to make the luma intensity transitions more acute, while preserving the color information of the image. To do this, you convert an R'G'B' image into the Y'CbCr color space and apply a highpass filter to the luma portion of the image only. Then, you transform the image back to the R'G'B' color space to view the results. To blur an image, you apply a lowpass filter to the luma portion of the image. This example shows how to use the 2-D FIR Filter block to sharpen an image. The prime notation indicates that the signals are gamma corrected.

`ex_vision_sharpen_image`

- 1 Define an R'G'B' image in the MATLAB workspace. To read in an R'G'B' image from a PNG file and cast it to the double-precision data type, at the MATLAB command prompt, type

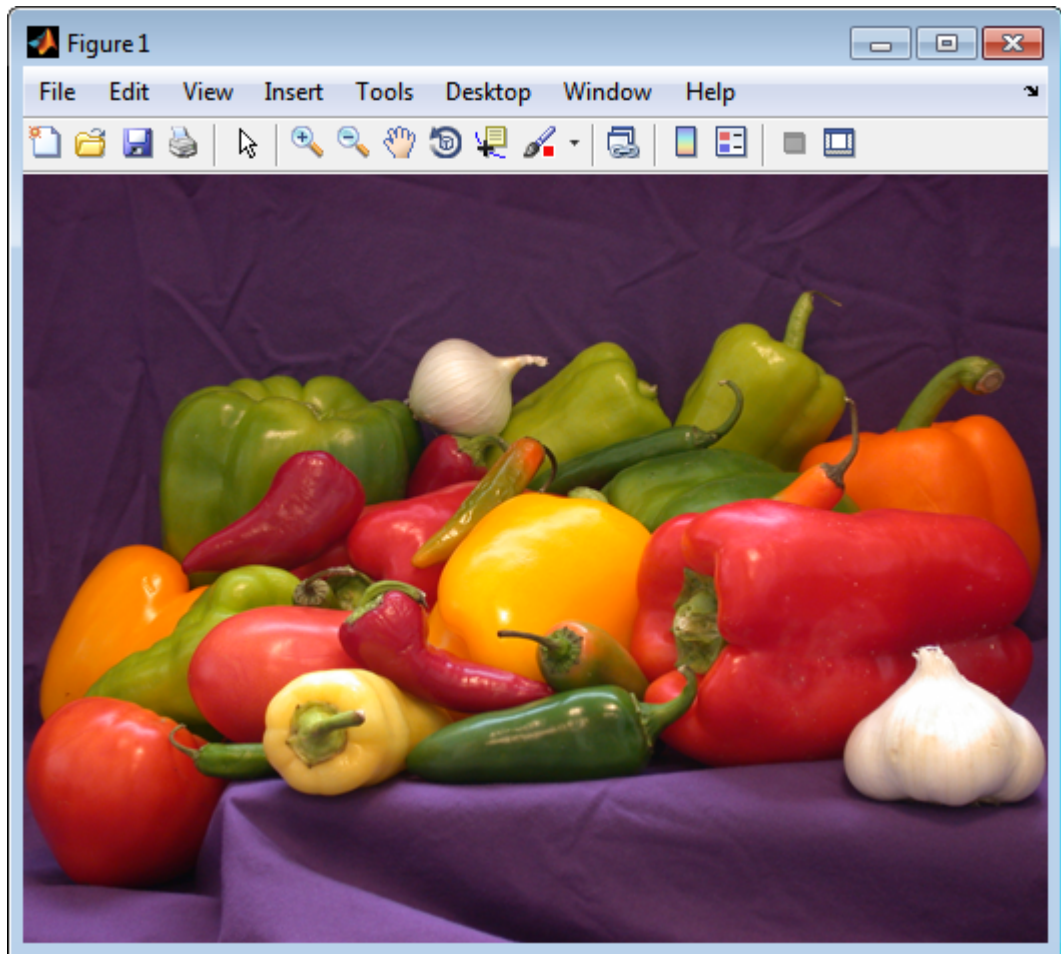
```
I = im2double(imread('peppers.png'));
```

`I` is a 384-by-512-by-3 array of double-precision floating-point values. Each plane of this array represents the red, green, or blue color values of the image.

The model provided with this example already includes this code in `file>Model Properties>Model Properties>InitFcn`, and executes it prior to simulation.

- 2 To view the image this array represents, type this command at the MATLAB command prompt:

```
imshow(I)
```



Now that you have defined your image, you can create your model.

- 3 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From Workspace	Computer Vision System Toolbox > Sources	1

Block	Library	Quantity
Color Space Conversion	Computer Vision System Toolbox > Conversions	2
2-D FIR Filter	Computer Vision System Toolbox > Filtering	1
Video Viewer	Computer Vision System Toolbox > Sinks	1

- 4 Use the Image From Workspace block to import the R'G'B' image from the MATLAB workspace. Set the parameters as follows:

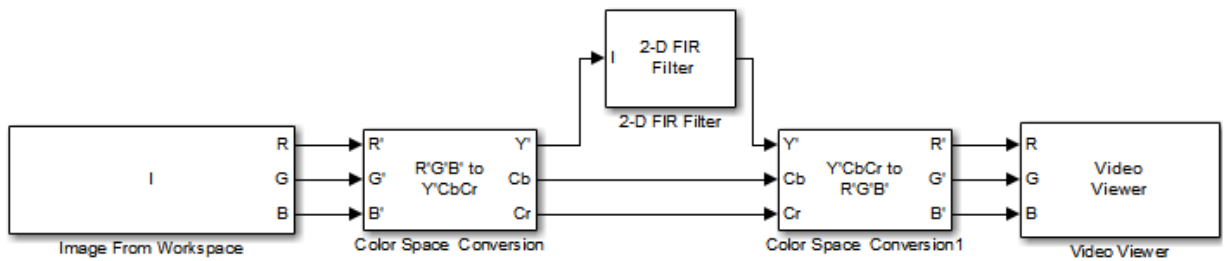
- **Main pane, Value** = I
- **Main pane, Image signal** = Separate color signals

The block outputs the R', G', and B' planes of the I array at the output ports.

- 5 The first Color Space Conversion block converts color information from the R'G'B' color space to the Y'CbCr color space. Set the **Image signal** parameter to **Separate color signals**
- 6 Use the 2-D FIR Filter block to filter the luma portion of the image. Set the block parameters as follows:
- **Coefficients** = `fspecial('unsharp')`
  - **Output size** = Same as input port I
  - **Padding options** = Symmetric
  - **Filtering based on** = Correlation

The `fspecial('unsharp')` command creates two-dimensional highpass filter coefficients suitable for correlation. This highpass filter sharpens the image by removing the low frequency noise in it.

- 7 The second Color Space Conversion block converts the color information from the Y'CbCr color space to the R'G'B' color space. Set the block parameters as follows:
- **Conversion** = Y'CbCr to R'G'B'
  - **Image signal** = Separate color signals
- 8 Use the Video Viewer block to automatically display the new, sharper image in the Video Viewer window when you run the model. Set the **Image signal** parameter to **Separate color signals**, by selecting **File > Image Signal**.
- 9 Connect the blocks as shown in the following figure.

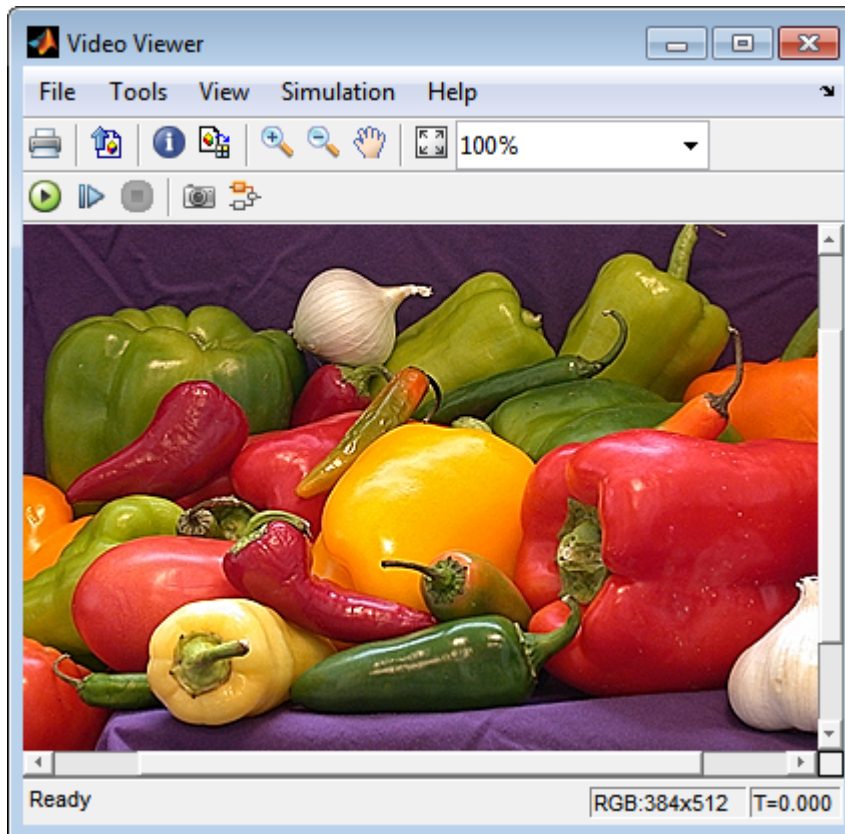


**10** Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = Discrete (no continuous states)

**11** Run the model.

A sharper version of the original image appears in the Video Viewer window.



To blur the image, double-click the 2-D FIR Filter block. Set **Coefficients** parameter to `fspecial('gaussian', [15 15], 7)` and then click **OK**. The `fspecial('gaussian', [15 15], 7)` command creates two-dimensional Gaussian lowpass filter coefficients. This lowpass filter blurs the image by removing the high frequency noise in it.

In this example, you used the Color Space Conversion and 2-D FIR Filter blocks to sharpen an image. For more information, see the Color Space Conversion and 2-D FIR Filter, and `fspecial` reference pages.

# Statistics and Morphological Operations

---

- “Find the Histogram of an Image” on page 9-2
- “Correct Nonuniform Illumination” on page 9-7
- “Count Objects in an Image” on page 9-14

## Find the Histogram of an Image

The Histogram block computes the frequency distribution of the elements in each input image by sorting the elements into a specified number of discrete bins. You can use the Histogram block to calculate the histogram of the R, G, and/or B values in an image. This example shows you how to accomplish this task:

---

**Note:** Running this example requires a DSP System Toolbox license.

---

You can open the example model by typing

```
ex_vision_find_histogram
```

on the MATLAB command line.

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Video Viewer	Computer Vision System Toolbox > Sinks	1
Matrix Concatenate	Simulink > Math Operations	1
Vector Scope	DSP System Toolbox > Sinks	1
Histogram	DSP System Toolbox > Statistics	3

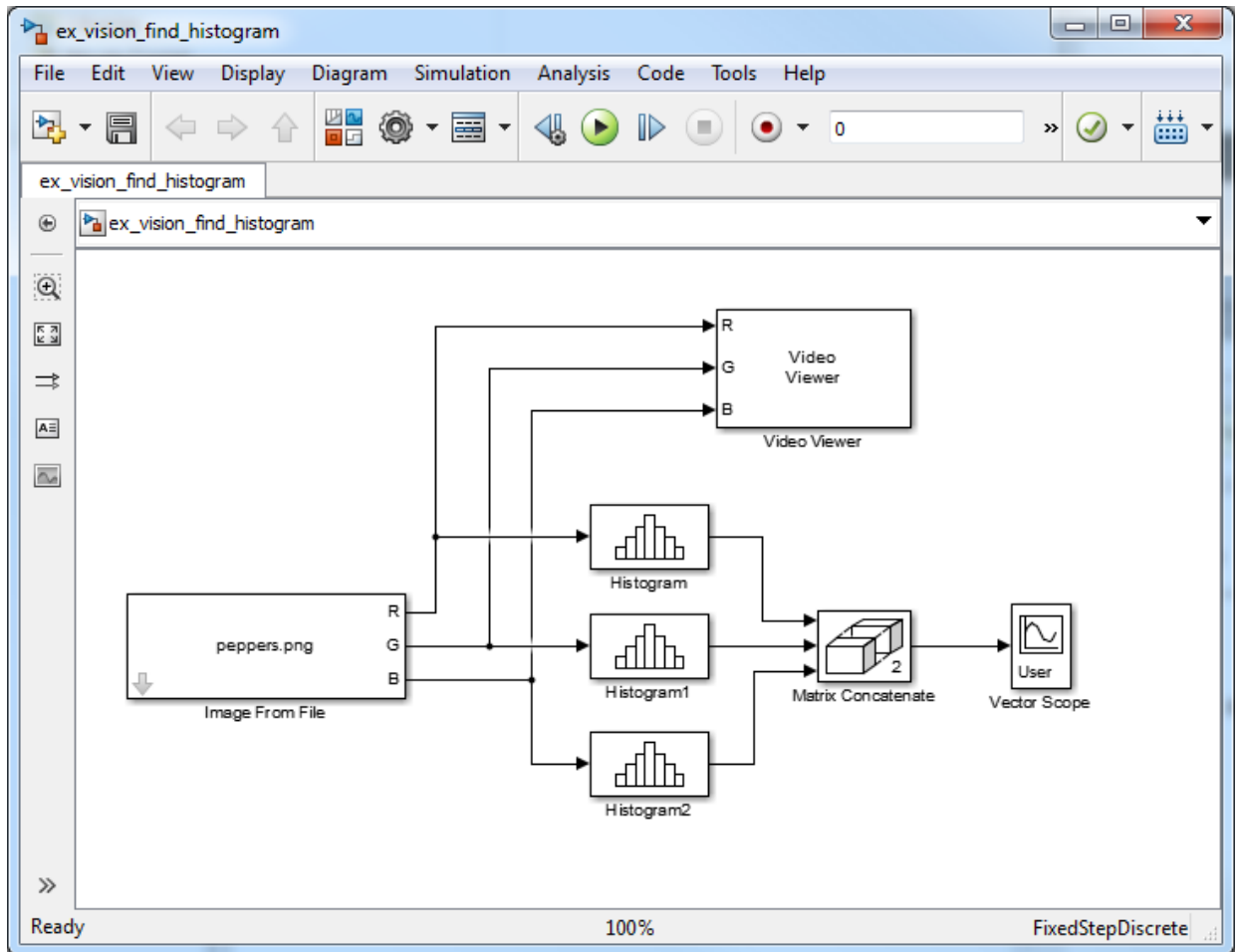
- 2 Use the Image From File block to import an RGB image. Set the block parameters as follows:
  - **Sample time** = `inf`
  - **Image signal** = `Separate color signals`
  - **Output port labels:** = `R|G|B`
  - On the Data Types tab, **Output data type:** = `double`
- 3 Use the Video Viewer block to automatically display the original image in the viewer window when you run the model. Set the **Image signal** parameter to `Separate color signals` from the File menu.
- 4 Use the Histogram blocks to calculate the histogram of the R, G, and B values in the image. Set the Main tab block parameters for the three Histogram blocks as follows:



- **Lower limit of histogram:** 0
- **Upper limit of histogram:** 1
- **Number of bins:** = 256
- **Find the histogram over:** = Entire Input

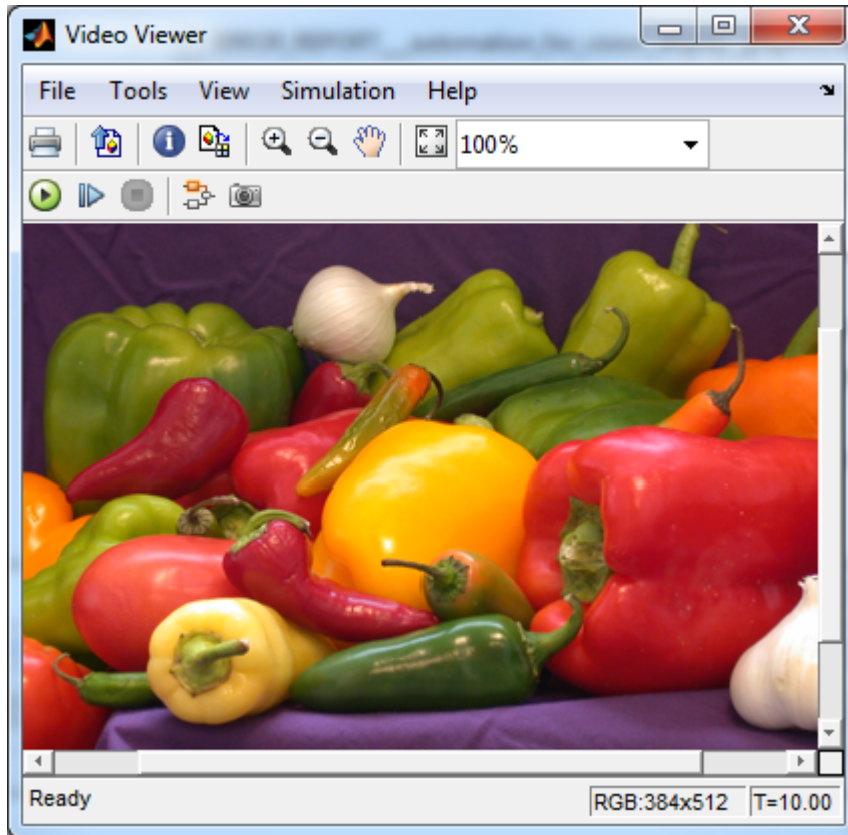
The **R**, **G**, and **B** input values to the Histogram block are double-precision floating point and range between 0 and 1. The block creates 256 bins between the maximum and minimum input values and counts the number of R, G, and B values in each bin.

- 5 Use the Matrix Concatenate block to concatenate the R, G, and B column vectors into a single matrix so they can be displayed using the Vector Scope block. Set the **Number of inputs** parameter to 3.
- 6 Use the Vector Scope block to display the histograms of the R, G, and B values of the input image. Set the block parameters as follows:
  - **Scope Properties** pane, **Input domain** = User-defined
  - **Display Properties** pane, clear the **Frame number** check box
  - **Display Properties** pane, select the **Channel legend** check box
  - **Display Properties** pane, select the **Compact display** check box
  - **Axis Properties** pane, clear the **Inherit sample increment from input** check box.
  - **Axis Properties** pane, **Minimum Y-limit** = 0
  - **Axis Properties** pane, **Maximum Y-limit** = 1
  - **Axis Properties** pane, **Y-axis label** = Count
  - **Line Properties** pane, **Line markers** = . | s | d
  - **Line Properties** pane, **Line colors** = [ 1 0 0 ] | [ 0 1 0 ] | [ 0 0 1 ]
- 7 Connect the blocks as shown in the following figure.



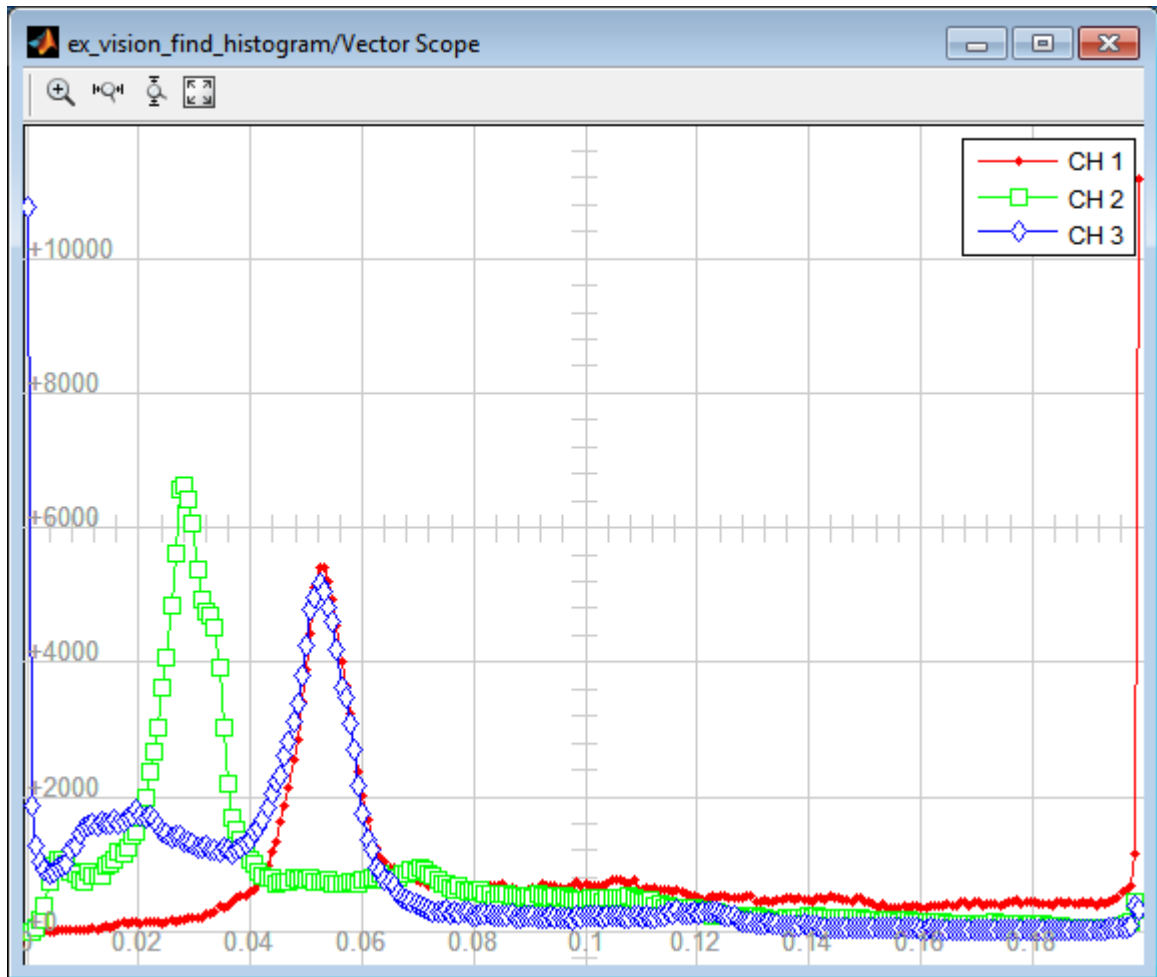
- 8 Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:
  - **Solver** pane, **Stop time** = 0
  - **Solver** pane, **Type** = Fixed-step
  - **Solver** pane, **Solver** = Discrete (no continuous states)
- 9 Run the model using either the simulation button, or by selecting Simulation > Start.

The original image appears in the Video Viewer window.



- 10 Right-click in the Vector Scope window and select **Autoscale**.

The scaled histogram of the image appears in the Vector Scope window.



You have now used the 2-D Histogram block to calculate the histogram of the R, G, and B values in an RGB image. To open a model that illustrates how to use this block to calculate the histogram of the R, G, and B values in an RGB video stream, type `viphistogram` at the MATLAB command prompt.

## Correct Nonuniform Illumination

Global threshold techniques, which are often the first step in object measurement, cannot be applied to unevenly illuminated images. To correct this problem, you can change the lighting conditions and take another picture, or you can use morphological operators to even out the lighting in the image. Once you have corrected for nonuniform illumination, you can pick a global threshold that delineates every object from the background. In this topic, you use the Opening block to correct for uneven lighting in an intensity image:

You can open the example model by typing

```
ex_vision_correct_uniform
on the MATLAB command line.
```

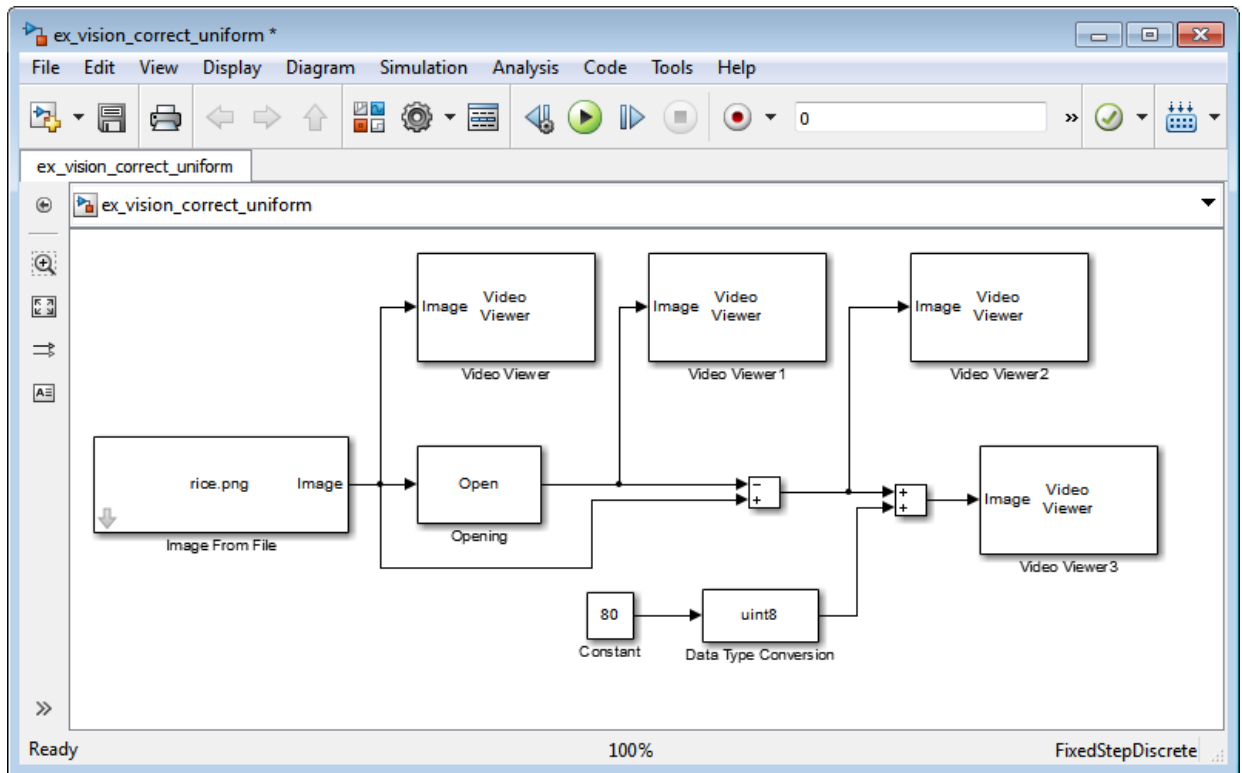
- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Opening	Computer Vision System Toolbox > Morphological Operations	1
Video Viewer	Computer Vision System Toolbox > Sinks	4
Constant	Simulink > Sources	1
Sum	Simulink > Math Operations	2
Data Type Conversion	Simulink > Signal Attributes	1

- 2 Use the Image From File block to import the intensity image. Set the **File name** parameter to `rice.png`. This image is a 256-by-256 matrix of 8-bit unsigned integer values.
- 3 Use the Video Viewer block to view the original image. Accept the default parameters.
- 4 Use the Opening block to estimate the background of the image. Set the **Neighborhood or structuring element** parameter to `strel('disk', 15)`.

The `strel` function creates a circular STREL object with a radius of 15 pixels. When working with the Opening block, pick a STREL object that fits within the objects you want to keep. It often takes experimentation to find the neighborhood or STREL object that best suits your application.

- 5 Use the Video Viewer1 block to view the background estimated by the Opening block. Accept the default parameters.
- 6 Use the first Sum block to subtract the estimated background from the original image. Set the block parameters as follows:
  - **Icon shape** = rectangular
  - **List of signs** = - +
- 7 Use the Video Viewer2 block to view the result of subtracting the background from the original image. Accept the default parameters.
- 8 Use the Constant block to define an offset value. Set the **Constant value** parameter to 80.
- 9 Use the Data Type Conversion block to convert the offset value to an 8-bit unsigned integer. Set the **Output data type mode** parameter to `uint8`.
- 10 Use the second Sum block to lighten the image so that it has the same brightness as the original image. Set the block parameters as follows:
  - **Icon shape** = rectangular
  - **List of signs** = + +
- 11 Use the Video Viewer3 block to view the corrected image. Accept the default parameters.
- 12 Connect the blocks as shown in the following figure.

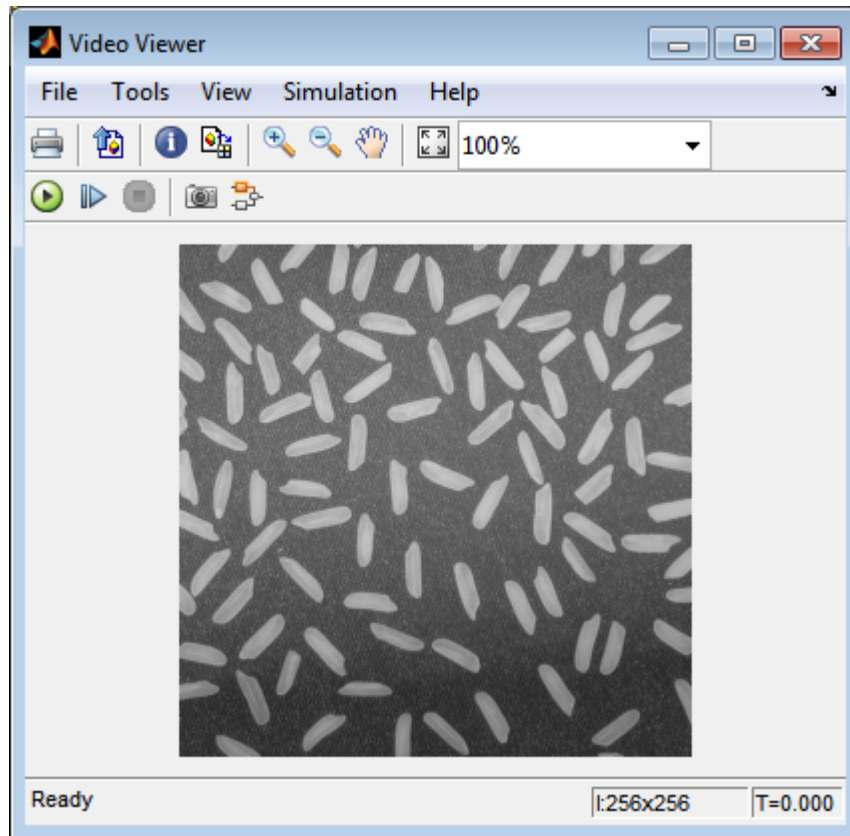


**13** Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = discrete (no continuous states)

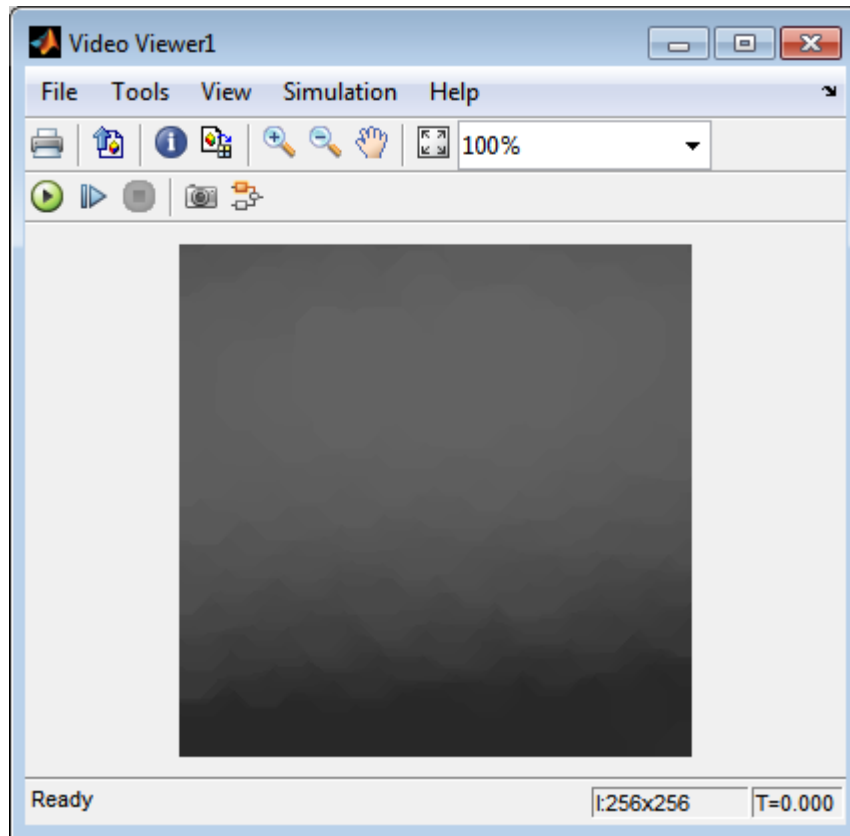
**14** Run the model.

The original image appears in the Video Viewer window.

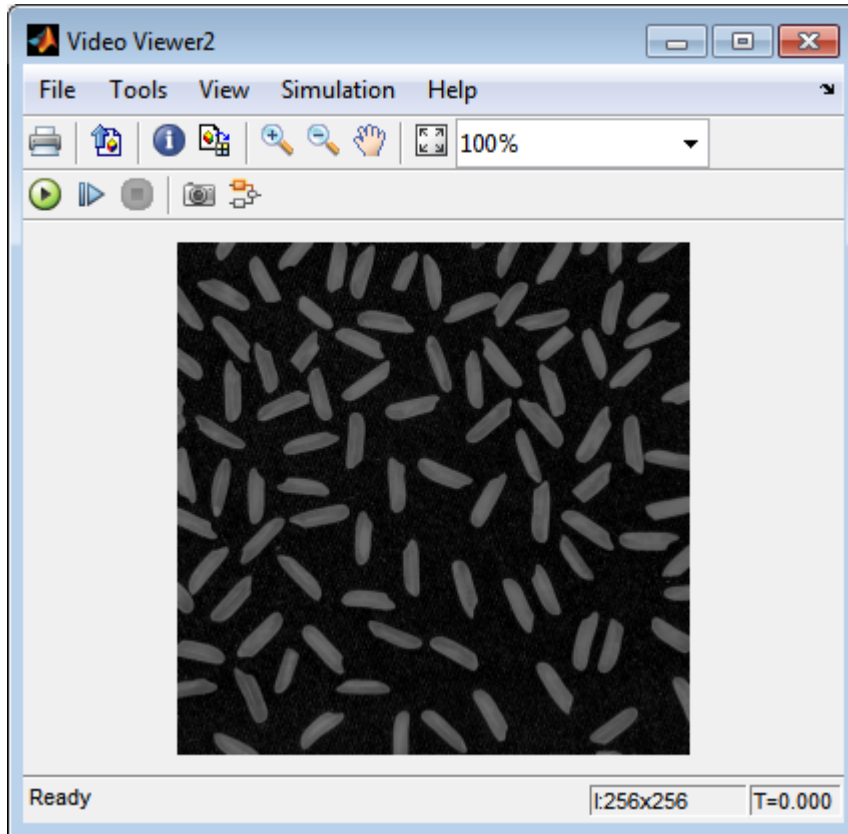


The estimated background appears in the Video Viewer1 window.



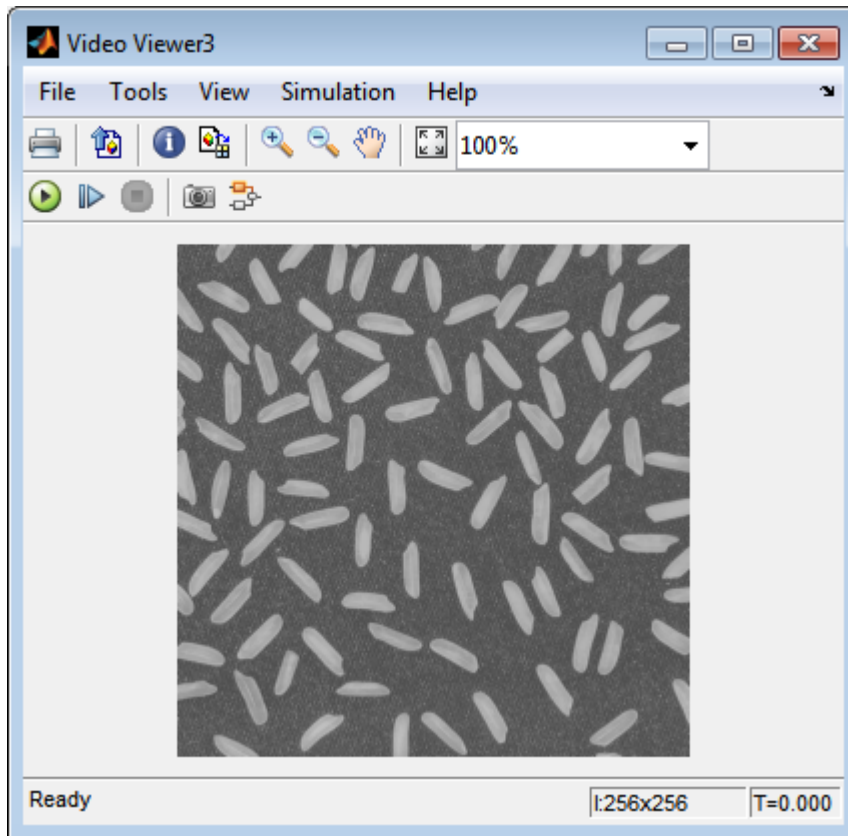


The image without the estimated background appears in the Video Viewer2 window.



The preceding image is too dark. The Constant block provides an offset value that you used to brighten the image.

The corrected image, which has even lighting, appears in the Video Viewer3 window. The following image is shown at its true size.



In this section, you have used the Opening block to remove irregular illumination from an image. For more information about this block, see the Opening reference page. For related information, see the Top-hat block reference page. For more information about STREL objects, see the `strel` function in the Image Processing Toolbox documentation.

## Count Objects in an Image

In this example, you import an intensity image of a wheel from the MATLAB workspace and convert it to binary. Then, using the Opening and Label blocks, you count the number of spokes in the wheel. You can use similar techniques to count objects in other intensity images. However, you might need to use additional morphological operators and different structuring elements.

---

**Note:** Running this example requires a DSP System Toolbox license.

---

You can open the example model by typing

```
ex_vision_count_objects  
on the MATLAB command line.
```

- 1 Create a new Simulink model, and add to it the blocks shown in the following table.

Block	Library	Quantity
Image From File	Computer Vision System Toolbox > Sources	1
Opening	Computer Vision System Toolbox > Morphological Operations	1
Label	Computer Vision System Toolbox > Morphological Operations	1
Video Viewer	Computer Vision System Toolbox > Sinks	2
Constant	Simulink > Sources	1
Relational Operator	Simulink > Logic and Bit Operations	1
Display	Simulink > Sinks	1

- 2 Use the Image From File block to import your image. Set the **File name** parameter to `testpat1.png`. This is a 256-by-256 matrix image of 8-bit unsigned integers.
- 3 Use the Constant block to define a threshold value for the Relational Operator block. Set the **Constant value** parameter to 200.
- 4 Use the Video Viewer block to view the original image. Accept the default parameters.

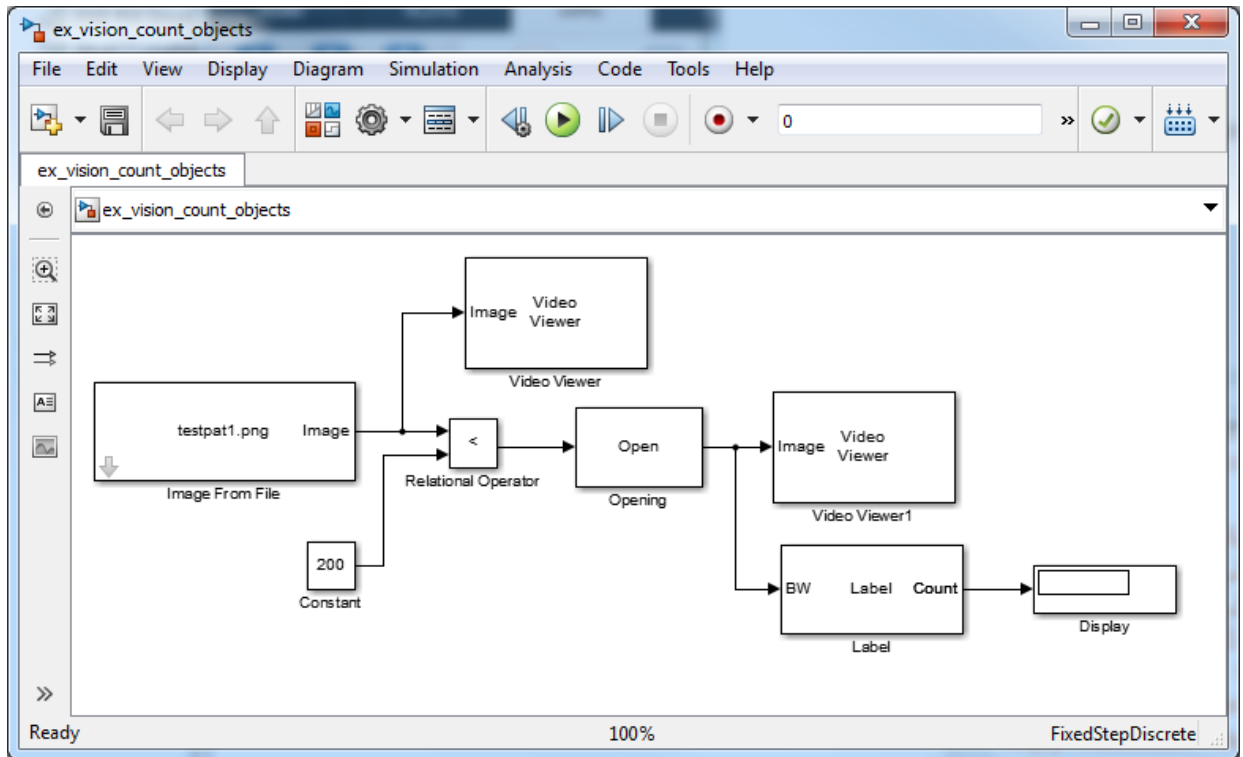
- 5 Use the Relational Operator block to perform a thresholding operation that converts your intensity image to a binary image. Set the **Relational Operator** parameter to `<`.

If the input to the Relational Operator block is less than 200, its output is 1; otherwise, its output is 0. You must threshold your intensity image because the Label block expects binary input. Also, the objects it counts must be white.

- 6 Use the Opening block to separate the spokes from the rim and from each other at the center of the wheel. Use the default parameters.

The `strel` function creates a circular STREL object with a radius of 5 pixels. When working with the Opening block, pick a STREL object that fits within the objects you want to keep. It often takes experimentation to find the neighborhood or STREL object that best suits your application.

- 7 Use the Video Viewer1 block to view the opened image. Accept the default parameters.
- 8 Use the Label block to count the number of spokes in the input image. Set the **Output** parameter to `Number of labels`.
- 9 The Display block displays the number of spokes in the input image. Use the default parameters.
- 10 Connect the block as shown in the following figure.

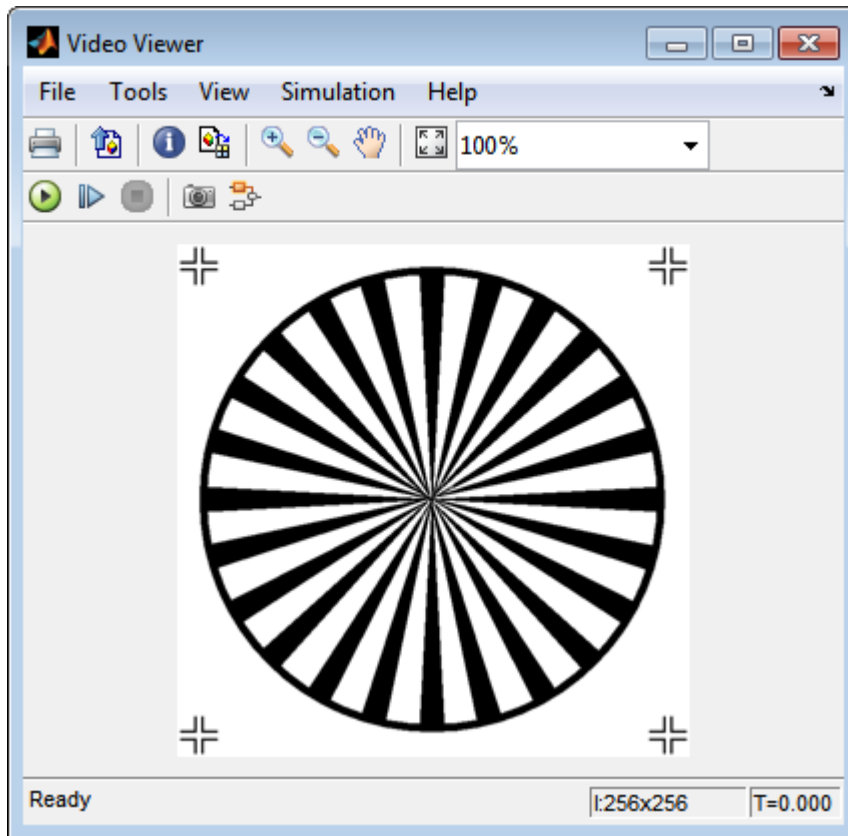


11 Set the configuration parameters. Open the Configuration dialog box by selecting **Model Configuration Parameters** from the **Simulation** menu. Set the parameters as follows:

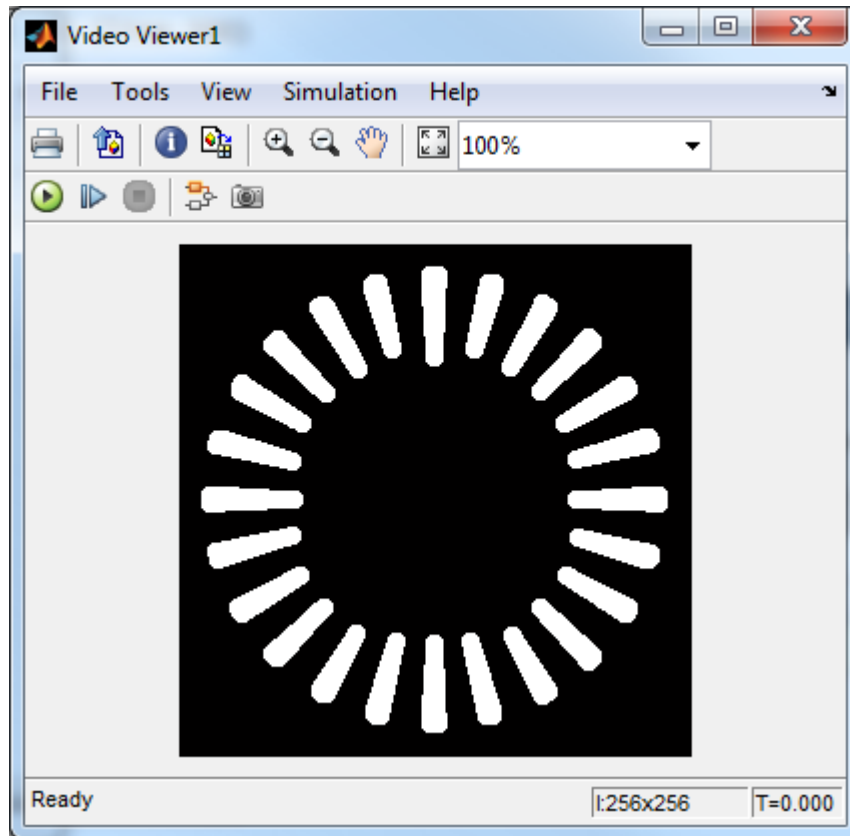
- **Solver** pane, **Stop time** = 0
- **Solver** pane, **Type** = Fixed-step
- **Solver** pane, **Solver** = discrete (no continuous states)

12 Run the model.

The original image appears in the Video Viewer1 window. To view the image at its true size, right-click the window and select **Set Display To True Size**.

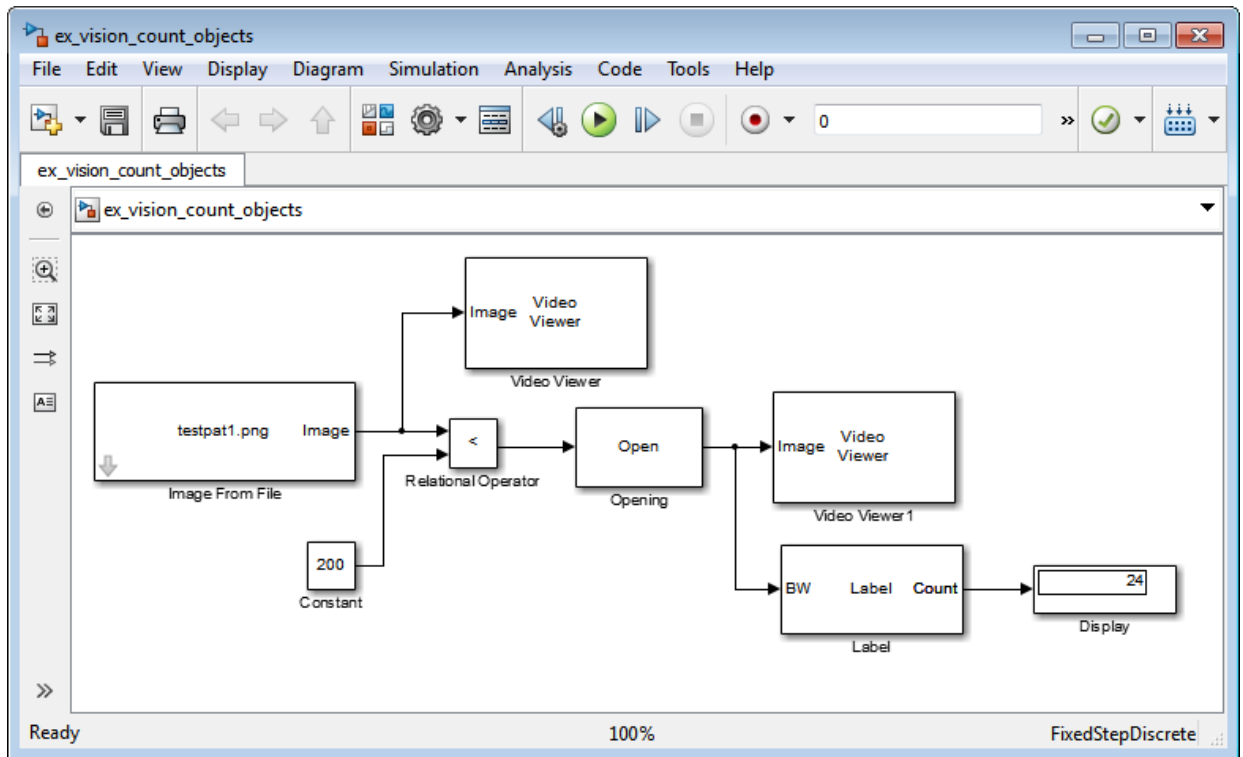


The opened image appears in the Video Viewer window. The following image is shown at its true size.



As you can see in the preceding figure, the spokes are now separate white objects. In the model, the Display block correctly indicates that there are 24 distinct spokes.





You have used the Opening and Label blocks to count the number of spokes in an image. For more information about these blocks, see the Opening and Label block reference pages in the *Computer Vision System Toolbox Reference*. If you want to send the number of spokes to the MATLAB workspace, use the To Workspace block in Simulink. For more information about STREL objects, see `strel` in the Image Processing Toolbox documentation.



# Fixed-Point Design

---

- “Fixed-Point Signal Processing” on page 10-2
- “Fixed-Point Concepts and Terminology” on page 10-4
- “Arithmetic Operations” on page 10-9
- “Fixed-Point Support for MATLAB System Objects” on page 10-19
- “Specify Fixed-Point Attributes for Blocks” on page 10-23

## Fixed-Point Signal Processing

In this section...
“Fixed-Point Features” on page 10-2
“Benefits of Fixed-Point Hardware” on page 10-2
“Benefits of Fixed-Point Design with System Toolboxes Software” on page 10-3

---

**Note:** To take full advantage of fixed-point support in System Toolbox software, you must install Fixed-Point Designer™ software.

---

### Fixed-Point Features

Many of the blocks in this product have fixed-point support, so you can design signal processing systems that use fixed-point arithmetic. Fixed-point support in DSP System Toolbox software includes

- Signed two's complement and unsigned fixed-point data types
- Word lengths from 2 to 128 bits in simulation
- Word lengths from 2 to the size of a long on the Simulink Coder C code-generation target
- Overflow handling and rounding methods
- C code generation for deployment on a fixed-point embedded processor, with Simulink Coder code generation software. The generated code uses all allowed data types supported by the embedded target, and automatically includes all necessary shift and scaling operations

### Benefits of Fixed-Point Hardware

There are both benefits and trade-offs to using fixed-point hardware rather than floating-point hardware for signal processing development. Many signal processing applications require low-power and cost-effective circuitry, which makes fixed-point hardware a natural choice. Fixed-point hardware tends to be simpler and smaller. As a result, these units require less power and cost less to produce than floating-point circuitry.

Floating-point hardware is usually larger because it demands functionality and ease of development. Floating-point hardware can accurately represent real-world numbers, and

its large dynamic range reduces the risk of overflow, quantization errors, and the need for scaling. In contrast, the smaller dynamic range of fixed-point hardware that allows for low-power, inexpensive units brings the possibility of these problems. Therefore, fixed-point development must minimize the negative effects of these factors, while exploiting the benefits of fixed-point hardware; cost- and size-effective units, less power and memory usage, and fast real-time processing.

## **Benefits of Fixed-Point Design with System Toolboxes Software**

Simulating your fixed-point development choices before implementing them in hardware saves time and money. The built-in fixed-point operations provided by the System Toolboxes software save time in simulation and allow you to generate code automatically.

This software allows you to easily run multiple simulations with different word length, scaling, overflow handling, and rounding method choices to see the consequences of various fixed-point designs before committing to hardware. The traditional risks of fixed-point development, such as quantization errors and overflow, can be simulated and mitigated in software before going to hardware.

Fixed-point C code generation with System Toolbox software and Simulink Coder code generation software produces code ready for execution on a fixed-point processor. All the choices you make in simulation in terms of scaling, overflow handling, and rounding methods are automatically optimized in the generated code, without necessitating time-consuming and costly hand-optimized code.

## Fixed-Point Concepts and Terminology

### In this section...

“Fixed-Point Data Types” on page 10-4

“Scaling” on page 10-5

“Precision and Range” on page 10-6

**Note:** The “Glossary” defines much of the vocabulary used in these sections. For more information on these subjects, see the “Fixed-Point Designer” documentation.

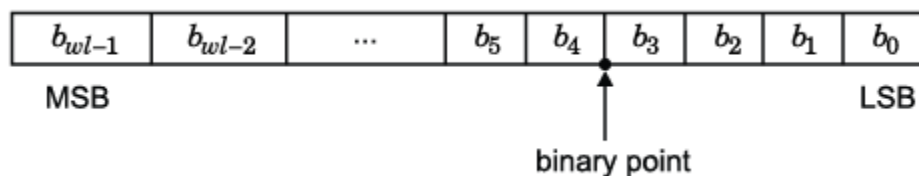
### Fixed-Point Data Types

In digital hardware, numbers are stored in binary words. A binary word is a fixed-length sequence of bits (1's and 0's). How hardware components or software functions interpret this sequence of 1's and 0's is defined by the data type.

Binary numbers are represented as either fixed-point or floating-point data types. In this section, we discuss many terms and concepts relating to fixed-point numbers, data types, and mathematics.

A fixed-point data type is characterized by the word length in bits, the position of the binary point, and whether it is signed or unsigned. The position of the binary point is the means by which fixed-point values are scaled and interpreted.

For example, a binary representation of a generalized fixed-point number (either signed or unsigned) is shown below:



where

- $b_i$  is the  $i^{\text{th}}$  binary digit.

- $wl$  is the word length in bits.
- $b_{wl-1}$  is the location of the most significant, or highest, bit (MSB).
- $b_0$  is the location of the least significant, or lowest, bit (LSB).
- The binary point is shown four places to the left of the LSB. In this example, therefore, the number is said to have four fractional bits, or a fraction length of four.

Fixed-point data types can be either signed or unsigned. Signed binary fixed-point numbers are typically represented in one of three ways:

- Sign/magnitude
- One's complement
- Two's complement

Two's complement is the most common representation of signed fixed-point numbers and is used by System Toolbox software. See “Two's Complement” on page 10-10 for more information.

## Scaling

Fixed-point numbers can be encoded according to the scheme

$$\text{real-world value} = (\text{slope} \times \text{integer}) + \text{bias}$$

where the slope can be expressed as

$$\text{slope} = \text{slope adjustment} \times 2^{\text{exponent}}$$

The integer is sometimes called the *stored integer*. This is the raw binary number, in which the binary point assumed to be at the far right of the word. In System Toolboxes, the negative of the exponent is often referred to as the *fraction length*.

The slope and bias together represent the scaling of the fixed-point number. In a number with zero bias, only the slope affects the scaling. A fixed-point number that is only scaled by binary point position is equivalent to a number in the Fixed-Point Designer [Slope Bias] representation that has a bias equal to zero and a slope adjustment equal to one. This is referred to as binary point-only scaling or power-of-two scaling:

$$\text{real-world value} = 2^{\text{exponent}} \times \text{integer}$$

or

$$\text{real-world value} = 2^{-\text{fraction length}} \times \text{integer}$$

In System Toolbox software, you can define a fixed-point data type and scaling for the output or the parameters of many blocks by specifying the word length and fraction length of the quantity. The word length and fraction length define the whole of the data type and scaling information for binary-point only signals.

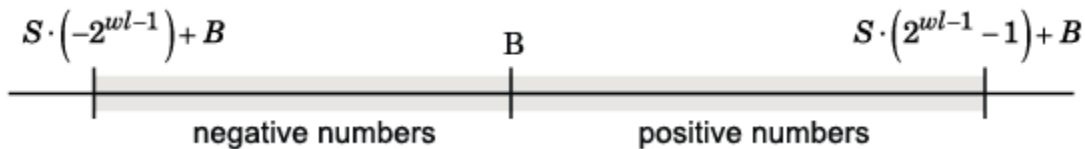
All System Toolbox blocks that support fixed-point data types support signals with binary-point only scaling. Many fixed-point blocks that do not perform arithmetic operations but merely rearrange data, such as Delay and Matrix Transpose, also support signals with [Slope Bias] scaling.

## Precision and Range

You must pay attention to the precision and range of the fixed-point data types and scalings you choose for the blocks in your simulations, in order to know whether rounding methods will be invoked or if overflows will occur.

### Range

The range is the span of numbers that a fixed-point data type and scaling can represent. The range of representable numbers for a two's complement fixed-point number of word length  $wl$ , scaling  $S$ , and bias  $B$  is illustrated below:

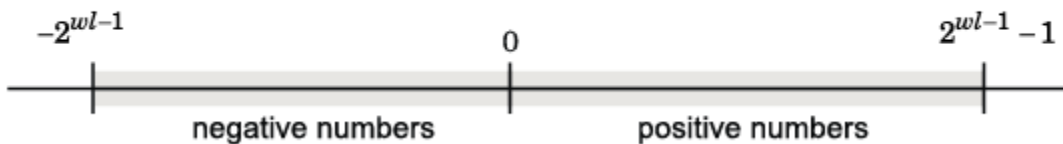


For both signed and unsigned fixed-point numbers of any data type, the number of different bit patterns is  $2^{wl}$ .

For example, in two's complement, negative numbers must be represented as well as zero, so the maximum value is  $2^{wl-1}$ . Because there is only one representation for zero, there are an unequal number of positive and negative numbers. This means there is a representation for  $-2^{wl-1}$  but not for  $2^{wl-1}$ :



For slope = 1 and bias = 0:



### Overflow Handling

Because a fixed-point data type represents numbers within a finite range, overflows can occur if the result of an operation is larger or smaller than the numbers in that range.

System Toolbox software does not allow you to add guard bits to a data type on-the-fly in order to avoid overflows. Any guard bits must be allocated upon model initialization. However, the software does allow you to either *saturate* or *wrap* overflows. Saturation represents positive overflows as the largest positive number in the range being used, and negative overflows as the largest negative number in the range being used. Wrapping uses modulo arithmetic to cast an overflow back into the representable range of the data type. See “Modulo Arithmetic” on page 10-9 for more information.

### Precision

The precision of a fixed-point number is the difference between successive values representable by its data type and scaling, which is equal to the value of its least significant bit. The value of the least significant bit, and therefore the precision of the number, is determined by the number of fractional bits. A fixed-point value can be represented to within half of the precision of its data type and scaling.

For example, a fixed-point representation with four bits to the right of the binary point has a precision of  $2^{-4}$  or 0.0625, which is the value of its least significant bit. Any number within the range of this data type and scaling can be represented to within  $(2^{-4})/2$  or 0.03125, which is half the precision. This is an example of representing a number with finite precision.

### Rounding Modes

When you represent numbers with finite precision, not every number in the available range can be represented exactly. If a number cannot be represented exactly by the specified data type and scaling, it is *rounded* to a representable number. Although precision is always lost in the rounding operation, the cost of the operation and the

amount of bias that is introduced depends on the rounding mode itself. To provide you with greater flexibility in the trade-off between cost and bias, DSP System Toolbox software currently supports the following rounding modes:

- **Ceiling** rounds the result of a calculation to the closest representable number in the direction of positive infinity.
- **Convergent** rounds the result of a calculation to the closest representable number. In the case of a tie, **Convergent** rounds to the nearest even number. This is the least biased rounding mode provided by the toolbox.
- **Floor**, which is equivalent to truncation, rounds the result of a calculation to the closest representable number in the direction of negative infinity.
- **Nearest** rounds the result of a calculation to the closest representable number. In the case of a tie, **Nearest** rounds to the closest representable number in the direction of positive infinity.
- **Round** rounds the result of a calculation to the closest representable number. In the case of a tie, **Round** rounds positive numbers to the closest representable number in the direction of positive infinity, and rounds negative numbers to the closest representable number in the direction of negative infinity.
- **Simplest** rounds the result of a calculation using the rounding mode (**Floor** or **Zero**) that adds the least amount of extra rounding code to your generated code. For more information, see “Rounding Mode: Simplest” in the Fixed-Point Designer documentation.
- **Zero** rounds the result of a calculation to the closest representable number in the direction of zero.

To learn more about each of these rounding modes, see “Rounding” in the Fixed-Point Designer documentation.

For a direct comparison of the rounding modes, see “Choosing a Rounding Method” in the Fixed-Point Designer documentation.

# Arithmetic Operations

**In this section...**

“Modulo Arithmetic” on page 10-9

“Two's Complement” on page 10-10

“Addition and Subtraction” on page 10-11

“Multiplication” on page 10-12

“Casts” on page 10-14

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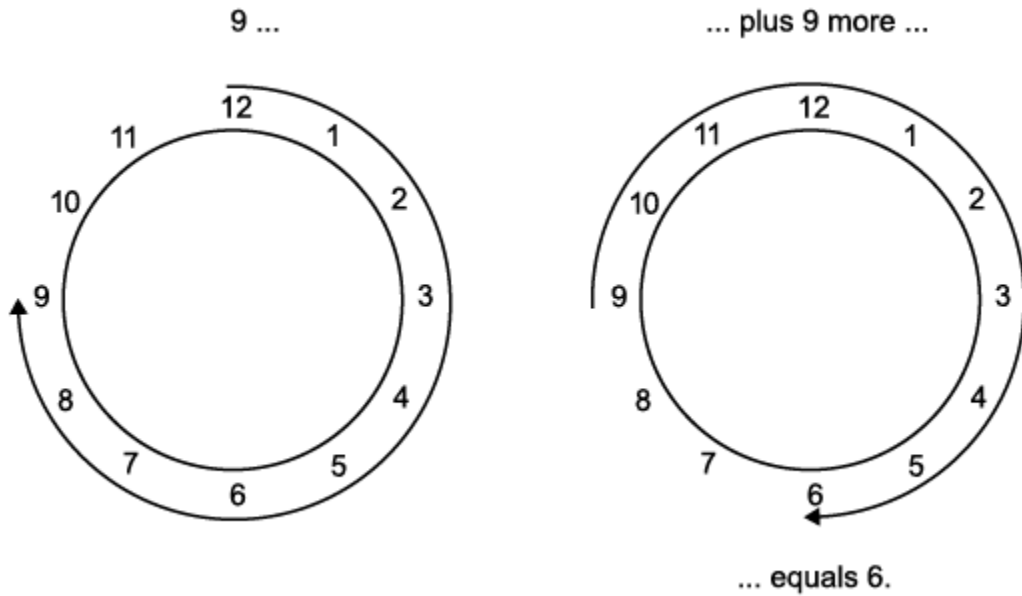
**Note:** These sections will help you understand what data type and scaling choices result in overflows or a loss of precision.

---

## Modulo Arithmetic

Binary math is based on modulo arithmetic. Modulo arithmetic uses only a finite set of numbers, wrapping the results of any calculations that fall outside the given set back into the set.

For example, the common everyday clock uses modulo 12 arithmetic. Numbers in this system can only be 1 through 12. Therefore, in the “clock” system, 9 plus 9 equals 6. This can be more easily visualized as a number circle:



Similarly, binary math can only use the numbers 0 and 1, and any arithmetic results that fall outside this range are wrapped “around the circle” to either 0 or 1.

## Two's Complement

Two's complement is a way to interpret a binary number. In two's complement, positive numbers always start with a 0 and negative numbers always start with a 1. If the leading bit of a two's complement number is 0, the value is obtained by calculating the standard binary value of the number. If the leading bit of a two's complement number is 1, the value is obtained by assuming that the leftmost bit is negative, and then calculating the binary value of the number. For example,

$$01 = (0 + 2^0) = 1$$

$$11 = ((-2^1) + (2^0)) = (-2 + 1) = -1$$

To compute the negative of a binary number using two's complement,

- 1 Take the one's complement, or “flip the bits.”
- 2 Add a 1 using binary math.

**3** Discard any bits carried beyond the original word length.

For example, consider taking the negative of 11010 (-6). First, take the one's complement of the number, or flip the bits:

$$11010 \rightarrow 00101$$

Next, add a 1, wrapping all numbers to 0 or 1:

$$\begin{array}{r} 00101 \\ +1 \\ \hline 00110 \text{ (6)} \end{array}$$

## Addition and Subtraction

The addition of fixed-point numbers requires that the binary points of the addends be aligned. The addition is then performed using binary arithmetic so that no number other than 0 or 1 is used.

For example, consider the addition of 010010.1 (18.5) with 0110.110 (6.75):

$$\begin{array}{r} 010010.1 \quad (18.5) \\ +0110.110 \quad (6.75) \\ \hline 011001.010 \quad (25.25) \end{array}$$

Fixed-point subtraction is equivalent to adding while using the two's complement value for any negative values. In subtraction, the addends must be sign extended to match each other's length. For example, consider subtracting 0110.110 (6.75) from 010010.1 (18.5):

$$\begin{array}{r} 010010.100 \quad (18.5) \\ - 0110.110 \quad (6.75) \\ \hline \end{array} \quad \begin{array}{l} \xrightarrow{\text{two's complement}} \\ \text{and sign extension} \end{array} \quad \begin{array}{r} 010010.100 \quad (18.5) \\ +111001.010 \quad (-6.75) \\ \hline 1001011.110 \quad (11.75) \end{array}$$

Carry bit is discarded.

Most fixed-point DSP System Toolbox blocks that perform addition cast the adder inputs to an accumulator data type before performing the addition. Therefore, no further

shifting is necessary during the addition to line up the binary points. See “Casts” on page 10-14 for more information.

## Multiplication

The multiplication of two's complement fixed-point numbers is directly analogous to regular decimal multiplication, with the exception that the intermediate results must be sign extended so that their left sides align before you add them together.

For example, consider the multiplication of 10.11 (-1.25) with 011 (3):

$$\begin{array}{r}
 10.11 \text{ (-1.25)} \\
 \quad 011 \text{ (3)} \\
 \hline
 11011 \\
 \quad 1011 \\
 \hline
 1100.01 \text{ (-3.75)}
 \end{array}$$

The extra 1 is the result of necessary sign extension.

The number of fractional bits of the result is the sum of the number of fractional bits of the factors.

### Multiplication Data Types

The following diagrams show the data types used for fixed-point multiplication in the System Toolbox software. The diagrams illustrate the differences between the data types used for real-real, complex-real, and complex-complex multiplication. See individual reference pages to determine whether a particular block accepts complex fixed-point inputs.

In most cases, you can set the data types used during multiplication in the block mask. See Accumulator Parameters, Intermediate Product Parameters, Product Output Parameters, and Output Parameters. These data types are defined in “Casts” on page 10-14.

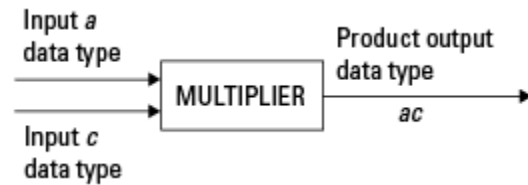
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**Note:** The following diagrams show the use of fixed-point data types in multiplication in System Toolbox software. They do not represent actual subsystems used by the software to perform multiplication.

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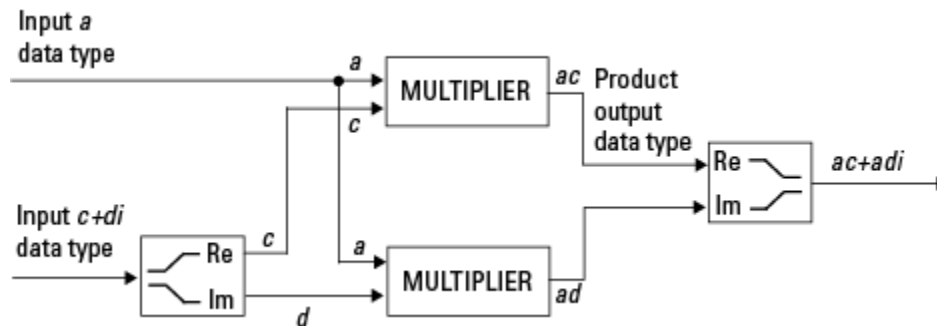
### Real-Real Multiplication

The following diagram shows the data types used in the multiplication of two real numbers in System Toolbox software. The software returns the output of this operation in the product output data type, as the next figure shows.



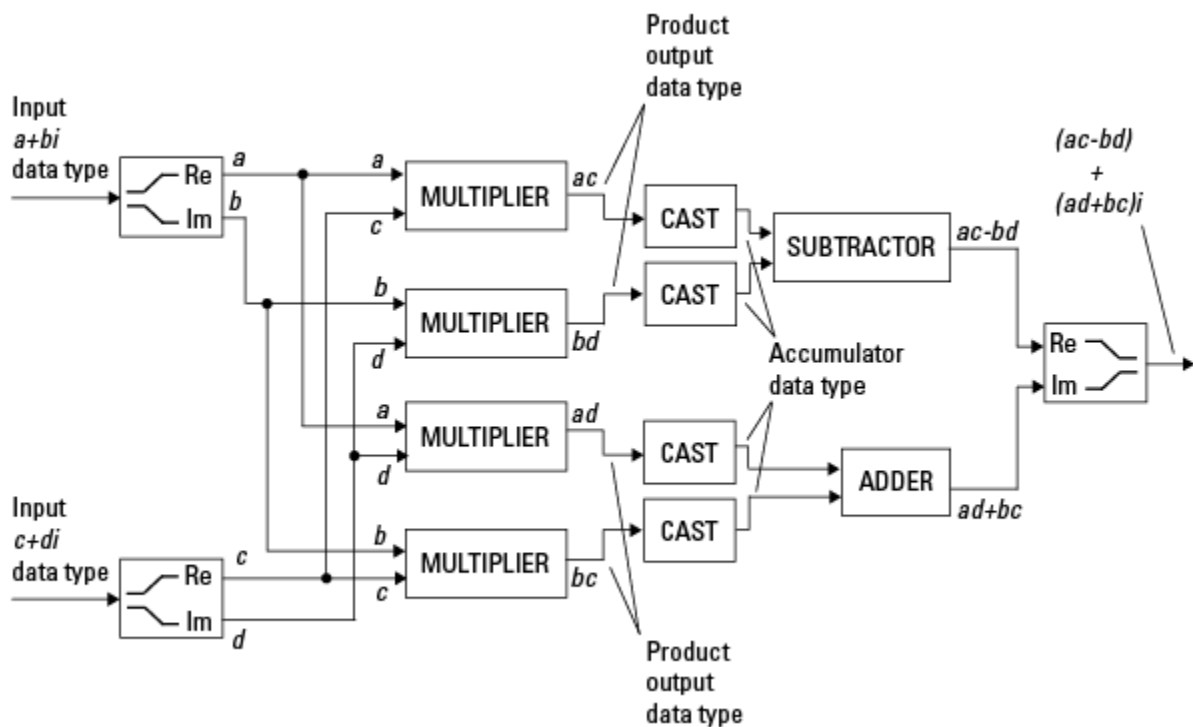
### Real-Complex Multiplication

The following diagram shows the data types used in the multiplication of a real and a complex fixed-point number in System Toolbox software. Real-complex and complex-real multiplication are equivalent. The software returns the output of this operation in the product output data type, as the next figure shows.



### Complex-Complex Multiplication

The following diagram shows the multiplication of two complex fixed-point numbers in System Toolbox software. Note that the software returns the output of this operation in the accumulator output data type, as the next figure shows.



System Toolbox blocks cast to the accumulator data type before performing addition or subtraction operations. In the preceding diagram, this is equivalent to the C code

```
acc=ac;
acc-=bd;
```

for the subtractor, and

```
acc=ad;
acc+=bc;
```

for the adder, where *acc* is the accumulator.

## Casts

Many fixed-point System Toolbox blocks that perform arithmetic operations allow you to specify the accumulator, intermediate product, and product output data types, as



applicable, as well as the output data type of the block. This section gives an overview of the casts to these data types, so that you can tell if the data types you select will invoke sign extension, padding with zeros, rounding, and/or overflow.

### **Casts to the Accumulator Data Type**

For most fixed-point System Toolbox blocks that perform addition or subtraction, the operands are first cast to an accumulator data type. Most of the time, you can specify the accumulator data type on the block mask. See Accumulator Parameters. Since the addends are both cast to the same accumulator data type before they are added together, no extra shift is necessary to insure that their binary points align. The result of the addition remains in the accumulator data type, with the possibility of overflow.

### **Casts to the Intermediate Product or Product Output Data Type**

For System Toolbox blocks that perform multiplication, the output of the multiplier is placed into a product output data type. Blocks that then feed the product output back into the multiplier might first cast it to an intermediate product data type. Most of the time, you can specify these data types on the block mask. See Intermediate Product Parameters and Product Output Parameters.

### **Casts to the Output Data Type**

Many fixed-point System Toolbox blocks allow you to specify the data type and scaling of the block output on the mask. Remember that the software does not allow mixed types on the input and output ports of its blocks. Therefore, if you would like to specify a fixed-point output data type and scaling for a System Toolbox block that supports fixed-point data types, you must feed the input port of that block with a fixed-point signal. The final cast made by a fixed-point System Toolbox block is to the output data type of the block.

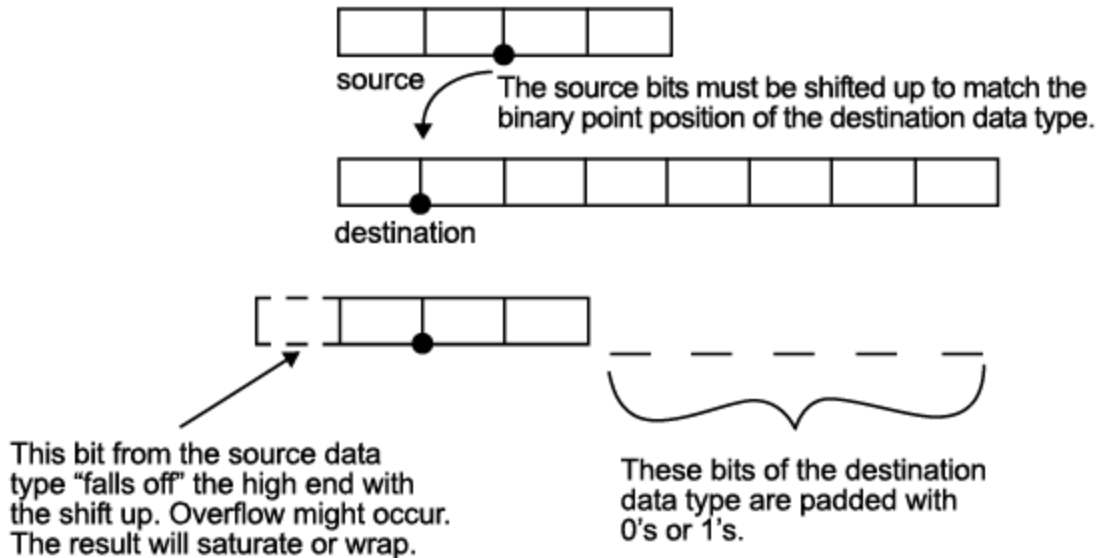
Note that although you can not mix fixed-point and floating-point signals on the input and output ports of blocks, you can have fixed-point signals with different word and fraction lengths on the ports of blocks that support fixed-point signals.

### **Casting Examples**

It is important to keep in mind the ramifications of each cast when selecting these intermediate data types, as well as any other intermediate fixed-point data types that are allowed by a particular block. Depending upon the data types you select, overflow and/or rounding might occur. The following two examples demonstrate cases where overflow and rounding can occur.

### Cast from a Shorter Data Type to a Longer Data Type

Consider the cast of a nonzero number, represented by a four-bit data type with two fractional bits, to an eight-bit data type with seven fractional bits:



As the diagram shows, the source bits are shifted up so that the binary point matches the destination binary point position. The highest source bit does not fit, so overflow might occur and the result can saturate or wrap. The empty bits at the low end of the destination data type are padded with either 0's or 1's:

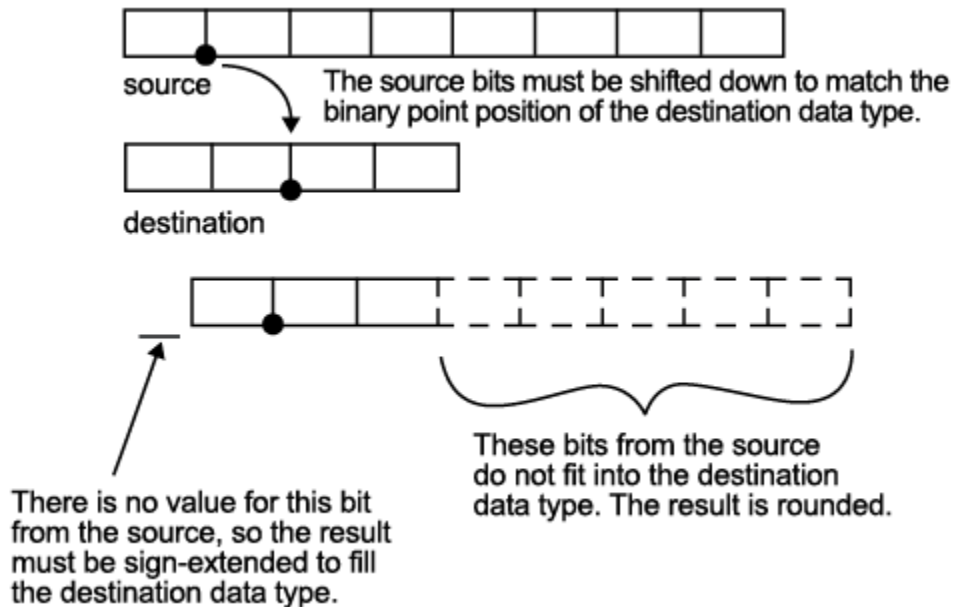
- If overflow does not occur, the empty bits are padded with 0's.
- If wrapping occurs, the empty bits are padded with 0's.
- If saturation occurs,
  - The empty bits of a positive number are padded with 1's.
  - The empty bits of a negative number are padded with 0's.

You can see that even with a cast from a shorter data type to a longer data type, overflow might still occur. This can happen when the integer length of the source data type (in this case two) is longer than the integer length of the destination data type (in this case

one). Similarly, rounding might be necessary even when casting from a shorter data type to a longer data type, if the destination data type and scaling has fewer fractional bits than the source.

### Cast from a Longer Data Type to a Shorter Data Type

Consider the cast of a nonzero number, represented by an eight-bit data type with seven fractional bits, to a four-bit data type with two fractional bits:



As the diagram shows, the source bits are shifted down so that the binary point matches the destination binary point position. There is no value for the highest bit from the source, so the result is sign extended to fill the integer portion of the destination data type. The bottom five bits of the source do not fit into the fraction length of the destination. Therefore, precision can be lost as the result is rounded.

In this case, even though the cast is from a longer data type to a shorter data type, all the integer bits are maintained. Conversely, full precision can be maintained even if you cast to a shorter data type, as long as the fraction length of the destination data type is the same length or longer than the fraction length of the source data type. In that case, however, bits are lost from the high end of the result and overflow might occur.

The worst case occurs when both the integer length and the fraction length of the destination data type are shorter than those of the source data type and scaling. In that case, both overflow and a loss of precision can occur.

# Fixed-Point Support for MATLAB System Objects

**In this section...**

“Getting Information About Fixed-Point System Objects” on page 10-19

“Displaying Fixed-Point Properties” on page 10-20

“Setting System Object Fixed-Point Properties” on page 10-21

For information on working with Fixed-Point features, refer to the “Fixed-Point” topic.

## Getting Information About Fixed-Point System Objects

System objects that support fixed-point data processing have fixed-point properties, which you can display for a particular object by typing `vision.<ObjectName>.helpFixedPoint` at the command line.

See “Displaying Fixed-Point Properties” on page 10-20 to set the display of System object fixed-point properties.

The following Computer Vision System Toolbox objects support fixed-point data processing.

**Fixed-Point Data Processing Support**

`vision.AlphaBlender`  
`vision.Autocorrelator`  
`vision.Autothresher`  
`vision.BlobAnalysis`  
`vision.BlockMatcher`  
`vision.ContrastAdjuster`  
`vision.Convolver`  
`vision.CornerDetector`  
`vision.Crosscorrelator`  
`vision.DCT`  
`vision.Deinterlacer`  
`vision.DemosaicInterpolator`  
`vision.EdgeDetector`  
`vision.FFT`  
`vision.GeometricRotator`

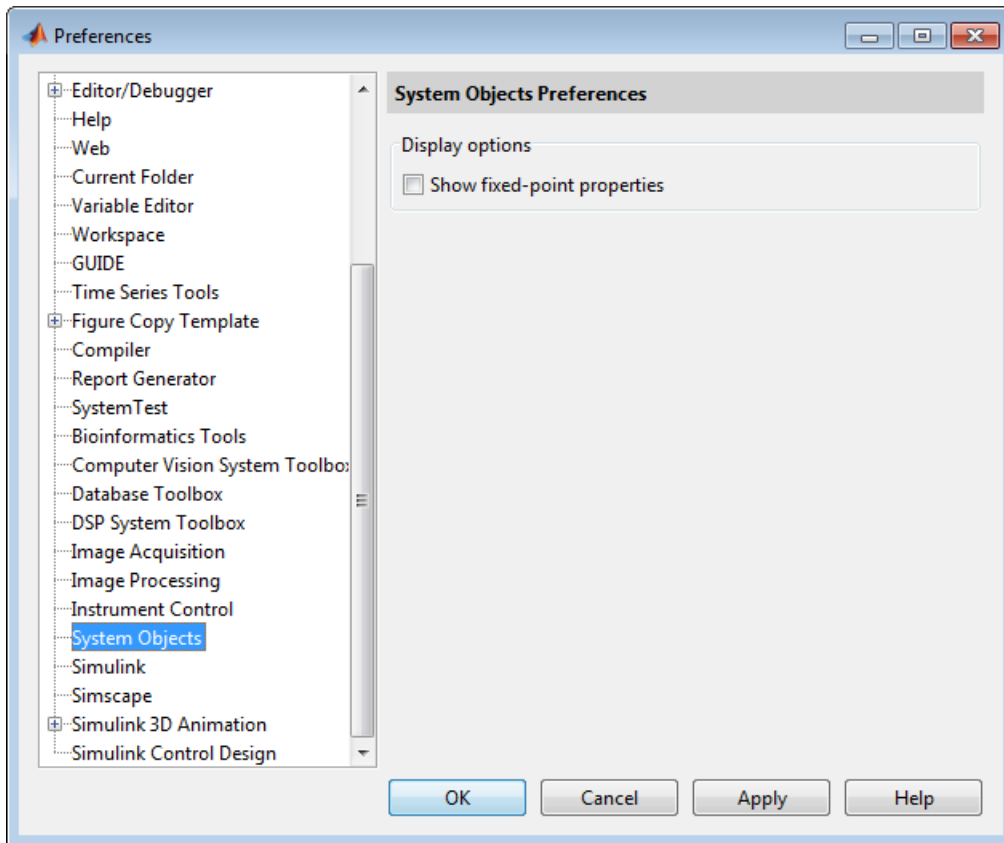
```
vision.GeometricScaler  
vision.GeometricTranslator  
vision.Histogram  
vision.HoughLines  
vision.HoughTransform  
vision.IDCT  
vision.IFFT  
vision.ImageDataTypeConverter  
vision.ImageFilter  
vision.MarkerInserter  
vision.Maximum  
vision.Mean  
vision.Median  
vision.MedianFilter  
vision.Minimum  
vision.OpticalFlow  
vision.PSNR  
vision.Pyramid  
vision.SAD  
vision.ShapeInserter  
vision.Variance
```

## Displaying Fixed-Point Properties

You can control whether the software displays fixed-point properties with either of the following commands:

- `matlab.system.showFixedPointProperties`
- `matlab.system.hideFixedPointProperties`

at the MATLAB command line. These commands set the **Show fixed-point properties** display option. You can also set the display option directly via the MATLAB preferences dialog box. Select the **Preferences** icon from the MATLAB desktop, and then select **System Objects**. Finally, select or deselect **Show fixed-point properties**.



If an object supports fixed-point data processing, its fixed-point properties are active regardless of whether they are displayed or not.

## Setting System Object Fixed-Point Properties

A number of properties affect the fixed-point data processing used by a System object. Objects perform fixed-point processing and use the current fixed-point property settings when they receive fixed-point input.

You change the values of fixed-point properties in the same way as you change any System object property value. You also use the Fixed-Point Designer `numericType` object to specify the desired data type as fixed-point, the signedness, and the word- and fraction-lengths.

In the same way as for blocks, the data type properties of many System objects can set the appropriate word lengths and scalings automatically by using full precision. System objects assume that the target specified on the Configuration Parameters Hardware Implementation target is ASIC/FPGA.

If you have not set the property that activates a dependent property and you attempt to change that dependent property, a warning message displays. For example, for the `vision.EdgeDetector` object, before you set `CustomProductDataType` to `numerictype(1,16,15)` you must set `ProductDataType` to `'Custom'`.

---

**Note:** System objects do not support fixed-point word lengths greater than 128 bits.

For any System object provided in the Toolbox, the `fimath` settings for any `fimath` attached to a `fi` input or a `fi` property are ignored. Outputs from a System object never have an attached `fimath`.

---



## Specify Fixed-Point Attributes for Blocks

In this section...
“Fixed-Point Block Parameters” on page 10-23
“Specify System-Level Settings” on page 10-26
“Inherit via Internal Rule” on page 10-27
“Specify Data Types for Fixed-Point Blocks” on page 10-37

### Fixed-Point Block Parameters

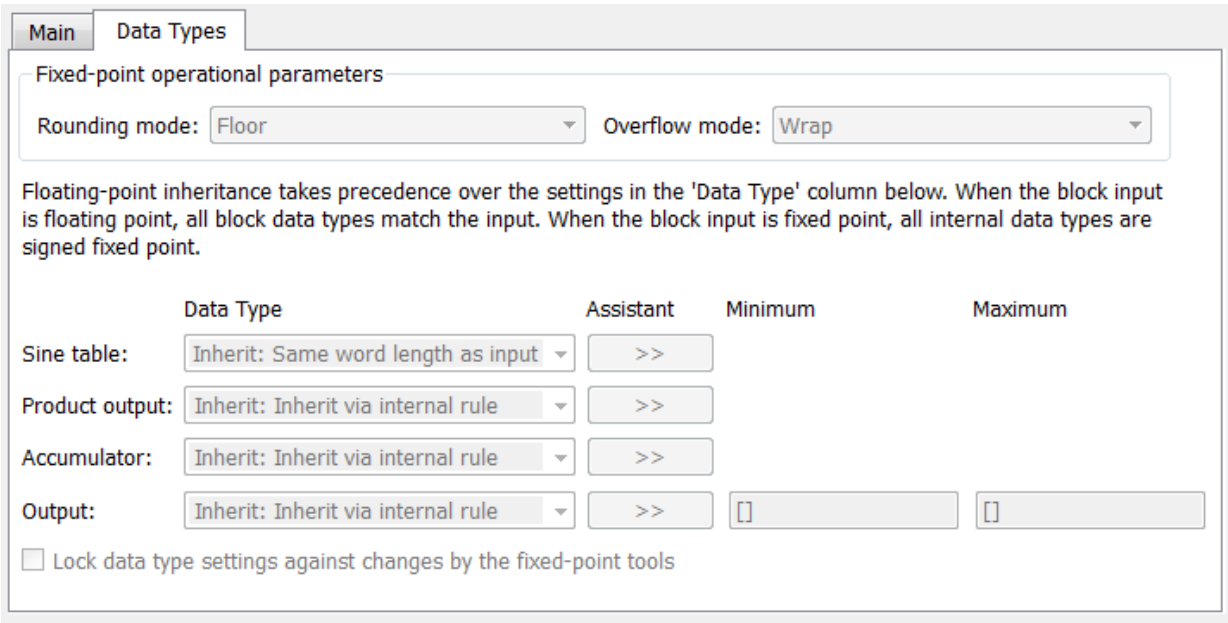
System Toolbox blocks that have fixed-point support usually allow you to specify fixed-point characteristics through block parameters. By specifying data type and scaling information for these fixed-point parameters, you can simulate your target hardware more closely.

---

**Note:** Floating-point inheritance takes precedence over the settings discussed in this section. When the block has floating-point input, all block data types match the input.

---

You can find most fixed-point parameters on the **Data Types** pane of System Toolbox blocks. The following figure shows a typical **Data Types** pane.



All System Toolbox blocks with fixed-point capabilities share a set of common parameters, but each block can have a different subset of these fixed-point parameters. The following table provides an overview of the most common fixed-point block parameters.

Fixed-Point Data Type Parameter	Description
Rounding Mode	Specifies the rounding mode for the block to use when the specified data type and scaling cannot exactly represent the result of a fixed-point calculation.  See “Rounding Modes” on page 10-7 for more information on the available options.
Overflow Mode	Specifies the overflow mode to use when the result of a fixed-point calculation does not fit into the representable range of the specified data type.  See “Overflow Handling” on page 10-7 for more information on the available options.

Fixed-Point Data Type Parameter	Description
Intermediate Product	<p>Specifies the data type and scaling of the intermediate product for fixed-point blocks. Blocks that feed multiplication results back to the input of the multiplier use the intermediate product data type.</p> <p>See the reference page of a specific block to learn about the intermediate product data type for that block.</p>
Product Output	<p>Specifies the data type and scaling of the product output for fixed-point blocks that must compute multiplication results.</p> <p>See the reference page of a specific block to learn about the product output data type for that block. For or complex-complex multiplication, the multiplication result is in the accumulator data type. See “Multiplication Data Types” on page 10-12 for more information on complex fixed-point multiplication in System toolbox software.</p>
Accumulator	<p>Specifies the data type and scaling of the accumulator (sum) for fixed-point blocks that must hold summation results for further calculation. Most such blocks cast to the accumulator data type before performing the add operations (summation).</p> <p>See the reference page of a specific block for details on the accumulator data type of that block.</p>
Output	Specifies the output data type and scaling for blocks.

### Using the Data Type Assistant

The **Data Type Assistant** is an interactive graphical tool available on the **Data Types** pane of some fixed-point System Toolbox blocks.

To learn more about using the **Data Type Assistant** to help you specify block data type parameters, see the following section of the Simulink documentation: “Specify Data Types Using Data Type Assistant”

## Checking Signal Ranges

Some fixed-point System Toolbox blocks have **Minimum** and **Maximum** parameters on the **Data Types** pane. When a fixed-point data type has these parameters, you can use them to specify appropriate minimum and maximum values for range checking purposes.

To learn how to specify signal ranges and enable signal range checking, see “Signal Ranges” in the Simulink documentation.

## Specify System-Level Settings

You can monitor and control fixed-point settings for System Toolbox blocks at a system or subsystem level with the Fixed-Point Tool. For additional information on these subjects, see

- The `fxptdlg` reference page — A reference page on the Fixed-Point Tool in the Simulink documentation
- “Fixed-Point Tool” — A tutorial that highlights the use of the Fixed-Point Tool in the Fixed-Point Designer software documentation

## Logging

The Fixed-Point Tool logs overflows, saturations, and simulation minimums and maximums for fixed-point System Toolbox blocks. The Fixed-Point Tool does not log overflows and saturations when the **Data overflow** line in the **Diagnostics > Data Integrity** pane of the Configuration Parameters dialog box is set to **None**.

## Autoscaling

You can use the Fixed-Point Tool autoscaling feature to set the scaling for System Toolbox fixed-point data types.

## Data type override

System Toolbox blocks obey the **Use local settings**, **Double**, **Single**, and **Off** modes of the **Data type override** parameter in the Fixed-Point Tool. The **Scaled double** mode is also supported for System Toolbox source and byte-shuffling blocks, and for some arithmetic blocks such as **Difference** and **Normalization**.

## Inherit via Internal Rule

Selecting appropriate word lengths and scalings for the fixed-point parameters in your model can be challenging. To aid you, an **Inherit via internal rule** choice is often available for fixed-point block data type parameters, such as the **Accumulator** and **Product output** signals. The following sections describe how the word and fraction lengths are selected for you when you choose **Inherit via internal rule** for a fixed-point block data type parameter in System Toolbox software:

- “Internal Rule for Accumulator Data Types” on page 10-27
- “Internal Rule for Product Data Types” on page 10-28
- “Internal Rule for Output Data Types” on page 10-28
- “The Effect of the Hardware Implementation Pane on the Internal Rule” on page 10-28
- “Internal Rule Examples” on page 10-30

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**Note:** In the equations in the following sections,  $WL$  = word length and  $FL$  = fraction length.

---

### Internal Rule for Accumulator Data Types

The internal rule for accumulator data types first calculates the ideal, full-precision result. Where  $N$  is the number of addends:

$$WL_{ideal\ accumulator} = WL_{input\ to\ accumulator} + \text{floor}(\log_2(N - 1)) + 1$$

$$FL_{ideal\ accumulator} = FL_{input\ to\ accumulator}$$

For example, consider summing all the elements of a vector of length 6 and data type `sfix10_En8`. The ideal, full-precision result has a word length of 13 and a fraction length of 8.

The accumulator can be real or complex. The preceding equations are used for both the real and imaginary parts of the accumulator. For any calculation, after the full-precision result is calculated, the final word and fraction lengths set by the internal rule are

affected by your particular hardware. See “The Effect of the Hardware Implementation Pane on the Internal Rule” on page 10-28 for more information.

### Internal Rule for Product Data Types

The internal rule for product data types first calculates the ideal, full-precision result:

$$WL_{ideal\ product} = WL_{input\ 1} + WL_{input\ 2}$$

$$FL_{ideal\ product} = FL_{input\ 1} + FL_{input\ 2}$$

For example, multiplying together the elements of a real vector of length 2 and data type `sfix10_En8`. The ideal, full-precision result has a word length of 20 and a fraction length of 16.

For real-complex multiplication, the ideal word length and fraction length is used for both the complex and real portion of the result. For complex-complex multiplication, the ideal word length and fraction length is used for the partial products, and the internal rule for accumulator data types described above is used for the final sums. For any calculation, after the full-precision result is calculated, the final word and fraction lengths set by the internal rule are affected by your particular hardware. See “The Effect of the Hardware Implementation Pane on the Internal Rule” on page 10-28 for more information.

### Internal Rule for Output Data Types

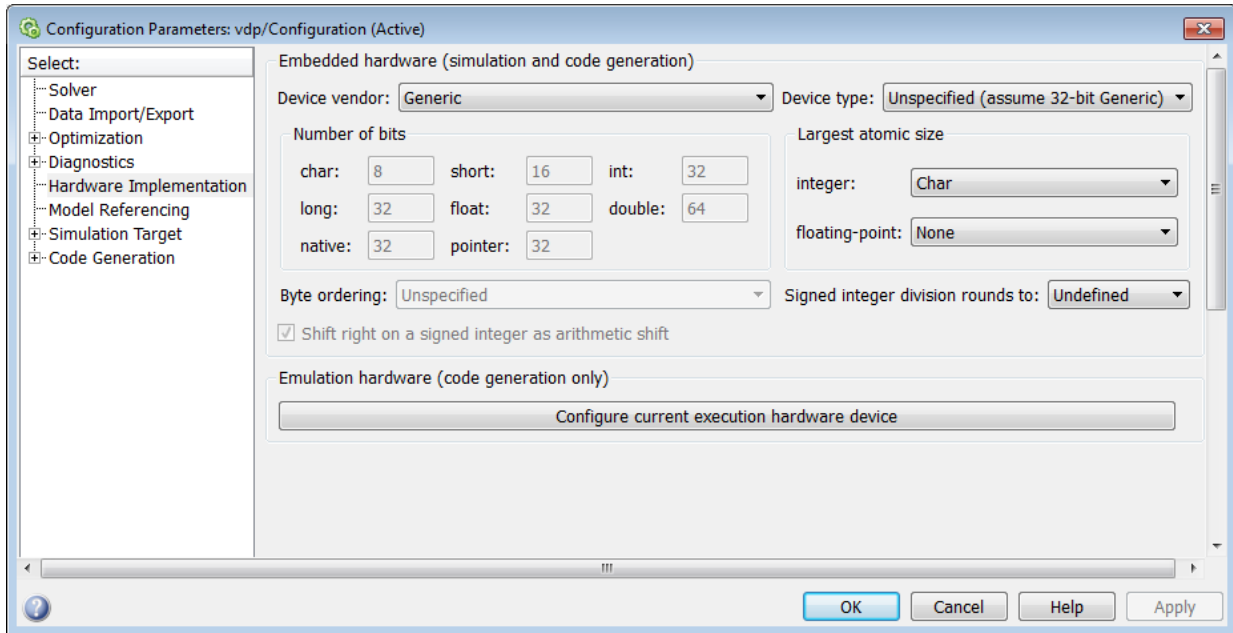
A few System Toolbox blocks have an `Inherit via internal rule` choice available for the block output. The internal rule used in these cases is block-specific, and the equations are listed in the block reference page.

As with accumulator and product data types, the final output word and fraction lengths set by the internal rule are affected by your particular hardware, as described in “The Effect of the Hardware Implementation Pane on the Internal Rule” on page 10-28.

### The Effect of the Hardware Implementation Pane on the Internal Rule

The internal rule selects word lengths and fraction lengths that are appropriate for your hardware. To get the best results using the internal rule, you must specify the type of hardware you are using on the **Hardware Implementation** pane of the Configuration

Parameters dialog box. You can open this dialog box from the **Simulation** menu in your model.



## ASIC/FPGA

On an ASIC/FPGA target, the ideal, full-precision word length and fraction length calculated by the internal rule are used. If the calculated ideal word length is larger than the largest allowed word length, you receive an error. The largest word length allowed for Simulink and System Toolbox software is 128 bits.

## Other targets

For all targets other than ASIC/FPGA, the ideal, full-precision word length calculated by the internal rule is rounded up to the next available word length of the target. The calculated ideal fraction length is used, keeping the least-significant bits.

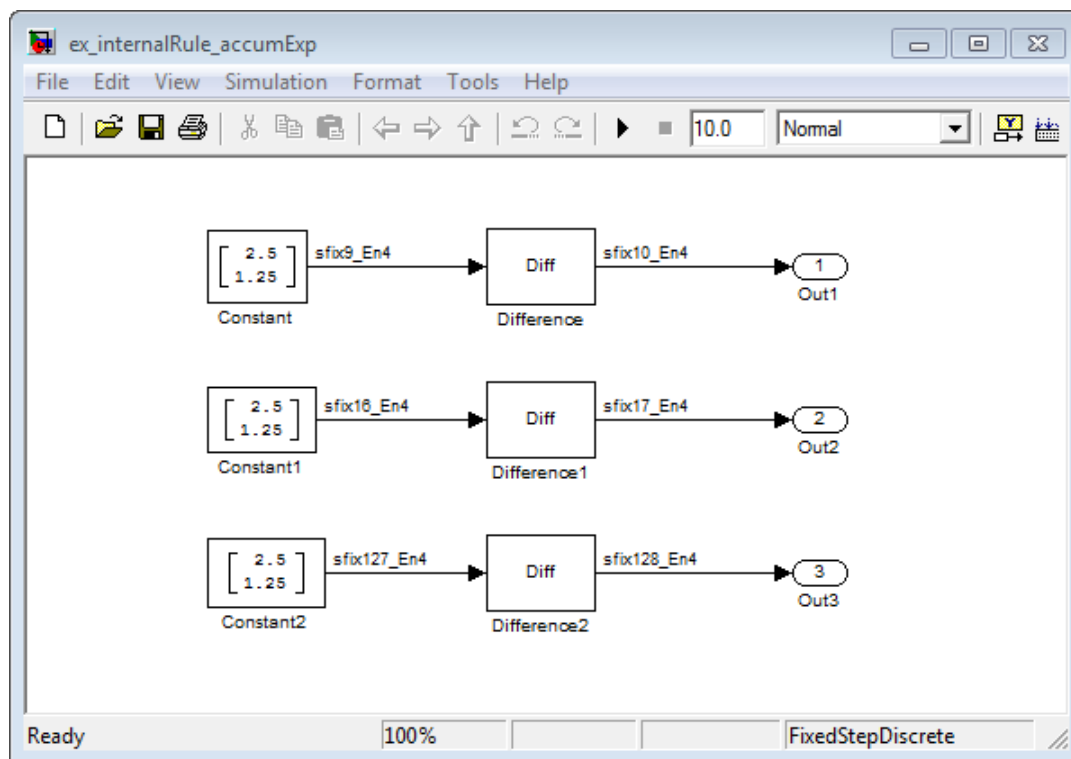
If the calculated ideal word length for a product data type is larger than the largest word length on the target, you receive an error. If the calculated ideal word length for an accumulator or output data type is larger than the largest word length on the target, the largest target word length is used.

## Internal Rule Examples

The following sections show examples of how the internal rule interacts with the **Hardware Implementation** pane to calculate accumulator data types and product data types.

### Accumulator Data Types

Consider the following model `ex_internalRule_accumExp`.



In the Difference blocks, the **Accumulator** parameter is set to `Inherit: Inherit` via `internal rule`, and the **Output** parameter is set to `Inherit: Same as accumulator`. Therefore, you can see the accumulator data type calculated by the internal rule on the output signal in the model.



In the preceding model, the **Device type** parameter in the **Hardware Implementation** pane of the Configuration Parameters dialog box is set to ASIC/FPGA. Therefore, the accumulator data type used by the internal rule is the ideal, full-precision result.

Calculate the full-precision word length for each of the Difference blocks in the model:

$$WL_{ideal\ accumulator} = WL_{input\ to\ accumulator} + \text{floor}(\log_2(\text{number of accumulations})) + 1$$

$$WL_{ideal\ accumulator} = 9 + \text{floor}(\log_2(1)) + 1$$

$$WL_{ideal\ accumulator} = 9 + 0 + 1 = 10$$

$$WL_{ideal\ accumulator1} = WL_{input\ to\ accumulator1} + \text{floor}(\log_2(\text{number of accumulations})) + 1$$

$$WL_{ideal\ accumulator1} = 16 + \text{floor}(\log_2(1)) + 1$$

$$WL_{ideal\ accumulator1} = 16 + 0 + 1 = 17$$

$$WL_{ideal\ accumulator2} = WL_{input\ to\ accumulator2} + \text{floor}(\log_2(\text{number of accumulations})) + 1$$

$$WL_{ideal\ accumulator2} = 127 + \text{floor}(\log_2(1)) + 1$$

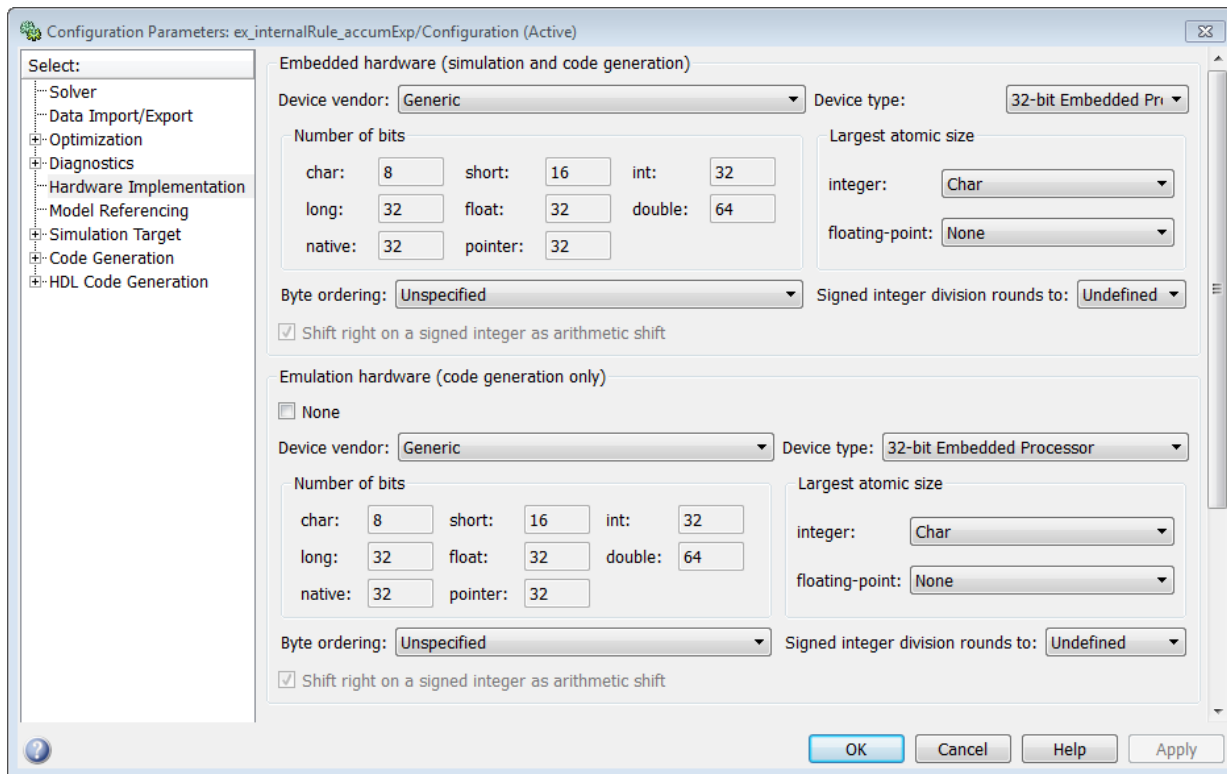
$$WL_{ideal\ accumulator2} = 127 + 0 + 1 = 128$$

Calculate the full-precision fraction length, which is the same for each Matrix Sum block in this example:

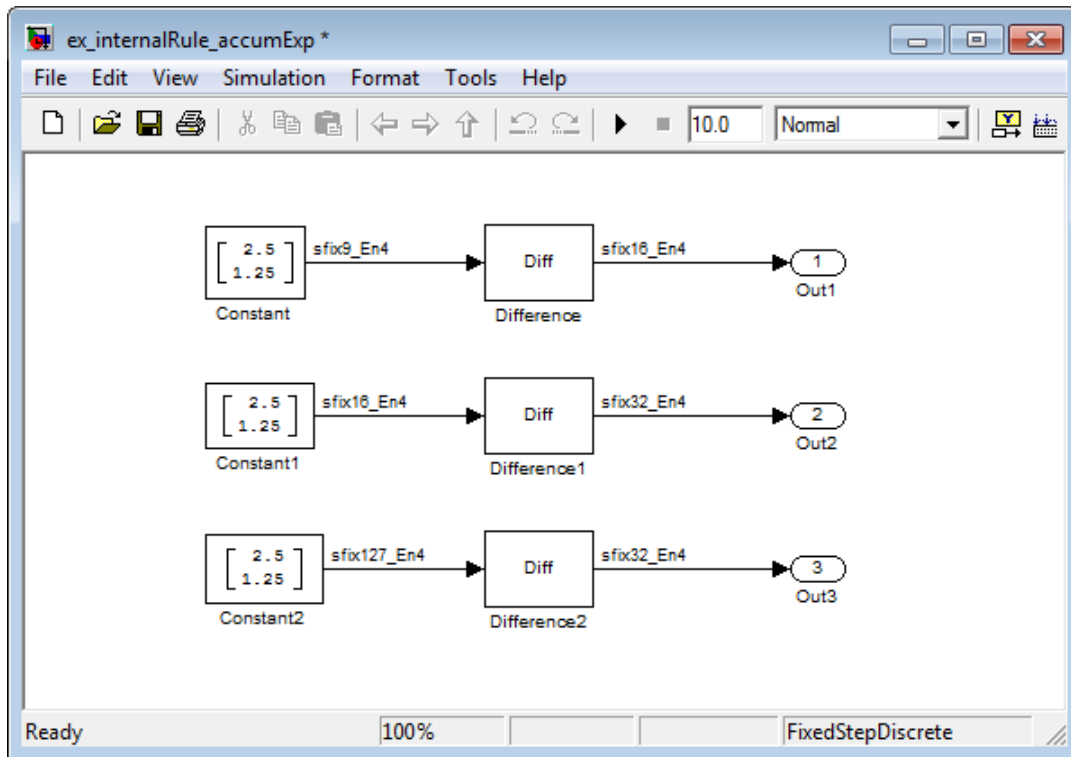
$$FL_{ideal\ accumulator} = FL_{input\ to\ accumulator}$$

$$FL_{ideal\ accumulator} = 4$$

Now change the **Device type** parameter in the **Hardware Implementation** pane of the Configuration Parameters dialog box to **32-bit Embedded Processor**, by changing the parameters as shown in the following figure.

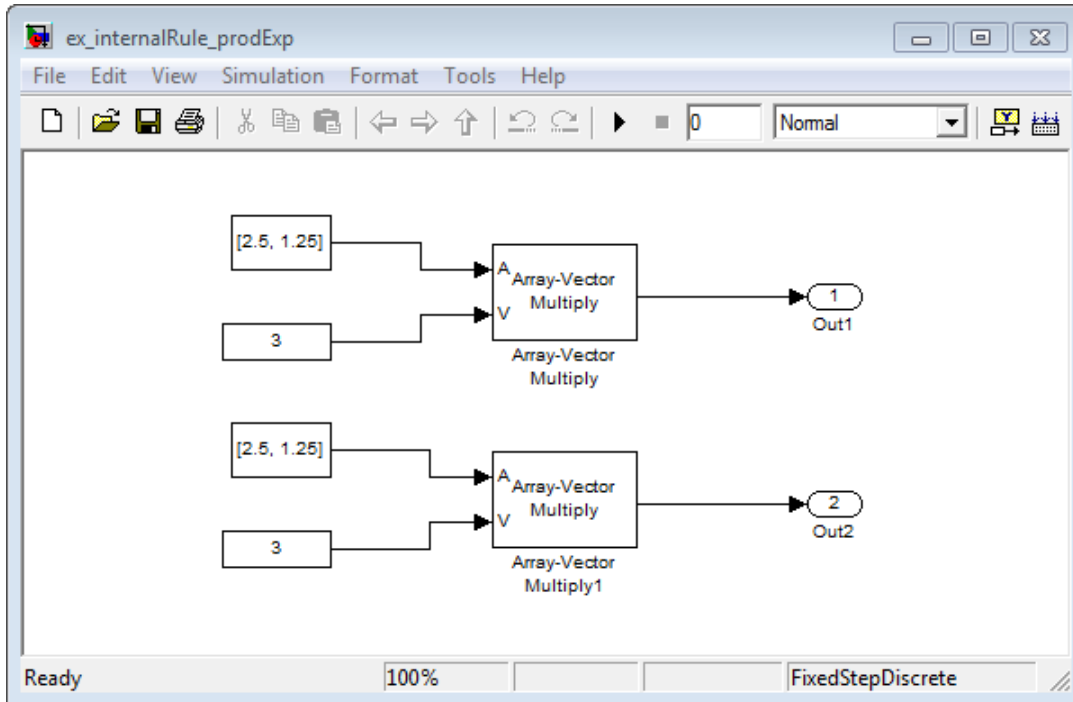


As you can see in the dialog box, this device has 8-, 16-, and 32-bit word lengths available. Therefore, the ideal word lengths of 10, 17, and 128 bits calculated by the internal rule cannot be used. Instead, the internal rule uses the next largest available word length in each case. You can see this if you rerun the model, as shown in the following figure.



### Product Data Types

Consider the following model `ex_internalRule_prodExp`.



In the Array-Vector Multiply blocks, the **Product Output** parameter is set to **Inherit: Inherit via internal rule**, and the **Output** parameter is set to **Inherit: Same as product output**. Therefore, you can see the product output data type calculated by the internal rule on the output signal in the model. The setting of the **Accumulator** parameter does not matter because this example uses real values.

For the preceding model, the **Device type** parameter in the **Hardware Implementation** pane of the Configuration Parameters dialog box is set to **ASIC/FPGA**. Therefore, the product data type used by the internal rule is the ideal, full-precision result.

Calculate the full-precision word length for each of the Array-Vector Multiply blocks in the model:

$$WL_{ideal\ product} = WL_{input\ a} + WL_{input\ b}$$

$$WL_{ideal\ product} = 7 + 5 = 12$$

$$WL_{ideal\ product1} = WL_{input\ a} + WL_{input\ b}$$

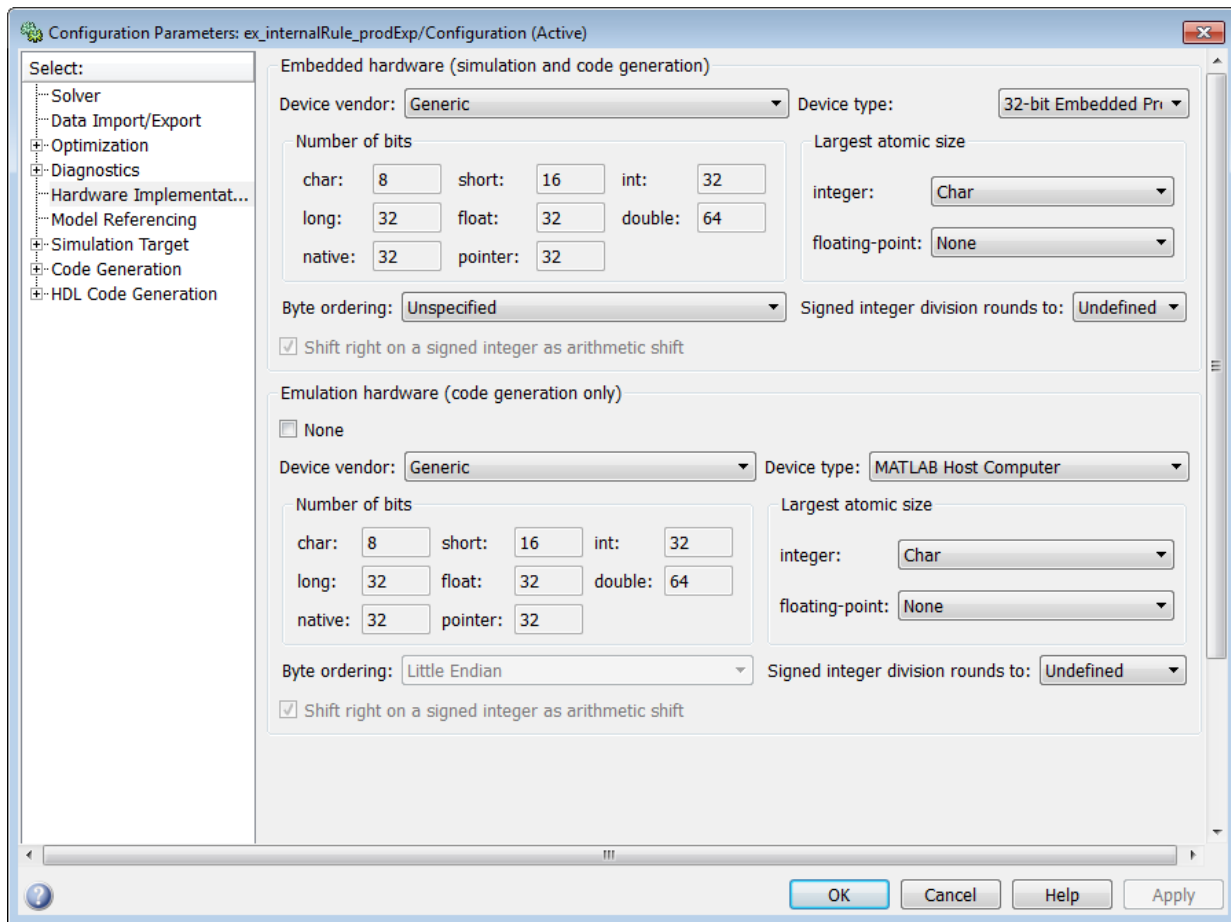
$$WL_{ideal\ product1} = 16 + 15 = 31$$

Calculate the full-precision fraction length, which is the same for each Array-Vector Multiply block in this example:

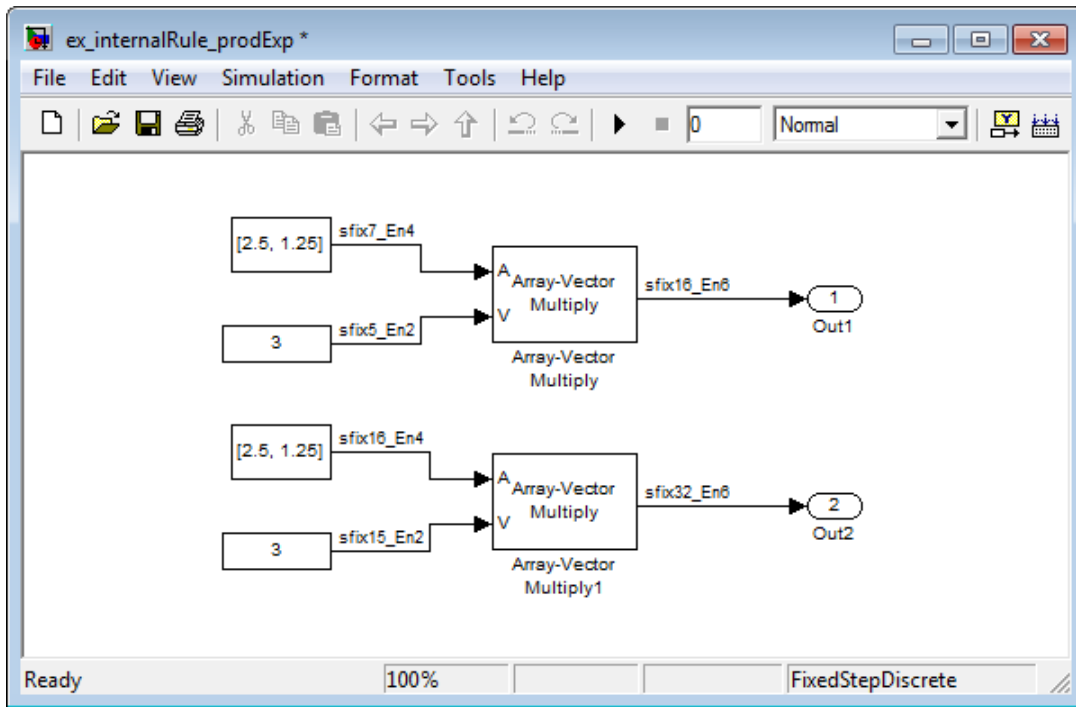
$$FL_{ideal\ accumulator} = FL_{input\ to\ accumulator}$$

$$FL_{ideal\ accumulator} = 4$$

Now change the **Device type** parameter in the **Hardware Implementation** pane of the Configuration Parameters dialog box to **32-bit Embedded Processor**, as shown in the following figure.



As you can see in the dialog box, this device has 8-, 16-, and 32-bit word lengths available. Therefore, the ideal word lengths of 12 and 31 bits calculated by the internal rule cannot be used. Instead, the internal rule uses the next largest available word length in each case. You can see this if you rerun the model, as shown in the following figure.



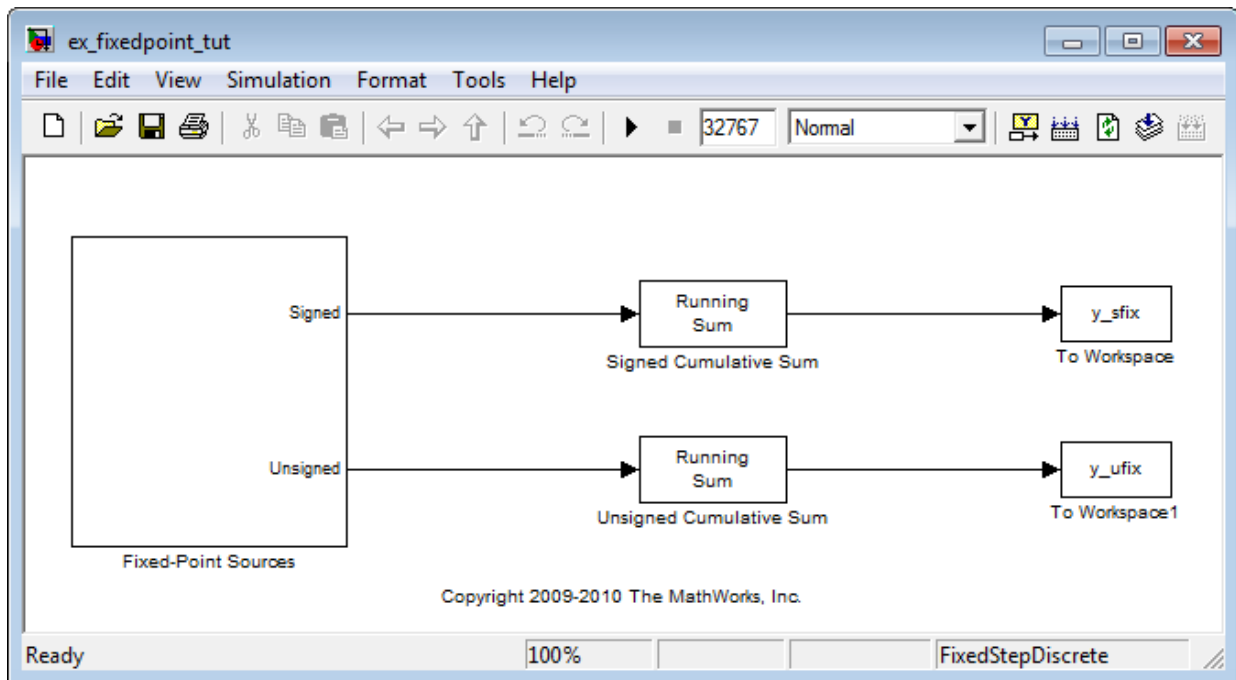
## Specify Data Types for Fixed-Point Blocks

The following sections show you how to use the Fixed-Point Tool to select appropriate data types for fixed-point blocks in the `ex_fixedpoint_tut` model:

- “Prepare the Model” on page 10-37
- “Use Data Type Override to Find a Floating-Point Benchmark” on page 10-42
- “Use the Fixed-Point Tool to Propose Fraction Lengths” on page 10-43
- “Examine the Results and Accept the Proposed Scaling” on page 10-43

### Prepare the Model

- 1 Open the model by typing `ex_fixedpoint_tut` at the MATLAB command line.



This model uses the Cumulative Sum block to sum the input coming from the Fixed-Point Sources subsystem. The Fixed-Point Sources subsystem outputs two signals with different data types:

- The Signed source has a word length of 16 bits and a fraction length of 15 bits.
  - The Unsigned source has a word length of 16 bits and a fraction length of 16 bits.
- 2 Run the model to check for overflow. MATLAB displays the following warnings at the command line:

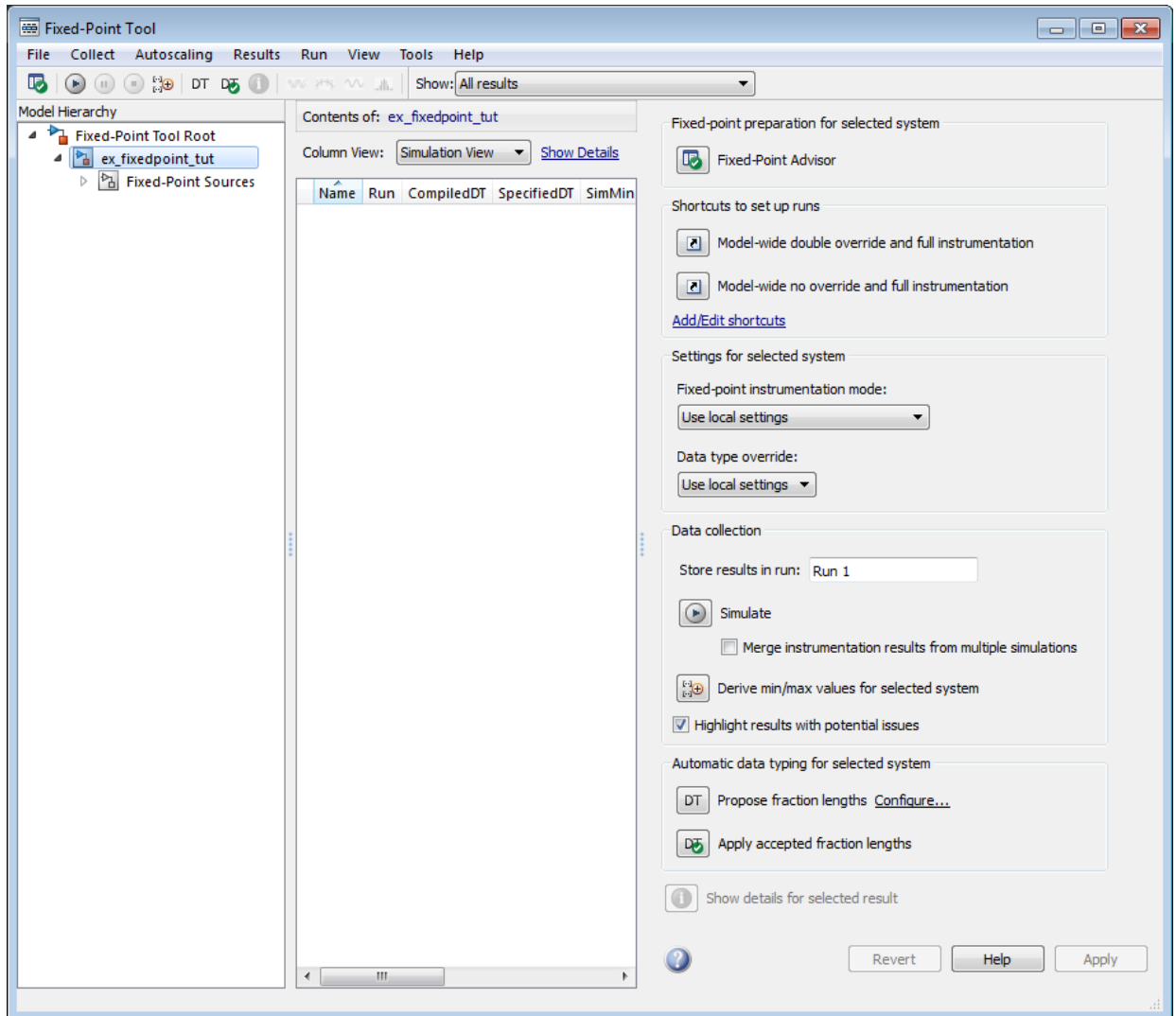
```
Warning: Overflow occurred. This originated from
'ex_fixedpoint_tut/Signed Cumulative Sum'.
Warning: Overflow occurred. This originated from
'ex_fixedpoint_tut/Unsigned Cumulative Sum'.
```

- 3 According to these warnings, overflow occurs in both Cumulative Sum blocks. To investigate the overflows in this model, use the Fixed-Point Tool. You can open the Fixed-Point Tool by selecting **Tools > Fixed-Point > Fixed-Point Tool**



from the model menu. Turn on logging for all blocks in your model by setting the **Fixed-point instrumentation mode** parameter to **Minimums**, **maximums** and **overflows**.

- 4 Now that you have turned on logging, rerun the model by clicking the Simulation button.


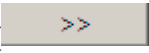


- 5 The results of the simulation appear in a table in the central **Contents** pane of the Fixed-Point Tool. Review the following columns:
- **Name** — Provides the name of each signal in the following format: **Subsystem Name/Block Name: Signal Name**.
  - **SimDT** — The simulation data type of each logged signal.
  - **SpecifiedDT** — The data type specified on the block dialog for each signal.
  - **SimMin** — The smallest representable value achieved during simulation for each logged signal.
  - **SimMax** — The largest representable value achieved during simulation for each logged signal.
  - **OverflowWraps** — The number of overflows that wrap during simulation.

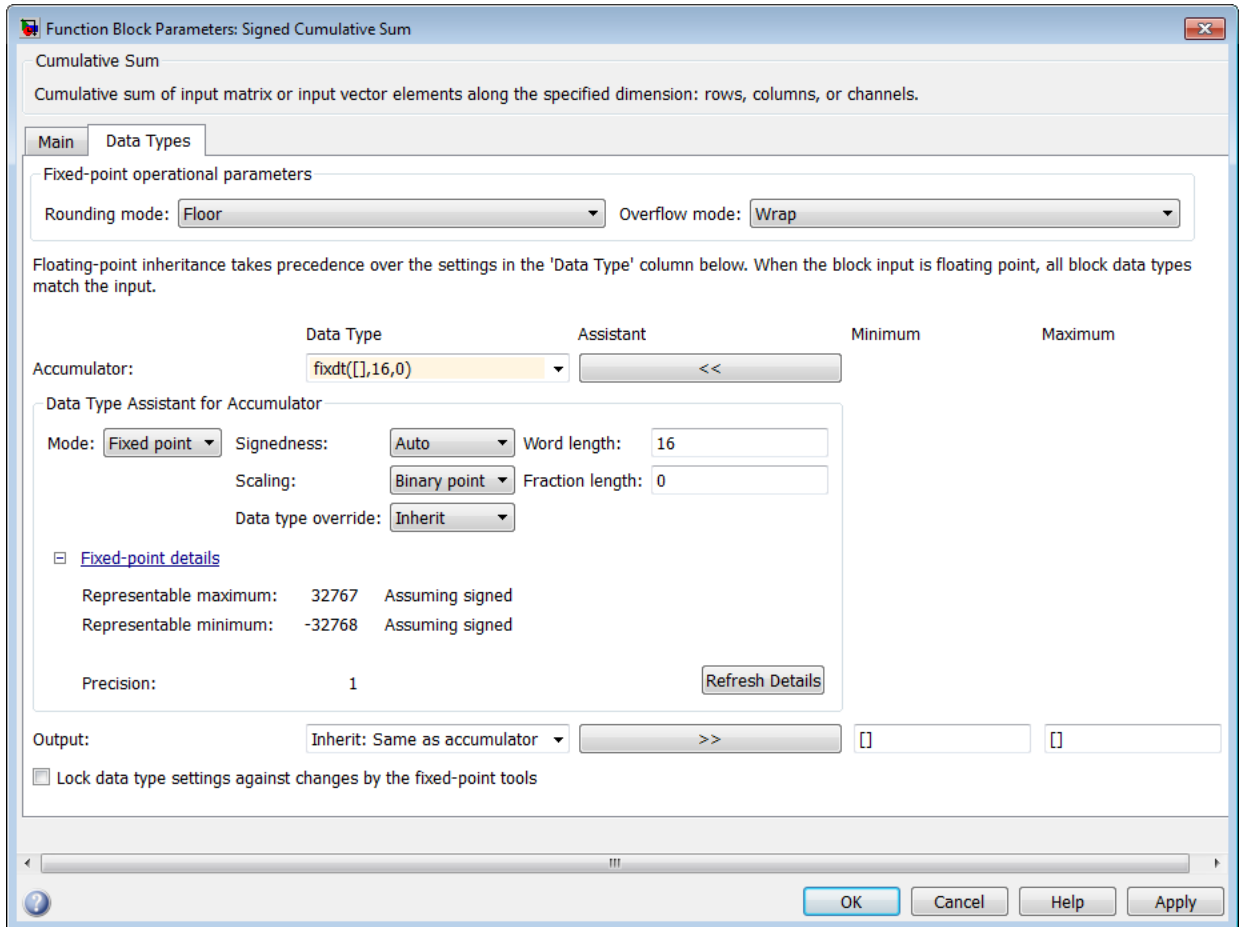
For more information on each of the columns in this table, see the “Contents Pane” section of the Simulink `fxptdlg` function reference page.

You can also see that the **SimMin** and **SimMax** values for the Accumulator data types range from 0 to .9997. The logged results indicate that 8,192 overflows wrapped during simulation in the Accumulator data type of the Signed Cumulative Sum block. Similarly, the Accumulator data type of the Unsigned Cumulative Sum block had 16,383 overflows wrap during simulation.

To get more information about each of these data types, highlight them in the

- Contents** pane, and click the **Show details for selected result** button ()
- 6 Assume a target hardware that supports 32-bit integers, and set the Accumulator word length in both Cumulative Sum blocks to 32. To do so, perform the following steps:
- 1 Right-click the **Signed Cumulative Sum: Accumulator** row in the Fixed-Point Tool pane, and select **Highlight Block In Model**.
  - 2 Double-click the block in the model, and select the **Data Types** pane of the dialog box.
  - 3 Open the **Data Type Assistant for Accumulator** by clicking the Assistant button () in the Accumulator data type row.
  - 4 Set the **Mode** to **Fixed Point**. To see the representable range of the current specified data type, click the **Fixed-point details** link. The tool displays the

representable maximum and representable minimum values for the current data type.



- 5 Change the **Word length** to 32, and click the **Refresh details** button in the **Fixed-point details** section to see the updated representable range. When you change the value of the **Word length** parameter, the data type string in the **Data Type** edit box automatically updates.
- 6 Click **OK** on the block dialog box to save your changes and close the window.

- 7 Set the word length of the Accumulator data type of the Unsigned Cumulative Sum block to 32 bits. You can do so in one of two ways:
  - Type the data type string `fixdt([],32,0)` directly into **Data Type** edit box for the Accumulator data type parameter.
  - Perform the same steps you used to set the word length of the Accumulator data type of the Signed Cumulative Sum block to 32 bits.
- 7 To verify your changes in word length and check for overflow, rerun your model. To do so, click the **Simulate** button in the Fixed-Point Tool.

The **Contents** pane of the Fixed-Point Tool updates, and you can see that no overflows occurred in the most recent simulation. However, you can also see that the **SimMin** and **SimMax** values range from 0 to 0. This underflow happens because the fraction length of the Accumulator data type is too small. The **SpecifiedDT** cannot represent the precision of the data values. The following sections discuss how to find a floating-point benchmark and use the Fixed-Point Tool to propose fraction lengths.

### Use Data Type Override to Find a Floating-Point Benchmark


The **Data type override** feature of the Fixed-Point tool allows you to override the data types specified in your model with floating-point types. Running your model in **Double** override mode gives you a reference range to help you select appropriate fraction lengths for your fixed-point data types. To do so, perform the following steps:

- 1 Open the Fixed-Point Tool and set **Data type override** to **Double**.
- 2 Run your model by clicking the **Run simulation and store active results** button.
- 3 Examine the results in the **Contents** pane of the Fixed-Point Tool. Because you ran the model in **Double** override mode, you get an accurate, idealized representation of the simulation minimums and maximums. These values appear in the **SimMin** and **SimMax** parameters.
- 4 Now that you have an accurate reference representation of the simulation minimum and maximum values, you can more easily choose appropriate fraction lengths. Before making these choices, save your active results to reference so you can use them as your floating-point benchmark. To do so, select **Results > Move Active Results To Reference** from the Fixed-Point Tool menu. The status displayed in the **Run** column changes from **Active** to **Reference** for all signals in your model.

## Use the Fixed-Point Tool to Propose Fraction Lengths


Now that you have your `Double` override results saved as a floating-point reference, you are ready to propose fraction lengths.


- 1 To propose fraction lengths for your data types, you must have a set of **Active** results available in the Fixed-Point Tool. To produce an active set of results, simply rerun your model. The tool now displays both the **Active** results and the **Reference** results for each signal.
- 2 Select the **Use simulation min/max if design min/max is not available** check box. You did not specify any design minimums or maximums for the data types in this model. Thus, the tool uses the logged information to compute and propose fraction lengths. For information on specifying design minimums and maximums, see “Signal Ranges” in the Simulink documentation.

- 3 Click the **Propose fraction lengths** button (). The tool populates the proposed data types in the **ProposedDT** column of the **Contents** pane. The corresponding proposed minimums and maximums are displayed in the **ProposedMin** and **ProposedMax** columns.

## Examine the Results and Accept the Proposed Scaling

Before accepting the fraction lengths proposed by the Fixed-Point Tool, it is important to look at the details of that data type. Doing so allows you to see how much of your data the suggested data type can represent. To examine the suggested data types and accept the proposed scaling, perform the following steps:

- 1 In the **Contents** pane of the Fixed-Point Tool, you can see the proposed fraction lengths for the data types in your model.
  - The proposed fraction length for the Accumulator data type of both the Signed and Unsigned Cumulative Sum blocks is 17 bits.
  - To get more details about the proposed scaling for a particular data type, highlight the data type in the **Contents** pane of the Fixed-Point Tool.
  - Open the Autoscale Information window for the highlighted data type by clicking the **Show autoscale information for the selected result** button (.
- 2 When the Autoscale Information window opens, check the **Value** and **Percent Proposed Representable** columns for the **Simulation Minimum** and **Simulation Maximum** parameters. You can see that the proposed data type can represent 100% of the range of simulation data.

- 3 To accept the proposed data types, select the check box in the **Accept** column for each data type whose proposed scaling you want to keep. Then, click the **Apply accepted fraction lengths** button (). The tool updates the specified data types on the block dialog boxes and the **SpecifiedDT** column in the **Contents** pane.
- 4 To verify the newly accepted scaling, set the **Data type override** parameter back to **Use local settings**, and run the model. Looking at **Contents** pane of the Fixed-Point Tool, you can see the following details:
  - The **SimMin** and **SimMax** values of the **Active** run match the **SimMin** and **SimMax** values from the floating-point **Reference** run.
  - There are no longer any overflows.
  - The **SimDT** does not match the **SpecifiedDT** for the Accumulator data type of either Cumulative Sum block. This difference occurs because the Cumulative Sum block always inherits its **Signedness** from the input signal and only allows you to specify a **Signedness** of **Auto**. Therefore, the **SpecifiedDT** for both Accumulator data types is `fixdt([], 32, 17)`. However, because the Signed Cumulative Sum block has a signed input signal, the **SimDT** for the Accumulator parameter of that block is also signed (`fixdt(1, 32, 17)`). Similarly, the **SimDT** for the Accumulator parameter of the Unsigned Cumulative Sum block inherits its **Signedness** from its input signal and thus is unsigned (`fixdt(0, 32, 17)`).

# Code Generation

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- “Code Generation in MATLAB” on page 11-2
- “Code Generation Support, Usage Notes, and Limitations” on page 11-3
- “Simulink Shared Library Dependencies” on page 11-12
- “Accelerating Simulink Models” on page 11-13

## Code Generation in MATLAB

Several Computer Vision System Toolbox functions have been enabled to generate C/C++ code. To use code generation with computer vision functions, follow these steps:

- Write your Computer Vision System Toolbox function or application as you would normally, using functions from the Computer Vision System Toolbox.
- Add the `%#codegen` compiler directive to your MATLAB code.
- Open the MATLAB Coder app, create a project, and add your file to the project. Once in MATLAB Coder, you can check the readiness of your code for code generation. For example, your code may contain functions that are not enabled for code generation. Make any modifications required for code generation.
- Generate code by clicking **Build** on the Build tab of the MATLAB Coder app. You can choose to build a MEX file, a C/C++ shared library, a C/C++ dynamic library, or a C/C++ executable.

Even if you addressed all readiness issues identified by MATLAB Coder, you might still encounter build issues. The readiness check only looks at function dependencies. When you try to generate code, MATLAB Coder might discover coding patterns that are not supported for code generation. View the error report and modify your MATLAB code until you get a successful build.

For more information about code generation, see the MATLAB Coder documentation and the “Introduction to Code Generation with Feature Matching and Registration” example.

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**Note:** To generate code from MATLAB code that contains Computer Vision System Toolbox functionality, you must have the MATLAB Coder software.

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When working with generated code, note the following:

- For some Computer Vision System Toolbox functions, code generation includes creation of a shared library.
- Refer to the “Code Generation Support, Usage Notes, and Limitations” on page 11-3 for supported functionality, usages, and limitations.



## Code Generation Support, Usage Notes, and Limitations

Code Generation Support, Usage Notes, and Limitations for Functions, Classes, and System Objects

To generate code from MATLAB code that contains Computer Vision System Toolbox functions, classes, or System objects, you must have the MATLAB Coder software.

Name	Remarks and Limitations
<b>Feature Detection, Extraction, and Matching</b>	
BRISKPoints	Supports MATLAB Function block: No To index locations with this object, use the syntax: <code>points.Location(idx, :)</code> , for <code>points</code> object. See <code>visionRecoverFromCodeGeneration_kernel.m</code> , which is used in the “Introduction to Code Generation with Feature Matching and Registration” example.
cornerPoints	Supports MATLAB Function block: No To index locations with this object, use the syntax: <code>points.Location(idx, :)</code> , for <code>points</code> object. See <code>visionRecoverFromCodeGeneration_kernel.m</code> , which is used in the “Introduction to Code Generation with Feature Matching and Registration” example.
detectBRISKFeatures	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
detectFASTFeatures	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
detectHarrisFeatures	Compile-time constant input: 'FilterSize' Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
detectMinEigenFeatures	Compile-time constant input: 'FilterSize'

Name	Remarks and Limitations
	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
detectMSERFeatures	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library. For code generation, the function outputs regions.PixelList as an array. The region sizes are defined in regions.Lengths.
detectSURFFeatures	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
extractFeatures	Generates platform-dependent library: Yes for BRISK, FREAK, and SURF methods only. Compile-time constant input restrictions: 'Method' Supports MATLAB Function block: Yes for Block method only. Generated code for this function uses a precompiled platform-specific shared library.
extractHOGFeatures	Supports MATLAB Function block: No
matchFeatures	Generates platform-dependent library: Yes for MATLAB host. Generates portable C code for non-host target. Compile-time constant input: 'Method' and 'Metric'. Supports MATLAB Function block: Yes
MSERRegions	Supports MATLAB Function block: Yes For code generation, you must specify both the pixellist cell array and the length of each array, as the second input. The object outputs, regions.PixelList as an array. The region sizes are defined in regions.Lengths. Generated code for this function uses a precompiled platform-specific shared library.

Name	Remarks and Limitations
SURFPoints	Supports MATLAB Function block: No To index locations with this object, use the syntax: <code>points.Location(idx, :)</code> , for <code>points</code> object. See <code>visionRecoverFromCodeGeneration_kernel.m</code> , which is used in the “Introduction to Code Generation with Feature Matching and Registration” example.
vision.BoundaryTracer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.EdgeDetector	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
<b>Image Registration and Geometric Transformations</b>	
estimateGeometricTransform	Supports MATLAB Function block: No
vision.GeometricRotator	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.GeometricScaler	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.GeometricShearer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.GeometricTransformer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.GeometricTranslator	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
<b>Object Detection and Recognition</b>	
ocr	Compile-time constant input: 'TextLayout', 'Language', and 'CharacterSet'. Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
ocrText	Supports MATLAB Function block: No

Name	Remarks and Limitations
vision.PeopleDetector	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”
vision.CascadeObjectDetector	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”
<b>Tracking and Motion Estimation</b>	
assignDetectionsToTracks	Supports MATLAB Function block: Yes
opticalFlowHS	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
opticalFlowLKDoG	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
opticalFlowLK	Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
opticalFlow	Supports MATLAB Function block: Yes
vision.BlockMatcher	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ForegroundDetector	Supports MATLAB Function block: No Generates platform-dependent library: Yes for MATLAB host. Generates portable C code for non-host target. Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”
vision.HistogramBasedTracker	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.KalmanFilter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”

Name	Remarks and Limitations
vision.PointTracker	Supports MATLAB Function block: No "System Objects in MATLAB Code Generation"
vision.TemplateMatcher	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
<b>Camera Calibration and Stereo Vision</b>	
bboxOverlapRatio	Supports MATLAB Function block: No
disparity	Compile-time constant input restriction: 'Method'. Supports MATLAB Function block: No Generated code for this function uses a precompiled platform-specific shared library.
cameraMatrix	Supports MATLAB Function block: No
cameraParameters	Supports MATLAB Function block: No
epipolarline	Supports MATLAB Function block: Yes
estimateFundamentalMatrix	Compile-time constant input restriction: 'Method', 'OutputClass', 'DistanceType', and 'ReportRuntimeError'. Supports MATLAB Function block: Yes
estimateUncalibratedRectification	Supports MATLAB Function block: Yes Only accepts input points as $M$ -by-2 matrices for C code generation
extrinsics	Supports MATLAB Function block: No
isEpipoleInImage	Supports MATLAB Function block: Yes
lineToBorderPoints	Supports MATLAB Function block: Yes
reconstructScene	Supports MATLAB Function block: No
rectifyStereoImages	Compile-time constant input restriction: 'interp' and 'OutputView' Supports MATLAB Function block: No
selectStrongestBbox	Supports MATLAB Function block: No
stereoParameters	Supports MATLAB Function block: No
triangulate	Supports MATLAB Function block: No

<b>Name</b>	<b>Remarks and Limitations</b>
undistortImage	Compile-time constant input restriction: 'interp' and 'OutputView' Supports MATLAB Function block: No
<b>Statistics</b>	
vision.Autocorrelator	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.BlobAnalysis	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Crosscorrelator	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Histogram	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.LocalMaximaFinder	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Maximum	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Mean	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Median	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Minimum	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.PSNR	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.StandardDeviation	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
vision.Variance	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"
<b>Morphological Operations</b>	
vision.ConnectedComponentLabeler	Supports MATLAB Function block: Yes "System Objects in MATLAB Code Generation"

Name	Remarks and Limitations
vision.MorphologicalBottomHat	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MorphologicalClose	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MorphologicalDilate	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MorphologicalErode	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MorphologicalOpen	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MorphologicalTopHat	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
<b>Filters, Transforms, and Enhancements</b>	
integralImage	Supports MATLAB Function block: Yes
vision.Convolver	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ContrastAdjuster	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.DCT	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.Deinterlacer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.EdgeDetector	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.FFT	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.HistogramEqualizer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.HoughLines	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.HoughTransform	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”

Name	Remarks and Limitations
vision.IDCT	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.IFFT	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ImageFilter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MedianFilter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.Pyramid	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
<b>Video Loading, Saving, and Streaming</b>	
vision.DeployableVideoPlayer	Supports MATLAB Function block: Yes Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”
vision.VideoFileReader	Supports MATLAB Function block: Yes Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”  Does not generate code for reading compressed images on the Mac.
vision.VideoFileWriter	Supports MATLAB Function block: Yes Generated code for this function uses a precompiled platform-specific shared library. “System Objects in MATLAB Code Generation”
<b>Color Space Formatting and Conversions</b>	
vision.Autothresolder	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ChromaResampler	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ColorSpaceConverter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”



Name	Remarks and Limitations
vision.DemosaicInterpolator	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.GammaCorrector	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ImageComplementer	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ImageDataTypeConverter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ImagePadder	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
<b>Graphics</b>	
insertMarker	Compile-time constant input: 'Shape' and 'Color' Supports MATLAB Function block: Yes
insertShape	Compile-time constant input: 'Color' and 'SmoothEdges' Supports MATLAB Function block: Yes
vision.AlphaBlender	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.MarkerInserter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.ShapeInserter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”
vision.TextInserter	Supports MATLAB Function block: Yes “System Objects in MATLAB Code Generation”

## Simulink Shared Library Dependencies

In general, the code you generate from Computer Vision System Toolbox blocks is portable ANSI<sup>®</sup> C code. After you generate the code, you can deploy it on another machine. For more information on how to do so, see “Relocate Code to Another Development Environment” in the Simulink Coder documentation.

There are a few Computer Vision System Toolbox blocks that generate code with limited portability. These blocks use precompiled shared libraries, such as DLLs, to support I/O for specific types of devices and file formats. To find out which blocks use precompiled shared libraries, open the Computer Vision System Toolbox Block Support Table. You can identify blocks that use precompiled shared libraries by checking the footnotes listed in the **Code Generation Support** column of the table. All blocks that use shared libraries have the following footnote:

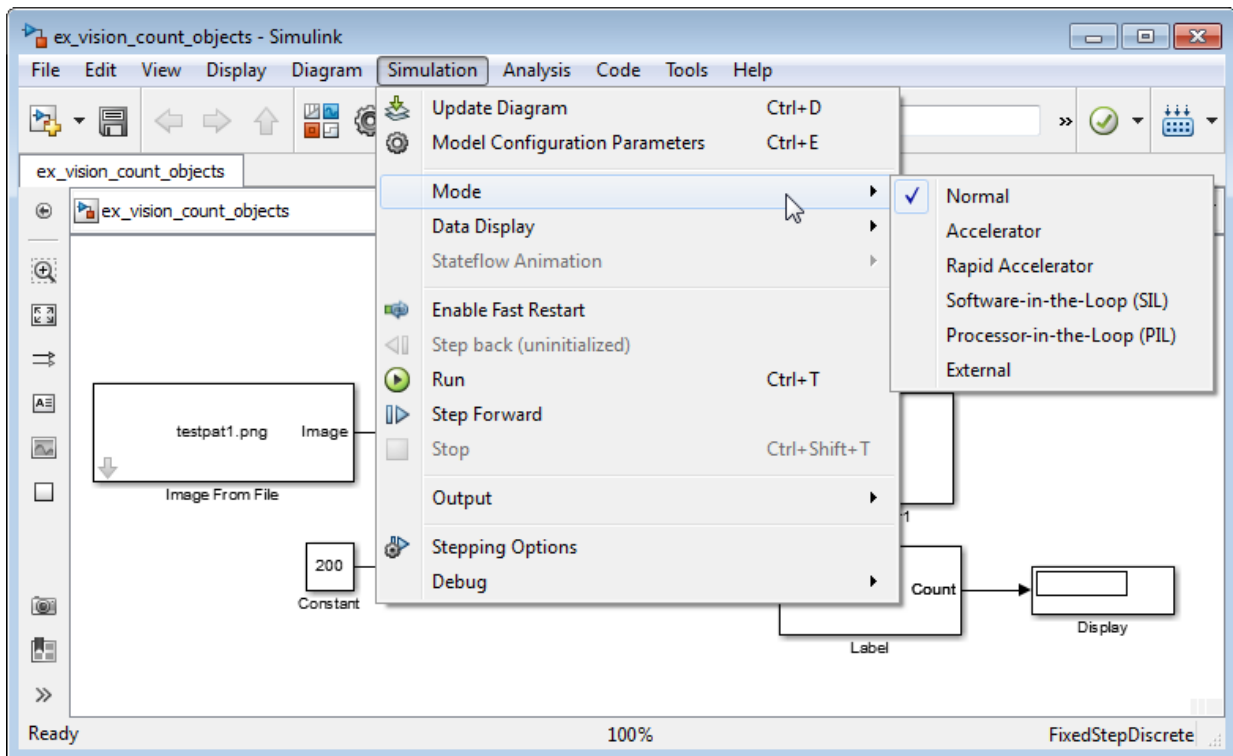
Host computer only. Excludes Simulink Desktop Real-Time<sup>™</sup> target.

Simulink Coder provides functions to help you set up and manage the build information for your models. For example, one of the Build Information functions that Simulink Coder provides is `getNonBuildFiles`. This function allows you to identify the shared libraries required by blocks in your model. If your model contains any blocks that use precompiled shared libraries, you can install those libraries on the target system. The folder that you install the shared libraries in must be on the system path. The target system does not need to have MATLAB installed, but it does need to be supported by MATLAB.

## Accelerating Simulink Models

The Simulink software offer **Accelerator** and **Rapid Accelerator** simulation modes that remove much of the computational overhead required by Simulink models. These modes compile target code of your model. Through this method, the Simulink environment can achieve substantial performance improvements for larger models. The performance gains are tied to the size and complexity of your model. Therefore, large models that contain Computer Vision System Toolbox blocks run faster in **Rapid Accelerator** or **Accelerator** mode.

To change between **Rapid Accelerator**, **Accelerator**, and **Normal** mode, use the drop-down list at the top of the model window.



For more information on the accelerator modes in Simulink, see “Choosing a Simulation Mode”.



# Define New System Objects

---

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- “Define Basic System Objects” on page 12-5
- “Change Number of Step Inputs or Outputs” on page 12-7
- “Specify System Block Input and Output Names” on page 12-11
- “Validate Property and Input Values” on page 12-13
- “Initialize Properties and Setup One-Time Calculations” on page 12-16
- “Set Property Values at Construction Time” on page 12-19
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- “Define Property Attributes” on page 12-23
- “Hide Inactive Properties” on page 12-27
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- “Specify Whether Output Is Fixed- or Variable-Size” on page 12-74
- “Specify Discrete State Output Specification” on page 12-76
- “Use Update and Output for Nondirect Feedthrough” on page 12-78
- “Enable For Each Subsystem Support” on page 12-81
- “Methods Timing” on page 12-83
- “System Object Input Arguments and ~ in Code Examples” on page 12-86
- “What Are Mixin Classes?” on page 12-87
- “Best Practices for Defining System Objects” on page 12-88

## Summary List of Methods for Defining New System Objects

The following Impl methods comprise the System objects API for defining new System objects. For more information see “Define System Objects”.

- cloneImpl
- getDiscreteStateImpl
- getDiscreteStateSpecificationImpl
- getHeaderImpl
- getIconImpl
- getInputNamesImpl
- getNumInputsImpl
- getNumOutputsImpl
- getOutputDataTypeImpl
- getOutputNamesImpl
- getOutputSizeImpl
- getPropertyGroupsImpl
- getSimulateUsingImpl
- infoImpl
- isInactivePropertyImpl
- isInputDirectFeedthroughImpl
- isOutputComplexImpl
- isOutputFixedSizeImpl
- loadObjectImpl
- outputImpl
- processTunedPropertiesImpl
- propagatedInputComplexity
- propagatedInputDataType
- propagatedInputFixedSize
- propagatedInputSize
- releaseImpl

- `resetImpl`
- `saveObjectImpl`
- `setPropertyies`
- `setupImpl`
- `showSimulateUsingImpl`
- `stepImpl`
- `supportsMultipleInstanceImpl`
- `updateImpl`
- `validateInputsImpl`
- `validatePropertiesImpl`



## Define Basic System Objects

This example shows how to create a basic System object that increments a number by one.

The class definition file contains the minimum elements required to define a System object.

### Create the Class Definition File

- 1 Create a MATLAB file named `AddOne.m` to contain the definition of your System object.

```
edit AddOne.m
```

- 2 Subclass your object from `matlab.System`. Insert this line as the first line of your file.

```
classdef AddOne < matlab.System
```

- 3 Add the `stepImpl` method, which contains the algorithm that runs when users call the `step` method on your object. You always set the `stepImpl` method access to `protected` because it is an internal method that users do not directly call or run.

All methods, except static methods, expect the System object handle as the first input argument. You can use any name for your System object handle.

In this example, instead of passing in the object handle, `~` is used to indicate that the object handle is not used in the function. Using `~` instead of an object handle prevents warnings about unused variables from occurring.

By default, the number of inputs and outputs are both one. To change the number of inputs or outputs, use the `getNumInputsImpl` or `getNumOutputsImpl` method, respectively.

```
methods (Access = protected)
    function y = stepImpl(~,x)
        y = x + 1;
    end
end
```

---

**Note:** Instead of manually creating your class definition file, you can use an option on the **New > System Object** menu to open a template. The **Basic** template opens a simple

System object template. The **Advanced** template includes more advanced features of System objects, such as backup and restore. The **Simulink Extension** template includes additional customizations of the System object for use in the Simulink MATLAB System block. You then can edit the template file, using it as guideline, to create your own System object.

---

### Complete Class Definition File for Basic System Object

```
classdef AddOne < matlab.System
% ADDONE Compute an output value one greater than the input value

% All methods occur inside a methods declaration.
% The stepImpl method has protected access
methods (Access = protected)

    function y = stepImpl(~,x)
        y = x + 1;
    end
end
end
```

### See Also

[matlab.System](#) | [getNumInputsImpl](#) | [getNumOutputsImpl](#) | [stepImpl](#)

### Related Examples

- “Change Number of Step Inputs or Outputs” on page 12-7

### More About

- “System Design and Simulation in MATLAB”

## Change Number of Step Inputs or Outputs

This example shows how to specify two inputs and two outputs for the `step` method.

If you specify the inputs and outputs to the `stepImpl` method, you do not need to specify the `getNumInputsImpl` and `getNumOutputsImpl` methods. If you have a variable number of inputs or outputs (using `varargin` or `varargout`), include the `getNumInputsImpl` or `getNumOutputsImpl` method, respectively, in your class definition file.

---

**Note:** You should only use `getNumInputsImpl` or `getNumOutputsImpl` methods to change the number of System object inputs or outputs. Do not use any other handle objects within a System object to change the number of inputs or outputs.

---

You always set the `getNumInputsImpl` and `getNumOutputsImpl` methods access to `protected` because they are internal methods that users do not directly call or run.

### Update the Algorithm for Multiple Inputs and Outputs

Update the `stepImpl` method to specify two inputs and two outputs. You do not need to implement associated `getNumInputsImpl` or `getNumOutputsImpl` methods.

```
methods (Access = protected)
    function [y1,y2] = stepImpl(~,x1,x2)
        y1 = x1 + 1;
        y2 = x2 + 1;
    end
end
```

### Update the Algorithm and Associated Methods

Update the `stepImpl` method to use `varargin` and `varargout`. In this case, you must implement the associated `getNumInputsImpl` and `getNumOutputsImpl` methods to specify two or three inputs and outputs.

```
methods (Access = protected)
    function varargout = stepImpl(obj,varargin)
        varargout{1} = varargin{1}+1;
        varargout{2} = varargin{2}+1;
        if (obj.numInputsOutputs == 3)
            varargout{3} = varargin{3}+1;
        end
    end
```

```
end

function validatePropertiesImpl(obj)
    if ~((obj.numInputsOutputs == 2) || ...
        (obj.numInputsOutputs == 3))
        error('Only 2 or 3 input and outputs allowed.');
```

```
    end
```

```
end
```

```
function numIn = getNumInputsImpl(obj)
```

```
    numIn = 3;
```

```
    if (obj.numInputsOutputs == 2)
```

```
        numIn = 2;
```

```
    end
```

```
end
```

```
function numOut = getNumOutputsImpl(obj)
```

```
    numOut = 3;
```

```
    if (obj.numInputsOutputs == 2)
```

```
        numOut = 2;
```

```
    end
```

```
end
```

```
end
```

Use this syntax to run the algorithm with two inputs and two outputs.

```
x1 = 3;
x2 = 7;
[y1,y2] = step(AddOne,x1,x2);
```

To change the number of inputs or outputs, you must release the object before rerunning it.

```
release(AddOne)
x1 = 3;
x2 = 7;
x3 = 10
[y1,y2,y3] = step(AddOne,x1,x2,x3);
```

### Complete Class Definition File with Multiple Inputs and Outputs

```
classdef AddOne < matlab.System
% ADDONE Compute output values one greater than the input values

    % This property is nontunable and cannot be changed
```

```
% after the setup or step method has been called.
properties (Nontunable)
    numInputsOutputs = 3;    % Default value
end

% All methods occur inside a methods declaration.
% The stepImpl method has protected access
methods (Access = protected)
    function varargout = stepImpl(obj,varargin)
        if (obj.numInputsOutputs == 2)
            varargout{1} = varargin{1}+1;
            varargout{2} = varargin{2}+1;
        else
            varargout{1} = varargin{1}+1;
            varargout{2} = varargin{2}+1;
            varargout{3} = varargin{3}+1;
        end
    end
end

function validatePropertiesImpl(obj)
    if ~(obj.numInputsOutputs == 2) ||...
        (obj.numInputsOutputs == 3)
        error('Only 2 or 3 input and outputs allowed.');
```

end

### See Also

getNumInputsImpl | getNumOutputsImpl

### Related Examples

- “Validate Property and Input Values” on page 12-13
- “Define Basic System Objects” on page 12-5

### More About

- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Specify System Block Input and Output Names

This example shows how to specify the names of the input and output ports of a System object-based block implemented using a MATLAB System block.

### Define Input and Output Names

This example shows how to use `getInputNamesImpl` and `getOutputNamesImpl` to specify the names of the input port as “source data” and the output port as “count.”

If you do not specify the `getInputNamesImpl` and `getOutputNamesImpl` methods, the object uses the `stepImpl` method input and output variable names for the input and output port names, respectively. If the `stepImpl` method uses *varargin* and *varargout* instead of variable names, the port names default to empty strings.

```
methods (Access = protected)
    function inputName = getInputNamesImpl(~)
        inputName = 'source data';
    end

    function outputName = getOutputNamesImpl(~)
        outputName = 'count';
    end
end
```

### Complete Class Definition File with Named Inputs and Outputs

```
classdef MyCounter < matlab.System

    % MyCounter Count values above a threshold

    properties
        Threshold = 1
    end
    properties (DiscreteState)
        Count
    end

    methods
        function obj = MyCounter(varargin)
            setProperties (obj,nargin,varargin{:});
        end
    end
end
```

```
methods (Access = protected)
    function setupImpl(obj)
        obj.Count = 0;
    end
    function resetImpl(obj)
        obj.Count = 0;
    end
    function y = stepImpl(obj,u)
        if (u > obj.Threshold)
            obj.Count = obj.Count + 1;
        end
        y = obj.Count;
    end
    function inputName = getInputNamesImpl(~)
        inputName = 'source data';
    end
    function outputName = getOutputNamesImpl(~)
        outputName = 'count';
    end
end
end
```

### See Also

[getInputNamesImpl](#) | [getNumInputsImpl](#) | [getNumOutputsImpl](#) | [getOutputNamesImpl](#)

### Related Examples

- “Change Number of Step Inputs or Outputs” on page 12-7

### More About

- “System Object Input Arguments and ~ in Code Examples” on page 12-86



## Validate Property and Input Values

This example shows how to verify that the user's inputs and property values are valid.

### Validate Properties

This example shows how to validate the value of a single property using `set.PropertyName` syntax. In this case, the *PropertyName* is `Increment`.

```
methods
    % Validate the properties of the object
    function set.Increment(obj, val)
        if val >= 10
            error('The increment value must be less than 10');
        end
        obj.Increment = val;
    end
end
```

This example shows how to validate the value of two interdependent properties using the `validatePropertiesImpl` method. In this case, the `UseIncrement` property value must be `true` and the `WrapValue` property value must be less than the `Increment` property value.

```
methods (Access = protected)
    function validatePropertiesImpl(obj)
        if obj.UseIncrement && obj.WrapValue > obj.Increment
            error('Wrap value must be less than increment value');
        end
    end
end
```

### Validate Inputs

This example shows how to validate that the first input is a numeric value.

```
methods (Access = protected)
    function validateInputsImpl(~, x)
        if ~isnumeric(x)
            error('Input must be numeric');
        end
    end
end
```

```
end
```

### Complete Class Definition File with Property and Input Validation

```
classdef AddOne < matlab.System
% ADDONE Compute an output value by incrementing the input value

% All properties occur inside a properties declaration.
% These properties have public access (the default)
properties (Logical)
    UseIncrement = true
end

properties (PositiveInteger)
    Increment = 1
    WrapValue = 10
end

methods
% Validate the properties of the object
function set.Increment(obj,val)
    if val >= 10
        error('The increment value must be less than 10');
    end
    obj.Increment = val;
end
end

methods (Access = protected)
function validatePropertiesImpl(obj)
    if obj.UseIncrement && obj.WrapValue > obj.Increment
        error('Wrap value must be less than increment value');
    end
end

% Validate the inputs to the object
function validateInputsImpl(~,x)
    if ~isnumeric(x)
        error('Input must be numeric');
    end
end

function out = stepImpl(obj,in)
    if obj.UseIncrement
        out = in + obj.Increment;
    end
end
end
```

```
    else
      out = in + 1;
    end
  end
end
end
end
```

---

**Note:** All inputs default to variable-size inputs. See “Change Input Complexity or Dimensions” for more information.

---

## See Also

[validateInputsImpl](#) | [validatePropertiesImpl](#)

## Related Examples

- “Define Basic System Objects” on page 12-5

## More About

- “Methods Timing” on page 12-83
- “Property Set Methods”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Initialize Properties and Setup One-Time Calculations

This example shows how to write code to initialize and set up a System object.

In this example, you allocate file resources by opening the file so the System object can write to that file. You do these initialization tasks one time during setup, rather than every time you call the step method.

### Define Public Properties to Initialize

In this example, you define the public `Filename` property and specify the value of that property as the nontunable string, `default.bin`. Users cannot change *nontunable* properties after the `setup` method has been called. Refer to the Methods Timing section for more information.

```
properties (Nontunable)
    Filename = 'default.bin'
end
```

### Define Private Properties to Initialize

Users cannot access *private* properties directly, but only through methods of the System object. In this example, you define the `pFileID` property as a private property. You also define this property as *hidden* to indicate it is an internal property that never displays to the user.

```
properties (Hidden,Access = private)
    pFileID;
end
```

### Define Setup

You use the `setupImpl` method to perform setup and initialization tasks. You should include code in the `setupImpl` method that you want to execute one time only. The `setupImpl` method is called once during the first call to the `step` method. In this example, you allocate file resources by opening the file for writing binary data.

```
methods
function setupImpl(obj)
    obj.pFileID = fopen(obj.Filename,'wb');
    if obj.pFileID < 0
        error('Opening the file failed');
```

```

    end
  end
end

```

Although not part of setup, you should close files when your code is done using them. You use the `releaseImpl` method to release resources.

### Complete Class Definition File with Initialization and Setup

```

classdef MyFile < matlab.System
% MyFile write numbers to a file

    % These properties are nontunable. They cannot be changed
    % after the setup or step method has been called.
    properties (Nontunable)
        Filename = 'default.bin' % the name of the file to create
    end

    % These properties are private. Customers can only access
    % these properties through methods on this object
    properties (Hidden,Access = private)
        pFileID; % The identifier of the file to open
    end

    methods (Access = protected)
        % In setup allocate any resources, which in this case
        % means opening the file.
        function setupImpl(obj)
            obj.pFileID = fopen(obj.Filename,'wb');
            if obj.pFileID < 0
                error('Opening the file failed');
            end
        end

        % This System object™ writes the input to the file.
        function stepImpl(obj,data)
            fwrite(obj.pFileID,data);
        end

        % Use release to close the file to prevent the
        % file handle from being left open.
        function releaseImpl(obj)
            fclose(obj.pFileID);
        end
    end
end

```

end

### **See Also**

releaseImpl | setupImpl | stepImpl

### **Related Examples**

- “Release System Object Resources” on page 12-34
- “Define Property Attributes” on page 12-23

### **More About**

- “Methods Timing” on page 12-83

## Set Property Values at Construction Time

This example shows how to define a System object constructor and allow it to accept name-value property pairs as input.

### Set Properties to Use Name-Value Pair Input

Define the System object constructor, which is a method that has the same name as the class (MyFile in this example). Within that method, you use the `setProperties` method to make all public properties available for input when the user constructs the object. `nargin` is a MATLAB function that determines the number of input arguments. `varargin` indicates all of the object's public properties.

```
methods
    function obj = MyFile(varargin)
        setProperties(obj,nargin,varargin{:});
    end
end
```

### Complete Class Definition File with Constructor Setup

```
classdef MyFile < matlab.System
% MyFile write numbers to a file

    % These properties are nontunable. They cannot be changed
    % after the setup or step method has been called.
    properties (Nontunable)
        Filename = 'default.bin' % the name of the file to create
        Access = 'wb' % The file access string (write, binary)
    end

    % These properties are private. Customers can only access
    % these properties through methods on this object
    properties (Hidden,Access = private)
        pFileID; % The identifier of the file to open
    end

    methods
        % You call setProperties in the constructor to let
        % a user specify public properties of object as
        % name-value pairs.
        function obj = MyFile(varargin)
            setProperties(obj,nargin,varargin{:});
        end
    end
end
```

```
end

methods (Access = protected)
    % In setup allocate any resources, which in this case is
    % opening the file.
    function setupImpl(obj)
        obj.pFileID = fopen(obj.Filename,obj.Access);
        if obj.pFileID < 0
            error('Opening the file failed');
        end
    end
end

% This System object™ writes the input to the file.
function stepImpl(obj,data)
    fwrite(obj.pFileID,data);
end

% Use release to close the file to prevent the
% file handle from being left open.
function releaseImpl(obj)
    fclose(obj.pFileID);
end
end
end
```

### See Also

nargin | setProperties

### Related Examples

- “Define Property Attributes” on page 12-23
- “Release System Object Resources” on page 12-34



## Reset Algorithm State

This example shows how to reset an object state.

### Reset Counter to Zero

pCount is an internal counter property of the System object obj. The user calls the reset method on the locked object, which calls the resetImpl method. In this example, pCount resets to 0.

---

**Note:** When resetting an object's state, make sure you reset the size, complexity, and data type correctly.

---

```
methods (Access = protected)
    function resetImpl(obj)
        obj.pCount = 0;
    end
end
```

### Complete Class Definition File with State Reset

```
classdef Counter < matlab.System
% Counter System object™ that increments a counter

    properties (Access = private)
        pCount
    end

    methods (Access = protected)
        % In step, increment the counter and return
        % its value as an output
        function c = stepImpl(obj)
            obj.pCount = obj.pCount + 1;
            c = obj.pCount;
        end

        % Reset the counter to zero.
        function resetImpl(obj)
            obj.pCount = 0;
        end
    end
end
```

end

See “Methods Timing” on page 12-83 for more information.

### **See Also**

resetImpl

### **More About**

- “Methods Timing” on page 12-83

## Define Property Attributes

This example shows how to specify property attributes.

*Property attributes*, which add details to a property, provide a layer of control to your properties. In addition to the MATLAB property attributes, System objects can use these three additional attributes—`nontunable`, `logical`, and `positiveInteger`. To specify multiple attributes, separate them with commas.

### Specify Property as Nontunable

Use the *nontunable* attribute for a property when the algorithm depends on the value being constant once data processing starts. Defining a property as nontunable may improve the efficiency of your algorithm by removing the need to check for or react to values that change. For code generation, defining a property as nontunable allows the memory associated with that property to be optimized. You should define all properties that affect the number of input or output ports as nontunable.

System object users cannot change nontunable properties after the `setup` or `step` method has been called. In this example, you define the `InitialValue` property, and set its value to 0.

```
properties (Nontunable)
    InitialValue = 0;
end
```

### Specify Property as Logical

Logical properties have the value, `true` or `false`. System object users can enter 1 or 0 or any value that can be converted to a logical. The value, however, displays as `true` or `false`. You can use sparse logical values, but they must be scalar values. In this example, the `Increment` property indicates whether to increase the counter. By default, `Increment` is tunable property. The following restrictions apply to a property with the `Logical` attribute,

- Cannot also be `Dependent` or `PositiveInteger`
- Default value must be `true` or `false`. You cannot use 1 or 0 as a default value.

```
properties (Logical)
    Increment = true
end
```

### Specify Property as Positive Integer

In this example, the private property `MaxValue` is constrained to accept only real, positive integers. You cannot use sparse values. The following restriction applies to a property with the `PositiveInteger` attribute,

- Cannot also be `Dependent` or `Logical`

```
properties (PositiveInteger)
    MaxValue
end
```

### Specify Property as DiscreteState

If your algorithm uses properties that hold state, you can assign those properties the `DiscreteState` attribute. Properties with this attribute display their state values when users call `getDiscreteStateImpl` via the `getDiscreteState` method. The following restrictions apply to a property with the `DiscreteState` attribute,

- Numeric, logical, or `fi` value, but not a scaled double `fi` value
- Does not have any of these attributes: `Nontunable`, `Dependent`, `Abstract`, `Constant`, or `Transient`.
- No default value
- Not publicly settable
- `GetAccess` = `Public` by default
- Value set only using the `setupImpl` method or when the `System` object is locked during `resetImpl` or `stepImpl`

In this example, you define the `Count` property.

```
properties (DiscreteState)
    Count;
end
```

### Complete Class Definition File with Property Attributes

```
classdef Counter < matlab.System
% Counter Increment a counter to a maximum value

    % These properties are nontunable. They cannot be changed
    % after the setup or step method has been called.
    properties (Nontunable)
```

```
% The initial value of the counter
InitialValue = 0
end
properties (Nontunable, PositiveInteger)
% The maximum value of the counter
MaxValue = 3
end

properties (Logical)
% Whether to increment the counter
Increment = true
end

properties (DiscreteState)
% Count state variable
Count
end

methods (Access = protected)
% In step, increment the counter and return its value
% as an output

function c = stepImpl(obj)
    if obj.Increment && (obj.Count < obj.MaxValue)
        obj.Count = obj.Count + 1;
    else
        disp(['Max count, ' num2str(obj.MaxValue) ',reached'])
    end
    c = obj.Count;
end

% Setup the Count state variable
function setupImpl(obj)
    obj.Count = 0;
end

% Reset the counter to one.
function resetImpl(obj)
    obj.Count = obj.InitialValue;
end
end
```

end

### **More About**

- “Class Attributes”
- “Property Attributes”
- “What You Cannot Change While Your System Is Running”
- “Methods Timing” on page 12-83

## Hide Inactive Properties

This example shows how to hide the display of a property that is not active for a particular object configuration.

### Hide an inactive property

You use the `isInactivePropertyImpl` method to hide a property from displaying. If the `isInactiveProperty` method returns `true` to the property you pass in, then that property does not display.

```
methods (Access = protected)
    function flag = isInactivePropertyImpl(obj,propertyName)
        if strcmp(propertyName,'InitialValue')
            flag = obj.UseRandomInitialValue;
        else
            flag = false;
        end
    end
end
```

### Complete Class Definition File with Hidden Inactive Property

```
classdef Counter < matlab.System
    % Counter Increment a counter

    % These properties are nontunable. They cannot be changed
    % after the setup or step method has been called.
    properties (Nontunable)
        % Allow the user to set the initial value
        UseRandomInitialValue = true
        InitialValue = 0
    end

    % The private count variable, which is tunable by default
    properties (Access = private)
        pCount
    end

    methods (Access = protected)
        % In step, increment the counter and return its value
        % as an output
        function c = stepImpl(obj)
            obj.pCount = obj.pCount + 1;
        end
    end
end
```

```
    c = obj.pCount;
end

% Reset the counter to either a random value or the initial
% value.
function resetImpl(obj)
    if obj.UseRandomInitialValue
        obj.pCount = rand();
    else
        obj.pCount = obj.InitialValue;
    end
end

% This method controls visibility of the object's properties
function flag = isInactivePropertyImpl(obj,propertyName)
    if strcmp(propertyName,'InitialValue')
        flag = obj.UseRandomInitialValue;
    else
        flag = false;
    end
end
end
end
```

### See Also

`isInactivePropertyImpl`



## Limit Property Values to Finite String Set

This example shows how to limit a property to accept only a finite set of string values.

### Specify a Set of Valid String Values

String sets use two related properties. You first specify the user-visible property name and default string value. Then, you specify the associated hidden property by appending “Set” to the property name. You must use a capital “S” in “Set.”

In the “Set” property, you specify the valid string values as a cell array of the `matlab.system.Stringset` class. This example uses `Color` and `ColorSet` as the associated properties.

```
properties
    Color = 'blue'
end

properties (Hidden,Transient)
    ColorSet = matlab.system.StringSet({'red','blue','green'});
end
```

### Complete Class Definition File with String Set

```
classdef Whiteboard < matlab.System
% Whiteboard Draw lines on a figure window
%
% This System object™ illustrates the use of StringSets

    properties
        Color = 'blue'
    end

    properties (Hidden,Transient)
        % Let them choose a color
        ColorSet = matlab.system.StringSet({'red','blue','green'});
    end

    methods (Access = protected)
        function stepImpl(obj)
            h = Whiteboard.getWhiteboard();
            plot(h, ...
                randn([2,1]),randn([2,1]), ...
                'Color',obj.Color(1));
        end
    end
end
```

```
end
function releaseImpl(obj)
    cla(Whiteboard.getWhiteboard());
    hold on
end
end

methods (Static)
function a = getWhiteboard()
    h = findobj('tag','whiteboard');
    if isempty(h)
        h = figure('tag','whiteboard');
        hold on
    end
    a = gca;
end
end
end
```

### **String Set System Object Example**

```
%%
% Each call to step draws lines on a whiteboard

%% Construct the System object
hGreenInk = Whiteboard;
hBlueInk = Whiteboard;

% Change the color
% Note: Press tab after typing the first single quote to
% display all enumerated values.
hGreenInk.Color = 'green';
hBlueInk.Color = 'blue';

% Take a few steps
for i=1:3
    hGreenInk.step();
    hBlueInk.step();
end

%% Clear the whiteboard
hBlueInk.release();

%% Display System object used in this example
```

```
type('Whiteboard.m');
```

### **See Also**

matlab.system.StringSet

## Process Tuned Properties

This example shows how to specify the action to take when a tunable property value changes during simulation.

The `processTunedPropertiesImpl` method is useful for managing actions to prevent duplication. In many cases, changing one of multiple interdependent properties causes an action. With the `processTunedPropertiesImpl` method, you can control when that action is taken so it is not repeated unnecessarily.

### Control When a Lookup Table Is Generated

This example of `processTunedPropertiesImpl` causes the `pLookupTable` to be regenerated when either the `NumNotes` or `MiddleC` property changes.

```
methods (Access = protected)
    function processTunedPropertiesImpl(obj)
        propChange = isChangedProperty(obj,obj.NumNotes)||...
                    isChangedProperty(obj,obj.MiddleC)
        if propChange
            obj.pLookupTable = obj.MiddleC *...
                (1+log(1:obj.NumNotes)/log(12));
        end
    endend
```

### Complete Class Definition File with Tuned Property Processing

```
classdef TuningFork < matlab.System
    % TuningFork Illustrate the processing of tuned parameters
    %

    properties
        MiddleC = 440
        NumNotes = 12
    end

    properties (Access = private)
        pLookupTable
    end

    methods (Access = protected)
        function resetImpl(obj)
            obj.MiddleC = 440;
            obj.pLookupTable = obj.MiddleC * ...

```

```
        (1+log(1:obj.NumNotes)/log(12));
end

function hz = stepImpl(obj,noteShift)
    % A noteShift value of 1 corresponds to obj.MiddleC
    hz = obj.pLookupTable(noteShift);
end

function processTunedPropertiesImpl(obj)
    propChange = isChangedProperty(obj,obj.NumNotes)||...
                isChangedProperty(obj,obj.MiddleC)
    if propChange
        obj.pLookupTable = obj.MiddleC *...
            (1+log(1:obj.NumNotes)/log(12));
    end
end
end
```

## See Also

processTunedPropertiesImpl

## Release System Object Resources

This example shows how to release resources allocated and used by the System object. These resources include allocated memory, files used for reading or writing, etc.

### Release Memory by Clearing the Object

This method allows you to clear the axes on the Whiteboard figure window while keeping the figure open.

```
methods
    function releaseImpl(obj)
        cla(Whiteboard.getWhiteboard());
        hold on
    end
end
```

### Complete Class Definition File with Released Resources

```
classdef Whiteboard < matlab.System
% Whiteboard Draw lines on a figure window
%
% This System object™ shows the use of StringSets
%
    properties
        Color = 'blue'
    end

    properties (Hidden)
        % Let user choose a color
        ColorSet = matlab.system.StringSet({'red','blue','green'});
    end

    methods (Access = protected)
        function stepImpl(obj)
            h = Whiteboard.getWhiteboard();
            plot(h, ...
                randn([2,1]), randn([2,1]), ...
                'Color',obj.Color(1));
        end

        function releaseImpl(obj)
            cla(Whiteboard.getWhiteboard());
            hold on
        end
    end
end
```

```
        end
    end

    methods (Static)
        function a = getWhiteboard()
            h = findobj('tag','whiteboard');
            if isempty(h)
                h = figure('tag','whiteboard');
                hold on
            end
            a = gca;
        end
    end
end
```

## See Also

releaseImpl

## Related Examples

- “Initialize Properties and Setup One-Time Calculations” on page 12-16

## Define Composite System Objects

This example shows how to define System objects that include other System objects.

This example defines a filter System object from an FIR System object and an IIR System object.

### Store System Objects in Properties

To define a System object from other System objects, store those objects in your class definition file as properties. In this example, FIR and IIR are separate System objects defined in their own class-definition files. You use those two objects to calculate the `pFir` and `pIir` property values.

```
properties (Nontunable, Access = private)
    pFir % Store the FIR filter
    pIir % Store the IIR filter
end

methods
    function obj = Filter(varargin)
        setProperties(obj,nargin,varargin{:});
        obj.pFir = FIR(obj.zero);
        obj.pIir = IIR(obj.pole);
    end
end
```

### Complete Class Definition File of Composite System Object

```
classdef Filter < matlab.System
% Filter System object with a single pole and a single zero
%
% This System object illustrates composition by
% composing an instance of itself.
%

    properties (Nontunable)
        zero = 0.01
        pole = 0.5
    end

    properties (Nontunable,Access = private)
        pZero % Store the FIR filter
        pPole % Store the IIR filter
    end
end
```



```

end

methods
function obj = Filter(varargin)
    setProperties(obj,nargin,varargin{:});
    % Create instances of FIR and IIR as
    % private properties
    obj.pZero = Zero(obj.zero);
    obj.pPole = Pole(obj.pole);
end
end

methods (Access = protected)
function setupImpl(obj,x)
    setup(obj.pZero,x);
    setup(obj.pPole,x);
end

function resetImpl(obj)
    reset(obj.pZero);
    reset(obj.pPole);
end

function y = stepImpl(obj,x)
    y = step(obj.pZero,x) + step(obj.pPole,x);
end
function releaseImpl(obj)
    release(obj.pZero);
    release(obj.pPole);
end
end
end
end

```

### Class Definition File for IIR Component of Filter

```

classdef Pole < matlab.System

    properties
        Den = 1
    end

    properties (Access = private)
        tap = 0
    end
end

```

```
methods
function obj = Pole(varargin)
    setProperties(obj,nargin,varargin{:},'Den');
end
end

methods (Access = protected)
function y = stepImpl(obj,x)
    y = x + obj.tap * obj.Den;
    obj.tap = y;
end
end

end
```

### Class Definition File for FIR Component of Filter

```
classdef Zero < matlab.System

    properties
        Num = 1
    end

    properties (Access = private)
        tap = 0
    end

    methods
        function obj = Zero(varargin)
            setProperties(obj,nargin,varargin{:},'Num');
        end
    end

    methods (Access = protected)
        function y = stepImpl(obj,x)
            y = x + obj.tap * obj.Num;
            obj.tap = x;
        end
    end

end
```

### See Also

nargin

## Define Finite Source Objects

This example shows how to define a System object that performs a specific number of steps or specific number of reads from a file.

### Use the FiniteSource Class and Specify End of the Source

- 1 Subclass from finite source class.

```
classdef RunTwice < matlab.System & ...
    matlab.system.mixin.FiniteSource
```

- 2 Specify the end of the source with the `isDoneImpl` method. In this example, the source has two iterations.

```
methods (Access = protected)
    function bDone = isDoneImpl(obj)
        bDone = obj.NumSteps==2
    end
```

### Complete Class Definition File with Finite Source

```
classdef RunTwice < matlab.System & ...
    matlab.system.mixin.FiniteSource
    % RunTwice System object that runs exactly two times
    %
    properties (Access = private)
        NumSteps
    end

    methods (Access = protected)
        function resetImpl(obj)
            obj.NumSteps = 0;
        end

        function y = stepImpl(obj)
            if ~obj.isDone()
                obj.NumSteps = obj.NumSteps + 1;
                y = obj.NumSteps;
            else
                y = 0;
            end
        end

        function bDone = isDoneImpl(obj)
```

```
        bDone = obj.NumSteps==2;
    end
end
end
```

### See Also

`matlab.system.mixin.FiniteSource`

### More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Save System Object

This example shows how to save a System object.

### Save System Object and Child Object

Define a `saveObjectImpl` method to specify that more than just public properties should be saved when the user saves a System object. Within this method, use the default `saveObjectImpl@matlab.System` to save public properties to the struct, `s`. Use the `saveObject` method to save child objects. Save protected and dependent properties, and finally, if the object is locked, save the object's state.

```
methods (Access = protected)
    function s = saveObjectImpl(obj)
        s = saveObjectImpl@matlab.System(obj);
        s.child = matlab.System.saveObject(obj.child);
        s.protectedprop = obj.protectedprop;
        s.pdependentprop = obj.pdependentprop;
        if isLocked(obj)
            s.state = obj.state;
        end
    end
end
end
```

### Complete Class Definition Files with Save and Load

The `Counter` class definition file sets up an object with a count property. This counter is used in the `MySaveLoader` class definition file to count the number of child objects.

```
classdef Counter < matlab.System
    properties(DiscreteState)
        Count
    end
    methods (Access=protected)
        function setupImpl(obj, ~)
            obj.Count = 0;
        end
        function y = stepImpl(obj, u)
            if u > 0
                obj.Count = obj.Count + 1;
            end
            y = obj.Count;
        end
    end
end
```

```
end
end

classdef MySaveLoader < matlab.System

    properties (Access = private)
        child
        pdependentprop = 1
    end

    properties (Access = protected)
        protectedprop = rand;
    end

    properties (DiscreteState = true)
        state
    end

    properties (Dependent)
        dependentprop
    end

    methods
        function obj = MySaveLoader(varargin)
            obj@matlab.System();
            setProperties(obj,nargin,varargin{:});
        end

        function set.dependentprop(obj, value)
            obj.pdependentprop = min(value, 5);
        end

        function value = get.dependentprop(obj)
            value = obj.pdependentprop;
        end
    end

    methods (Access = protected)
        function setupImpl(obj)
            obj.state = 42;
            obj.child = Counter;
        end
        function out = stepImpl(obj,in)
            obj.state = in + obj.state + obj.protectedprop + obj.pdependentprop;
            out = step(obj.child, obj.state);
        end
    end
end
```

```
    end
end

% Serialization
methods (Access = protected)
function s = saveObjectImpl(obj)
    % Call the base class method
    s = saveObjectImpl@matlab.System(obj);

    % Save the child System objects
    s.child = matlab.System.saveObject(obj.child);

    % Save the protected & private properties
    s.protectedprop = obj.protectedprop;
    s.pdependentprop = obj.pdependentprop;

    % Save the state only if object locked
    if isLocked(obj)
        s.state = obj.state;
    end
end

function loadObjectImpl(obj,s,wasLocked)
    % Load child System objects
    obj.child = matlab.System.loadObject(s.child);

    % Load protected and private properties
    obj.protectedprop = s.protectedprop;
    obj.pdependentprop = s.pdependentprop;

    % Load the state only if object locked
    if wasLocked
        obj.state = s.state;
    end

    % Call base class method to load public properties
    loadObjectImpl@matlab.System(obj,s,wasLocked);
end
end
end
```

## See Also

loadObjectImpl | saveObjectImpl

### **Related Examples**

- “Load System Object” on page 12-45



## Load System Object

This example shows how to load and save a System object.

### Load System Object and Child Object

Define a `loadObjectImpl` method to load a previously saved System object. Within this method, use the `matlab.System.loadObject` to load the child System object, load protected and private properties, load the state if the object is locked, and use `loadObjectImpl` from the base class to load public properties.

```
methods (Access = protected)
    function loadObjectImpl(obj,s,wasLocked)
        obj.child = matlab.System.loadObject(s.child);

        obj.protectedprop = s.protectedprop;
        obj.pdependentprop = s.pdependentprop;

        if wasLocked
            obj.state = s.state;
        end

        loadObjectImpl@matlab.System(obj,s,wasLocked);
    end
end
```

### Complete Class Definition Files with Save and Load

The Counter class definition file sets up an object with a count property. This counter is used in the MySaveLoader class definition file to count the number of child objects.

```
classdef Counter < matlab.System
    properties (DiscreteState)
        Count
    end
    methods (Access=protected)
        function setupImpl(obj, ~)
            obj.Count = 0;
        end
        function y = stepImpl(obj, u)
            if u > 0
                obj.Count = obj.Count + 1;
            end
            y = obj.Count;
        end
    end
end
```

```
        end
    end
end

classdef MySaveLoader < matlab.System

    properties (Access = private)
        child
        pdependentprop = 1
    end

    properties (Access = protected)
        protectedprop = rand;
    end

    properties (DiscreteState = true)
        state
    end

    properties (Dependent)
        dependentprop
    end

    methods
        function obj = MySaveLoader(varargin)
            obj@matlab.System();
            setProperties(obj,nargin,varargin{:});
        end

        function set.dependentprop(obj, value)
            obj.pdependentprop = min(value, 5);
        end

        function value = get.dependentprop(obj)
            value = obj.pdependentprop;
        end
    end

    methods (Access = protected)
        function setupImpl(obj)
            obj.state = 42;
            obj.child = Counter;
        end
        function out = stepImpl(obj,in)
            obj.state = in + obj.state + obj.protectedprop + obj.pdependentprop;
        end
    end
end
```

```
        out = step(obj.child, obj.state);
    end
end

% Serialization
methods (Access = protected)
function s = saveObjectImpl(obj)
    % Call the base class method
    s = saveObjectImpl@matlab.System(obj);

    % Save the child System objects
    s.child = matlab.System.saveObject(obj.child);

    % Save the protected & private properties
    s.protectedprop = obj.protectedprop;
    s.pdependentprop = obj.pdependentprop;

    % Save the state only if object locked
    if isLocked(obj)
        s.state = obj.state;
    end
end

function loadObjectImpl(obj,s,wasLocked)
    % Load child System objects
    obj.child = matlab.System.loadObject(s.child);

    % Load protected and private properties
    obj.protectedprop = s.protectedprop;
    obj.pdependentprop = s.pdependentprop;

    % Load the state only if object locked
    if wasLocked
        obj.state = s.state;
    end

    % Call base class method to load public properties
    loadObjectImpl@matlab.System(obj,s,wasLocked);
end
```

end

### See Also

loadObjectImpl | saveObjectImpl

### Related Examples

- “Save System Object” on page 12-41

## Clone System Object

This example shows how to clone a System object.

### Clone System Object

You can define your own clone method, which is useful for copying objects without saving their state. The default `cloneImpl` method copies both a System object™ and its current state. If an object is locked, the default `cloneImpl` creates a cloned object that is also locked. An example of when you may want to write your own clone method is for cloning objects that handle resources. These objects cannot allocate resources twice and you would not want to save their states. To write your clone method, use the `saveObject` and `loadObject` methods to perform the clone within the `cloneImpl` method.

```
methods (Access = protected)
    function obj2 = cloneImpl(obj1)
        s = saveObject (obj1);
        obj2 = loadObject(s);
    end
end
```

### Complete Class Definition File with Clone

```
classdef PassThrough < matlab.System
    methods (Access = protected)
        function y = stepImpl(~,u)
            y = u;
        end
        function obj2 = cloneImpl(obj1)
            s = matlab.System.saveObject(obj1);
            obj2 = matlab.System.loadObject(s);
        end
    end
end
```

### See Also

[cloneImpl](#) | [loadObjectImpl](#) | [saveObjectImpl](#)

## Define System Object Information

This example shows how to define information to display for a System object.

### Define System Object Info

You can define your own `info` method to display specific information for your System object. The default `infoImpl` method returns an empty struct. This `infoImpl` method returns detailed information when the `info` method is called using `info(x, 'details')` or only count information if it is called using `info(x)`.

```
methods (Access = protected)
    function s = infoImpl(obj,varargin)
        if nargin>1 && strcmp('details',varargin(1))
            s = struct('Name','Counter',...
                'Properties', struct('CurrentCount', ...
                    obj.pCount,'Threshold',obj.Threshold));
        else
            s = struct('Count',obj.pCount);
        end
    end
end
```

### Complete Class Definition File with InfoImpl

```
classdef Counter < matlab.System
    % Counter Count values above a threshold

    properties
        Threshold = 1
    end

    properties (DiscreteState)
        Count
    end

    methods (Access = protected)
        function setupImpl(obj)
            obj.Count = 0;
        end

        function resetImpl(obj)
            obj.Count = 0;
        end
    end
end
```

```
function y = stepImpl(obj,u)
    if (u > obj.Threshold)
        obj.Count = obj.Count + 1;
    end
    y = obj.Count;
end

function s = infoImpl(obj,varargin)
    if nargin>1 && strcmp('details',varargin(1))
        s = struct('Name','Counter',...
            'Properties', struct('CurrentCount', ...
                obj.pCount, 'Threshold',obj.Threshold));
    else
        s = struct('Count',obj.pCount);
    end
end
end
end
```

## See Also

infoImpl

## Define System Block Icon

This example shows how to define the block icon of a System object–based block implemented using a MATLAB System block.

### Use the CustomIcon Class and Define the Icon

- 1 Subclass from custom icon class.

```
classdef MyCounter < matlab.System & ...  
    matlab.system.mixin.CustomIcon
```

- 2 Use `setIconImpl` to specify the block icon as `New Counter` with a line break (`\n`) between the two words.

```
methods (Access = protected)  
    function icon = getIconImpl(~)  
        icon = sprintf('New\nCounter');  
    end  
end
```

### Complete Class Definition File with Defined Icon

```
classdef MyCounter < matlab.System & ...  
    matlab.system.mixin.CustomIcon  
  
    % MyCounter Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
    properties (DiscreteState)  
        Count  
    end  
  
    methods  
        function obj = MyCounter(varargin)  
            setProperties(obj,nargin,varargin{:});  
        end  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end
```



```
function resetImpl(obj)
    obj.Count = 0;
end
function y = stepImpl(obj,u)
    if (u > obj.Threshold)
        obj.Count = obj.Count + 1;
    end
    y = obj.Count;
end
function icon = getIconImpl(~)
    icon = sprintf('New\nCounter');
end
end
end
```

## See Also

matlab.system.mixin.CustomIcon | getIconImpl

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Add Header to System Block Dialog

This example shows how to add a header panel to a System object–based block implemented using a MATLAB System block.

### Define Header Title and Text

This example shows how to use `getHeaderImpl` to specify a panel title and text for the `MyCounter` System object.

If you do not specify the `getHeaderImpl`, the block does not display any title or text for the panel.

You always set the `getHeaderImpl` method access to `protected` because it is an internal method that end users do not directly call or run.

```
methods (Static, Access = protected)
    function header = getHeaderImpl
        header = matlab.system.display.Header('MyCounter',...
            'Title', 'My Enhanced Counter');
    end
end
```

### Complete Class Definition File with Defined Header

```
classdef MyCounter < matlab.System

    % MyCounter Count values

    properties
        Threshold = 1
    end
    properties (DiscreteState)
        Count
    end

    methods (Static, Access = protected)
        function header = getHeaderImpl
            header = matlab.system.display.Header('MyCounter',...
                'Title', 'My Enhanced Counter',...
                'Text', 'This counter is an enhanced version.');
```

```
methods (Access = protected)
    function setupImpl(obj,u)
        obj.Count = 0;
    end
    function y = stepImpl(obj,u)
        if (u > obj.Threshold)
            obj.Count = obj.Count + 1;
        end
        y = obj.Count;
    end
    function resetImpl(obj)
        obj.Count = 0;
    end
end
end
```

## See Also

matlab.system.display.Header | getHeaderImpl

## Add Property Groups to System Object and Block Dialog

This example shows how to define property sections and section groups for System object display. The sections and section groups display as panels and tabs, respectively, in the MATLAB System block dialog.

### Define Section of Properties

This example shows how to use `matlab.system.display.Section` and `getPropertyGroupsImpl` to define two property group sections by specifying their titles and property lists.

If you do not specify a property in `getPropertyGroupsImpl`, the block does not display that property.

```
methods (Static, Access = protected)
    function groups = getPropertyGroupsImpl
        valueGroup = matlab.system.display.Section(...
            'Title', 'Value parameters', ...
            'PropertyList', {'StartValue', 'EndValue'});

        thresholdGroup = matlab.system.display.Section(...
            'Title', 'Threshold parameters', ...
            'PropertyList', {'Threshold', 'UseThreshold'});
        groups = [valueGroup, thresholdGroup];
    end
end
```

### Define Group of Sections

This example shows how to use `matlab.system.display.SectionGroup`, `matlab.system.display.Section`, and `getPropertyGroupsImpl` to define two tabs, each containing specific properties.

```
methods (Static, Access = protected)
    function groups = getPropertyGroupsImpl
        upperGroup = matlab.system.display.Section(...
            'Title', 'Upper threshold', ...
            'PropertyList', {'UpperThreshold'});
        lowerGroup = matlab.system.display.Section(...
            'Title', 'Lower threshold', ...
            'PropertyList', {'UseLowerThreshold', 'LowerThreshold'});

        thresholdGroup = matlab.system.display.SectionGroup(...
```

```

        'Title', 'Parameters', ...
        'Sections', [upperGroup,lowerGroup]);

    valuesGroup = matlab.system.display.SectionGroup(...
        'Title', 'Initial conditions', ...
        'PropertyList', {'StartValue'});

    groups = [thresholdGroup, valuesGroup];
end
end

```

### Complete Class Definition File with Property Group and Separate Tab

```

classdef EnhancedCounter < matlab.System
    % EnhancedCounter Count values considering thresholds

    properties
        UpperThreshold = 1;
        LowerThreshold = 0;
    end

    properties (Nontunable)
        StartValue = 0;
    end

    properties(Logical,Nontunable)
        % Count values less than lower threshold
        UseLowerThreshold = true;
    end

    properties (DiscreteState)
        Count;
    end

    methods (Static, Access = protected)
        function groups = getPropertyGroupsImpl
            upperGroup = matlab.system.display.Section(...
                'Title', 'Upper threshold', ...
                'PropertyList', {'UpperThreshold'});
            lowerGroup = matlab.system.display.Section(...
                'Title', 'Lower threshold', ...
                'PropertyList', {'UseLowerThreshold', 'LowerThreshold'});

            thresholdGroup = matlab.system.display.SectionGroup(...
                'Title', 'Parameters', ...

```

```
        'Sections', [upperGroup,lowerGroup]);

    valuesGroup = matlab.system.display.SectionGroup(...
        'Title', 'Initial conditions', ...
        'PropertyList', {'StartValue'});

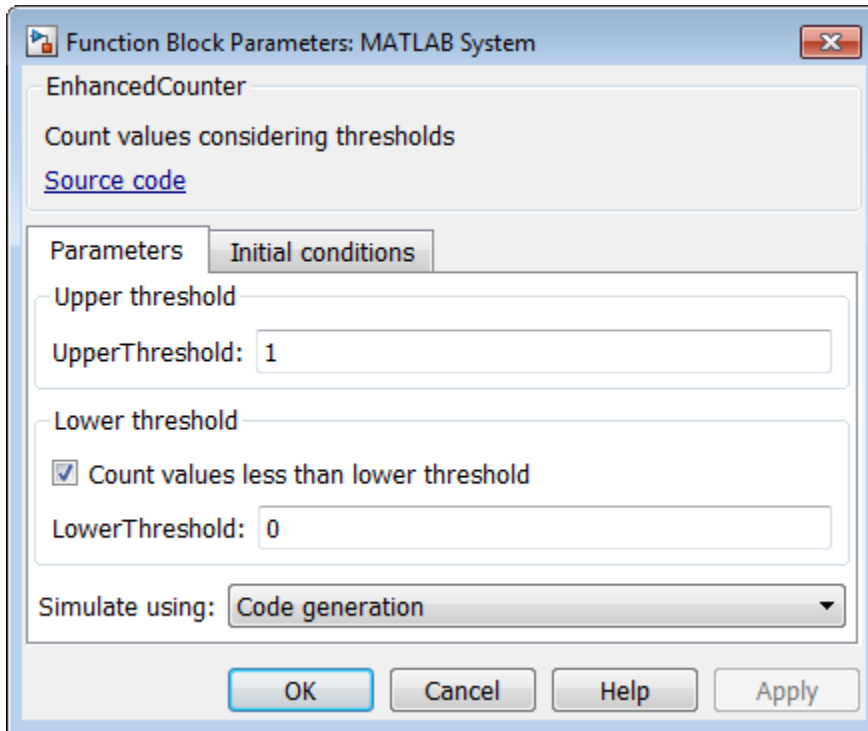
    groups = [thresholdGroup, valuesGroup];
end
end

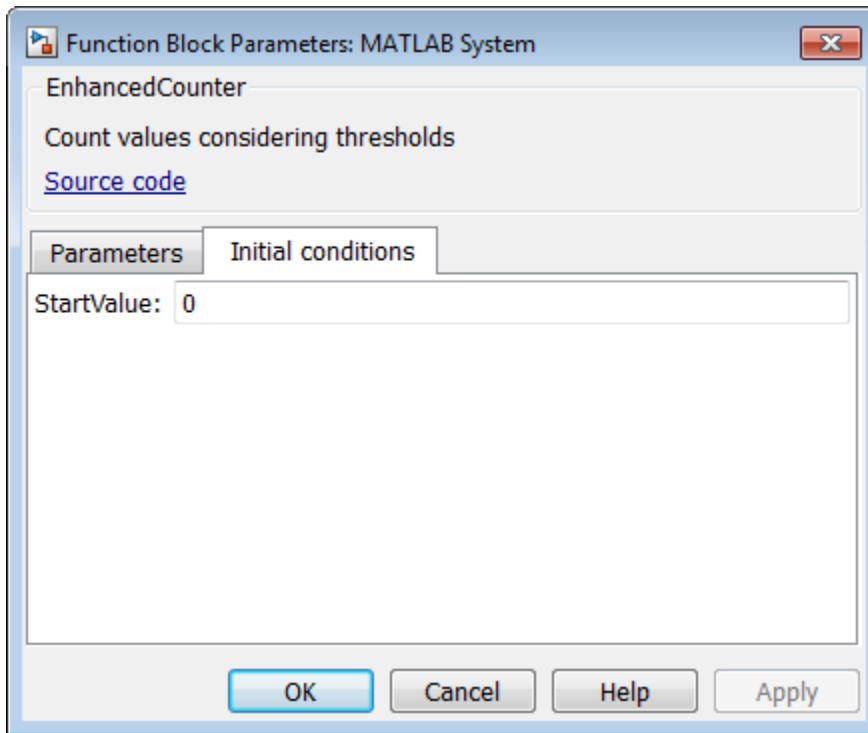
methods (Access = protected)
function setupImpl(obj)
    obj.Count = obj.StartValue;
end

function y = stepImpl(obj,u)
    if obj.UseLowerThreshold
        if (u > obj.UpperThreshold) || ...
            (u < obj.LowerThreshold)
            obj.Count = obj.Count + 1;
        end
    else
        if (u > obj.UpperThreshold)
            obj.Count = obj.Count + 1;
        end
    end
    y = obj.Count;
end
function resetImpl(obj)
    obj.Count = obj.StartValue;
end

function flag = isInactivePropertyImpl(obj, prop)
    flag = false;
    switch prop
        case 'LowerThreshold'
            flag = ~obj.UseLowerThreshold;
    end
end
end
```

end





### See Also

`matlab.system.display.Section` | `matlab.system.display.SectionGroup` | `getPropertyGroupsImpl`

### More About

- “System Object Input Arguments and ~ in Code Examples” on page 12-86



## Control Simulation Type in System Block Dialog

This example shows how to specify a simulation type and whether the **Simulate using** parameter appears on the Simulink MATLAB System block dialog box. The simulation options are 'Code generation' and 'Interpreted mode'.

If you do not include the `getSimulateUsingImpl` method in your class definition file, the System object allows both simulation modes and defaults to 'Code generation'. If you do not include the `showSimulateUsingImpl` method, the **Simulate using** parameter appears on the block dialog box.

You must set the `getSimulateUsingImpl` and `showSimulateUsingImpl` methods to **static** and the access for these methods to **protected**.

Use `getSimulateUsingImpl` to specify that only interpreted execution is allowed for the System object.

```
methods(Static,Access = protected)
    function simMode = getSimulateUsingImpl
        simMode = 'Interpreted execution';
    end
end
```

View the method in the complete class definition file.

```
classdef PlotRamp < matlab.System
    % Display a button to launch a plot figure.

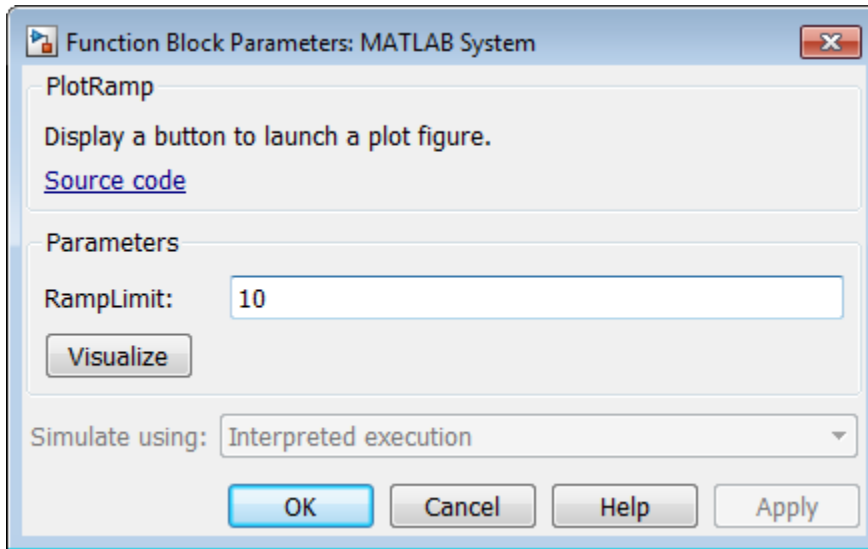
    properties (Nontunable)
        RampLimit = 10;
    end

    methods(Static, Access=protected)
        function group = getPropertyGroupsImpl
            group = matlab.system.display.Section(mfilename('class'));
            group.Actions = matlab.system.display.Action(@(~,obj)...
                visualize(obj),'Label','Visualize');
        end

        function simMode = getSimulateUsingImpl
            simMode = 'Interpreted execution';
        end
    end
end
```

```
methods
function obj = ActionDemo(varargin)
    setProperties(obj,nargin,varargin{:});
end

function visualize(obj)
    figure;
    d = 1:obj.RampLimit;
    plot(d);
end
methods(Static,Access = protected)
end
end
end
```



### See Also

`getSimulateUsingImp` | `showSimulateUsingImpl`

### More About

- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Add Button to System Block Dialog Box

This example shows how to add a button to the MATLAB System block dialog box. This button launches a figure that plots a ramp function.

### Define Action for Dialog Button

This example shows how to use `matlab.system.display.Action` to define the MATLAB function or code associated with a button in the MATLAB System block dialog. The example also shows how to set button options.

```
methods(Static,Access = protected)
    function group = getPropertyGroupsImpl
        group = matlab.system.display.Section(mfilename('class'));
        group.Actions = matlab.system.display.Action(@(-,obj)...
            visualize(obj),'Label','Visualize');
    end
end

methods
    function obj = ActionDemo(varargin)
        setProperties(obj,nargin,varargin{:});
    end

    function visualize(obj)
        figure;
        d = 1:obj.RampLimit;
        plot(d);
    end
end
```

### Complete Class Definition File for Dialog Button

Define a property group and a second tab in the class definition file.

```
classdef PlotRamp < matlab.System
    % Display a button to launch a plot figure.

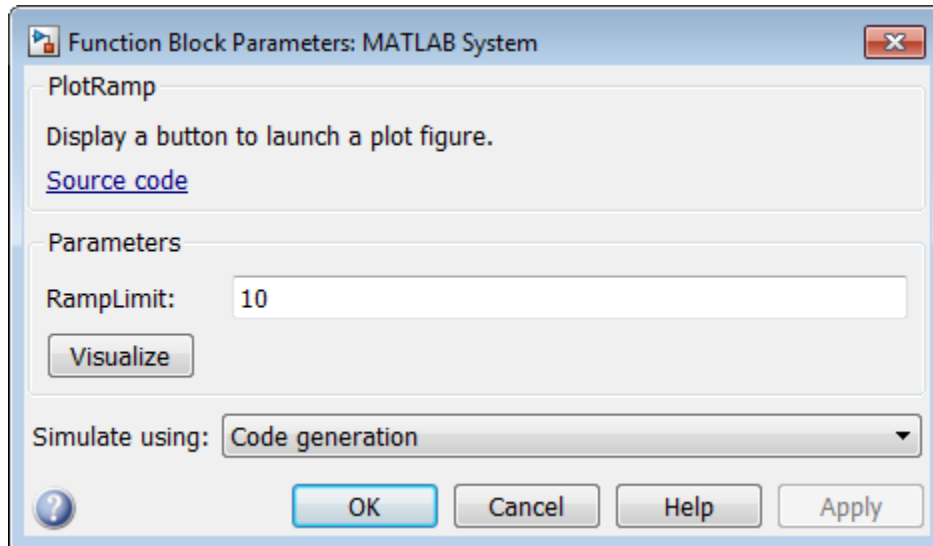
    properties (Nontunable)
        RampLimit = 10;
    end

    methods(Static, Access=protected)
```

```
function group = getPropertyGroupsImpl
group = matlab.system.display.Section(mfilename('class'));
group.Actions = matlab.system.display.Action(@(-,obj)...
    visualize(obj),'Label','Visualize');
end
end

methods
function obj = ActionDemo(varargin)
    setProperties(obj,nargin,varargin{:});
end

function visualize(obj)
    figure;
    d = 1:obj.RampLimit;
    plot(d);
end
end
end
```



## See Also

getPropertyGroupsImpl

## **More About**

- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Specify Locked Input Size

This example shows how to specify whether the size of a System object input is locked. The size of a locked input cannot change until the System object is unlocked. Use the `step` method and run the object to lock it. Use `release` to unlock the object.

For information on locking and unlocking, see “What You Cannot Change While Your System Is Running”.

Use the `isInputSizeLockedImpl` method to specify that the input size is locked.

```
methods (Access = protected)
    function flag = isInputSizeLockedImpl(~,~)
        flag = true;
    end
end
```

View the method in the complete class definition file.

```
classdef Counter < matlab.System
    %Counter Count values above a threshold

    properties
        Threshold = 1
    end

    properties (DiscreteState)
        Count
    end

    methods
        function obj = Counter(varargin)
            setProperties(obj,nargin,varargin{:});
        end
    end

    methods (Access=protected)
        function resetImpl(obj)
            obj.Count = 0;
        end

        function y = stepImpl(obj, u1)
            if (any(u1 >= obj.Threshold))
                obj.Count = obj.Count + 1;
            end
        end
    end
end
```

```
    end
    y = obj.Count;
end

function flag = isInputSizeLockedImpl(~,~)
    flag = true;
end
end
end
```

## See Also

`isInputSizeLockedImpl`

## Set Output Size

This example shows how to specify the size of a System object output using the `getOutputSizeImpl` method. Use this method when Simulink cannot infer the output size from the inputs during model compilation.

Subclass from both the `matlab.System` base class and the `Propagates` mixin class.

```
classdef CounterReset < matlab.System & ...  
    matlab.system.mixin.Propagates
```

Use the `getOutputSizeImpl` method to specify the output size.

```
methods (Access = protected)  
    function sizeout = getOutputSizeImpl(~)  
        sizeout = [1 1];  
    end  
end
```

View the method in the complete class definition file.

```
classdef CounterReset < matlab.System & matlab.system.mixin.Propagates  
    % CounterReset Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
  
    properties (DiscreteState)  
        Count  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end  
  
        function y = stepImpl(obj,u1,u2)  
            % Add to count if u1 is above threshold  
            % Reset if u2 is true  
            if (u2)  
                obj.Count = 0;  
            elseif (u1 > obj.Threshold)  
                obj.Count = obj.Count + 1;  
            end  
        end  
    end  
end
```



```

        end
        y = obj.Count;
    end

    function resetImpl(obj)
        obj.Count = 0;
    end

    function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)
        if strcmp(name,'Count')
            sz = [1 1];
            dt = 'double';
            cp = false;
        else
            error(['Error: Incorrect State Name: 'name'.']);
        end
    end
end
function dataout = getOutputDataTypeImpl(~)
    dataout = 'double';
end
function sizeout = getOutputSizeImpl(~)
    sizeout = [1 1];
end
function cplxout = isOutputComplexImpl(~)
    cplxout = false;
end
function fixedout = isOutputFixedSizeImpl(~)
    fixedout = true;
end
end
end

```

## See Also

`matlab.system.mixin.Propagates` | `getOutputSizeImpl`

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Set Output Data Type

This example shows how to specify the data type of a System object output using the `getOutputDataTypeImpl` method. Use this method when Simulink cannot infer the data type from the inputs during model compilation.

Subclass from both the `matlab.System` base class and the `Propagates` mixin class.

```
classdef CounterReset < matlab.System & ...  
    matlab.system.mixin.Propagates
```

Use the `getOutputDataTypeImpl` method to specify the output data type as a double.

```
methods (Access = protected)  
    function dataout = getOutputDataTypeImpl(~)  
        dataout = 'double';  
    end  
end
```

View the method in the complete class definition file.

```
classdef CounterReset < matlab.System & matlab.system.mixin.Propagates  
    % CounterReset Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
  
    properties (DiscreteState)  
        Count  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end  
  
        function resetImpl(obj)  
            obj.Count = 0;  
        end  
  
        function y = stepImpl(obj,u1,u2)  
            % Add to count if u1 is above threshold  
            % Reset if u2 is true
```

```

    if (u2)
        obj.Count = 0;
    elseif (u1 > obj.Threshold)
        obj.Count = obj.Count + 1;
    end
    y = obj.Count;
end

function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)
    if strcmp(name,'Count')
        sz = [1 1];
        dt = 'double';
        cp = false;
    else
        error(['Error: Incorrect State Name: 'name'.']);
    end
end
function dataout = getOutputDataTypeImpl(~)
    dataout = 'double';
end
function sizeout = getOutputSizeImpl(~)
    sizeout = [1 1];
end
function cplxout = isOutputComplexImpl(~)
    cplxout = false;
end
function fixedout = isOutputFixedSizeImpl(~)
    fixedout = true;
end
end
end

```

## See Also

[matlab.system.mixin.Propagates](#) | [getOutputDataTypeImpl](#)

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Set Output Complexity

This example shows how to specify whether a System object output is complex or real using the `isOutputComplexImpl` method. Use this method when Simulink cannot infer the output complexity from the inputs during model compilation.

Subclass from both the `matlab.System` base class and the `Propagates` mixin class.

```
classdef CounterReset < matlab.System & ...  
    matlab.system.mixin.Propagates
```

Use the `isOutputComplexImpl` method to specify that the output is real.

```
methods (Access = protected)  
    function cplxout = isOutputComplexImpl(~)  
        cplxout = false;  
    end  
end
```

View the method in the complete class definition file.

```
classdef CounterReset < matlab.System & matlab.system.mixin.Propagates  
    % CounterReset Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
  
    properties (DiscreteState)  
        Count  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end  
  
        function resetImpl(obj)  
            obj.Count = 0;  
        end  
  
        function y = stepImpl(obj,u1,u2)  
            % Add to count if u1 is above threshold  
            % Reset if u2 is true
```

```

    if (u2)
        obj.Count = 0;
    elseif (u1 > obj.Threshold)
        obj.Count = obj.Count + 1;
    end
    y = obj.Count;
end

function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)
    if strcmp(name,'Count')
        sz = [1 1];
        dt = 'double';
        cp = false;
    else
        error(['Error: Incorrect State Name: 'name'.']);
    end
end
function dataout = getOutputDataTypeImpl(~)
    dataout = 'double';
end
function sizeout = getOutputSizeImpl(~)
    sizeout = [1 1];
end
function cplxout = isOutputComplexImpl(~)
    cplxout = false;
end
function fixedout = isOutputFixedSizeImpl(~)
    fixedout = true;
end
end
end

```

## See Also

matlab.system.mixin.Propagates | isOutputComplexImpl

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Specify Whether Output Is Fixed- or Variable-Size

This example shows how to specify whether a System object output is fixed- or variable-size. Use the `isOutputFixedSizeImpl` method when Simulink cannot infer the output type from the inputs during model compilation.

Subclass from both the `matlab.System` base class and the `Propagates` mixin class.

```
classdef CounterReset < matlab.System & ...  
    matlab.system.mixin.Propagates
```

Use the `isOutputFixedSizeImpl` method to specify that the output is fixed size.

```
methods (Access = protected)  
    function fixedout = isOutputFixedSizeImpl(~)  
        fixedout = true;  
    end  
end
```

View the method in the complete class definition file.

```
classdef CounterReset < matlab.System & matlab.system.mixin.Propagates  
    % CounterReset Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
  
    properties (DiscreteState)  
        Count  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end  
  
        function resetImpl(obj)  
            obj.Count = 0;  
        end  
  
        function y = stepImpl(obj,u1,u2)  
            % Add to count if u1 is above threshold  
            % Reset if u2 is true
```

```

    if (u2)
        obj.Count = 0;
    elseif (u1 > obj.Threshold)
        obj.Count = obj.Count + 1;
    end
    y = obj.Count;
end

function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)
    if strcmp(name,'Count')
        sz = [1 1];
        dt = 'double';
        cp = false;
    else
        error(['Error: Incorrect State Name: 'name'.']);
    end
end
function dataout = getOutputDataTypeImpl(~)
    dataout = 'double';
end
function sizeout = getOutputSizeImpl(~)
    sizeout = [1 1];
end
function cplxout = isOutputComplexImpl(~)
    cplxout = false;
end
function fixedout = isOutputFixedSizeImpl(~)
    fixedout = true;
end
end
end

```

## See Also

matlab.system.mixin.Propagates | isOutputFixedSizeImpl

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Specify Discrete State Output Specification

This example shows how to specify the size, data type, and complexity of a discrete state property using the `getDiscreteStateSpecificationImpl` method. Use this method when your System object has a property with the `DiscreteState` attribute and Simulink cannot infer the output specifications during model compilation.

Subclass from both the `matlab.System` base class and from the `Propagates` mixin class.

```
classdef CounterReset < matlab.System & ...  
    matlab.system.mixin.Propagates
```

Use the `getDiscreteStateSpecificationImpl` method to specify the size and data type. Also specify the complexity of a discrete state property, which is used in the counter reset example.

```
methods (Access = protected)  
    function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)  
        sz = [1 1];  
        dt = 'double';  
        cp = false;  
    end  
end
```

View the method in the complete class definition file.

```
classdef CounterReset < matlab.System & matlab.system.mixin.Propagates  
    % CounterReset Count values above a threshold  
  
    properties  
        Threshold = 1  
    end  
  
    properties (DiscreteState)  
        Count  
    end  
  
    methods (Access = protected)  
        function setupImpl(obj)  
            obj.Count = 0;  
        end  
  
        function resetImpl(obj)
```



```

        obj.Count = 0;
    end

    function y = stepImpl(obj,u1,u2)
        % Add to count if u1 is above threshold
        % Reset if u2 is true
        if (u2)
            obj.Count = 0;
        elseif (u1 > obj.Threshold)
            obj.Count = obj.Count + 1;
        end
        y = obj.Count;
    end

    function [sz,dt,cp] = getDiscreteStateSpecificationImpl(~,name)
        sz = [1 1];
        dt = 'double';
        cp = false;
    end
    function dataout = getOutputDataTypeImpl(~)
        dataout = 'double';
    end
    function sizeout = getOutputSizeImpl(~)
        sizeout = [1 1];
    end
    function cplxout = isOutputComplexImpl(~)
        cplxout = false;
    end
    function fixedout = isOutputFixedSizeImpl(~)
        fixedout = true;
    end
end
end
end

```

## See Also

[matlab.system.mixin.Propagates | getDiscreteStateSpecificationImpl](#)

## More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Use Update and Output for Nondirect Feedthrough

This example shows how to implement nondirect feedthrough for a System object using the `updateImpl`, `outputImpl` and `isInputDirectFeedthroughImpl` methods. In nondirect feedthrough, the object's outputs depend only on the internal states and properties of the object, rather than the input at that instant in time. You use these methods to separate the output calculation from the state updates of a System object. This enables you to use that object in a feedback loop and prevent algebraic loops.

### Subclass from the Nondirect Mixin Class

To use the `updateImpl`, `outputImpl`, and `isInputDirectFeedthroughImpl` methods, you must subclass from both the `matlab.System` base class and the `Nondirect` mixin class.

```
classdef IntegerDelaySysObj < matlab.System & ...  
    matlab.system.mixin.Nondirect
```

### Implement Updates to the Object

Implement an `updateImpl` method to update the object with previous inputs.

```
methods (Access = protected)  
    function updateImpl(obj,u)  
        obj.PreviousInput = [u obj.PreviousInput(1:end-1)];  
    end  
end
```

### Implement Outputs from Object

Implement an `outputImpl` method to output the previous, not the current input.

```
methods (Access = protected)  
    function [y] = outputImpl(obj,~)  
        y = obj.PreviousInput(end);  
    end  
end
```

### Implement Whether Input Is Direct Feedthrough

Implement an `isInputDirectFeedthroughImpl` method to indicate that the input is nondirect feedthrough.

```
methods (Access = protected)
```

```

function flag = isInputDirectFeedthroughImpl(~,~)
    flag = false;
end
end

```

### Complete Class Definition File with Update and Output

```

classdef intDelaySysObj < matlab.System &...
    matlab.system.mixin.Nondirect &...
    matlab.system.mixin.CustomIcon
    % intDelaySysObj Delay input by specified number of samples.

    properties
        InitialOutput = 0;
    end
    properties (Nontunable)
        NumDelays = 1;
    end
    properties (DiscreteState)
        PreviousInput;
    end

    methods (Access = protected)
        function validatePropertiesImpl(obj)
            if ((numel(obj.NumDelays)>1) || (obj.NumDelays <= 0))
                error('Number of delays must be positive non-zero scalar value.');
            end
            if (numel(obj.InitialOutput)>1)
                error('Initial Output must be scalar value.');
            end
        end

        function setupImpl(obj)
            obj.PreviousInput = ones(1,obj.NumDelays)*obj.InitialOutput;
        end

        function resetImpl(obj)
            obj.PreviousInput = ones(1,obj.NumDelays)*obj.InitialOutput;
        end

        function [y] = outputImpl(obj,~)
            y = obj.PreviousInput(end);
        end
        function updateImpl(obj, u)
            obj.PreviousInput = [u obj.PreviousInput(1:end-1)];
        end
    end
end

```

```
    end
    function flag = isInputDirectFeedthroughImpl(~,~)
        flag = false;
    end
end
end
```

### See Also

matlab.system.mixin.Nondirect | isInputDirectFeedthroughImpl |  
outputImpl | updateImpl

### More About

- “What Are Mixin Classes?” on page 12-87
- “Subclassing Multiple Classes”
- “System Object Input Arguments and ~ in Code Examples” on page 12-86

## Enable For Each Subsystem Support

This example shows how to enable using a System object in a Simulink For Each subsystem. Include the `supportsMultipleInstanceImpl` method in your class definition file. This method applies only when the System object is used in Simulink via the MATLAB System block.

Use the `supportsMultipleInstanceImpl` method and have it return `true` to indicate that the System object supports multiple calls in a Simulink For Each subsystem.

```
methods (Access = protected)
    function flag = supportsMultipleInstanceImpl(obj)
        flag = true;
    end
end
```

View the method in the complete class definition file.

```
classdef RandSeed < matlab.System
% RANDSEED Random noise with seed for use in For Each subsystem

    properties (DiscreteState)
        count;
    end

    properties (Nontunable)
        seed = 20;
    end

    properties (Nontunable,Logical)
        useSeed = false;
    end

    methods (Access = protected)
        function y = stepImpl(obj,u1)
            % Initial use after reset/setup
            % and use the seed
            if (obj.useSeed && ~obj.count)
                rng(obj.seed);
            end
            obj.count = obj.count + 1;
            [m,n] = size(u1);
            % Uses default rng seed
            y = rand(m,n) + u1;
        end
    end
end
```

```
    end

    function setupImpl(obj)
        obj.count = 0;
    end
    function resetImpl(obj)
        obj.count = 0;
    end

    function flag = supportsMultipleInstanceImpl(obj)
        flag = obj.useSeed;
    end
end
end
```

### See Also

matlab.System | supportsMultipleInstanceImpl

## Methods Timing

### In this section...

“Setup Method Call Sequence” on page 12-83

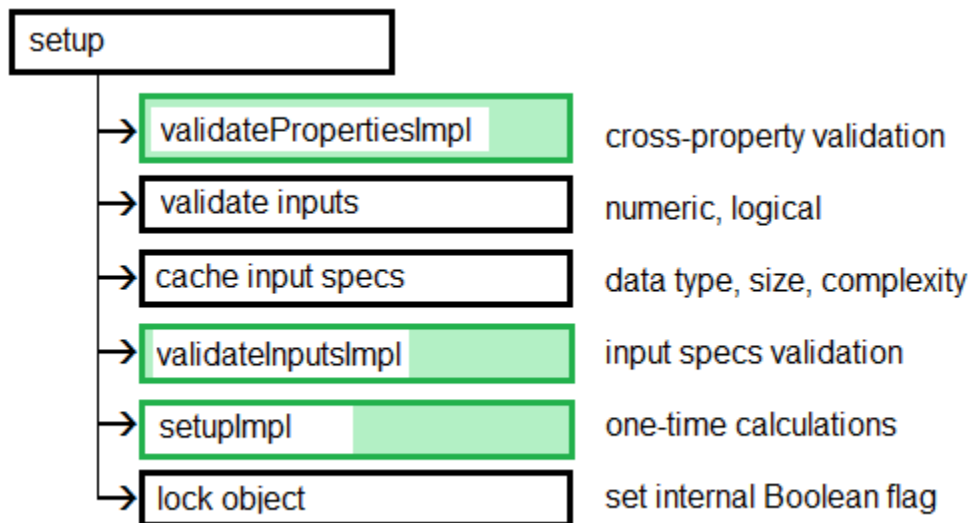
“Step Method Call Sequence” on page 12-83

“Reset Method Call Sequence” on page 12-84

“Release Method Call Sequence” on page 12-85

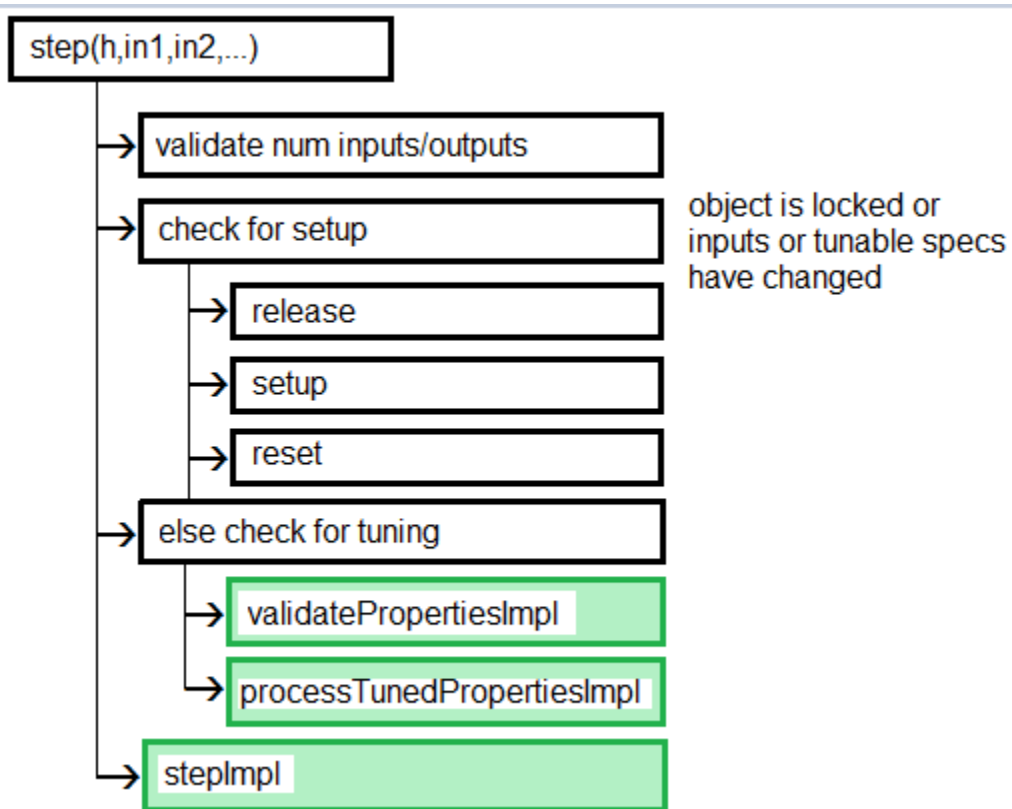
### Setup Method Call Sequence

This hierarchy shows the actions performed when you call the `setup` method.



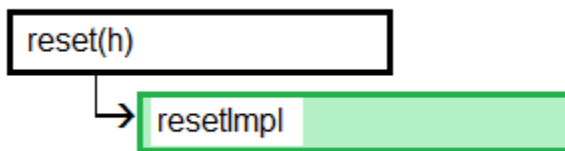
### Step Method Call Sequence

This hierarchy shows the actions performed when you call the `step` method.



### Reset Method Call Sequence

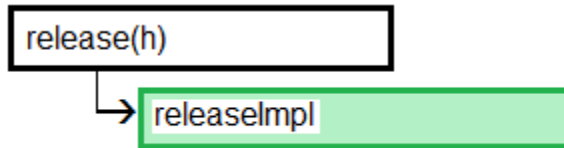
This hierarchy shows the actions performed when you call the `reset` method.





## Release Method Call Sequence

This hierarchy shows the actions performed when you call the `release` method.



## See Also

`releaseImpl` | `resetImpl` | `setupImpl` | `stepImpl`

## Related Examples

- “Release System Object Resources” on page 12-34
- “Reset Algorithm State” on page 12-21
- “Set Property Values at Construction Time” on page 12-19
- “Define Basic System Objects” on page 12-5

## More About

- “What Are System Object Methods?”
- “The Step Method”
- “Common Methods”
- “Common Methods”

### System Object Input Arguments and ~ in Code Examples

All methods, except static methods, expect the System object handle as the first input argument. You can use any name for your System object handle. In many examples, instead of passing in the object handle, ~ is used to indicate that the object handle is not used in the function. Using ~ instead of an object handle prevents warnings about unused variables.

## What Are Mixin Classes?

Mixin classes are partial classes that you can combine in various combinations to form desired behaviors using multiple inheritance. System objects are composed of a base class, `matlab.System` and may include one or more mixin classes. You specify the base class and mixin classes on the first line of your class definition file.

The following mixin classes are available for use with System objects.

- `matlab.system.mixin.CustomIcon` — Defines a block icon for System objects in the MATLAB System block
- `matlab.system.mixin.FiniteSource` — Adds the `isDone` method to System objects that are sources
- `matlab.system.mixin.Nondirect` — Allows the System object, when used in the MATLAB System block, to support nondirect feedthrough by making the runtime callback functions, `output` and `update` available
- `matlab.system.mixin.Propagates` — Enables System objects to operate in the MATLAB System block using the interpreted execution

## Best Practices for Defining System Objects

A System object is a specialized kind of MATLAB object that is optimized for iterative processing. Use System objects when you need to call the `step` method multiple times or process data in a loop. When defining your own System object, use the following suggestions to help your code run efficiently.

- Define all one-time calculations in the `setupImpl` method and cache the results in a private property. Use the `stepImpl` method for repeated calculations.
- If properties are accessed more than once in the `stepImpl` method, cache those properties as local variables inside the method. A typical example of multiple property access is a loop. Iterative calculations using cached local variables run faster than calculations that must access the properties of an object. When the calculations for the method complete, you can save the local cached results back to the properties of that System object. Copy frequently used tunable properties into private properties. This best practice also applies to the `updateImpl` and `outputImpl` methods.

In this example, `k` is accessed multiple times in each loop iteration, but is saved to the object property only once.

```
function y = stepImpl(obj,x)
    k = obj.MyProp;
    for p=1:100
        y = k * x;
        k = k + 0.1;
    end
    obj.MyProp = k;
end
```

- Do not use string comparisons or string-based switch statements in the `stepImpl` method. Instead, create a method handle in `setupImpl`. This handle points to a method in the same class definition file. Use that handle in a loop in `stepImpl`.

This example shows how to use method handles and cached local variables in a loop to implement an efficient object. In `setupImpl`, choose `myMethod1` or `myMethod2` based on a string comparison and assign the method handle to the `pMethodHandle` property. Because there is a loop in `stepImpl`, assign the `pMethodHandle` property to a local method handle, `myFun`, and then use `myFun` inside the loop.

```
classdef MyClass < matlab.System
    function setupImpl(obj)
        if strcmp(obj.Method, 'Method1')
```

```

        obj.pMethodHandle = @myMethod1;
    else
        obj.pMethodHandle = @myMethod2;
    end
end
function y = stepImpl(obj,x)
    myFun = obj.pMethodHandle;
    for p=1:1000
        y = myFun(obj,x)
    end
end
end
function y = myMethod1(x)
    y = x+1;
end
function y = myMethod2(x)
    y = x-1;
end
end
end

```

- If the number of System object inputs does not change, do not implement the `getNumInputsImpl` method. Also do not implement the `getNumInputsImpl` method when you explicitly list the inputs in the `stepImpl` method instead of using `varargin`. The same caveats apply to the `getNumOutputsImpl` and `varargout` outputs.
- For the `getNumInputsImpl` and `getNumOutputsImpl` methods, if you set the return argument from an object property, that object property must have the `Nontunable` attribute.
- If the variables in a method do not need to retain their values between calls use local scope for those variables in that method.
- For properties that do not change, define them in as `Nontunable` properties. `Tunable` properties have slower access times than `Nontunable` properties
- Use the `protected` or `private` attribute instead of the `public` attribute for a property, whenever possible. Some `public` properties have slower access times than `protected` and `private` properties.
- Avoid using customized `step`, `get`, or `set` methods, whenever possible.
- Avoid using string comparisons within customized `step`, `get`, or `set` methods, whenever possible. Use `setupImpl` for string comparisons instead.

