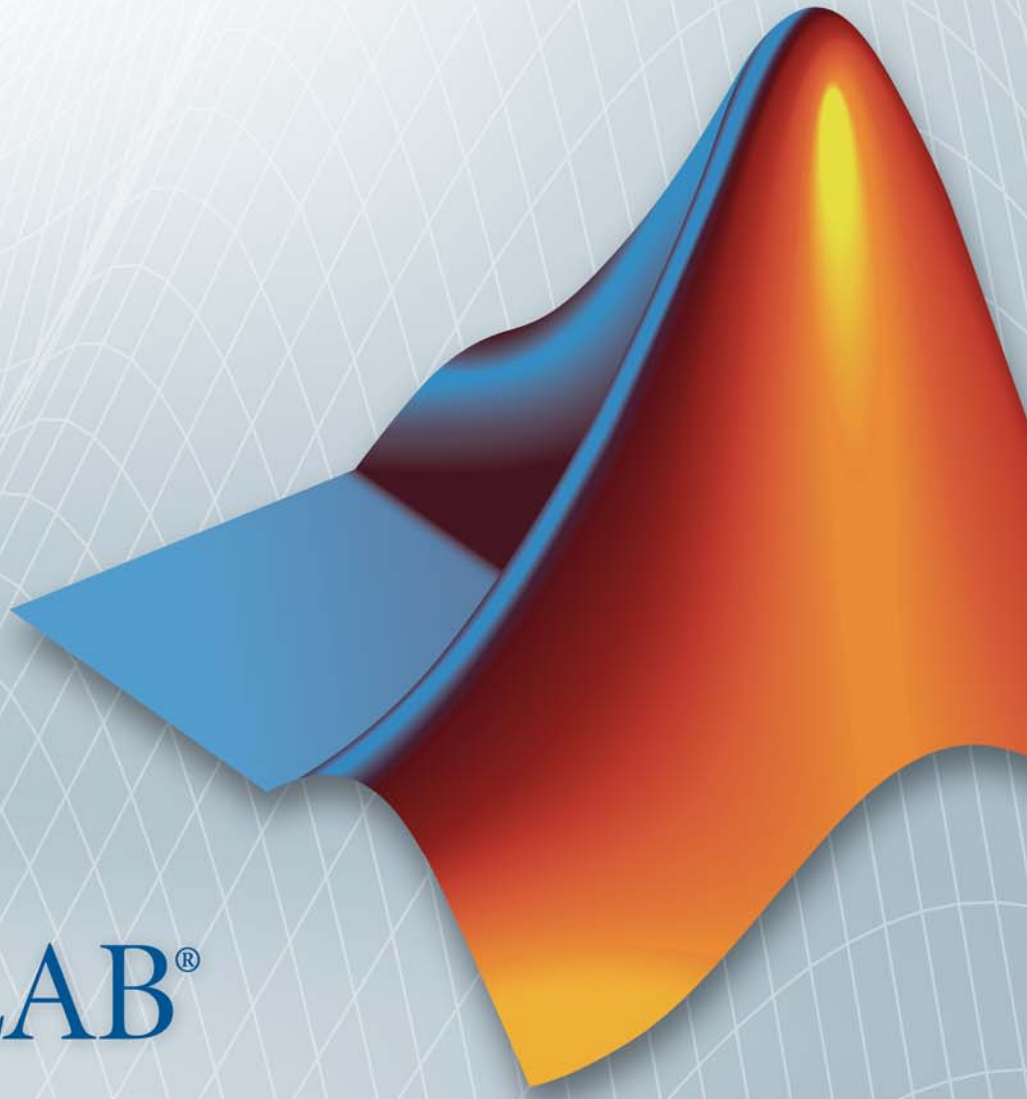
Fixed-Point Toolbox™

User's Guide

R2012a



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Fixed-Point Toolbox™ User's Guide

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1

Getting Started

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- “System Setup” on page 1-3
- “Getting Help” on page 1-5
- “Display Settings” on page 1-7
- “Demos” on page 1-11

Product Description

Design and execute fixed-point algorithms and analyze fixed-point data

Fixed-Point Toolbox™ provides fixed-point data types and arithmetic in MATLAB®. The toolbox lets you design fixed-point algorithms using MATLAB syntax and execute them at compiled C-code speed. You can reuse these algorithms in Simulink® and pass fixed-point data to and from Simulink models, facilitating bit-true simulation, implementation, and analysis and enabling you to generate test sequences for fixed-point software and hardware verification.

Key Features

- Fixed-point data types in MATLAB with word lengths up to 65535 bits
- Global and local settings for performing fixed-point arithmetic
- Logical and bitwise operators and native integers
- Fixed-point data types usable in both MATLAB and Simulink
- Data logging, data-type override, and other tools for floating-to-fixed-point conversion
- Accelerated execution of fixed-point algorithms in MATLAB

System Setup

In this section...
"Installation" on page 1-3
"Required Products" on page 1-3
"Related Products" on page 1-4
"Licensing" on page 1-4

Installation

Before you begin working, you need to install the product on your computer.

Installing the Fixed-Point Toolbox Software

Fixed-Point Toolbox software uses the same installation procedure as the MATLAB toolboxes. See the MATLAB installation documentation for instructions.

Installing Online Documentation

Installing the documentation is part of the installation process:

- Installation from a DVD — Start the MathWorks® installer. When prompted, select the **Product** check boxes for the products you want to install. The documentation is installed along with the products.
- Installation from a Web download — If you update the Fixed-Point Toolbox software using a Web download and you want to view the documentation with the MATLAB Help browser, you must install the documentation on your hard drive.

  Download the files from the Web. Then, start the installer, and select the **Product** check boxes for the products you want to install. The documentation is installed along with the products.

Required Products

The Fixed-Point Toolbox product is part of a family of MathWorks products. To use the toolbox, you must also have a MATLAB license. For more

information about Fixed-Point Toolbox system and product requirements, see `System Requirements` on the MathWorks Web site.

Note You can accelerate Fixed-Point Toolbox software when you have a compiler installed on your machine. For the current list of supported compilers, see Supported and Compatible Compilers on the MathWorks Web site. To setup or modify your compiler configuration, run `mex -setup` at the MATLAB command line.

Related Products

MathWorks provides several products that are relevant to the kinds of tasks you can perform with Fixed-Point Toolbox software.

See `Related Products` on the MathWorks Web site for more information.

Licensing

You can use `fi` objects with the `DataType` property set to `double` *without* a Fixed-Point Toolbox ™ license when you set the `fipref` `LoggingMode` property to `off`. A Fixed-Point Toolbox license *is* checked out when you

- Use any `fi` object with any `DataType` other than `double`.
- Create any `fi` object with the `fipref` `LoggingMode` property set to `on`, including `fi` objects with `DataType` `double`.
- Load a MAT-file that contains any `fi` object with the `DataType` property set to `single`, `boolean`, `ScaledDouble`, or `Fixed`.

You can prevent the checkout of a Fixed-Point Toolbox™ license when working with Fixed-Point Toolbox™ code by setting the `fipref` `DataTypeOverride` property to `TrueDoubles`.

Getting Help

In this section...
"Getting Help in This Document" on page 1-5
"Getting Help at the MATLAB Command Line" on page 1-5

Getting Help in This Document

The following chapters discuss the objects of Fixed-Point Toolbox software:

- Chapter 3, "Working with fi Objects"
- Chapter 4, "Working with fimath Objects"
- Chapter 5, "Working with fipref Objects"
- Chapter 6, "Working with numerictype Objects"
- Chapter 7, "Working with quantizer Objects"

To get in-depth information about the properties of these objects, refer to the Property Reference.

To get in-depth information about the functions of these objects, refer to the Function Reference.

Getting Help at the MATLAB Command Line

To get command-line help for Fixed-Point Toolbox objects, type

```
help objectname
```

For example,

```
help fi
help fimath
help fipref
help numerictype
help quantizer
```

To get command-line help for Fixed-Point Toolbox functions, type

```
help embedded.fi/functionname
```

For example,

```
help embedded.fi/abs
help embedded.fi/bitset
help embedded.fi/sqrt
```

To invoke Help Browser documentation for Fixed-Point Toolbox functions from the MATLAB command line, type

```
doc fixedpoint/functionname
```

For example,

```
doc fixedpoint/int
doc fixedpoint/add
doc fixedpoint/savefipref
doc fixedpoint/quantize
```

Display Settings

In Fixed-Point Toolbox software, the `fipref` object determines the display properties of `fi` objects. Code examples throughout this User's Guide generally show `fi` objects as they appear with the following `fipref` object properties:

- `NumberDisplay` — `'RealWorldValue'`
- `NumericTypeDisplay` — `'full'`
- `FimathDisplay` — `'full'`

Setting `'FimathDisplay'` to `'full'` provides a quick and easy way to determine if a `fi` object has a local fimath. When `'FimathDisplay'` is set to `'full'`, MATLAB displays `fimath` object properties for `fi` objects with a local fimath. MATLAB never displays `fimath` object properties for `fi` objects that do not have a local fimath.

Additionally, unless otherwise specified, examples throughout the Fixed-Point Toolbox documentation use the following configuration of the default fimath:

```
            RoundMode: nearest
         OverflowMode: saturate
          ProductMode: FullPrecision
MaxProductWordLength: 128
              SumMode: FullPrecision
    MaxSumWordLength: 128
```

For more information on display settings, refer to Chapter 5, "Working with fipref Objects".

Displaying the fimath Properties of fi Objects

To see the output as it appears in most Fixed-Point Toolbox code examples, set your `fipref` properties as follows and create two `fi` objects:

```
p = fipref('NumberDisplay', 'RealWorldValue',...
'NumericTypeDisplay', 'full', 'FimathDisplay', 'full');
a = fi(pi,'RoundMode', 'floor', 'OverflowMode', 'wrap')
b = fi(pi)
```

MATLAB returns the following:

```
a =
    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

             RoundMode: floor
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

b =
    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
```

MATLAB displays `fimath` object properties in the output of `fi` object `a` because `a` has a local fimath.

MATLAB does not display any `fimath` object properties in the output of `fi` object `b` because `b` has no local fimath.

Hiding the fimath Properties of fi Objects

If you are working with multiple `fi` objects that have local fimaths, you may want to turn off the `fimath` object display:

- `NumberDisplay` — `'RealWorldValue'`
- `NumericTypeDisplay` — `'full'`

- `FimathDisplay` — `'none'`

For example,

```
p = fipref('NumberDisplay', 'RealWorldValue',...
'NumericTypeDisplay', 'full', 'FimathDisplay', 'none')

p =

         NumberDisplay: 'RealWorldValue'
    NumericTypeDisplay: 'full'
         FimathDisplay: 'none'
           LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'

F = fimath('RoundMode', 'floor', 'OverflowMode', 'wrap');
a = fi(pi, F)

a =
    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
```

Although this setting helps decrease the amount of output produced, it also makes it impossible to tell from the output whether a `fi` object has a local fimath. To do so, you can use the `isfimathlocal` function. For example,

```
isfimathlocal(a)

ans =
     1
```

When the `isfimathlocal` function returns `1`, the `fi` object has a local fimath. If the function returns `0`, the `fi` object doe not have a local fimath.

Shortening the numerictype Display of fi Objects

To reduce the amount of output even further, you can set the `NumericTypeDisplay` to `'short'`. For example,

```
p = fipref('NumberDisplay', 'RealWorldValue',...
'NumericTypeDisplay', 'short', 'FimathDisplay', 'full');

a = fi(pi)

a =
    3.1416
      s16,13
```

Demos

You can find interactive Fixed-Point Toolbox demos in the MATLAB Help browser. Fixed-Point Toolbox software includes the following demos:

- Fixed-Point Basics — Demonstrates the basic use of the fixed-point `fi` object
- Number Circle — Illustrates the definitions of unsigned and signed two's complement integer and fixed-point numbers
- Binary Point Scaling — Explains binary point-only scaling
- Fixed-Point Data Type Override, Min/Max Logging, and Scaling — Steps through the workflow of using doubles override and min/max logging in the toolbox to choose appropriate scaling for a fixed-point algorithm
- Fixed-Point C Development — Shows how to use the parameters from a fixed-point MATLAB program in a fixed-point C program
- Fixed-Point Algorithm Development — Presents the development and verification of a simple fixed-point algorithm
- Fixed-Point Fast Fourier Transform (FFT) — Provides an example of converting a textbook Fast Fourier Transform algorithm into fixed-point MATLAB code and then into fixed-point C code
- Analysis of a Fixed-Point State-Space System with Limit Cycles — Demonstrates a limit cycle detection routine applied to a state-space system
- Quantization Error — Demonstrates the statistics of the error when signals are quantized using various rounding methods
- Fixed-Point Lowpass Filtering UsingMATLAB for Code Generation — Steps through generating a MEX function from MATLAB code, running the generated MEX function, and displaying the results
- Fixed-Point ATAN2 Calculation — Uses the CORDIC algorithm and polynomial approximation to perform a fixed-point calculation of the four quadrant inverse tangent
- Fixed-Point Sine and Cosine Calculation — Uses the CORDIC approximation functions to compute the sine and cosine of fixed-point data

To access these demos, click the `Demos` entry for Fixed-Point Toolbox in the **Contents** pane of the Help browser, or type demo('toolbox','fixed-point') at the MATLAB command line.

2

Fixed-Point Concepts

- "Fixed-Point Data Types" on page 2-2
- "Scaling" on page 2-4
- "Precision and Range" on page 2-5
- "Arithmetic Operations" on page 2-10
- "fi Objects Compared to C Integer Data Types" on page 2-22

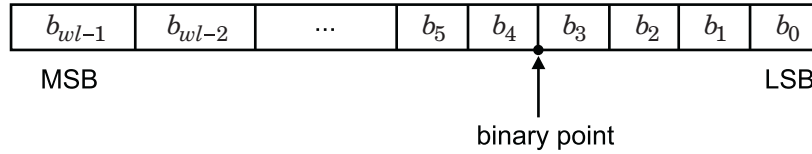
Fixed-Point Data Types

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. This chapter discusses 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^{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 the only representation used by Fixed-Point Toolbox documentation. Refer to "Two's Complement" on page 2-11 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

$$\text{slope} = \text{slope adjustment factor} \times 2^{\text{fixed exponent}}$$

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 Fixed-Point Toolbox documentation, the negative of the fixed 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 [Slope Bias] representation that has a bias equal to zero and a slope adjustment factor equal to one. This is referred to as binary point-only scaling or power-of-two scaling:

$$\text{real-world value} = 2^{\text{fixed exponent}} \times \text{integer}$$

or

$$\text{real-world value} = 2^{-\text{fixed exponent}} \times \text{integer}$$

Fixed-Point Toolbox software supports both binary point-only scaling and [Slope Bias] scaling.

Note For examples of binary point-only scaling, see the Fixed-Point Toolbox Binary-Point Scaling demo.

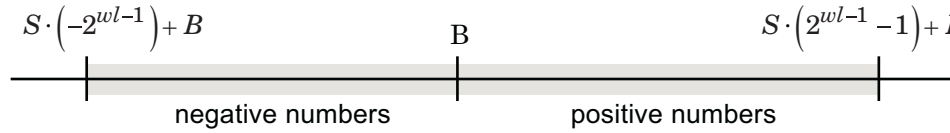
Precision and Range

In this section...
"Range" on page 2-5
"Precision" on page 2-6

Note You must pay attention to the precision and range of the fixed-point data types and scalings you choose in order to know whether rounding methods will be invoked or if overflows or underflows will occur.

Range

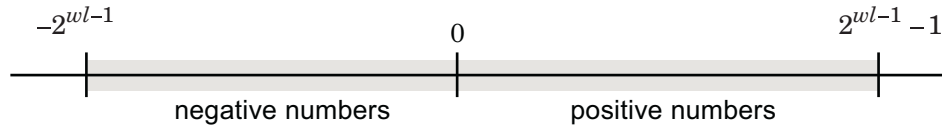
The range is the span of numbers that a fixed-point data type and scaling can represent. The range of representable numbers for a two's complement fixed-point number of word length wl, scaling S and bias B is illustrated below:



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 $2^{wl-1} - 1$. 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 and underflows can occur if the result of an operation is larger or smaller than the numbers in that range.

Fixed-Point Toolbox software allows 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. Refer to "Modulo Arithmetic" on page 2-10 for more information.

When you create a `fi` object, any overflows are saturated. The `OverflowMode` property of the default fimath is `saturate`. You can log overflows and underflows by setting the `LoggingMode` property of the `fipref` object to `on`. Refer to "LoggingMode" 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 Methods

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, a rounding method is used to cast the value 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 method itself. To provide you with

greater flexibility in the trade-off between cost and bias, Fixed-Point Toolbox software currently supports the following rounding methods:

- `ceil` rounds to the closest representable number in the direction of positive infinity.
- `convergent` rounds to the closest representable number. In the case of a tie, `convergent` rounds to the nearest even number. This is the least biased rounding method provided by the toolbox.
- `fix` rounds to the closest representable number in the direction of zero.
- `floor`, which is equivalent to two's complement truncation, rounds to the closest representable number in the direction of negative infinity.
- `nearest` rounds to the closest representable number. In the case of a tie, `nearest` rounds to the closest representable number in the direction of positive infinity. This rounding method is the default for `fi` object creation and `fi` arithmetic.
- `round` rounds to the closest representable number. In the case of a tie, the `round` method rounds:
  - Positive numbers to the closest representable number in the direction of positive infinity.
  - Negative numbers to the closest representable number in the direction of negative infinity.

Choosing a Rounding Method. Each rounding method has a set of inherent properties. Depending on the requirements of your design, these properties could make the rounding method more or less desirable to you. By knowing the requirements of your design and understanding the properties of each rounding method, you can determine which is the best fit for your needs. The most important properties to consider are:

- Cost — Independent of the hardware being used, how much processing expense does the rounding method require?
  - Low — The method requires few processing cycles.
  - Moderate — The method requires a moderate number of processing cycles.
  - High — The method requires more processing cycles.

Note The cost estimates provided here are hardware independent. Some processors have rounding modes built-in, so consider carefully the hardware you are using before calculating the true cost of each rounding mode.

- Bias — What is the expected value of the rounded values minus the original values: $E\left(\hat{\theta}-\theta\right)$?
  - $E\left(\hat{\theta}-\theta\right)<0$ — The rounding method introduces a negative bias.
  - $E\left(\hat{\theta}-\theta\right)=0$ — The rounding method is unbiased.
  - $E\left(\hat{\theta}-\theta\right)>0$ — The rounding method introduces a positive bias.
- Possibility of Overflow — Does the rounding method introduce the possibility of overflow?
  - Yes — The rounded values may exceed the minimum or maximum representable value.
  - No — The rounded values will never exceed the minimum or maximum representable value.

The following table shows a comparison of the different rounding methods available in both Fixed-Point Toolbox and Simulink Fixed Point™ products.

Fixed-Point Toolbox Rounding Method	Simulink Fixed Point Rounding Mode	Cost	Bias	Possibility of Overflow
`ceil`	`Ceiling`	Low	Large positive	Yes
`convergent`	`Convergent`	High	Unbiased	Yes
`fix`	`Zero`	Low	• Large positive for negative samples • Unbiased for samples with evenly distributed positive and negative values • Large negative for positive samples	No
`floor`	`Floor`	Low	Large negative	No
`nearest`	`Nearest`	Moderate	Small positive	Yes
`round`	`Round`	High	• Small negative for negative samples • Unbiased for samples with evenly distributed positive and negative values • Small positive for positive samples	Yes
N/A	`Simplest` (Simulink Fixed Point only)	Low	Depends on the operation	No

Arithmetic Operations

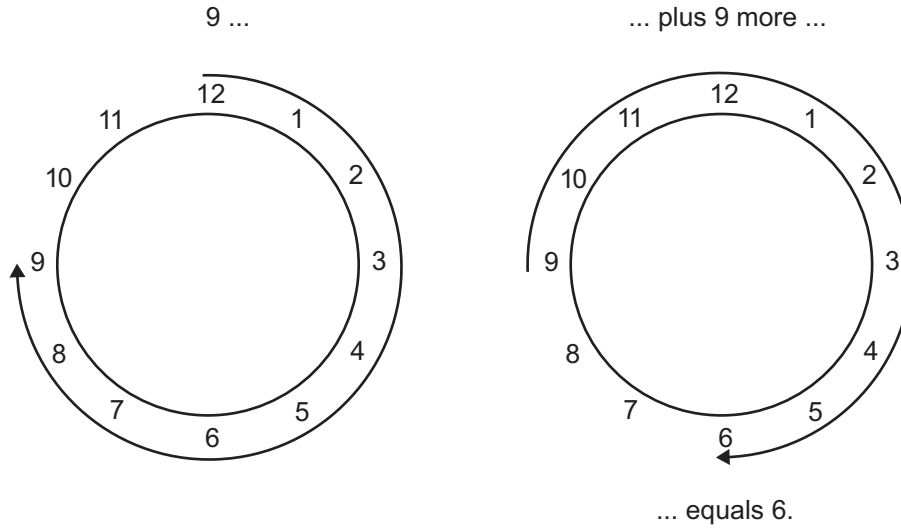
In this section...
"Modulo Arithmetic" on page 2-10
"Two's Complement" on page 2-11
"Addition and Subtraction" on page 2-12
"Multiplication" on page 2-13
"Casts" on page 2-19

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,

$$01 = (0 + 2^0) = 1$$
$$11 = \left(\left(-2^1\right) + \left(2^0\right)\right) = (-2 + 1) = -1$$

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 2^(-*FL*) using binary math, where *FL* is the fraction length.

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:

```
00101
    +1
-----
00110   (6)
```

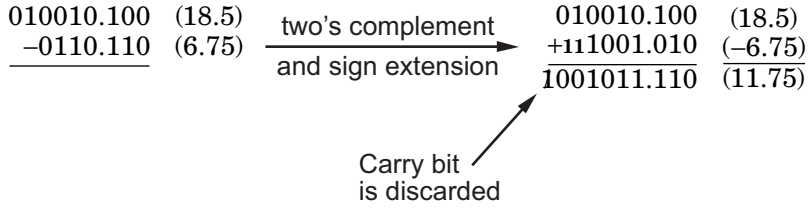
Addition and Subtraction

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):

```
010010.1     (18.5)
 +0110.110   (6.75)
---------
011001.010   (25.25)
```

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):



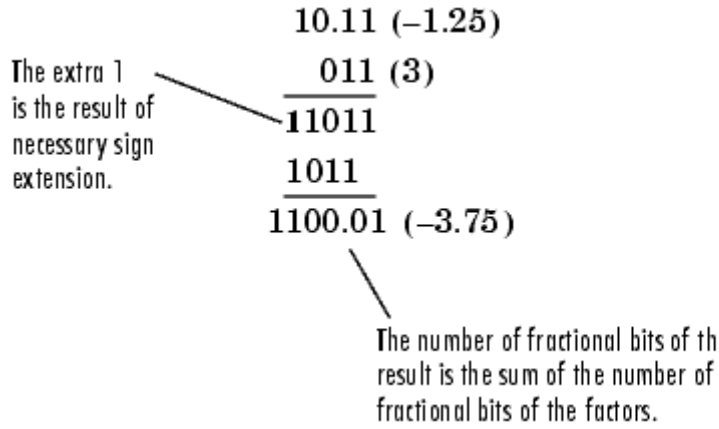
The default fimath has a value of `1` (true) for the `CastBeforeSum` property. This casts addends to the sum data type before addition. Therefore, no further shifting is necessary during the addition to line up the binary points.

If `CastBeforeSum` has a value of `0` (false), the addends are added with full precision maintained. After the addition the sum is then quantized.

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.

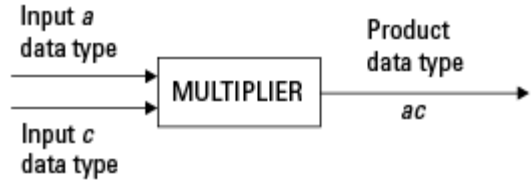
For example, consider the multiplication of 10.11 (-1.25) with 011 (3):



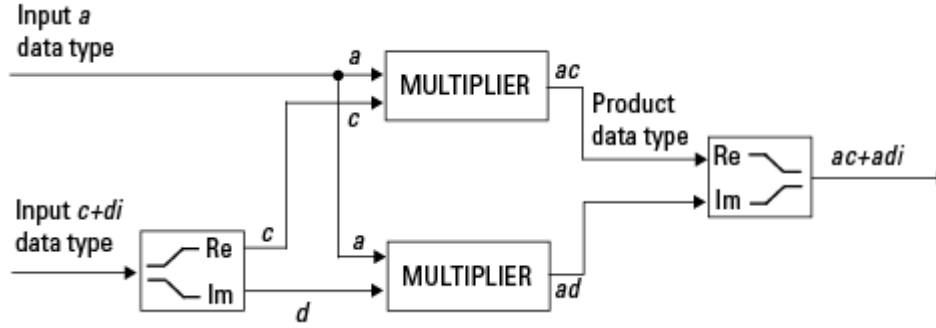
Multiplication Data Types

The following diagrams show the data types used for fixed-point multiplication using Fixed-Point Toolbox software. The diagrams illustrate the differences between the data types used for real-real, complex-real, and complex-complex multiplication.

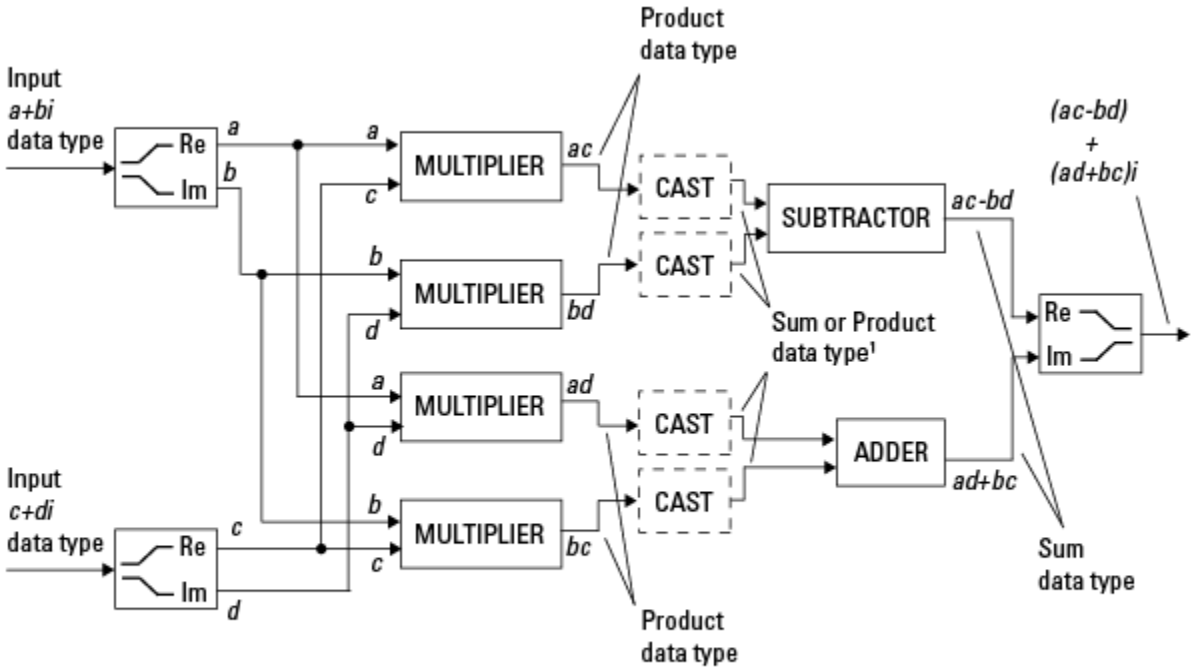
Real-Real Multiplication. The following diagram shows the data types used by the toolbox in the multiplication of two real numbers. The software returns the output of this operation in the product data type, which is governed by the `fimath` object `ProductMode` property.



Real-Complex Multiplication. The following diagram shows the data types used by the toolbox in the multiplication of a real and a complex fixed-point number. Real-complex and complex-real multiplication are equivalent. The software returns the output of this operation in the product data type, which is governed by the `fimath` object `ProductMode` property:



Complex-Complex Multiplication. The following diagram shows the multiplication of two complex fixed-point numbers. Note that the software returns the output of this operation in the sum data type, which is governed by the `fimath` object `SumMode` property. The intermediate product data type is determined by the `fimath` object `ProductMode` property.



When the `fimath` object `CastBeforeSum` property is `true`, the casts to the sum data type are present after the multipliers in the preceding diagram. In C code, this is equivalent to

```
acc=ac;
acc-=bd;
```

for the subtractor, and

```
acc=ad;
acc+=bc;
```

for the adder, where *acc* is the accumulator. When the `CastBeforeSum` property is `false`, the casts are not present, and the data remains in the product data type before the subtraction and addition operations.

Multiplication with fimath

In the following examples, let

```
F = fimath('ProductMode','FullPrecision',...
'SumMode','FullPrecision')
T1 = numerictype('WordLength',24,'FractionLength',20)
T2 = numerictype('WordLength',16,'FractionLength',10)
```

Real*Real. Notice that the word length and fraction length of the result `z` are equal to the sum of the word lengths and fraction lengths, respectively, of the multiplicands. This is because the `fimath` `SumMode` and `ProductMode` properties are set to `FullPrecision`:

```
P = fipref;
P.FimathDisplay = 'none';
x = fi(5, T1, F)

x =

     5


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 24
        FractionLength: 20

y = fi(10, T2, F)

y =

    10


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 10

z = x*y
```

```
z =

    50


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 40
        FractionLength: 30
```

Real*Complex. Notice that the word length and fraction length of the result `z` are equal to the sum of the word lengths and fraction lengths, respectively, of the multiplicands. This is because the `fimath` `SumMode` and `ProductMode` properties are set to `FullPrecision`:

```
x = fi(5,T1,F)

x =

     5


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 24
        FractionLength: 20

y = fi(10+2i,T2,F)

y =

  10.0000 + 2.0000i


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 10
```

```
z = x*y

z =

  50.0000 +10.0000i


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 40
        FractionLength: 30
```

Complex*Complex. Complex-complex multiplication involves an addition as well as multiplication, so the word length of the full-precision result has one more bit than the sum of the word lengths of the multiplicands:

```
x = fi(5+6i,T1,F)

x =

   5.0000 + 6.0000i


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 24
        FractionLength: 20

y = fi(10+2i,T2,F)

y =

  10.0000 + 2.0000i


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 10
```

```
z = x*y

z =

  38.0000 +70.0000i


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 41
        FractionLength: 30
```

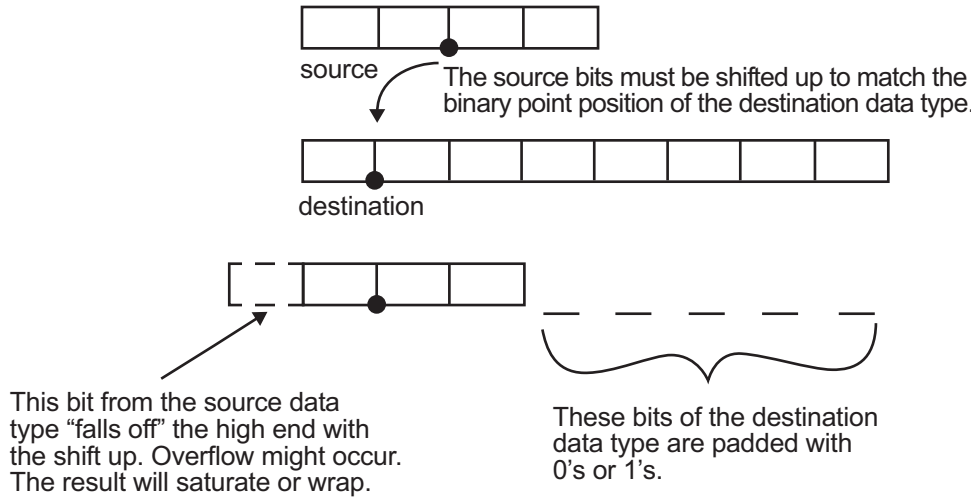
Casts

The `fimath` object allows you to specify the data type and scaling of intermediate sums and products with the `SumMode` and `ProductMode` properties. It is important to keep in mind the ramifications of each cast when you set the `SumMode` and `ProductMode` properties. 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.

Note For more examples of casting, see "Casting fi Objects" on page 3-12.

Casting from a Shorter Data Type to a Longer Data Type

Consider the cast of a nonzero number, represented by a 4-bit data type with two fractional bits, to an 8-bit data type with seven fractional bits:



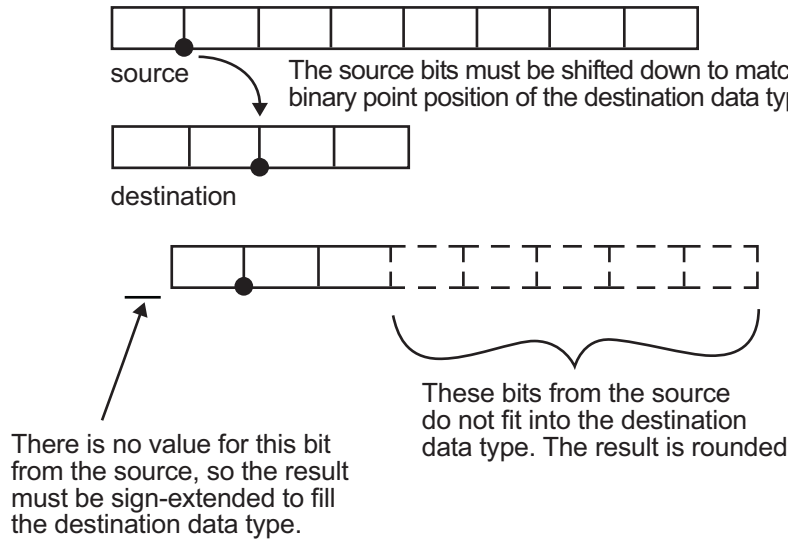
As the diagram shows, the source bits are shifted up so that the binary point matches the destination binary point position. The highest source bit does not fit, so overflow might occur and the result can saturate or wrap. The empty bits at the low end of the destination data type are padded with either 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 can 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.

Casting from a Longer Data Type to a Shorter Data Type

Consider the cast of a nonzero number, represented by an 8-bit data type with seven fractional bits, to a 4-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 sign extension is used 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 can 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.

fi Objects Compared to C Integer Data Types

In this section...

"Integer Data Types" on page 2-22
"Unary Conversions" on page 2-24
"Binary Conversions" on page 2-25
"Overflow Handling" on page 2-28

Note The sections in this topic compare the `fi` object with fixed-point data types and operations in C. In these sections, the information on ANSI C is adapted from Samuel P. Harbison and Guy L. Steele Jr., *C: A Reference Manual*, 3rd ed., Prentice Hall, 1991.

Integer Data Types

This section compares the numerical range of `fi` integer data types to the minimum numerical range of C integer data types, assuming a two's complement representation.

C Integer Data Types

Many C compilers support a two's complement representation of signed integer data types. The following table shows the minimum ranges of C integer data types using a two's complement representation. The integer ranges can be larger than or equal to those shown, but cannot be smaller. The range of a `long` must be larger than or equal to the range of an `int`, which must be larger than or equal to the range of a `short`.

In the two's complement representation, a signed integer with n bits has a range from -2^{n-1} to $2^{n-1}-1$, inclusive. An unsigned integer with n bits has a range from 0 to 2^n-1, inclusive. The negative side of the range has one more value than the positive side, and zero is represented uniquely.

Integer Type	Minimum	Maximum
`signed char`	–128	127
`unsigned char`	0	255
`short int`	–32,768	32,767
`unsigned short`	0	65,535
`int`	–32,768	32,767
`unsigned int`	0	65,535
`long int`	–2,147,483,648	2,147,483,647
`unsigned long`	0	4,294,967,295

fi Integer Data Types

The following table lists the numerical ranges of the integer data types of the `fi` object, in particular those equivalent to the C integer data types. The ranges are large enough to accommodate the two's complement representation, which is the only signed binary encoding technique supported by Fixed-Point Toolbox software.

Constructor	Signed	Word Length	Fraction Length	Minimum	Maximum	Closest ANSI C Equivalent
`fi(x,1,`*n*`,0)`	Yes	*n* (2 to 65,535)	0	-2^{n-1}	$2^{n-1}-1$	N/A
`fi(x,0,`*n*`,0)`	No	*n* (2 to 65,535)	0	0	$2^{n}-1$	N/A
`fi(x,1,8,0)`	Yes	8	0	–128	127	`signed char`
`fi(x,0,8,0)`	No	8	0	0	255	`unsigned char`
`fi(x,1,16,0)`	Yes	16	0	–32,768	32,767	`short int`
`fi(x,0,16,0)`	No	16	0	0	65,535	`unsigned short`

Constructor	Signed	Word Length	Fraction Length	Minimum	Maximum	Closest ANSI C Equivalent
`fi(x,1,32,0)`	Yes	32	0	–2,147,483,648	2,147,483,647	`long int`
`fi(x,0,32,0)`	No	32	0	0	4,294,967,295	`unsigned long`

Unary Conversions

Unary conversions dictate whether and how a single operand is converted before an operation is performed. This section discusses unary conversions in ANSI C and of `fi` objects.

ANSI C Usual Unary Conversions

Unary conversions in ANSI C are automatically applied to the operands of the unary `!`, –, ~, and `*` operators, and of the binary `<<` and `>>` operators, according to the following table:

Original Operand Type	ANSI C Conversion
`char` or `short`	`int`
`unsigned char` or `unsigned short`	`int` or `unsigned int`[1]
`float`	`float`
Array of T	Pointer to T
Function returning T	Pointer to function returning T

[1] If type `int` cannot represent all the values of the original data type without overflow, the converted type is `unsigned int`.

fi Usual Unary Conversions

The following table shows the `fi` unary conversions:

C Operator	fi Equivalent	fi Conversion
`!x`	`~x = not(x)`	Result is `logical`.
`~x`	`bitcmp(x)`	Result is same numeric type as operand.
`*x`	No equivalent	N/A
`x<<n`	`bitshift(x,n)` positive `n`	Result is same numeric type as operand. Round mode is always `floor`. Overflow mode is obeyed. 0-valued bits are shifted in on the right.
`x>>n`	`bitshift(x,-n)`	Result is same numeric type as operand. Round mode is always `floor`. Overflow mode is obeyed. 0-valued bits are shifted in on the left if the operand is unsigned or signed and positive. 1-valued bits are shifted in on the left if the operand is signed and negative.
`+x`	`+x`	Result is same numeric type as operand.
`-x`	`-x`	Result is same numeric type as operand. Overflow mode is obeyed. For example, overflow might occur when you negate an unsigned `fi` or the most negative value of a signed `fi`.

Binary Conversions

This section describes the conversions that occur when the operands of a binary operator are different data types.

ANSI C Usual Binary Conversions

In ANSI C, operands of a binary operator must be of the same type. If they are different, one is converted to the type of the other according to the first applicable conversion in the following table:

Type of One Operand	Type of Other Operand	ANSI C Conversion
`long double`	Any	`long double`
`double`	Any	`double`
`float`	Any	`float`
`unsigned long`	Any	`unsigned long`
`long`	`unsigned`	`long` or `unsigned long`[1]
`long`	`int`	`long`
`unsigned`	`int` or `unsigned`	`unsigned`
`int`	`int`	`int`

[1]Type `long` is only used if it can represent all values of type `unsigned`.

fi Usual Binary Conversions

When one of the operands of a binary operator (+, –, *, .*) is a `fi` object and the other is a MATLAB built-in numeric type, then the non-`fi` operand is converted to a `fi` object before the operation is performed, according to the following table:

Type of One Operand	Type of Other Operand	Properties of Other Operand After Conversion to a fi Object
`fi`	`double` or `single`	• `Signed` = same as the original `fi` operand • `WordLength` = same as the original `fi` operand • `FractionLength` = set to best precision possible
`fi`	`int8`	• `Signed` = `1` • `WordLength` = `8` • `FractionLength` = `0`

Type of One Operand	Type of Other Operand	Properties of Other Operand After Conversion to a fi Object
`fi`	`uint8`	• `Signed = 0` • `WordLength = 8` • `FractionLength = 0`
`fi`	`int16`	• `Signed = 1` • `WordLength = 16` • `FractionLength = 0`
`fi`	`uint16`	• `Signed = 0` • `WordLength = 16` • `FractionLength = 0`
`fi`	`int32`	• `Signed = 1` • `WordLength = 32` • `FractionLength = 0`
`fi`	`uint32`	• `Signed = 0` • `WordLength = 32` • `FractionLength = 0`
`fi`	`int64`	• `Signed = 1` • `WordLength = 64` • `FractionLength = 0`
`fi`	`uint64`	• `Signed = 0` • `WordLength = 64` • `FractionLength = 0`

Overflow Handling

The following sections compare how ANSI C and Fixed-Point Toolbox software handle overflows.

ANSI C Overflow Handling

In ANSI C, the result of signed integer operations is whatever value is produced by the machine instruction used to implement the operation. Therefore, ANSI C has no rules for handling signed integer overflow.

The results of unsigned integer overflows wrap in ANSI C.

fi Overflow Handling

Addition and multiplication with `fi` objects yield results that can be exactly represented by a `fi` object, up to word lengths of 65,535 bits or the available memory on your machine. This is not true of division, however, because many ratios result in infinite binary expressions. You can perform division with `fi` objects using the `divide` function, which requires you to explicitly specify the numeric type of the result.

The conditions under which a `fi` object overflows and the results then produced are determined by the associated `fimath` object. You can specify certain overflow characteristics separately for sums (including differences) and products. Refer to the following table:

fimath Object Properties Related to Overflow Handling	Property Value	Description
`OverflowMode`	`'saturate'`	Overflows are saturated to the maximum or minimum value in the range.
	`'wrap'`	Overflows wrap using modulo arithmetic if unsigned, two's complement wrap if signed.

fimath Object Properties Related to Overflow Handling	Property Value	Description
`ProductMode`	`'FullPrecision'`	Full-precision results are kept. Overflow does not occur. An error is thrown if the resulting word length is greater than `MaxProductWordLength`. The rules for computing the resulting product word and fraction lengths are given in "ProductMode" in the Property Reference.
	`'KeepLSB'`	The least significant bits of the product are kept. Full precision is kept, but overflow is possible. This behavior models the C language integer operations. The resulting word length is determined by the `ProductWordLength` property. If `ProductWordLength` is greater than is necessary for the full-precision product, then the result is stored in the least significant bits. If `ProductWordLength` is less than is necessary for the full-precision product, then overflow occurs. The rule for computing the resulting product fraction length is given in "ProductMode" in the Property Reference.

fimath Object Properties Related to Overflow Handling	Property Value	Description
	`'KeepMSB'`	The most significant bits of the product are kept. Overflow is prevented, but precision may be lost. The resulting word length is determined by the `ProductWordLength` property. If `ProductWordLength` is greater than is necessary for the full-precision product, then the result is stored in the most significant bits. If `ProductWordLength` is less than is necessary for the full-precision product, then rounding occurs. The rule for computing the resulting product fraction length is given in "ProductMode" in the Property Reference.
	`'SpecifyPrecision'`	You can specify both the word length and the fraction length of the resulting product.
`ProductWordLength`	Positive integer	The word length of product results when `ProductMode` is `'KeepLSB'`, `'KeepMSB'`, or `'SpecifyPrecision'`.
`MaxProductWordLength`	Positive integer	The maximum product word length allowed when `ProductMode` is `'FullPrecision'`. The default is 128 bits. The maximum is 65,535 bits. This property can help ensure that your simulation does not exceed your hardware requirements.
`ProductFractionLength`	Integer	The fraction length of product results when `ProductMode` is `'Specify Precision'`.

fimath Object Properties Related to Overflow Handling	Property Value	Description
SumMode	'FullPrecision'	Full-precision results are kept. Overflow does not occur. An error is thrown if the resulting word length is greater than MaxSumWordLength. The rules for computing the resulting sum word and fraction lengths are given in "SumMode" in the Property Reference.
	'KeepLSB'	The least significant bits of the sum are kept. Full precision is kept, but overflow is possible. This behavior models the C language integer operations. The resulting word length is determined by the SumWordLength property. If SumWordLength is greater than is necessary for the full-precision sum, then the result is stored in the least significant bits. If SumWordLength is less than is necessary for the full-precision sum, then overflow occurs. The rule for computing the resulting sum fraction length is given in "SumMode" in the Property Reference.
	'KeepMSB'	The most significant bits of the sum are kept. Overflow is prevented, but precision may be lost. The resulting word length is determined by the SumWordLength property. If SumWordLength is greater than is necessary for the full-precision sum, then the result is stored in the most significant bits. If SumWordLength is less than is necessary for the full-precision sum, then rounding occurs.

fimath Object Properties Related to Overflow Handling	Property Value	Description
		The rule for computing the resulting sum fraction length is given in “SumMode” in the Property Reference.
	`'SpecifyPrecision'`	You can specify both the word length and the fraction length of the resulting sum.
`SumWordLength`	Positive integer	The word length of sum results when `SumMode` is `'KeepLSB'`, `'KeepMSB'`, or `'SpecifyPrecision'`.
`MaxSumWordLength`	Positive integer	The maximum sum word length allowed when `SumMode` is `'FullPrecision'`. The default is 128 bits. The maximum is 65,535 bits. This property can help ensure that your simulation does not exceed your hardware requirements.
`SumFractionLength`	Integer	The fraction length of sum results when `SumMode` is `'SpecifyPrecision'`.

3

Working with fi Objects

- “Constructing fi Objects” on page 3-2
- “Casting fi Objects” on page 3-12
- “fi Object Properties” on page 3-17
- “fi Object Functions” on page 3-24

Constructing fi Objects

In this section...

"fi Object Syntaxes" on page 3-2

"Examples of Constructing fi Objects" on page 3-3

fi Object Syntaxes

You can create `fi` objects using Fixed-Point Toolbox software in any of the following ways:

- You can use the `fi` constructor function to create a new `fi` object.
- You can use the `sfi` constructor function to create a new signed `fi` object.
- You can use the `ufi` constructor function to create a new unsigned `fi` object.
- You can use any of the `fi` constructor functions to copy an existing `fi` object.

To get started, type

```
a = fi(0)
```

to create a `fi` object with the default data type and a value of 0.

```
a =

     0


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15
```

This constructor syntax creates a signed `fi` object with a value of 0, word length of 16 bits, and fraction length of 15 bits. Because you did not specify any `fimath` object properties in the `fi` constructor, the resulting `fi` object `a` has no local fimath.

To see all of the `fi`, `sfi`, and `ufi` constructor syntaxes, refer to the respective reference pages.

Note For information on the display format of `fi` objects, refer to "Display Settings" on page 1-7.

Examples of Constructing fi Objects

The following examples show you several different ways to construct `fi` objects. For other, more basic examples of constructing `fi` objects, see the Examples section of the following constructor function reference pages:

- `fi`
- `sfi`
- `ufi`

Note The `fi` constructor creates the `fi` object using a `RoundMode` of `Nearest` and an `OverflowMode` of `Saturate`. If you construct a `fi` from floating-point values, the default `RoundMode` and `OverflowMode` property settings are not used.

Constructing a fi Object with Property Name/Property Value Pairs

You can use property name/property value pairs to set `fi` and `fimath` object properties when you create the `fi` object:

```
a = fi(pi, 'roundmode', 'floor', 'overflowmode', 'wrap')

a =

    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
```

```
        FractionLength: 13

             RoundMode: floor
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```

You do not have to specify every `fimath` object property in the `fi` constructor. The `fi` object uses default values for all unspecified `fimath` object properties.

- If you specify at least one `fimath` object property in the `fi` constructor, the `fi` object will have a local `fimath` object. The `fi` object uses default values for the remaining unspecified `fimath` object properties.
- If you do not specify any `fimath` object properties in the `fi` object constructor, the `fi` object uses default fimath values.

Constructing a fi Object Using a numerictype Object

You can use a `numerictype` object to define a `fi` object:

```
T = numerictype

T =


           DataTypeMode: Fixed-point: binary point scaling
             Signedness: Signed
             WordLength: 16
         FractionLength: 15

a = fi(pi, T)

a =

    1.0000


           DataTypeMode: Fixed-point: binary point scaling
```

```
            Signedness: Signed
            WordLength: 16
        FractionLength: 15
```

You can also use a `fimath` object with a `numerictype` object to define a `fi` object:

```
F = fimath('RoundMode', 'nearest',...
'OverflowMode', 'saturate',...
'ProductMode','FullPrecision',...
'MaxProductWordLength', 128,...
'SumMode','FullPrecision',...
'MaxSumWordLength', 128)

F =

             RoundMode: nearest
          OverflowMode: saturate
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

a = fi(pi, T, F)

a =

    1.0000


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15

             RoundMode: nearest
          OverflowMode: saturate
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
```

```
      MaxSumWordLength: 128
```

Note The syntax `a = fi(pi,T,F)` is equivalent to `a = fi(pi,F,T)`. You can use both statements to define a `fi` object using a `fimath` object and a `numerictype` object.

Constructing a fi Object Using a fimath Object

You can create a `fi` object using a specific `fimath` object. When you do so, a local `fimath` object is assigned to the `fi` object you create. If you do not specify any `numerictype` object properties, the word length of the `fi` object defaults to 16 bits. The fraction length is determined by best precision scaling:

```
F = fimath('RoundMode', 'nearest',...
'OverflowMode', 'saturate',...
'ProductMode','FullPrecision',...
'MaxProductWordLength', 128,...
'SumMode','FullPrecision',...
'MaxSumWordLength', 128)

F =


            RoundMode: nearest
         OverflowMode: saturate
          ProductMode: FullPrecision
  MaxProductWordLength: 128
              SumMode: FullPrecision
      MaxSumWordLength: 128

F.OverflowMode = 'wrap'

F =


            RoundMode: nearest
         OverflowMode: wrap
          ProductMode: FullPrecision
```

```
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

a = fi(pi, F)

a =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

             RoundMode: nearest
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```

You can also create `fi` objects using a `fimath` object while specifying various `numerictype` properties at creation time:

```
b = fi(pi, 0, F)

b =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 16
        FractionLength: 14

             RoundMode: nearest
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
```

```
                SumMode: FullPrecision
      MaxSumWordLength: 128

c = fi(pi, 0, 8, F)

c =

    3.1406

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 8
        FractionLength: 6

             RoundMode: nearest
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
                SumMode: FullPrecision
      MaxSumWordLength: 128

d = fi(pi, 0, 8, 6, F)

d =

    3.1406

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 8
        FractionLength: 6

             RoundMode: nearest
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
                SumMode: FullPrecision
      MaxSumWordLength: 128
```

Building fi Object Constructors in a GUI

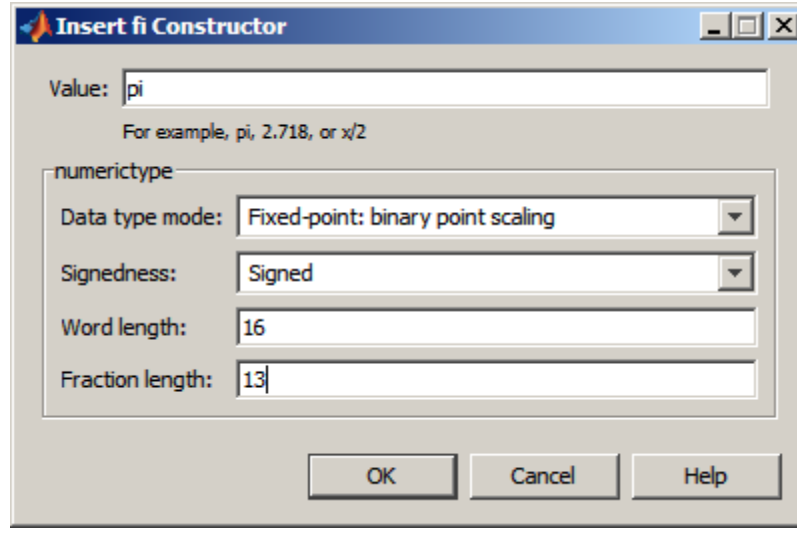
When you are working with files in MATLAB, you can build your `fi` object constructors using the **Insert fi Constructor** dialog box. After specifying the value and properties of the `fi` object in the dialog box, you can insert the prepopulated `fi` object constructor string at a specific location in your file.

For example, to create a signed `fi` object with a value of pi, a word length of 16 bits and a fraction length of 13 bits, perform the following steps:

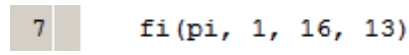
1. Open the **Insert fi Constructor** dialog box by selecting **Tools > Fixed-Point Toolbox > Insert fi Constructor** from the editor menu.

2. Use the edit boxes and drop-down menus to specify the following properties of the `fi` object:

   - **Value** = `pi`
   - **Data type mode** = `Fixed-point:  binary point scaling`
   - **Signedness** = `Signed`
   - **Word length** = `16`
   - **Fraction length** = `13`



3 To insert the `fi` object constructor string in your file, place your cursor at the desired location in the file, and click **OK** on the **Insert fi Constructor** dialog box. Clicking **OK** closes the **Insert fi Constructor** dialog box and automatically populates the `fi` object constructor string in your file:



Determining Property Precedence

The value of a property is taken from the last time it is set. For example, create a `numerictype` object with a value of `true` for the `Signed` property and a fraction length of `14`:

```
T = numerictype('Signed', true, 'FractionLength', 14)

T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 14
```

Now, create the following `fi` object in which you specify the `numerictype` property *after* the `Signed` property, so that the resulting `fi` object is signed:

```
a = fi(pi,'Signed',false,'numerictype',T)

a =

    1.9999

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 14
```

Contrast the `fi` object in this code sample with the `fi` object in the following code sample. The `numerictype` property in the following code sample is specified *before* the `Signed` property, so the resulting `fi` object is unsigned:

```
b = fi(pi,'numerictype',T,'Signed',false)

b =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 16
        FractionLength: 14
```

Copying a fi Object

To copy a `fi` object, simply use assignment, as in the following example:

```
a = fi(pi)

a =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
b = a

b =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
```

Casting fi Objects

In this section...

"Overwriting by Assignment" on page 3-12

"Ways to Cast with MATLAB Software" on page 3-12

Overwriting by Assignment

Because MATLAB software does not have type declarations, an assignment like `A = B` replaces the type and content of `A` with the type and content of `B`. If `A` does not exist at the time of the assignment, MATLAB creates the variable `A` and assigns it the same type and value as `B`. Such assignment happens with all types in MATLAB—objects and built-in types alike—including `fi`, `double`, `single`, `int8`, `uint8`, `int16`, etc.

For example, the following code overwrites the value and `int8` type of `A` with the value and `int16` type of `B`:

```
A = int8(0);
B = int16(32767);
A = B

A =

  32767

class(A)

ans =

int16
```

Ways to Cast with MATLAB Software

You may find it useful to cast data into another type—for example, when you are casting data from an accumulator to memory. There are several ways to cast data in MATLAB. The following sections provide examples of three different methods:

- Casting by Subscripted Assignment
- Casting by Conversion Function
- Casting with the Fixed-Point Toolbox `reinterpretcast` Function

Casting by Subscripted Assignment

The following subscripted assignment statement retains the type of `A` and saturates the value of `B` to an `int8`:

```
A = int8(0);
B = int16(32767);
A(:) = B

A =

  127

class(A)

ans =

int8
```

The same is true for `fi` objects:

```
fipref('NumericTypeDisplay', 'short');
A = fi(0, true, 8, 0);
B = fi(32767, true, 16, 0);
A(:) = B

A =

   127
      s8,0
```

Note For more information on subscripted assignments, see the `subsasgn` function.

Casting by Conversion Function

You can convert from one data type to another by using a conversion function. In this example, `A` does not have to be predefined because it is overwritten.

```
B = int16(32767);
A = int8(B)

A =

  127

class(A)

ans =

int8
```

The same is true for `fi` objects:

```
B = fi(32767, true, 16, 0)
A = fi(B, 1, 8, 0)

B =

       32767
      s16,0

A =

   127
      s8,0
```

Using a numerictype Object in the fi Conversion Function. Often a specific `numerictype` is used in many places, and it is convenient to predefine `numerictype` objects for use in the conversion functions. Predefining these objects is a good practice because it also puts the data type specification in one place.

```
T8 = numerictype(1,8,0)

T8 =
```

```
          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 8
        FractionLength: 0

T16 = numerictype(1,16,0)

T16 =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 0

B = fi(32767,T16)

B =

       32767
      s16,0

A = fi(B, T8)

A =

   127
      s8,0
```

Casting with the reinterpretcast Function

You can convert fixed-point and built-in data types without changing the underlying data. The Fixed-Point Toolbox `reinterpretcast` function performs this type of conversion.

In the following example, `B` is an unsigned `fi` object with a word length of 8 bits and a fraction length of 5 bits. The `reinterpretcast` function converts `B` into a signed `fi` object `A` with a word length of 8 bits and a fraction length of 1

bit. The real-world values of A and B differ, but their binary representations are the same.

```
B = fi([pi/4 1 pi/2 4], false, 8, 5)
T = numerictype(true, 8, 1);
A = reinterpretcast(B, T)

B =

    0.7813    1.0000    1.5625    4.0000

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 8
        FractionLength: 5

A =

   12.5000   16.0000   25.0000   -64.0000

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 8
        FractionLength: 1
```

To verify that the underlying data has not changed, compare the binary representations of A and B:

```
binary_B = bin(B)
binary_A = bin(A)

binary_A =

00011001   00100000   00110010   10000000

binary_B =

00011001   00100000   00110010   10000000
```

fi Object Properties

In this section...

"Data Properties" on page 3-17

"fimath Properties" on page 3-17

"numerictype Properties" on page 3-19

"Setting fi Object Properties" on page 3-20

Data Properties

The data properties of a `fi` object are always writable.

- `bin` — Stored integer value of a `fi` object in binary
- `data` — Numerical real-world value of a `fi` object
- `dec` — Stored integer value of a `fi` object in decimal
- `double` — Real-world value of a `fi` object, stored as a MATLAB `double` data type
- `hex` — Stored integer value of a `fi` object in hexadecimal
- `oct` — Stored integer value of a `fi` object in octal

To learn more about these properties, see "fi Object Properties" in the Fixed-Point Toolbox Reference.

fimath Properties

In general, the `fimath` properties associated with `fi` objects depend on how you create the `fi` object:

- When you specify one or more `fimath` object properties in the `fi` constructor, the resulting `fi` object has a local `fimath` object.
- When you do not specify any `fimath` object properties in the `fi` constructor, the resulting `fi` object has no local fimath.

To determine whether a `fi` object has a local `fimath` object, use the `isfimathlocal` function.

The `fimath` properties associated with `fi` objects determine how fixed-point arithmetic is performed. These `fimath` properties can come from a local `fimath` object or from default fimath property values. To learn more about `fimath` objects in fixed-point arithmetic, see "fimath Rules for Fixed-Point Arithmetic" on page 4-11.

The following `fimath` properties are, by transitivity, also properties of the `fi` object. You can set these properties for individual `fi` objects. The following `fimath` properties are always writable.

- `CastBeforeSum` — Whether both operands are cast to the sum data type before addition

  Note This property is hidden when the `SumMode` is set to `FullPrecision`.

- `MaxProductWordLength` — Maximum allowable word length for the product data type
- `MaxSumWordLength` — Maximum allowable word length for the sum data type
- `OverflowMode` — Overflow mode
- `ProductBias` — Bias of the product data type
- `ProductFixedExponent` — Fixed exponent of the product data type
- `ProductFractionLength` — Fraction length, in bits, of the product data type
- `ProductMode` — Defines how the product data type is determined
- `ProductSlope` — Slope of the product data type
- `ProductSlopeAdjustmentFactor` — Slope adjustment factor of the product data type
- `ProductWordLength` — Word length, in bits, of the product data type
- `RoundMode` — Rounding mode

- `SumBias` — Bias of the sum data type
- `SumFixedExponent` — Fixed exponent of the sum data type
- `SumFractionLength` — Fraction length, in bits, of the sum data type
- `SumMode` — Defines how the sum data type is determined
- `SumSlope` — Slope of the sum data type
- `SumSlopeAdjustmentFactor` — Slope adjustment factor of the sum data type
- `SumWordLength` — The word length, in bits, of the sum data type

To learn more about these properties, see the "fimath Object Properties" in the Fixed-Point Toolbox Reference.

numerictype Properties

When you create a `fi` object, a `numerictype` object is also automatically created as a property of the `fi` object:

`numerictype` — Object containing all the data type information of a `fi` object, Simulink signal or model parameter

The following `numerictype` properties are, by transitivity, also properties of a `fi` object. The following properties of the `numerictype` object become read only after you create the `fi` object. However, you can create a copy of a `fi` object with new values specified for the `numerictype` properties:

- `Bias` — Bias of a `fi` object
- `DataType` — Data type category associated with a `fi` object
- `DataTypeMode` — Data type and scaling mode of a `fi` object
- `FixedExponent` — Fixed-point exponent associated with a `fi` object
- `FractionLength` — Fraction length of the stored integer value of a `fi` object in bits
- `Scaling` — Fixed-point scaling mode of a `fi` object
- `Signed` — Whether a `fi` object is signed or unsigned

- `Signedness` — Whether a `fi` object is signed or unsigned

> **Note** `numerictype` objects can have a `Signedness` of `Auto`, but all `fi` objects must be `Signed` or `Unsigned`. If a `numerictype` object with `Auto` `Signedness` is used to create a `fi` object, the `Signedness` property of the `fi` object automatically defaults to `Signed`.

- `Slope` — Slope associated with a `fi` object
- `SlopeAdjustmentFactor` — Slope adjustment associated with a `fi` object
- `WordLength` — Word length of the stored integer value of a `fi` object in bits

For further details on these properties, see the Property Reference.

There are two ways to specify properties for `fi` objects in Fixed-Point Toolbox software. Refer to the following sections:

- "Setting Fixed-Point Properties at Object Creation" on page 3-20
- "Using Direct Property Referencing with fi" on page 3-21

Setting fi Object Properties

You can set `fi` object properties in two ways:

- Setting the properties when you create the object
- Using direct property referencing

Setting Fixed-Point Properties at Object Creation

You can set properties of `fi` objects at the time of object creation by including properties after the arguments of the `fi` constructor function. For example, to set the overflow mode to `wrap` and the rounding mode to `convergent`,

```
a = fi(pi, 'OverflowMode', 'wrap', 'RoundMode', 'convergent')

a =

    3.1416
```

```
          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

             RoundMode: convergent
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```

Using Direct Property Referencing with fi

You can reference directly into a property for setting or retrieving `fi` object property values using MATLAB structure-like referencing. You do so by using a period to index into a property by name.

For example, to get the `WordLength` of `a`,

```
a.WordLength

ans =

    16
```

To set the `OverflowMode` of `a`,

```
a.OverflowMode = 'wrap'

a =

    3.1416


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
```

```
        FractionLength: 13

             RoundMode: convergent
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```

If you have a `fi` object `b` with a local `fimath` object, you can remove the local `fimath` object and force `b` to use default fimath values:

```
b = fi(pi, 1, 'RoundMode', 'Floor')

b =
    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

             RoundMode: floor
          OverflowMode: saturate
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

b.fimath = []

b =
    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

isfimathlocal(b)
```

```
ans =
     0
```

fi Object Functions

You can learn about the functions associated with `fi` objects in the Function Reference.

The following data-access functions can be also used to get the data in a `fi` object using dot notation.

- `bin`
- `data`
- `dec`
- `double`
- `hex`
- `storedInteger`
- `storedIntegerToDouble`
- `oct`

For example,

```
a = fi(pi);
n = storedInteger(a)

n =

  25736



ans =

  25736

h = hex(a)

h =
```

```
6488

a.hex

ans =

6488
```

4

Working with fimath Objects

- "Constructing fimath Objects" on page 4-2
- "fimath Object Properties" on page 4-6
- "Using fimath Properties to Perform Fixed-Point Arithmetic" on page 4-11
- "Using fimath to Specify Rounding and Overflow Modes" on page 4-20
- "Using fimath to Share Arithmetic Rules" on page 4-22
- "Using fimath ProductMode and SumMode" on page 4-25
- "fimath Object Functions" on page 4-31

Constructing fimath Objects

In this section...

"fimath Object Syntaxes" on page 4-2

"Building fimath Object Constructors in a GUI" on page 4-4

fimath Object Syntaxes

The arithmetic attributes of a `fi` object are defined by a local `fimath` object, which is attached to that `fi` object. If a `fi` object has no local `fimath`, the following default fimath values are used:

```
            RoundMode: nearest
         OverflowMode: wrap
          ProductMode: FullPrecision
MaxProductWordLength: 128
              SumMode: FullPrecision
    MaxSumWordLength: 128
```

You can create `fimath` objects in Fixed-Point Toolbox software in one of two ways:

- You can use the `fimath` constructor function to create new `fimath` objects.
- You can use the `fimath` constructor function to copy an existing `fimath` object.

To get started, type

```
F = fimath
```

to create a `fimath` object.

```
F =

            RoundMode: nearest
         OverflowMode: wrap
          ProductMode: FullPrecision
MaxProductWordLength: 128
              SumMode: FullPrecision
```

```
      MaxSumWordLength: 128
```

To copy a `fimath` object, simply use assignment as in the following example:

```
F = fimath;
G = F;
isequal(F,G)

ans =

     1
```

The syntax

```
F = fimath(...'PropertyName',PropertyValue...)
```

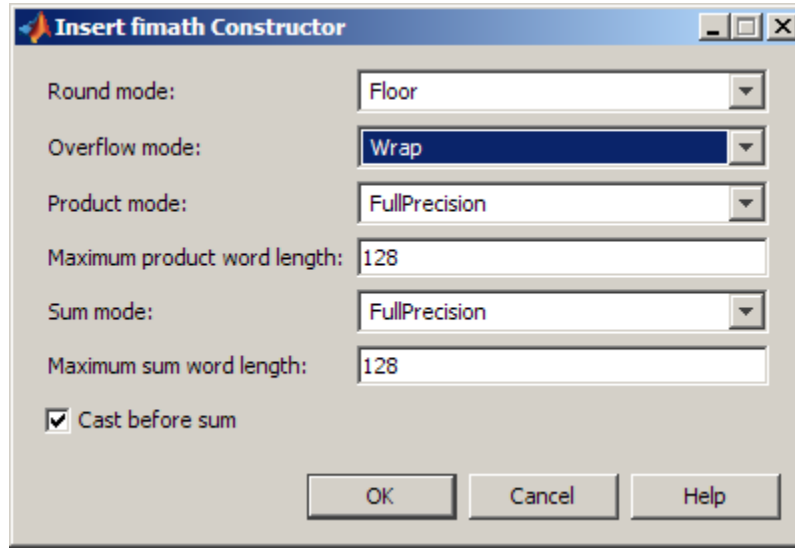
allows you to set properties for a `fimath` object at object creation with property name/property value pairs. Refer to "Setting fimath Properties at Object Creation" on page 4-7.

Building fimath Object Constructors in a GUI

When you are working with files in MATLAB, you can build your `fimath` object constructors using the **Insert fimath Constructor** dialog box. After specifying the properties of the `fimath` object in the dialog box, you can insert the prepopulated `fimath` object constructor string at a specific location in your file.

For example, to create a `fimath` object that uses convergent rounding and wraps on overflow, perform the following steps:

1. Open the **Insert fimath Constructor** dialog box by selecting **Tools > Fixed-Point Toolbox > Insert fimath Constructor** from the editor menu.
2. Use the edit boxes and drop-down menus to specify the following properties of the `fimath` object:
   - **Round mode** = `Floor`
   - **Overflow mode** = `Wrap`
   - **Product mode** = `FullPrecision`
   - **Maximum product word length** = `128`
   - **Sum mode** = `FullPrecision`
   - **Maximum sum word length** = `128`
   - **Cast before sum** = Checked



3 To insert the `fimath` object constructor string in your file, place your cursor at the desired location in the file. Then click **OK** on the **Insert fimath Constructor** dialog box. Clicking **OK** closes the **Insert fimath Constructor** dialog box and automatically populates the `fimath` object constructor string in your file:

```
6       F = fimath('RoundMode', 'Floor', ...
7           'OverflowMode', 'Wrap', ...
8           'ProductMode', 'FullPrecision', ...
9           'MaxProductWordLength', 128, ...
10          'SumMode', 'FullPrecision', ...
11          'MaxSumWordLength', 128, ...
12          'CastBeforeSum', true)
```

fimath Object Properties

In this section...
“Math, Rounding, and Overflow Properties” on page 4-6
“Setting fimath Object Properties” on page 4-7

Math, Rounding, and Overflow Properties

You can always write to the following properties of `fimath` objects:

Property	Description
`CastBeforeSum`	Whether both operands are cast to the sum data type before addition
`MaxProductWordLength`	Maximum allowable word length for the product data type
`MaxSumWordLength`	Maximum allowable word length for the sum data type
`OverflowMode`	Overflow-handling mode
`ProductBias`	Bias of the product data type
`ProductFixedExponent`	Fixed exponent of the product data type
`ProductFractionLength`	Fraction length, in bits, of the product data type
`ProductMode`	Defines how the product data type is determined
`ProductSlope`	Slope of the product data type
`ProductSlopeAdjustmentFactor`	Slope adjustment factor of the product data type
`ProductWordLength`	Word length, in bits, of the product data type
`RoundMode`	Rounding mode

Property	Description
SumBias	Bias of the sum data type
SumFixedExponent	Fixed exponent of the sum data type
SumFractionLength	Fraction length, in bits, of the sum data type
SumMode	Defines how the sum data type is determined
SumSlope	Slope of the sum data type
SumSlopeAdjustmentFactor	Slope adjustment factor of the sum data type
SumWordLength	Word length, in bits, of the sum data type

For details about these properties, refer to the Property Reference. To learn how to specify properties for `fimath` objects in Fixed-Point Toolbox software, refer to "Setting fimath Object Properties" on page 4-7.

Setting fimath Object Properties

- "Setting fimath Properties at Object Creation" on page 4-7
- "Using Direct Property Referencing with fimath" on page 4-8
- "Setting fimath Properties in the Model Explorer" on page 4-9

Setting fimath Properties at Object Creation

You can set properties of `fimath` objects at the time of object creation by including properties after the arguments of the `fimath` constructor function.

For example, to set the overflow mode to `saturate` and the rounding mode to `convergent`,

```
F = fimath('OverflowMode','saturate','RoundMode','convergent')

F =
```

```
            RoundMode: convergent
         OverflowMode: saturate
          ProductMode: FullPrecision
MaxProductWordLength: 128
              SumMode: FullPrecision
    MaxSumWordLength: 128
```

Using Direct Property Referencing with fimath

You can reference directly into a property for setting or retrieving `fimath` object property values using MATLAB structure-like referencing. You do so by using a period to index into a property by name.

For example, to get the `RoundMode` of `F`,

```
F.RoundMode

ans =

convergent
```

To set the `OverflowMode` of `F`,

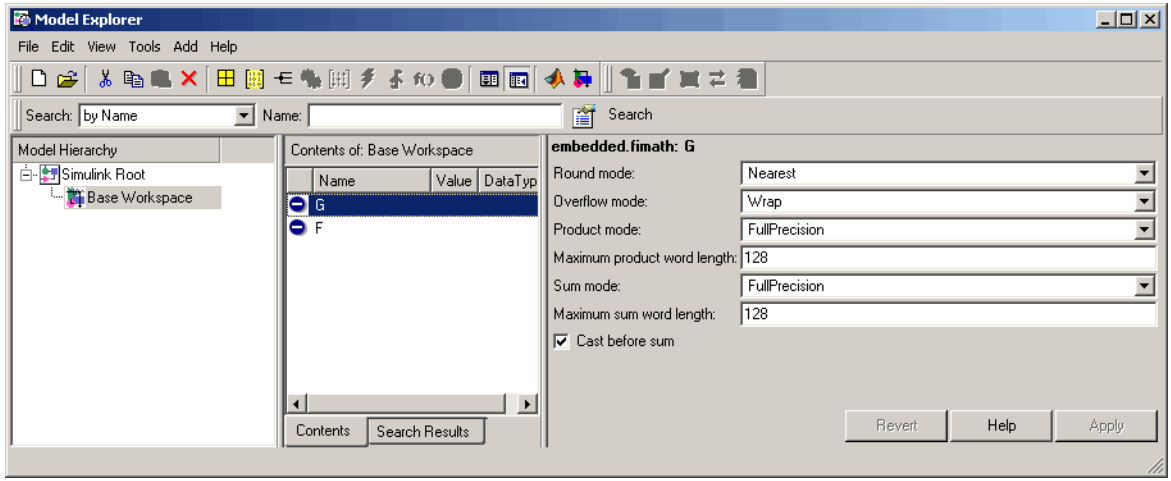
```
F.OverflowMode = 'wrap'

F =


            RoundMode: convergent
         OverflowMode: wrap
          ProductMode: FullPrecision
MaxProductWordLength: 128
              SumMode: FullPrecision
    MaxSumWordLength: 128
```

Setting fimath Properties in the Model Explorer

You can view and change the properties for any `fimath` object defined in the MATLAB workspace in the Model Explorer. Open the Model Explorer by selecting **View > Model Explorer** in any Simulink model, or by typing `daexplr` at the MATLAB command line.

The following figure shows the Model Explorer when you define the following `fimath` objects in the MATLAB workspace:

```
F = fimath

F =


             RoundMode: nearest
          OverflowMode: saturate
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

G = fimath('OverflowMode','wrap')

G =

             RoundMode: nearest
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```



Select the **Base Workspace** node in the **Model Hierarchy** pane to view the current objects in the **Contents** pane. When you select a `fimath` object in the **Contents** pane, you can view and change its properties in the **Dialog** pane.

For more information on working with the Model Explorer, see the following sections of the Fixed-Point Toolbox documentation:

- “Specifying Fixed-Point Parameters in the Model Explorer” on page 8-79
- “Sharing Models with Fixed-Point MATLAB Function Blocks” on page 8-83

Using fimath Properties to Perform Fixed-Point Arithmetic

In this section...

"fimath Rules for Fixed-Point Arithmetic" on page 4-11

"Binary-Point Arithmetic" on page 4-13

"[Slope Bias] Arithmetic" on page 4-17

fimath Rules for Fixed-Point Arithmetic

`fimath` properties define the rules for performing arithmetic operations on `fi` objects. The `fimath` properties that govern fixed-point arithmetic operations can come from a local `fimath` object or the `fimath` default values.

To determine whether a `fi` object has a local `fimath` object, use the `isfimathlocal` function.

The following sections discuss how `fi` objects with local `fimath` objects interact with `fi` objects without local fimath.

Binary Operations

In binary fixed-point operations such as `c = a + b`, the following rules apply:

- If both `a` and `b` have no local fimath, the operation uses default fimath values to perform the fixed-point arithmetic. The output `fi` object `c` also has no local fimath.
- If either `a` or `b` has a local `fimath` object, the operation uses that `fimath` object to perform the fixed-point arithmetic. The output `fi` object `c` has the same local `fimath` object as the input.

Unary Operations

In unary fixed-point operations such as `b = abs(a)`, the following rules apply:

- If `a` has no local fimath, the operation uses default fimath values to perform the fixed-point arithmetic. The output `fi` object `b` has no local fimath.

- If `a` has a local `fimath` object, the operation uses that `fimath` object to perform the fixed-point arithmetic. The output `fi` object `b` has the same local `fimath` object as the input `a`.

When you specify a `fimath` object in the function call of a unary fixed-point operation, the operation uses the `fimath` object you specify to perform the fixed-point arithmetic. For example, when you use a syntax such as `b = abs(a,F)` or `b = sqrt(a,F)`, the `abs` and `sqrt` operations use the `fimath` object `F` to compute intermediate quantities. The output `fi` object `b` always has no local fimath.

Concatenation Operations

In fixed-point concatenation operations such as `c = [a b]`, `c = [a;b]` and `c = bitconcat(a,b)`, the following rule applies:

- The `fimath` properties of the left-most `fi` object in the operation determine the `fimath` properties of the output `fi` object `c`.

For example, consider the following scenarios for the operation `d = [a b c]`:

- If `a` is a `fi` object with no local fimath, the output `fi` object `d` also has no local fimath.
- If `a` has a local `fimath` object, the output `fi` object `d` has the same local `fimath` object.
- If `a` is not a `fi` object, the output `fi` object `d` inherits the `fimath` properties of the next left-most `fi` object. For example, if `b` is a `fi` object with a local `fimath` object, the output `fi` object `d` has the same local `fimath` object as the input `fi` object `b`.

fimath Object Operations: add, mpy, sub

The output of the `fimath` object operations `add`, `mpy`, and `sub` always have no local fimath. The operations use the `fimath` object you specify in the function call, but the output `fi` object never has a local `fimath` object.

MATLAB Function Block Operations

Fixed-point operations performed with the MATLAB Function block use the same rules as fixed-point operations performed in MATLAB.

All input signals to the MATLAB Function block that you treat as `fi` objects associate with whatever you specify for the **MATLAB Function block fimath** parameter. When you set this parameter to `Same as MATLAB`, your `fi` objects do not have local fimath. When you set the **MATLAB Function block fimath** parameter to `Specify other`, you can define your own set of `fimath` properties for all `fi` objects in the MATLAB Function block to associate with. You can choose to treat only fixed-point input signals as `fi` objects or both fixed-point and integer input signals as `fi` objects. See "Using fimath Objects in MATLAB Function Blocks" on page 8-81.

Binary-Point Arithmetic

The `fimath` object encapsulates the math properties of Fixed-Point Toolbox software.

`fi` objects only have a local `fimath` object when you explicitly specify `fimath` properties in the `fi` constructor. When you use the `sfi` or `ufi` constructor or do not specify any `fimath` properties in the `fi` constructor, the resulting `fi` object does not have any local fimath and uses default fimath values.

```
a = fi(pi)

a =
    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

a.fimath
isfimathlocal(a)

ans =


             RoundMode: nearest
          OverflowMode: saturate
           ProductMode: FullPrecision
  MaxProductWordLength: 128
```

```
                SumMode: FullPrecision
      MaxSumWordLength: 128

ans =
     0
```

To perform arithmetic with +, -, .*, or * on two fi operands with local fimath objects, the local fimath objects must be identical. If one of the fi operands does not have a local fimath, the fimath properties of the two operands need not be identical. See "fimath Rules for Fixed-Point Arithmetic" on page 4-11 for more information.

```
a = fi(pi);
b = fi(8);
isequal(a.fimath, b.fimath)

ans =

     1

a + b

ans =

   11.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 19
        FractionLength: 13
```

To perform arithmetic with +, -, .*, or *, two fi operands must also have the same data type. For example, you can perform addition on two fi objects with data type double, but not on an object with data type double and one with data type single:

```
a = fi(3, 'DataType', 'double')

a =
```

```
     3

          DataTypeMode: Double

b = fi(27, 'DataType', 'double')

b =

    27

          DataTypeMode: Double

a + b

ans =

    30

          DataTypeMode: Double

c = fi(12, 'DataType', 'single')

c =

    12

          DataTypeMode: Single

a + c
??? Math operations are not allowed on FI objects with
  different data types.
```

Fixed-point `fi` object operands do not have to have the same scaling. You can perform binary math operations on a `fi` object with a fixed-point data type and a `fi` object with a scaled doubles data type. In this sense, the scaled double data type acts as a fixed-point data type:

```
a = fi(pi)

a =
```

```
    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

b = fi(magic(2), ...
'DataTypeMode', 'Scaled double: binary point scaling')

b =

     1     3
     4     2


          DataTypeMode: Scaled double: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 12

a + b

ans =

    4.1416    6.1416
    7.1416    5.1416


          DataTypeMode: Scaled double: binary point scaling
            Signedness: Signed
            WordLength: 18
        FractionLength: 13
```

Use the `divide` function to perform division with doubles, singles, or binary point-only scaling `fi` objects.

[Slope Bias] Arithmetic

Fixed-Point Toolbox software supports fixed-point arithmetic using the local `fimath` object or default fimath for all binary point-only signals. The toolbox also supports arithmetic for [Slope Bias] signals with the following restrictions:

- [Slope Bias] signals must be real.
- You must set the `SumMode` and `ProductMode` properties of the governing `fimath` to `'SpecifyPrecision'` for sum and multiply operations, respectively.
- You must set the `CastBeforeSum` property of the governing `fimath` to `'true'`.
- Fixed-Point Toolbox does not support the `divide` function for [Slope Bias] signals.

```
f = fimath('SumMode', 'SpecifyPrecision', ...
           'SumFractionLength', 16)

f =

                  RoundMode: nearest
                 OverflowMode: saturate
                  ProductMode: FullPrecision
         MaxProductWordLength: 128
                      SumMode: SpecifyPrecision
                 SumWordLength: 32
              SumFractionLength: 16
                  CastBeforeSum: true

a = fi(pi, 'fimath', f)

a =

    3.1416

                DataTypeMode: Fixed-point: binary point scaling
                  Signedness: Signed
```

```
                    WordLength: 16
                FractionLength: 13

                     RoundMode: nearest
                  OverflowMode: saturate
                   ProductMode: FullPrecision
            MaxProductWordLength: 128
                       SumMode: SpecifyPrecision
                  SumWordLength: 32
              SumFractionLength: 16
                  CastBeforeSum: true

b = fi(22, true, 16, 2^-8, 3, 'fimath', f)

b =

    22

        DataTypeMode: Fixed-point: slope and bias scaling
                  Signedness: Signed
                  WordLength: 16
                       Slope: 0.00390625
                        Bias: 3

                     RoundMode: nearest
                  OverflowMode: saturate
                   ProductMode: FullPrecision
            MaxProductWordLength: 128
                       SumMode: SpecifyPrecision
                  SumWordLength: 32
              SumFractionLength: 16
                  CastBeforeSum: true

a + b

ans =

   25.1416

                DataTypeMode: Fixed-point: binary point scaling
```

```
              Signedness: Signed
              WordLength: 32
          FractionLength: 16

               RoundMode: nearest
            OverflowMode: saturate
             ProductMode: FullPrecision
   MaxProductWordLength: 128
                SumMode: SpecifyPrecision
           SumWordLength: 32
      SumFractionLength: 16
          CastBeforeSum: true
```

Setting the `SumMode` and `ProductMode` properties to `SpecifyPrecision` are mutually exclusive except when performing the `*` operation between matrices. In this case, you must set both the `SumMode` and `ProductMode` properties to `SpecifyPrecision` for [Slope Bias] signals. Doing so is necessary because the `*` operation performs both sum and multiply operations to calculate the result.

Using fimath to Specify Rounding and Overflow Modes

Only rounding and overflow modes set prior to an operation with `fi` objects affect the outcome of those operations. Once you create a `fi` object in MATLAB, changing its rounding or overflow mode does not affect its value. For example, consider the `fi` objects `a` and `b`:

```
p = fipref('NumberDisplay', 'RealWorldValue',...
'NumericTypeDisplay', 'none', 'FimathDisplay', 'none');
T = numerictype('WordLength',8,'FractionLength',7);
F = fimath('RoundMode','floor','OverflowMode','wrap');
a = fi(1,T,F)

a =

    -1

b = fi(1,T)

b =

    0.9922
```

Because you create `a` with a `fimath` object `F` that has `OverflowMode` set to `wrap`, the value of `a` wraps to -1. Conversely, because you create `b` with the default `OverflowMode` value of `saturate`, its value saturates to 0.9922.

Now, assign the `fimath` object `F` to `b`:

```
b.fimath = F

b =

    0.9922
```

Because the assignment operation and corresponding overflow and saturation happened when you created `b`, its value does not change when you assign it the new `fimath` object `F`.

Note `fi` objects with no local fimath and created from a floating-point value always get constructed with a `RoundMode` of `nearest` and an `OverflowMode` of `saturate`. To construct `fi` objects with different `RoundMode` and `OverflowMode` properties, specify the desired `RoundMode` and `OverflowMode` properties in the `fi` constructor.

Using fimath to Share Arithmetic Rules

There are two ways of sharing `fimath` properties in Fixed-Point Toolbox software:

- "Using Default fimath Values to Share Arithmetic Rules " on page 4-22
- "Using Local fimath Objects to Share Arithmetic Rules" on page 4-22

Sharing `fimath` properties across `fi` objects ensures that the `fi` objects are using the same arithmetic rules and helps you avoid "mismatched `fimath`" errors.

Using Default fimath Values to Share Arithmetic Rules

You can ensure that your `fi` objects are all using the same `fimath` properties by not specifying any local fimath. To assure no local `fimath` is associated with a `fi` object, you can:

- Create a `fi` object using the `fi` constructor without specifying any `fimath` properties in the constructor call. For example:

  ```
  a = fi(pi)
  ```

- Create a `fi` object using the `sfi` or `ufi` constructor. All `fi` objects created with these constructors have no local fimath.

  ```
  b = sfi(pi)
  ```

- Use dot notation to remove a local `fimath` object from an existing `fi` object. For example:

  ```
  b = fi(pi, 'RoundMode', 'Fix')
  b.fimath = []
  ```

Using Local fimath Objects to Share Arithmetic Rules

You can also use a `fimath` object to define common arithmetic rules that you would like to use for multiple `fi` objects. You can then create your `fi` objects, using the same `fimath` object for each. To do so, you must also create a `numerictype` object to define a common data type and scaling. Refer to Chapter 6, "Working with numerictype Objects" for more information

on numerictype objects. The following example shows the creation of a numerictype object and fimath object, and then uses those objects to create two fi objects with the same numerictype and fimath attributes:

```
T = numerictype('WordLength', 32, 'FractionLength', 30)

T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 30

F = fimath('RoundMode', 'floor', 'OverflowMode', 'wrap')

F =


             RoundMode: floor
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128

a = fi(pi, T, F)

a =

   -0.8584


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 30

             RoundMode: floor
          OverflowMode: wrap
```

```
          ProductMode: FullPrecision
  MaxProductWordLength: 128
              SumMode: FullPrecision
      MaxSumWordLength: 128

b = fi(pi/2, T, F)

b =

    1.5708


         DataTypeMode: Fixed-point: binary point scaling
           Signedness: Signed
           WordLength: 32
       FractionLength: 30

            RoundMode: floor
         OverflowMode: wrap
          ProductMode: FullPrecision
  MaxProductWordLength: 128
              SumMode: FullPrecision
      MaxSumWordLength: 128
```

Using fimath ProductMode and SumMode

In this section...

"Example Setup" on page 4-25
"FullPrecision" on page 4-26
"KeepLSB" on page 4-27
"KeepMSB" on page 4-28
"SpecifyPrecision" on page 4-29

Example Setup

The examples in the sections of this topic show the differences among the four settings of the `ProductMode` and `SumMode` properties:

- `FullPrecision`
- `KeepLSB`
- `KeepMSB`
- `SpecifyPrecision`

To follow along, first set the following preferences:

```
p = fipref;
p.NumericTypeDisplay = 'short';
p.FimathDisplay = 'none';
p.LoggingMode = 'on';
F = fimath('OverflowMode','wrap','RoundMode','floor',...
  'CastBeforeSum',false);
warning off
format compact
```

Next, define `fi` objects `a` and `b`. Both have signed 8-bit data types. The fraction length gets chosen automatically for each `fi` object to yield the best possible precision:

```
a = fi(pi, true, 8)
a =
```

```
    3.1563
      s8,5

b = fi(exp(1), true, 8)
b =
    2.7188
      s8,5
```

FullPrecision

Now, set `ProductMode` and `SumMode` for `a` and `b` to `FullPrecision` and look at some results:

```
F.ProductMode = 'FullPrecision';
F.SumMode = 'FullPrecision';
a.fimath = F;
b.fimath = F;
a
a =
    3.1563   %011.00101
      s8,5

b
b =
    2.7188   %010.10111
      s8,5

a*b
ans =
    8.5811   %001000.1001010011
      s16,10

a+b
ans =
    5.8750   %0101.11100
      s9,5
```

In `FullPrecision` mode, the product word length grows to the sum of the word lengths of the operands. In this case, each operand has 8 bits, so the product word length is 16 bits. The product fraction length is the sum of the fraction lengths of the operands, in this case 5 + 5 = 10 bits.

The sum word length grows by one most significant bit to accommodate the possibility of a carry bit. The sum fraction length aligns with the fraction lengths of the operands, and all fractional bits are kept for full precision. In this case, both operands have 5 fractional bits, so the sum has 5 fractional bits.

KeepLSB

Now, set `ProductMode` and `SumMode` for `a` and `b` to `KeepLSB` and look at some results:

```
F.ProductMode = 'KeepLSB';
F.ProductWordLength = 12;
F.SumMode = 'KeepLSB';
F.SumWordLength = 12;
a.fimath = F;
b.fimath = F;
a
a =
    3.1563   %011.00101
      s8,5

b
b =
    2.7188   %010.10111
      s8,5

a*b
ans =
    0.5811   %00.1001010011
      s12,10

a+b
ans =
    5.8750   %0000101.11100
      s12,5
```

In `KeepLSB` mode, you specify the word lengths and the least significant bits of results are automatically kept. This mode models the behavior of integer operations in the C language.

The product fraction length is the sum of the fraction lengths of the operands. In this case, each operand has 5 fractional bits, so the product fraction length is 10 bits. In this mode, all 10 fractional bits are kept. Overflow occurs because the full-precision result requires 6 integer bits, and only 2 integer bits remain in the product.

The sum fraction length aligns with the fraction lengths of the operands, and in this model all least significant bits are kept. In this case, both operands had 5 fractional bits, so the sum has 5 fractional bits. The full-precision result requires 4 integer bits, and 7 integer bits remain in the sum, so no overflow occurs in the sum.

KeepMSB

Now, set `ProductMode` and `SumMode` for `a` and `b` to `KeepMSB` and look at some results:

```
F.ProductMode = 'KeepMSB';
F.ProductWordLength = 12;
F.SumMode = 'KeepMSB';
F.SumWordLength = 12;
a.fimath = F;
b.fimath = F;
a
a =
    3.1563   %011.00101
      s8,5

b
b =
    2.7188   %010.10111
      s8,5

a*b
ans =
    8.5781   %001000.100101
      s12,6

a+b
ans =
```

```
    5.8750   %0101.11100000
      s12,8
```

In `KeepMSB` mode, you specify the word lengths and the most significant bits of sum and product results are automatically kept. This mode models the behavior of many DSP devices where the product and sum are kept in double-wide registers, and the programmer chooses to transfer the most significant bits from the registers to memory after each operation.

The full-precision product requires `6` integer bits, and the fraction length of the product is adjusted to accommodate all `6` integer bits in this mode. No overflow occurs. However, the full-precision product requires `10` fractional bits, and only `6` are available. Therefore, precision is lost.

The full-precision sum requires `4` integer bits, and the fraction length of the sum is adjusted to accommodate all `4` integer bits in this mode. The full-precision sum requires only `5` fractional bits; in this case there are `8`, so there is no loss of precision.

SpecifyPrecision

Now set `ProductMode` and `SumMode` for `a` and `b` to `SpecifyPrecision` and look at some results:

```
F.ProductMode = 'SpecifyPrecision';
F.ProductWordLength = 8;
F.ProductFractionLength = 7;
F.SumMode = 'SpecifyPrecision';
F.SumWordLength = 8;
F.SumFractionLength = 7;
a.fimath = F;
b.fimath = F;
a
a =
    3.1563   %011.00101
      s8,5

b
b =
    2.7188   %010.10111
```

```
      s8,5

a*b
ans =
    0.5781   %0.1001010
      s8,7

a+b
ans =
   -0.1250   %1.1110000
      s8,7
```

In `SpecifyPrecision` mode, you must specify both word length and fraction length for sums and products. This example unwisely uses fractional formats for the products and sums, with `8`-bit word lengths and `7`-bit fraction lengths.

The full-precision product requires `6` integer bits, and the example specifies only `1`, so the product overflows. The full-precision product requires `10` fractional bits, and the example only specifies `7`, so there is precision loss in the product.

The full-precision sum requires `4` integer bits, and the example specifies only `1`, so the sum overflows. The full-precision sum requires `5` fractional bits, and the example specifies `7`, so there is no loss of precision in the sum.

fimath Object Functions

You can learn about the functions associated with `fimath` objects in the Function Reference.

5

Working with fipref Objects

- "Constructing fipref Objects" on page 5-2
- "fipref Object Properties" on page 5-3
- "Using fipref Objects to Set Display Preferences" on page 5-5
- "Using fipref Objects to Set Logging Preferences" on page 5-7
- "Using fipref Objects to Set Data Type Override Preferences" on page 5-12
- "fipref Object Functions" on page 5-15

Constructing fipref Objects

The `fipref` object defines the display and logging attributes for all `fi` objects. You can use the `fipref` constructor function to create a new object.

To get started, type

```
P = fipref
```

to create a default `fipref` object.

```
P =
          NumberDisplay: 'RealWorldValue'
    NumericTypeDisplay: 'full'
          FimathDisplay: 'full'
            LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'
```

The syntax

```
P = fipref(...'PropertyName','PropertyValue'...)
```

allows you to set properties for a `fipref` object at object creation with property name/property value pairs.

Your `fipref` settings persist throughout your MATLAB session. Use `reset(fipref)` to return to the default settings during your session. Use `savefipref` to save your display preferences for subsequent MATLAB sessions.

fipref Object Properties

In this section...

"Display, Data Type Override, and Logging Properties" on page 5-3

"Setting fipref Object Properties" on page 5-3

Display, Data Type Override, and Logging Properties

The following properties of `fipref` objects are always writable:

- `FimathDisplay` — Display options for the local `fimath` attributes of a `fi` object
- `DataTypeOverride` — Data type override options
- `LoggingMode` — Logging options for operations performed on `fi` objects
- `NumericTypeDisplay` — Display options for the numeric type attributes of a `fi` object
- `NumberDisplay` — Display options for the value of a `fi` object

These properties are described in detail in the Property Reference. To learn how to specify properties for `fipref` objects in Fixed-Point Toolbox software, refer to "Setting fipref Object Properties" on page 5-3.

Setting fipref Object Properties

Setting fipref Properties at Object Creation

You can set properties of `fipref` objects at the time of object creation by including properties after the arguments of the `fipref` constructor function. For example, to set `NumberDisplay` to `bin` and `NumericTypeDisplay` to `short`,

```
P = fipref('NumberDisplay', 'bin', ...
           'NumericTypeDisplay', 'short')

P =
         NumberDisplay: 'bin'
    NumericTypeDisplay: 'short'
```

```
         FimathDisplay: 'full'
           LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'
```

Using Direct Property Referencing with fipref

You can reference directly into a property for setting or retrieving `fipref` object property values using MATLAB structure-like referencing. You do this by using a period to index into a property by name.

For example, to get the `NumberDisplay` of `P`,

```
P.NumberDisplay

ans =

bin
```

To set the `NumericTypeDisplay` of `P`,

```
P.NumericTypeDisplay = 'full'

P =
          NumberDisplay: 'bin'
    NumericTypeDisplay: 'full'
          FimathDisplay: 'full'
            LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'
```

Using fipref Objects to Set Display Preferences

You use the `fipref` object to specify three aspects of the display of `fi` objects: the object value, the local `fimath` properties, and the `numerictype` properties.

For example, the following code shows the default `fipref` display for a `fi` object with a local `fimath` object:

```
a = fi(pi, 'RoundMode', 'floor', 'OverflowMode', 'wrap')

a =
    3.1415

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13

             RoundMode: floor
          OverflowMode: wrap
           ProductMode: FullPrecision
  MaxProductWordLength: 128
               SumMode: FullPrecision
      MaxSumWordLength: 128
```

The default `fipref` display for a `fi` object with no local fimath is as follows:

```
a = fi(pi)

a =

    3.1416


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
```

Next, change the `fipref` display properties:

```
P = fipref;
P.NumberDisplay = 'bin';
P.NumericTypeDisplay = 'short';
P.FimathDisplay = 'none'

P =
          NumberDisplay: 'bin'
    NumericTypeDisplay: 'short'
          FimathDisplay: 'none'
            LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'
a

a =
0110010010000111
      s16,13
```

For more information on the default `fipref` display, see “Display Settings” on page 1-7 in the Getting Started section of the Fixed-Point Toolbox User’s Guide.

Using fipref Objects to Set Logging Preferences

In this section...

"Logging Overflows and Underflows as Warnings" on page 5-7

"Accessing Logged Information with Functions" on page 5-9

Logging Overflows and Underflows as Warnings

Overflows and underflows are logged as warnings for all assignment, plus, minus, and multiplication operations when the `fipref` `LoggingMode` property is set to `on`. For example, try the following:

1. Create a signed `fi` object that is a vector of values from 1 to 5, with 8-bit word length and 6-bit fraction length.

   ```
   a = fi(1:5,1,8,6);
   ```

2. Define the `fimath` object associated with `a`, and indicate that you will specify the sum and product word and fraction lengths.

   ```
   F = a.fimath;
   F.SumMode = 'SpecifyPrecision';
   F.ProductMode = 'SpecifyPrecision';
   a.fimath = F;
   ```

3. Define the `fipref` object and turn on overflow and underflow logging.

   ```
   P = fipref;
   P.LoggingMode = 'on';
   ```

4. Suppress the `numerictype` and `fimath` displays.

   ```
   P.NumericTypeDisplay = 'none';
   P.FimathDisplay = 'none';
   ```

5. Specify the sum and product word and fraction lengths.

   ```
   a.SumWordLength = 16;
   a.SumFractionLength = 15;
   ```

```
a.ProductWordLength = 16;
a.ProductFractionLength = 15;
```

6 Warnings are displayed for overflows and underflows in assignment operations. For example, try:

```
a(1) = pi
Warning: 1 overflow occurred in the fi assignment operation.

a =

    1.9844    1.9844    1.9844    1.9844    1.9844

a(1) = double(eps(a))/10
Warning: 1 underflow occurred in the fi assignment operation.

a =

         0    1.9844    1.9844    1.9844    1.9844
```

7 Warnings are displayed for overflows and underflows in addition and subtraction operations. For example, try:

```
a+a
Warning: 12 overflows occurred in the fi + operation.

ans =

         0    1.0000    1.0000    1.0000    1.0000

a-a
Warning: 8 overflows occurred in the fi - operation.

ans =

     0     0     0     0     0
```

8 Warnings are displayed for overflows and underflows in multiplication operations. For example, try:

```
a.*a
Warning: 4 product overflows occurred in the fi .* operation.

ans =

         0    1.0000    1.0000    1.0000    1.0000

a*a'
Warning: 4 product overflows occurred in the fi * operation.
Warning: 3 sum overflows occurred in the fi * operation.

ans =

    1.0000
```

The final example above is a complex multiplication that requires both multiplication and addition operations. The warnings inform you of overflows and underflows in both.

Because overflows and underflows are logged as warnings, you can use the `dbstop` MATLAB function with the syntax

```
dbstop if warning
```

to find the exact lines in a file that are causing overflows or underflows.

Use

```
dbstop if warning fi:underflow
```

to stop only on lines that cause an underflow. Use

```
dbstop if warning fi:overflow
```

to stop only on lines that cause an overflow.

Accessing Logged Information with Functions

When the `fipref LoggingMode` property is set to `on`, you can use the following functions to return logged information about assignment and creation operations to the MATLAB command line:

- `maxlog` — Returns the maximum real-world value
- `minlog` — Returns the minimum value
- `noverflows` — Returns the number of overflows
- `nunderflows` — Returns the number of underflows

`LoggingMode` must be set to `on` before you perform any operation in order to log information about it. To clear the log, use the function `resetlog`.

For example, consider the following. First turn logging on, then perform operations, and then finally get information about the operations:

```
fipref('LoggingMode','on');
x = fi([-1.5 eps 0.5], true, 16, 15);
x(1) = 3.0;
maxlog(x)

ans =

      1.0000

minlog(x)

ans =
    -1

noverflows(x)

ans =

           2

nunderflows(x)

ans =

           1
```

Next, reset the log and request the same information again. Note that the functions return empty [], because logging has been reset since the operations were run:

```
resetlog(x)
maxlog(x)

ans =

     []

minlog(x)

ans =

     []

noverflows(x)

ans =

     []

nunderflows(x)

ans =

     []
```

Using fipref Objects to Set Data Type Override Preferences

In this section...

"Overriding the Data Type of fi Objects" on page 5-12

"Using Data Type Override to Help Set Fixed-Point Scaling" on page 5-13

Overriding the Data Type of fi Objects

Use the `fipref` `DataTypeOverride` property to override `fi` objects with singles, doubles, or scaled doubles. Data type override only occurs when the `fi` constructor function is called. Objects that are created while data type override is on have the overridden data type. They maintain that data type when data type override is later turned off. To obtain an object with a data type that is not the override data type, you must create an object when data type override is off:

```
p = fipref('DataTypeOverride', 'TrueDoubles')

p =

         NumberDisplay: 'RealWorldValue'
    NumericTypeDisplay: 'full'
         FimathDisplay: 'full'
           LoggingMode: 'Off'
      DataTypeOverride: 'TrueDoubles'

a = fi(pi)

a =

    3.1416

          DataTypeMode: Double

p = fipref('DataTypeOverride', 'ForceOff')

p =
```

```
          NumberDisplay: 'RealWorldValue'
    NumericTypeDisplay: 'full'
         FimathDisplay: 'full'
           LoggingMode: 'Off'
      DataTypeOverride: 'ForceOff'

a

a =

    3.1416

          DataTypeMode: Double

b = fi(pi)

b =

    3.1416

          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 13
```

Tip To reset the `fipref` object to its default values use `reset(fipref)` or `reset(p)`, where `p` is a `fipref` object. This is useful to ensure that data type override and logging are off.

Using Data Type Override to Help Set Fixed-Point Scaling

Choosing the scaling for the fixed-point variables in your algorithms can be difficult. In Fixed-Point Toolbox software, you can use a combination of data type override and min/max logging to help you discover the numerical ranges that your fixed-point data types need to cover. These ranges dictate the appropriate scalings for your fixed-point data types. In general, the procedure is

1. Implement your algorithm using fixed-point `fi` objects, using initial "best guesses" for word lengths and scalings.

2. Set the `fipref` `DataTypeOverride` property to `ScaledDoubles`, `TrueSingles`, or `TrueDoubles`.

3. Set the `fipref` `LoggingMode` property to `on`.

4. Use the `maxlog` and `minlog` functions to log the maximum and minimum values achieved by the variables in your algorithm in floating-point mode.

5. Set the `fipref` `DataTypeOverride` property to `ForceOff`.

6. Use the information obtained in step 4 to set the fixed-point scaling for each variable in your algorithm such that the full numerical range of each variable is representable by its data type and scaling.

   A detailed example of this process is shown in the Fixed-Point Toolbox Fixed-Point Data Type Override, Min/Max Logging, and Scaling demo.

fipref Object Functions

You can learn about the functions associated with `fipref` objects in the Function Reference.

6

Working with numerictype Objects

- "Constructing numerictype Objects" on page 6-2
- "numerictype Object Properties" on page 6-7
- "The numerictype Structure" on page 6-11
- "Using numerictype Objects to Share Data Type and Scaling Settings of fi objects" on page 6-14
- "numerictype Object Functions" on page 6-17

Constructing numerictype Objects

In this section...

"numerictype Object Syntaxes" on page 6-2

"Example: Constructing a numerictype Object with Property Name and Property Value Pairs" on page 6-3

"Example: Copying a numerictype Object" on page 6-4

"Example: Building numerictype Object Constructors in a GUI" on page 6-5

numerictype Object Syntaxes

`numerictype` objects define the data type and scaling attributes of `fi` objects, as well as Simulink signals and model parameters. You can create `numerictype` objects in Fixed-Point Toolbox software in one of two ways:

- You can use the `numerictype` constructor function to create a new object.
- You can use the `numerictype` constructor function to copy an existing `numerictype` object.

To get started, type

```
T = numerictype
```

to create a default `numerictype` object.

```
T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15
```

To see all of the `numerictype` object syntaxes, refer to the `numerictype` constructor function reference page.

The following examples show different ways of constructing `numerictype` objects. For more examples of constructing `numerictype` objects, see the "Examples" on the `numerictype` constructor function reference page.

Example: Constructing a numerictype Object with Property Name and Property Value Pairs

When you create a `numerictype` object using property name and property value pairs, Fixed-Point Toolbox software first creates a default `numerictype` object, and then, for each property name you specify in the constructor, assigns the corresponding value.

This behavior differs from the behavior that occurs when you use a syntax such as `T = numerictype(s,w)`, where you only specify the property values in the constructor. Using such a syntax results in no default `numerictype` object being created, and the `numerictype` object receives only the assigned property values that are specified in the constructor.

The following example shows how the property name/property value syntax creates a slightly different `numerictype` object than the property values syntax, even when you specify the same property values in both constructors.

To demonstrate this difference, suppose you want to create an unsigned `numerictype` object with a word length of `32` bits.

First, create the `numerictype` object using property name/property value pairs.

```
T1 = numerictype('signed',0,'wordlength',32)

T1 =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Unsigned
            WordLength: 32
        FractionLength: 15
```

The numerictype object T1 has the same DataTypeMode and FractionLength as a default numerictype object, but the WordLength and Signed properties are overwritten with the values you specified.

Now, create another unsigned 32 bit numerictype object, but this time specify only property values in the constructor.

```
T2 = numerictype(0,32)

T2 =


          DataTypeMode: Fixed-point: unspecified scaling
            Signedness: Unsigned
            WordLength: 32
```

Unlike T1, T2 only has the property values you specified. The DataTypeMode of T2 is Fixed-Point: unspecified scaling, so no fraction length is assigned.

fi objects cannot have unspecified numerictype properties. Thus, all unspecified numerictype object properties become specified at the time of fi object creation.

Example: Copying a numerictype Object

To copy a numerictype object, simply use assignment as in the following example:

```
T = numerictype;
U = T;
isequal(T,U)

ans =

     1
```

Example: Building numerictype Object Constructors in a GUI

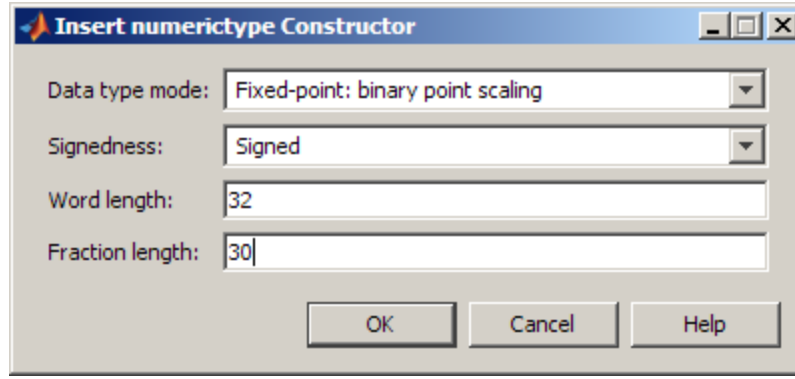
When you are working with files in MATLAB, you can build your `numerictype` object constructors using the **Insert numerictype Constructor** dialog box. After specifying the properties of the `numerictype` object in the dialog box, you can insert the prepopulated `numerictype` object constructor string at a specific location in your file.

For example, to create a signed `numerictype` object with binary-point scaling, a word length of 32 bits and a fraction length of 30 bits, perform the following steps:

1. Open the **Insert numerictype Constructor** dialog box by selecting **Tools > Fixed-Point Toolbox > Insert numerictype Constructor** from the editor menu.

2. Use the edit boxes and drop-down menus to specify the following properties of the `numerictype` object:

   - **Data type mode** = `Fixed-point:  binary point scaling`
   - **Signedness** = `Signed`
   - **Word length** = `32`
   - **Fraction length** = `30`



3. To insert the `numerictype` object constructor string in your file, place your cursor at the desired location in the file, and click **OK** on the **Insert**

numerictype Constructor dialog box. Clicking **OK** closes the **Insert numerictype Constructor** dialog box and automatically populates the `numerictype` object constructor string in your file:

```
5     T = numerictype(1, 32, 30)
```

numerictype Object Properties

In this section...

"Data Type and Scaling Properties" on page 6-7

"Setting numerictype Object Properties" on page 6-8

Data Type and Scaling Properties

All properties of a `numerictype` object are writable. However, the `numerictype` properties of a `fi` object become read only after the `fi` object has been created. Any `numerictype` properties of a `fi` object that are unspecified at the time of `fi` object creation are automatically set to their default values. The properties of a `numerictype` object are:

- `Bias` — Bias
- `DataType` — Data type category
- `DataTypeMode` — Data type and scaling mode
- `FixedExponent` — Fixed-point exponent
- `SlopeAdjustmentFactor` — Slope adjustment
- `FractionLength` — Fraction length of the stored integer value, in bits
- `Scaling` — Fixed-point scaling mode
- `Signed` — Signed or unsigned
- `Signedness` — Signed, unsigned, or auto
- `Slope` — Slope
- `WordLength` — Word length of the stored integer value, in bits

These properties are described in detail in the Property Reference. To learn how to specify properties for `numerictype` objects in Fixed-Point Toolbox software, refer to "Setting numerictype Object Properties" on page 6-8.

Setting numerictype Object Properties

Setting numerictype Properties at Object Creation

You can set properties of `numerictype` objects at the time of object creation by including properties after the arguments of the `numerictype` constructor function.

For example, to set the word length to 32 bits and the fraction length to 30 bits,

```
T = numerictype('WordLength', 32, 'FractionLength', 30)

T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 30
```

Using Direct Property Referencing with numerictype Objects

You can reference directly into a property for setting or retrieving `numerictype` object property values using MATLAB structure-like referencing. You do this by using a period to index into a property by name.

For example, to get the word length of `T`,

```
T.WordLength

ans =

32
```

To set the fraction length of `T`,

```
T.FractionLength = 31

T =
```

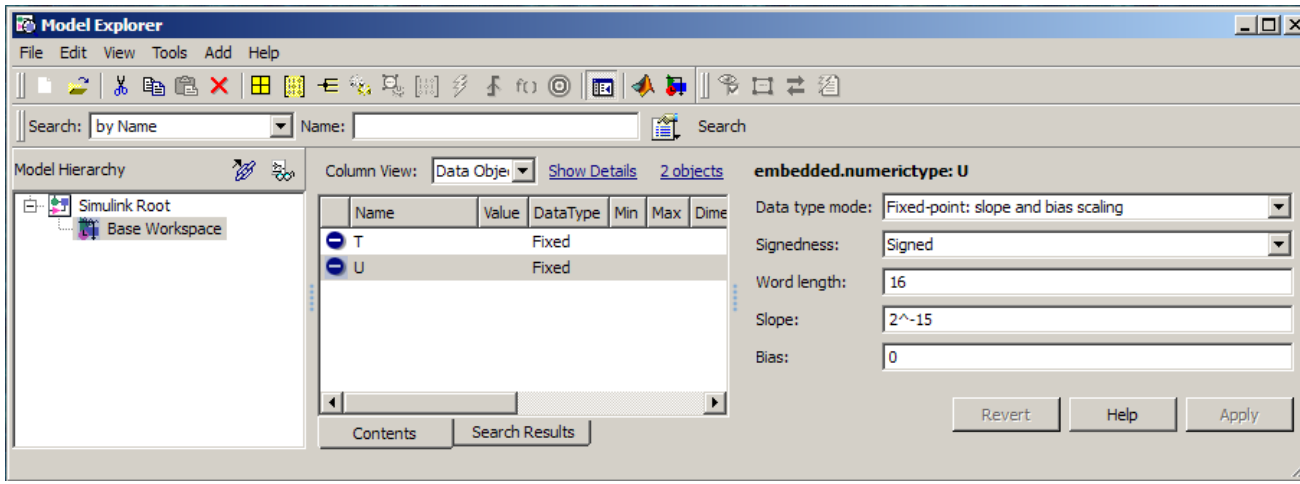
```
          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 31
```

Setting numerictype Properties in the Model Explorer

You can view and change the properties for any `numerictype` object defined in the MATLAB workspace in the Model Explorer. Open the Model Explorer by selecting **View** > **Model Explorer** in any Simulink model, or by typing `daexplr` at the MATLAB command line.

The figure below shows the Model Explorer when you define the following `numerictype` objects in the MATLAB workspace:

```
T = numerictype

T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15

U = numerictype('DataTypeMode', 'Fixed-point: slope and bias')

U =


          DataTypeMode: Fixed-point: slope and bias scaling
            Signedness: Signed
            WordLength: 16
                 Slope: 2^-15
                  Bias: 0
```



Select the **Base Workspace** node in the **Model Hierarchy** pane to view the current objects in the **Contents** pane. When you select a `numerictype` object in the **Contents** pane, you can view and change its properties in the **Dialog** pane.

The numerictype Structure

In this section...

"Valid Values for numerictype Structure Properties" on page 6-11

"Properties That Affect the Slope" on page 6-13

"Stored Integer Value and Real World Value" on page 6-13

Valid Values for numerictype Structure Properties

The `numerictype` object contains all the data type and scaling attributes of a fixed-point object. The `numerictype` object behaves like any MATLAB structure, except that it only lets you set valid values for defined fields. The following table shows the possible settings of each field of the structure.

Note When you create a `fi` object, any unspecified field of the `numerictype` object reverts to its default value. Thus, if the `DataTypeMode` is set to `unspecified scaling`, it defaults to `binary point scaling` when the `fi` object is created. If the `Signedness` property of the `numerictype` object is set to `Auto`, it defaults to `Signed` when the `fi` object is created.

DataTypeMode	DataType	Scaling	Signedness	Word-Length	Fraction-Length	Slope	Bias
Fixed-point data types							
`Fixed-point: binary point scaling`	`Fixed`	`BinaryPoint`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	Positive or negative integer	2^(-fraction length)	0
`Fixed-point: slope and bias scaling`	`Fixed`	`SlopeBias`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	`N/A`	Any floating-point number	Any floating-point number

DataTypeMode	DataType	Scaling	Signedness	Word-Length	Fraction-Length	Slope	Bias
`Fixed-point: unspecified scaling`	`Fixed`	`Unspecified`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	`N/A`	`N/A`	`N/A`
Scaled double data types							
`Scaled double: binary point scaling`	`ScaledDouble`	`BinaryPoint`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	Positive or negative integer	2^(-fraction length)	0
`Scaled double: slope and bias scaling`	`ScaledDouble`	`SlopeBias`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	`N/A`	Any floating-point number	Any floating-point number
`Scaled double: unspecified scaling`	`ScaledDouble`	`Unspecified`	`Signed` `Unsigned` `Auto`	Positive integer from 1 to 65,536	`N/A`	`N/A`	`N/A`
Built-in data types							
`Double`	`double`	`N/A`	`1` `true`	`64`	`0`	`1`	`0`
`Single`	`single`	`N/A`	`1` `true`	`32`	`0`	`1`	`0`
`Boolean`	`boolean`	`N/A`	`0` `false`	`1`	`0`	`1`	`0`

You cannot change the `numerictype` properties of a `fi` object after `fi` object creation.

Properties That Affect the Slope

The **Slope** field of the `numerictype` structure is related to the `SlopeAdjustmentFactor` and `FixedExponent` properties by

$$slope = slope\ adjustment\ factor \times 2^{fixed\ exponent}$$

The `FixedExponent` and `FractionLength` properties are related by

$$fixed\ exponent = -fraction\ length$$

If you set the `SlopeAdjustmentFactor`, `FixedExponent`, or `FractionLength` property, the **Slope** field is modified.

Stored Integer Value and Real World Value

The `numerictype` `StoredIntegerValue` and `RealWorldValue` properties are related according to

$$real\text{-}world\ value = stored\ integer\ value \times 2^{-fraction\ length}$$

which is equivalent to

$$real\text{-}world\ value = stored\ integer\ value \times (slope\ adjustment\ factor \times 2^{fixed\ exponent}) + bias$$

If any of these properties is updated, the others are modified accordingly.

Using numerictype Objects to Share Data Type and Scaling Settings of fi objects

You can use a `numerictype` object to define common data type and scaling rules that you would like to use for many `fi` objects. You can then create multiple `fi` objects, using the same `numerictype` object for each.

Example 1

In the following example, you create a `numerictype` object `T` with word length `32` and fraction length `28`. Next, to ensure that your `fi` objects have the same `numerictype` attributes, create `fi` objects `a` and `b` using your `numerictype` object `T`.

```
format long g
T = numerictype('WordLength',32,'FractionLength',28)

T =


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 28

a = fi(pi,T)

a =

           3.1415926553309


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 28

b = fi(pi/2, T)
```

```
b =

           1.5707963258028


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 28
```

Example 2

In this example, start by creating a `numerictype` object `T` with [Slope Bias] scaling. Next, use that object to create two `fi` objects, `c` and `d` with the same `numerictype` attributes:

```
T = numerictype('scaling','slopebias','slope', 2^2, 'bias', 0)

T =

          DataTypeMode: Fixed-point: slope and bias scaling
            Signedness: Signed
            WordLength: 16
                 Slope: 2^2
                  Bias: 0

c = fi(pi, T)

c =

     4

          DataTypeMode: Fixed-point: slope and bias scaling
            Signedness: Signed
            WordLength: 16
                 Slope: 2^2
                  Bias: 0

d = fi(pi/2, T)
```

```
d =

     0

          DataTypeMode: Fixed-point: slope and bias scaling
            Signedness: Signed
            WordLength: 16
                 Slope: 2^2
                  Bias: 0
```

numerictype Object Functions

You can learn about the functions associated with `numerictype` objects in the Function Reference.

7

Working with quantizer Objects

- "Constructing quantizer Objects" on page 7-2
- "quantizer Object Properties" on page 7-3
- "Quantizing Data with quantizer Objects" on page 7-4
- "Transformations for Quantized Data" on page 7-6
- "quantizer Object Functions" on page 7-7

Constructing quantizer Objects

You can use `quantizer` objects to quantize data sets. You can create `quantizer` objects in Fixed-Point Toolbox software in one of two ways:

- You can use the `quantizer` constructor function to create a new object.
- You can use the `quantizer` constructor function to copy a `quantizer` object.

To create a `quantizer` object with default properties, type

```
q = quantizer

q =

        DataMode = fixed
       RoundMode = floor
    OverflowMode = saturate
          Format = [16  15]
```

To copy a `quantizer` object, simply use assignment as in the following example:

```
q = quantizer;
r = q;
isequal(q,r)

ans =

     1
```

A listing of all the properties of the `quantizer` object `q` you just created is displayed along with the associated property values. All property values are set to defaults when you construct a `quantizer` object this way. See "quantizer Object Properties" on page 7-3 for more details.

quantizer Object Properties

The following properties of `quantizer` objects are always writable:

- `DataMode` — Type of arithmetic used in quantization
- `Format` — Data format of a `quantizer` object
- `OverflowMode` — Overflow-handling mode
- `RoundMode` — Rounding mode

See the Property Reference for more details about these properties, including their possible values.

For example, to create a fixed-point `quantizer` object with

- The `Format` property value set to `[16,14]`
- The `OverflowMode` property value set to `'saturate'`
- The `RoundMode` property value set to `'ceil'`

type

```
q = quantizer('datamode','fixed','format',[16,14],...
    'overflowmode','saturate','roundmode','ceil')
```

You do not have to include `quantizer` object property names when you set `quantizer` object property values.

For example, you can create `quantizer` object `q` from the previous example by typing

```
q = quantizer('fixed',[16,14],'saturate','ceil')
```

Note You do not have to include default property values when you construct a `quantizer` object. In this example, you could leave out `'fixed'` and `'saturate'`.

Quantizing Data with quantizer Objects

You construct a `quantizer` object to specify the quantization parameters to use when you quantize data sets. You can use the `quantize` function to quantize data according to a `quantizer` object's specifications.

Once you quantize data with a `quantizer` object, its state values might change.

The following example shows

- How you use `quantize` to quantize data
- How quantization affects `quantizer` object states
- How you reset `quantizer` object states to their default values using `reset`

1 Construct an example data set and a `quantizer` object.

```
format long g
randn('state',0);
x = randn(100,4);
q = quantizer([16,14]);
```

2 Retrieve the values of the `maxlog` and `noverflows` states.

```
q.maxlog

ans =

    -1.79769313486232e+308

q.noverflows

ans =

     0
```

Note that `maxlog` is equal to `-realmax`, which indicates that the quantizer `q` is in a reset state.

3 Quantize the data set according to the `quantizer` object's specifications.

```
y = quantize(q,x);
Warning: 15 overflows.
```

4 Check the values of `maxlog` and `noverflows`.

```
q.maxlog

ans =

           1.99993896484375

q.noverflows

ans =

    15
```

Note that the maximum logged value was taken after quantization, that is, `q.maxlog == max(y)`.

5 Reset the `quantizer` states and check them.

```
reset(q)
q.maxlog

ans =

    -1.79769313486232e+308

q.noverflows

ans =

     0
```

Transformations for Quantized Data

You can convert data values from numeric to hexadecimal or binary according to a `quantizer` object's specifications.

Use

- `num2bin` to convert data to binary
- `num2hex` to convert data to hexadecimal
- `hex2num` to convert hexadecimal data to numeric
- `bin2num` to convert binary data to numeric

For example,

```
q = quantizer([3 2]);
x = [0.75   -0.25
     0.50   -0.50
     0.25   -0.75
       0      -1 ];
b = num2bin(q,x)

b =
011
010
001
000
111
110
101
100
```

produces all two's complement fractional representations of 3-bit fixed-point numbers.

quantizer Object Functions

You can learn about the functions associated with `quantizer` objects in the Function Reference.

8

Code Acceleration and Code Generation from MATLAB for Fixed-Point Algorithms

- "What Are Code Acceleration and Code Generation from MATLAB?" on page 8-3
- "Requirements for Generating MEX Files from MATLAB Algorithms" on page 8-4
- "Functions Supported for Code Acceleration and Code Generation from MATLAB" on page 8-5
- "Workflow for Code Acceleration and Code Generation from MATLAB for Fixed-Point Algorithms" on page 8-15
- "Setting Up a Supported C Compiler to Generate MEX Functions" on page 8-16
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- "Defining Input Properties Programmatically in the MATLAB File" on page 8-64
- "Controlling Run-Time Checks" on page 8-73
- "MATLAB® Coder™" on page 8-76
- "MATLAB Function Block" on page 8-77

What Are Code Acceleration and Code Generation from MATLAB?

In many cases, you may want your code to run faster and more efficiently. *Code acceleration* provides optimizations for accelerating fixed-point algorithms through MEX file generation. In Fixed-Point Toolbox the `fiaccel` function converts your MATLAB code to a MEX function and can greatly accelerate the execution speed of your fixed-point algorithms.

Code generation creates efficient, production-quality C/C++ code for desktop and embedded applications. There are several ways to use Fixed-Point Toolbox software to generate C/C++ code.

Use...	To...	Requires...	See...
MATLAB Coder™ (`codegen`) function	Automatically convert MATLAB code to C/C++ code	MATLAB Coder code generation software license	"Generating C Code from MATLAB Code at the Command Line" in the MATLAB Coder documentation
MATLAB Function	Use MATLAB code in your Simulink models that generate embeddable C/C++ code	Simulink license	"Using the MATLAB Function Block" in the Simulink documentation

MATLAB code generation supports variable-size arrays and matrices with known upper bounds. To learn more about using variable-size signals, see "What Is Variable-Size Data?" in the Code Generation for MATLAB documentation.

Requirements for Generating MEX Files from MATLAB Algorithms

You use the `fiaccel` function to generate MEX code from a MATLAB algorithm. The algorithm must meet these requirements:

- Must be a MATLAB function, not a script
- Must meet the requirements listed on the `fiaccel` reference page
- Does not call custom C code using any of the following constructs:
  - `coder.ceval`
  - `coder.ref`
  - `coder.rref`
  - `coder.wref`

Functions Supported for Code Acceleration and Code Generation from MATLAB

In addition to any function-specific limitations listed in the table, the following general limitations always apply to the use of Fixed-Point Toolbox functions in generated code or with `fiaccel`:

- `fipref` and `quantizer` objects are not supported.
- Dot notation is only supported for getting the values of `fimath` and `numerictype` properties. Dot notation is not supported for `fi` objects, and it is not supported for setting properties.
- Word lengths greater than 128 bits are not supported.
- You cannot change the `fimath` or `numerictype` of a given variable after that variable has been created.
- The `boolean` and `ScaledDouble` values of the `DataTypeMode` and `DataType` properties are not supported.
- For all `SumMode` property settings other than `FullPrecision`, the `CastBeforeSum` property must be set to `true`.
- The `numel` function returns the number of elements of `fi` objects in the generated code.
- When you compile code containing `fi` objects with nontrivial slope and bias scaling, you may see different results in generated code than you achieve by running the same code in MATLAB.
- All general limitations of C/C++ code generated from MATLAB apply. See "MATLAB Language Features Not Supported for Code Generation" for more information.

Function	Remarks/Limitations
`abs`	N/A
`add`	N/A
`all`	N/A
`any`	N/A

Function	Remarks/Limitations
`bitand`	Not supported for slope-bias scaled `fi` objects.
`bitandreduce`	N/A
`bitcmp`	N/A
`bitconcat`	N/A
`bitget`	N/A
`bitor`	Not supported for slope-bias scaled `fi` objects.
`bitorreduce`	N/A
`bitreplicate`	N/A
`bitrol`	N/A
`bitror`	N/A
`bitset`	N/A
`bitshift`	N/A
`bitsliceget`	N/A
`bitsll`	N/A
`bitsra`	N/A
`bitsrl`	N/A
`bitxor`	Not supported for slope-bias scaled `fi` objects.
`bitxorreduce`	N/A
`ceil`	N/A
`complex`	N/A
`conj`	N/A

Function	Remarks/Limitations
`conv`	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`. • For variable-sized signals, you may see different results between generated code and MATLAB. - In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`. - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
`convergent`	N/A
`cordicabs`	Variable-size signals are not supported.
`cordicangle`	Variable-size signals are not supported.
`cordicatan2`	Variable-size signals are not supported.
`cordiccart2pol`	Variable-size signals are not supported.
`cordiccexp`	Variable-size signals are not supported.
`cordiccos`	Variable-size signals are not supported.
`cordicpol2cart`	Variable-size signals are not supported.
`cordicrotate`	Variable-size signals are not supported.
`cordicsin`	Variable-size signals are not supported.
`cordicsincos`	Variable-size signals are not supported.
`ctranspose`	N/A
`diag`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`disp`	—

Function	Remarks/Limitations
`divide`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • Complex and imaginary divisors are not supported. • Code generation in MATLAB does not support the syntax `T.divide(a,b)`.
`double`	N/A
`end`	N/A
`eps`	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and `fi` double signals.
`eq`	Not supported for fixed-point signals with different biases.
`fi`	• Use to create a fixed-point constant or variable in the generated code. • The default constructor syntax without any input arguments is not supported. • The syntax `fi('PropertyName',PropertyValue...)` is not supported. To use property name/property value pairs, you must first specify the value `v` of the `fi` object as in `fi(v,'PropertyName',PropertyValue...)`. • Works for all input values when complete `numerictype` information of the `fi` object is provided. • Works only for constant input values (value of input must be known at compile time) when complete `numerictype` information of the `fi` object is not specified.

Function	Remarks/Limitations
	• `numerictype` object information must be available for nonfixed-point Simulink inputs.
`filter`	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
`fimath`	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned a `fimath` object. You define this object in the MATLAB Function block dialog in the Model Explorer. • Use to create `fimath` objects in the generated code.
`fix`	N/A
`floor`	N/A
`ge`	Not supported for fixed-point signals with different biases.
`get`	The syntax `structure = get(o)` is not supported.
`getlsb`	N/A
`getmsb`	N/A
`gt`	Not supported for fixed-point signals with different biases.
`horzcat`	N/A
`imag`	N/A
`int8`, `int16`, `int32`	N/A
`iscolumn`	N/A
`isempty`	N/A
`isequal`	N/A
`isfi`	N/A
`isfimath`	N/A
`isfimathlocal`	N/A

Function	Remarks/Limitations
`isfinite`	N/A
`isinf`	N/A
`isnan`	N/A
`isnumeric`	N/A
`isnumerictype`	N/A
`isreal`	N/A
`isrow`	N/A
`isscalar`	N/A
`issigned`	N/A
`isvector`	N/A
`le`	Not supported for fixed-point signals with different biases.
`length`	N/A
`logical`	N/A
`lowerbound`	N/A
`lsb`	• Supported for scalar fixed-point signals only. • Supported for scalar, vector, and matrix, `fi` single and double signals.
`lt`	Not supported for fixed-point signals with different biases.
`max`	N/A
`mean`	N/A
`median`	N/A
`min`	N/A
`minus`	Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.

Function	Remarks/Limitations

`mpower`	• The exponent input, *k*, must be constant; that is, its value must be known at compile time.
	• Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.
	• For variable-sized signals, you may see different results between the generated code and MATLAB.
	  - In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`.
	  - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when the first input, *a*, is nonscalar. However, when *a* is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.

`mpy`	When you provide complex inputs to the `mpy` function inside of a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`mrdivide`	N/A
`mtimes`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`. • For variable-sized signals, you may see different results between the generated code and MATLAB.

Function	Remarks/Limitations
	- In the generated code, the output for variable-sized signals is always computed using the `SumMode` property of the governing `fimath`. - In MATLAB, the output for variable-sized signals is computed using the `SumMode` property of the governing `fimath` when both inputs are nonscalar. However, if either input is a scalar, MATLAB computes the output using the `ProductMode` of the governing `fimath`.
`ndims`	N/A
`ne`	Not supported for fixed-point signals with different biases.
`nearest`	N/A
`numberofelements`	`numberofelements` and `numel` both work the same as MATLAB `numel` for `fi` objects in the generated code.
`numerictype`	• Fixed-point signals coming in to a MATLAB Function block from Simulink are assigned a `numerictype` object that is populated with the signal's data type and scaling information. • Returns the data type when the input is a nonfixed-point signal. • Use to create `numerictype` objects in generated code.
`permute`	N/A
`plus`	Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object.
`pow2`	N/A
`power`	The exponent input, *k*, must be constant; that is, its value must be known at compile time.
`range`	N/A

Function	Remarks/Limitations
`rdivide`	N/A
`real`	N/A
`realmax`	N/A
`realmin`	N/A
`reinterpretcast`	N/A
`repmat`	N/A
`rescale`	N/A
`reshape`	N/A
`round`	N/A
`sfi`	N/A
`sign`	N/A
`single`	N/A
`size`	N/A
`sort`	N/A
`sqrt`	• Complex and [Slope Bias] inputs error out. • Negative inputs yield a 0 result.
`storedInteger`	N/A
`storedIntegerToDouble`	N/A
`sub`	N/A
`subsasgn`	N/A
`subsref`	N/A
`sum`	Variable-sized inputs are only supported when the `SumMode` property of the governing `fimath` is set to `Specify precision` or `Keep LSB`.

Function	Remarks/Limitations
`times`	• Any non-`fi` input must be constant; that is, its value must be known at compile time so that it can be cast to a `fi` object. • When you provide complex inputs to the `times` function inside of a MATLAB Function block, you must declare the input as complex before running the simulation. To do so, go to the **Ports and data manager** and set the **Complexity** parameter for all known complex inputs to `On`.
`transpose`	N/A
`tril`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`triu`	If supplied, the index, *k*, must be a real and scalar integer value that is not a `fi` object.
`ufi`	N/A
`uint8`, `uint16`, `uint32`	N/A
`uminus`	N/A
`uplus`	N/A
`upperbound`	N/A
`vertcat`	N/A

Workflow for Code Acceleration and Code Generation from MATLAB for Fixed-Point Algorithms

Step	Action	Details
1	Set up your C compiler.	See "Setting Up a Supported C Compiler to Generate MEX Functions" on page 8-16
2	Set up your file infrastructure.	See "Setting Up File Infrastructure and Paths" on page 8-22.
3	Make your MATLAB algorithm suitable for code generation	See "Best Practices for Accelerating Fixed-Point MATLAB Code" on page 8-49.
4	Set compilation options.	See "Setting MEX Compilation Options" on page 8-29
5	Specify properties of primary function inputs.	See "Specifying Properties of Primary Function Inputs" on page 8-37.
6	Run `fiaccel` with the appropriate command-line options.	See "Recommended Compilation Options for fiaccel" on page 8-49

Setting Up a Supported C Compiler to Generate MEX Functions

Set up your C compiler by running `mex -setup`, as described in the documentation for `mex` in the MATLAB Function Reference. You must run this command even if you use the default C compiler that comes with MATLAB for Windows® platforms. You can also use `mex` to choose and configure a different C compiler, as described in "What You Need to Build MEX-Files" in the MATLAB External Interfaces documentation.

You can use the following compilers to generate MEX functions with `fiaccel`:

- Lcc-win32 C 2.4.1
- Microsoft® Visual C++® 2008 Express
- Microsoft Visual C++ 2005
- Microsoft Visual C++ 6.0
- Open WATCOM C++ 1.7
- GCC

Using fiaccel

In this section...
"Speeding Up Fixed-Point Execution with the fiaccel Function" on page 8-17
"Running fiaccel" on page 8-17
"Generated Files and Locations" on page 8-18
"Using Data Type Override with fiaccel" on page 8-21

Speeding Up Fixed-Point Execution with the fiaccel Function

You can convert fixed-point MATLAB code to MEX functions using `fiaccel`. The generated MEX functions contain optimizations to automatically accelerate fixed-point algorithms to compiled C/C++ code speed in MATLAB. The `fiaccel` function can greatly increase the execution speed of your algorithms.

Running fiaccel

The basic command is:

```
fiaccel M_fcn
```

By default, `fiaccel` performs the following actions:

- Searches for the function *`M_fcn`* stored in the file *`M_fcn`*`.m` as specified in "Compile Path Search Order" on page 8-22.
- Compiles *`M_fcn`* to MEX code.
- If there are no errors or warnings, generates a platform-specific MEX file in the current folder, using the naming conventions described in "File Naming Conventions" on page 8-52.
- If there are errors, does not generate a MEX file, but produces an error report in a default output folder, as described in "Generated Files and Locations" on page 8-18.

- If there are warnings, but no errors, generates a platform-specific MEX file in the current folder, but does report the warnings.

You can modify this default behavior by specifying one or more compiler options with `fiaccel`, separated by spaces on the command line.

Generated Files and Locations

`fiaccel` generates files in the following locations:

Generates:	In:
Platform-specific MEX files	Current folder
HTML reports (if errors or warnings occur during compilation)	Default output folder: `fiaccel/mex/M_fcn_name/html`

You can change the name and location of generated files by using the options `-o` and `-d` when you run `fiaccel`.

In this example, you will use the `fiaccel` function to compile different parts of a simple algorithm. By comparing the run times of the two cases, you will see the benefits and best use of the `fiaccel` function.

Example: Comparing Run Times When Accelerating Different Algorithm Parts

The algorithm used throughout this example replicates the functionality of the MATLAB `sum` function, which sums the columns of a matrix. To see the algorithm, type `open fi_matrix_column_sum.m` at the MATLAB command line.

```
function B = fi_matrix_column_sum(A)
% Sum the columns of matrix A.
%#codegen
    [m,n] = size(A);
    w = get(A,'WordLength') + ceil(log2(m));
    f = get(A,'FractionLength');
    B = fi(zeros(1,n),true,w,f);
```

```
for j = 1:n
    for i = 1:m
        B(j) = B(j) + A(i,j);
    end
end
```

Trial 1: Best Performance

The best way to speed up the execution of the algorithm is to compile the entire algorithm using the `fiaccel` function. To evaluate the performance improvement provided by the `fiaccel` function when the entire algorithm is compiled, run the following code.

The first portion of code executes the algorithm using only MATLAB functions. The second portion of the code compiles the entire algorithm using the `fiaccel` function. The MATLAB `tic` and `toc` functions keep track of the run times for each method of execution.

```
% MATLAB
fipref('NumericTypeDisplay','short');
A = fi(randn(1000,10));
tic
B = fi_matrix_column_sum(A)
t_matrix_column_sum_m = toc

% fiaccel
fiaccel fi_matrix_column_sum -args {A} ...
-I [matlabroot '/toolbox/fixedpoint/fidemos']
tic
B = fi_matrix_column_sum_mex(A);
t_matrix_column_sum_mex = toc
```

Trial 2: Worst Performance

Compiling only the smallest unit of computation using the `fiaccel` function leads to much slower execution. In some cases, the overhead that results from calling the `mex` function inside a nested loop can cause even slower execution than using MATLAB functions alone. To evaluate the performance of the `mex` function when only the smallest unit of computation is compiled, run the following code.

The first portion of code executes the algorithm using only MATLAB functions. The second portion of the code compiles the smallest unit of computation with the `fiaccel` function, leaving the rest of the computations to MATLAB.

```
% MATLAB
tic
[m,n] = size(A);
w = get(A,'WordLength') + ceil(log2(m));
f = get(A,'FractionLength');
B = fi(zeros(1,n),true,w,f);
for j = 1:n
    for i = 1:m
        B(j) = fi_scalar_sum(B(j),A(i,j));
        % B(j) = B(j) + A(i,j);
    end
end
t_scalar_sum_m = toc

% fiaccel
fiaccel fi_scalar_sum -args {B(1),A(1,1)} ...
-I [matlabroot '/toolbox/fixedpoint/fidemos']
tic
[m,n] = size(A);
w = get(A,'WordLength') + ceil(log2(m));
f = get(A,'FractionLength');
B = fi(zeros(1,n),true,w,f);
for j = 1:n
    for i = 1:m
        B(j) = fi_scalar_sum_mex(B(j),A(i,j));
        % B(j) = B(j) + A(i,j);
    end
end
t_scalar_sum_mex = toc
```

Ratio of Times

A comparison of Trial 1 and Trial 2 appears in the following table. Your computer may record different times than the ones the table shows, but the ratios should be approximately the same. There is an extreme difference in ratios between the trial where the entire algorithm was compiled using

`fiaccel` (`t_matrix_column_sum_mex.m`) and where only the scalar sum was compiled (`t_scalar_sum_mex.m`). Even the file with no `fiaccel` compilation (`t_matrix_column_sum_m`) did better than when only the smallest unit of computation was compiled using `fiaccel` (`t_scalar_sum_mex`).

X (Overall Performance Rank)	Time	X/Best	X_m/X_mex
Trial 1: Best Performance			
t_matrix_column_sum_m (2)	1.99759	84.4917	84.4917
t_matrix_column_sum_mex (1)	0.0236424	1	
Trial 2: Worst Performance			
t_scalar_sum_m (4)	10.2067	431.71	2.08017
t_scalar_sum_mex (3)	4.90664	207.536	

Using Data Type Override with fiaccel

Fixed-Point Toolbox software ships with a demonstration of how to generate a MEX function from MATLAB code. The code in the demo takes the weighted average of a signal to create a lowpass filter. To run the demo in the Help browser select Demos under Fixed-Point Toolbox, and then select the Fixed-Point Lowpass Filtering Using MATLAB for Code Generation demo.

You can specify data type override in this demo by typing an extra command at the MATLAB prompt in the "Define Fixed-Point Parameters" section of the demo. To turn data type override on, type the following command at the MATLAB prompt after running the `reset(fipref)` demo command in that section:

```
fipref('DataTypeOverride','TrueDoubles')
```

This command tells Fixed-Point Toolbox software to create all `fi` objects with type `fi double`. When you compile the code using the `fiaccel` command in the "Compile the M-File into a MEX File" section of the demo, the resulting MEX-function uses floating-point data.

Setting Up File Infrastructure and Paths

In this section...

"Compile Path Search Order" on page 8-22
"When to Use the Code Generation Path" on page 8-22
"Add Files to the Code Generation Path" on page 8-23
"Adding Folders to Search Paths" on page 8-23
"Naming Conventions" on page 8-23

Compile Path Search Order

`fiaccel` resolves function calls by searching first on the code generation path and then on the MATLAB path. By default, `fiaccel` tries to compile and generate code for functions it finds on the path unless you explicitly declare the function to be extrinsic. An *extrinsic function* is a function on the MATLAB path that is dispatched to MATLAB software for execution. `fiaccel` does not compile extrinsic functions, but rather dispatches them to MATLAB for execution.

When to Use the Code Generation Path

Use the code generation path to override a MATLAB function with a customized version. Because `fiaccel` searches the code generation path first, a MATLAB file on that path always shadows a MATLAB file of the same name on the MATLAB path.

To override a MATLAB function with a customized version:

1. Create each version of the MATLAB function in identically named files.
2. Add the MATLAB version to the MATLAB path.
3. Add the customized version to the code generation path.

   See "Adding Folders to Search Paths" on page 8-23.

Add Files to the Code Generation Path

With `fiaccel`, you can prepend folders and files to the code generation path, as described in "Adding Folders to Search Paths" on page 8-23. By default, the code generation path contains the current folder and the toolbox functions supported for code generation.

Adding Folders to Search Paths

To add folders to:	Do this:
Code generation path	Prepend folders to the code generation path by using the `fiaccel -I` option.
MATLAB path	Follow the instructions in "Adding a Folder to the Search Path" in the MATLAB Programming documentation.

Naming Conventions

MATLAB enforces naming conventions for functions and generated files.

- "Reserved Prefixes" on page 8-23
- "Reserved Keywords" on page 8-23
- "Conventions for Naming Generated files" on page 8-25

Reserved Prefixes

MATLAB reserves the prefix `eml` for global C functions and variables in generated code. For example, run-time library function names all begin with the prefix `emlrt`, such as `emlrtCallMATLAB`. To avoid naming conflicts, do not name C functions or primary MATLAB functions with the prefix `eml`.

Reserved Keywords

- "C Reserved Keywords" on page 8-24
- "C++ Reserved Keywords" on page 8-24
- "Reserved Keywords for Code Generation" on page 8-25

MATLAB Coder software reserves certain words for its own use as keywords of the generated code language. MATLAB Coder keywords are reserved for use internal to MATLAB Coder software and should not be used in MATLAB code as identifiers or function names. C reserved keywords should also not be used in MATLAB code as identifiers or function names. If your MATLAB code contains any reserved keywords, the code generation build does not complete and an error message is displayed. To address this error, modify your code to use identifiers or names that are not reserved.

If you are generating C++ code using the MATLAB Coder software, in addition, your MATLAB code must not contain the "C++ Reserved Keywords" on page 8-24.

C Reserved Keywords.

auto	double	int	struct
break	else	long	switch
case	enum	register	typedef
char	extern	return	union
const	float	short	unsigned
continue	for	signed	void
default	goto	sizeof	volatile
do	if	static	while

C++ Reserved Keywords.

catch	friend	protected	try
class	inline	public	typeid
const_cast	mutable	reinterpret_cast	typename
delete	namespace	static_cast	using
dynamic_cast	new	template	virtual
explicit	operator	this	wchar_t
export	private	throw	

Reserved Keywords for Code Generation.

abs	fortran	localZCE	rtNaN
asm	HAVESTDIO	localZCSV	SeedFileBuffer
bool	id_t	matrix	SeedFileBufferLen
boolean_T	int_T	MODEL	single
byte_T	int8_T	MT	TID01EQ
char_T	int16_T	NCSTATES	time_T
cint8_T	int32_T	NULL	true
cint16_T	int64_T	NUMST	TRUE
cint32_T	INTEGER_CODE	pointer_T	uint_T
creal_T	LINK_DATA_BUFFER_SIZE	PROFILING_ENABLED	uint8_T
creal32_T	LINK_DATA_STREAM	PROFILING_NUM_SAMPLES	uint16_T
creal64_T	localB	real_T	uint32_T
cuint8_T	localC	real32_T	uint64_T
cuint16_T	localDWork	real64_T	UNUSED_PARAMETER
cuint32_T	localP	RT	USE_RTMODEL
ERT	localX	RT_MALLOC	VCAST_FLUSH_DATA
false	localXdis	rtInf	vector
FALSE	localXdot	rtMinusInf	

Conventions for Naming Generated files

MATLAB provides platform-specific extensions for MEX files.

Platform	MEX File Extension
Linux® (32-bit)	.mexglx
Linux x86-64	.mexa64
Windows (32-bit)	.mexw32
Windows x64	.mexw64

Preparing MATLAB Algorithms for Code Generation

In this section...

"Debugging Strategies" on page 8-26

"Detecting Errors at Design Time" on page 8-27

"Detecting Errors at Compile Time" on page 8-27

Debugging Strategies

To prepare your algorithms for code generation, MathWorks recommends that you choose a debugging strategy for detecting and correcting violations in your MATLAB applications, especially if they consist of a large number of MATLAB files that call each other's functions. Here are two best practices:

Debugging Strategy	What to Do	Pros	Cons
Bottom-up verification	**1** Verify that your lowest-level (leaf) functions are suitable for code generation. **2** Work your way up the function hierarchy incrementally to compile and verify each function, ending with the top-level function.	• Efficient • Safe • Easy to isolate syntax violations	Requires application tests that work from the bottom up

Debugging Strategy	What to Do	Pros	Cons
Top-down verification	**1** Declare all functions called by the top-level function to be extrinsic so `fiaccel` does not compile them. **2** Verify that your top-level function is suitable for code generation. **3** Work downward in the function hierarchy to: a. Remove extrinsic declarations one by one b. Compile and verify each function, ending with the leaf functions.	Lets you retain your top-level tests	Introduces extraneous code that you must remove after code verification, including: • Extrinsic declarations • Additional assignment statements as necessary to convert opaque values returned by extrinsic functions to nonopaque values.

Detecting Errors at Design Time

To detect potential issues for MEX generation as you write your MATLAB algorithm, add the `%#codegen` directive to the code that you want `fiaccel` to compile. Adding this directive indicates that you intend to generate code from the algorithm and turns on detailed diagnostics during MATLAB code analysis (see "Check Code for Errors and Warnings" in the MATLAB Desktop Tools and Development Environment documentation).

Detecting Errors at Compile Time

Before you can successfully generate code from a MATLAB algorithm, you must verify that the algorithm does not contain syntax and semantics violations that would cause compile-time errors, as described in "Preparing MATLAB Algorithms for Code Generation" on page 8-26.

`fiaccel` checks for all potential syntax violations at compile time. When `fiaccel` detects errors or warnings, it automatically produces a code generation report that describes the issues and provides links to the offending code. See "Working with Fixed-Point Code Generation Reports" on page 8-53.

If your MATLAB code calls functions on the MATLAB path, `fiaccel` attempts to compile these functions unless you declare them to be extrinsic.

Setting MEX Compilation Options

In this section...

"Working with the MEX Compiler Configuration Object" on page 8-29

"Modifying Compilation Options at the Command Line Using Dot Notation" on page 8-29

"MEX Configuration Dialog Box Options " on page 8-30

"How fiaccel Resolves Conflicting Options" on page 8-36

Working with the MEX Compiler Configuration Object

For MEX code generation, MATLAB provides a configuration object `coder.MEXConfig` for fine-tuning the compilation. To set MEX compilation options:

1. Define the compiler configuration object in the MATLAB workspace by issuing a constructor command:

   ```
   comp_cfg = coder.mexconfig
   ```

   MATLAB displays the list of compiler options and their current values in the command window.

2. Modify the compilation options as necessary. See "Modifying Compilation Options at the Command Line Using Dot Notation" on page 8-29

3. Invoke `fiaccel` with the `-config` option and specify the configuration object as its argument:

   ```
   fiaccel -config comp_cfg myMfile
   ```

   The `-config` option instructs `fiaccel` to convert `myFile.m` to a MEX function, based on the compilation settings in `comp_cfg`.

Modifying Compilation Options at the Command Line Using Dot Notation

Use dot notation to modify the value of compilation options, using this syntax:

```
configuration_object.property = value
```

Dot notation uses assignment statements to modify configuration object properties. For example, to change the maximum size function to inline and the stack size limit for inlined functions during MEX generation, enter this code at the command line:

```
co_cfg = coder.MEXConfig
co_cfg.InlineThreshold = 25;
co_cfg.InlineStackLimit = 4096;
fiaccel -config co_cfg myFun
```

MEX Configuration Dialog Box Options

The following table describes parameters for fine-tuning the behavior of `fiaccel` for converting MATLAB files to MEX:

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Report		
Create code generation report	`GenerateReport` `true`, **`false`**	Document generated code in an HTML report.
Launch report automatically	`LaunchReport` `true`, **`false`**	Specify whether to automatically display HTML reports after code generation completes. **Note** Requires that you enable **Create code generation report**
Debugging		
Echo expressions without semicolons	`EchoExpressions` **`true`**, `false`	Specify whether or not actions that do not terminate with a semicolon appear in the MATLAB Command Window.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Enable debug build	`EnableDebugging` `true`, **`false`**	Compile the generated code in debug mode.
Language and Semantics		
Constant Folding Timeout	`ConstantFoldingTimeout` *`integer`*, **`10000`**	Specify the maximum number of instructions to be executed by the constant folder.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Dynamic memory allocation	`DynamicMemoryAllocation` `'off'`, `'AllVariableSizeArrays'`	Enable dynamic memory allocation for variable-size data. By default, dynamic memory allocation is disabled and `fiaccel` allocates memory statically on the stack. When you select dynamic memory allocation, `fiaccel` allocates memory for all variable-size data dynamically on the heap. You *must* use dynamic memory allocation for all unbounded variable-size data.
Enable variable sizing	`EnableVariableSizing` **`true`**, `false`	Enable support for variable-size arrays.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Extrinsic calls	`ExtrinsicCalls` **`true`**, `false`	Allow calls to extrinsic functions. When enabled (`true`), the compiler generates code for the call to a MATLAB function, but does not generate the function's internal code. When disabled (`false`), the compiler ignores the extrinsic function. Does not generate code for the call to the MATLAB function—as long as the extrinsic function does not affect the output of the caller function. Otherwise, the compiler issues a compiler error.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Global Data Synchronization Mode	`GlobalDataSyncMethod` *`string`*,**`SyncAlways`**, `SyncAtEntryAndExits`, `NoSync`	Controls when global data is synchronized with the MATLAB global workspace. By default, (`SyncAlways`), synchronizes global data at MEX function entry and exit and for all extrinsic calls. This synchronization ensures maximum consistency between MATLAB and generated code. If the extrinsic calls do not affect global data, use this option with the `coder.extrinsic -sync:off` option to turn off synchronization for these calls. `SyncAtEntryAndExits` synchronizes global data at MEX function entry and exit only. If only a few extrinsic calls affect global data, use this option with the `coder.extrinsic -sync:on` option to turn on synchronization for these calls. `NoSync` disables synchronization. Ensure that your generated code does not interact with MATLAB before disabling synchronization. Otherwise, inconsistencies might occur.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
Saturate on integer overflow	`SaturateOnIntegerOverflow` **`true`**, `false`	Add checks in the generated code to detect integer overflow or underflow.
Safety (disable for faster MEX)		
Ensure memory integrity	`IntegrityChecks` **`true`**, `false`	Detects violations of memory integrity in code generated from MATLAB algorithms and stops execution with a diagnostic message. Setting `IntegrityChecks` to `false` also disables the run-time stack.
Ensure responsiveness	`ResponsivenessChecks` **`true`**, `false`	Enables responsiveness checks in code generated from MATLAB algorithms.
Function Inlining and Stack Allocation		
Inline Stack Limit	`InlineStackLimit` *`integer`*, **`4000`**	Specify the stack size limit on inlined functions.
Inline Threshold	`InlineThreshold` *`integer`*, **`10`**	Specify the maximum size of functions to be inlined.
Inline Threshold Max	`InlineThresholdMax` *`integer`*, **`200`**	Specify the maximum size of functions after inlining.
Stack Usage Max	`StackUsageMax` *`integer`*, **`200000`**	Specify the maximum stack usage per application in bytes. Set a limit that is lower than the available stack size. Otherwise, a runtime stack overflow might occur. Overflows are detected and reported by the C compiler, not by `fiaccel`.

Parameter	Equivalent Command-Line Property and Values (default in bold)	Description
	Optimizations	
Use BLAS library if possible	`EnableBLAS` **`true`**, `false`	Speed up low-level matrix operations during simulation by calling the Basic Linear Algebra Subprograms (BLAS) library.

See Also

- "Controlling Run-Time Checks" on page 8-73
- "How Working with Variable-Size Data Is Different for Code Generation"
- "Generating MEX Functions from MATLAB Code That Uses Global Data" on page 8-58

How fiaccel Resolves Conflicting Options

`fiaccel` takes the union of all options, including those specified using configuration objects, so that you can specify options in any order.

Specifying Properties of Primary Function Inputs

In this section...

"Why You Must Specify Input Properties" on page 8-37

"Properties to Specify" on page 8-37

"Rules for Specifying Properties of Primary Inputs" on page 8-40

"Methods for Defining Properties of Primary Inputs" on page 8-41

"Defining Input Properties by Example at the Command Line" on page 8-41

Why You Must Specify Input Properties

To generate code in a statically typed language, `fiaccel` must determine the properties of all variables in the MATLAB code at compile time. Therefore, you must specify the class, size, and complexity of inputs to the primary function (also known as the *top-level* or *entry-point* function). If your primary function has no input parameters, `fiaccel` can compile your MATLAB algorithm without modification. You do not need to specify properties of inputs to subfunctions or external functions called by the primary function. For `fiaccel` requirements, refer to its reference page.

Properties to Specify

If your primary function has inputs, you must specify the following properties for each input:

For:	Specify Properties:				
	Class	Size	Complexity	numerictype	fimath
Fixed-point inputs	✓	✓	✓	✓	✓
Structure inputs*	✓	✓	✓	✓ (if structure field is fixed-point)	✓ (if structure field is fixed-point)
All other inputs	✓	✓	✓		

* When a primary input is a structure, `fiaccel` treats each field as a separate input.

Default Property Values

`fiaccel` assigns the following default values for properties of primary function inputs:

Property	Default
class	`double`
size	`scalar`
complexity	`real`
`numerictype`	No default
`fimath`	MATLAB default `fimath` object

Specifying Default Values for Structure Fields. In most cases, `fiaccel` uses defaults when you don't explicitly specify values for properties—except for structure fields. The only way to name a field in a structure is to set at least one of its properties. Therefore, you may need to specify default values for properties of structure fields. For examples, see "Example: Specifying Class and Size of Scalar Structure" on page 8-70 and "Example: Specifying Class and Size of Structure Array" on page 8-71.

Specifying Default fimath Values for MEX Functions. MEX functions generated with `fiaccel` use the MATLAB default `fimath`. The MATLAB factory default `fimath` has the following properties:

```
           RoundMode: nearest
        OverflowMode: saturate
         ProductMode: FullPrecision
MaxProductWordLength: 128
             SumMode: FullPrecision
    MaxSumWordLength: 128
```

For more information, see Chapter 4, "Working with fimath Objects".

When running MEX functions that depend on the MATLAB default `fimath` value, do not change this value during your MATLAB session. Otherwise, you receive a run-time error, alerting you to a mismatch between the compile-time and run-time `fimath` values.

For example, suppose you define the following MATLAB function `test`:

```
function y = test %#codegen
y = fi(0);
```

The function `test` constructs a `fi` object without explicitly specifying a `fimath` object. Therefore, `test` will rely on the default `fimath` object at compile time. At the MATLAB prompt, generate the MEX function `text_mex` to use the factory setting of the MATLAB default `fimath`:

```
fiaccel test
% fiaccel generates a MEX function, test_mex,
% in the current folder
```

Next, run `test_mex` to display the MATLAB default `fimath` value:

```
test_mex

ans =

     0

          DataTypeMode: Fixed-point: binary point scaling
```

```
    Signedness: Signed
    WordLength: 16
FractionLength: 15
```

Supported Classes

The following table presents the class names supported by `fiaccel`:

Class Name	Description
`logical`	Logical array of true and false values
`char`	Character array
`int8`	8-bit signed integer array
`uint8`	8-bit unsigned integer array
`int16`	16-bit signed integer array
`uint16`	16-bit unsigned integer array
`int32`	32-bit signed integer array
`uint32`	32-bit unsigned integer array
`single`	Single-precision floating-point or fixed-point number array
`double`	Double-precision floating-point or fixed-point number array
`struct`	Structure array
`embedded.fi`	Fixed-point number array

Rules for Specifying Properties of Primary Inputs

Follow these rules when specifying the properties of primary inputs:

- For each primary function input whose class is fixed point (`fi`), you must specify the input's `numerictype` and `fimath` properties.
- For each primary function input whose class is `struct`, you must specify the properties of each of its fields in the order that they appear in the structure definition.

Methods for Defining Properties of Primary Inputs

You can use any of the following methods to define the properties of primary function inputs:

Method	Pros	Cons
"Defining Input Properties by Example at the Command Line" on page 8-41	• Easy to use • Does not alter original MATLAB code • Designed for prototyping a function that has a small number of primary inputs	• Must be specified at the command line every time you invoke `fiaccel` (unless you use a script) • Not efficient for specifying memory-intensive inputs such as large structures and arrays
"Defining Input Properties Programmatically in the MATLAB File" on page 8-64	• Integrated with MATLAB code so you do not need to redefine properties each time you invoke `fiaccel` • Provides documentation of property specifications in the MATLAB code • Efficient for specifying memory-intensive inputs such as large structures	• Uses complex syntax

Note To specify the properties of inputs for any given primary function, use one of these methods or the other, but not both.

Defining Input Properties by Example at the Command Line

- "Command Line Option -args" on page 8-42
- "Rules for using the -args option" on page 8-43
- "Specifying Constant Inputs" on page 8-44

• "Specifying Variable-Size Inputs" on page 8-45

Command Line Option -args

`fiaccel` provides a command-line option `-args` for specifying the properties of primary function inputs as a cell array of example values. The cell array can be a variable or literal array of constant values.

Example: Specifying Properties of Primary Inputs by Example. Consider a function that adds its two inputs:

```
function y = emcf(u,v) %#codegen
% The directive %#codegen indicates that you
% intend to generate code for this algorithm
y = u + v;
```

The following examples show how to specify different properties of the primary inputs `u` and `v` by example at the command line:

- Use a literal cell array of constants to specify that both inputs are real, scalar, fixed-point values:

  ```
  fiaccel -o emcfx emcf ...
     -args {fi(0,1,16,15),fi(0,1,16,15)}
  ```

- Use a literal cell array of constants to specify that input `u` is an unsigned 16-bit, 1-by-4 vector and input `v` is a scalar, fixed-point value:

  ```
  fiaccel -o emcfx emcf ...
     -args {zeros(1,4,'uint16'),fi(0,1,16,15)}
  ```

- Assign sample values to a cell array variable to specify that both inputs are real, unsigned 8-bit integer vectors:

  ```
  a = fi([1;2;3;4],0,8,0)
  b = fi([5;6;7;8],0,8,0)
  ex = {a,b}
  fiaccel -o emcfx emcf -args ex
  ```

Example: Specifying Properties of Primary Fixed-Point Inputs by Example. Consider a function that calculates the square root of a fixed-point number:

```
function y = sqrtfi(x) %#codegen
y = sqrt(x);
```

To specify the properties of the primary fixed-point input `x` by example on the MATLAB command line, follow these steps:

1. Define the `numerictype` properties for `x`, as in this example:

```
T = numerictype('WordLength',32,...
   'FractionLength',23,'Signed',true);
```

2. Define the `fimath` properties for `x`, as in this example:

```
F = fimath('SumMode','SpecifyPrecision',...
    'SumWordLength',32,'SumFractionLength',23,...
    'ProductMode','SpecifyPrecision', ...
     ProductWordLength',32,'ProductFractionLength',23);
```

3. Create a fixed-point variable with the `numerictype` and `fimath` properties you just defined, as in this example:

```
myeg = { fi(4.0,T,F) };
```

4. Compile the function `sqrtfi` using the `fiaccel` command, passing the variable `myeg` as the argument to the `-args` option, as in this example:

```
fiaccel sqrtfi -args myeg;
```

Rules for using the -args option

Follow these rules when using the `-args` command-line option to define properties by example:

- The cell array of sample values must contain the same number of elements as primary function inputs.
- The order of elements in the cell array must correspond to the order in which inputs appear in the primary function signature — for example, the first element in the cell array defines the properties of the first primary function input.

Specifying Constant Inputs

In cases where you know your primary inputs will not change at run time, you can specify them as constant values than as variables to eliminate unnecessary overhead in generated code. Common uses of constant inputs are for flags that control how an algorithm executes and values that specify the sizes or types of data.

You can define inputs to be constants using this command-line option:

```
-args {coder.Constant(constant_input)}
```

This expression specifies that an input will be a constant with the size, class, complexity, and value of *constant_input*.

Calling Functions with Constant Inputs. `fiaccel` compiles constant function inputs into the generated code. As a result, the MEX function signature differs from the MATLAB function signature. At run time you supply the constant argument to the MATLAB function, but not to the MEX function.

For example, consider the following function `identity` which copies its input to its output:

```
function y = identity(u) %#codegen
y = u;
```

To generate a MEX function `identity_mex` with a constant input, type the following command at the MATLAB prompt:

```
fiaccel -o identity_mex identity...
    -args {coder.Constant(fi(0.1,1,16,15))}
```

To run the MATLAB function, supply the constant argument as follows:

```
identity(fi(0.1,1,16,15))
```

You get the following result:

```
ans =

    0.1000
```

Now, try running the MEX function with this command:

```
identity_mex
```

You should get the same answer.

Example: Specifying a Structure as a Constant Input. Suppose you define a structure `tmp` in the MATLAB workspace to specify the dimensions of a matrix, as follows:

```
tmp = struct('rows', 2, 'cols', 3);
```

The following MATLAB function `rowcol` accepts a structure input `p` to define matrix `y`:

```
function y = rowcol(u,p) %#codegen
y = fi(zeros(p.rows,p.cols),1,16,15) + u;
```

The following example shows how to specify that primary input `u` is a double scalar variable and primary input `p` is a constant structure:

```
fiaccel rowcol ...
   -args {fi(0,1,16,15),coder.Constant(tmp)}
```

To run this code, use

```
u = fi(0.5,1,16,15)
y_m = rowcol(u,tmp)

y_mex = rowcol_mex(u)
```

Specifying Variable-Size Inputs

Variable-size data is data whose size might change at run time. MATLAB supports bounded and unbounded variable-size data for code generation.

- *Bounded variable-size data* has fixed upper bounds; this data can be allocated statically on the stack or dynamically on the heap.
- *Unbounded variable-size data* does not have fixed upper bounds; this data must be allocated on the heap.

You can define inputs to have one or more variable-size dimensions and specify their upper bounds using the `-args` option:

Expression	Description

Expression	Description
`-args {coder.typeof(` *`example_value`*, *`size_vector`*, *`dim_vector`*`)}`	Specifies a variable-size input with: • Same class and complexity as *`example_value`* • Same size and upper bounds as *`size_vector`* *`dim_vector`* specifies which dimensions are variable. A value of `true` or one means that the corresponding dimension is variable. A value of `false` or zero means that the corresponding dimension is fixed.

Example: Specifying a Variable-Size Vector Input.

1 Write a function that computes the sum of every `n` elements of a vector `A` and stores them in a vector `B`:

```
function B = nway(A,n) %#codegen
% Compute sum of every N elements of A and put them in B.

coder.extrinsic('error');
Tb = numerictype(1,32,24);
if ((mod(numberofelements(A),n) == 0) && ...
  (n>=1 && n<=numberofelements(A)))
    B = fi(zeros(1,numberofelements(A)/n),Tb);
    k = 1;
    for i = 1 : numberofelements(A)/n
        B(i) = sum(A(k + (0:n-1)));
        k = k + n;
    end
else
    B = fi(zeros(1,0),Tb);
    error('n<=0 or does not divide evenly');
```

```
end
```

2 Specify the first input `A` as a `fi` object. Its first dimension stays fixed in size and its second dimension can grow to an upper bound of 100. Specify the second input `n` as a double scalar.

```
fiaccel nway ...
    -args {coder.typeof(fi(0,1,16,15),[1 100],1),0}...
    -report
```

Note You do not need to explicitly cast these inputs as `double` because `fiaccel` assumes the default properties of inputs are real, double scalars.

---

3 As an alternative, assign the `coder.typeof` expression to a MATLAB variable, then pass the variable as an argument to `-args`:

```
vareg = coder.typeof(fi(0,1,16,15),[1 100],1)
fiaccel nway -args {vareg, double(0)}
```

Note For comparison, this command does explicitly cast the inputs to `double`.

Best Practices for Accelerating Fixed-Point MATLAB Code

In this section...

"Recommended Compilation Options for fiaccel" on page 8-49

"Using Build Scripts" on page 8-50

"Using the MATLAB Code Analyzer to Check Code Interactively at Design Time" on page 8-51

"Separating Your Test Bench from Your Function Code" on page 8-52

"Preserving Your Code" on page 8-52

"File Naming Conventions" on page 8-52

Recommended Compilation Options for fiaccel

- `-args` – Specify input parameters by example

  Use the `-args` option to specify the properties of primary function inputs as a cell array of example values at the same time as you generate code for the MATLAB file with `fiaccel`. The cell array can be a variable or literal array of constant values. The cell array should provide the same number and order of inputs as the primary function.

  When you use the `-args` option you are specifying the data types and array dimensions of these parameters, not the values of the variables. For more information, see "Defining Input Properties by Example at the Command Line" in the MATLAB Coder documentation.

  Note Alternatively, you can use the `assert` function to define properties of primary function inputs directly in your MATLAB file. For more information, see "Defining Input Properties Programmatically in the MATLAB File" on page 8-64.

- `-report` – Generate code generation report

  Use the `-report` option to generate a report in HTML format at code generation time to help you debug your MATLAB code and verify that it

is suitable for code generation. If you do not specify the `-report` option, `fiaccel` generates a report only if build errors or warnings occur.

The code generation report contains the following information:

- Summary of code generation results, including type of target and number of warnings or errors
- Target build log that records build and linking activities
- Links to generated files
- Error and warning messages (if any)

For more information, see `fiaccel`.

Using Build Scripts

Use build scripts to call `fiaccel` to generate MEX functions from your MATLAB function.

A build script automates a series of MATLAB commands that you want to perform repeatedly from the command line, saving you time and eliminating input errors. For instance, you can use a build script to clear your workspace before each build and to specify code generation options.

This example shows a build script to run `fiaccel` to process `lms_02.m`:

```
close all;
clear all;
clc;

N = 73113;

fiaccel  -report lms_02.m ...
  -args { zeros(N,1) zeros(N,1) }
```

In this example, the following actions occur:

- `close all` deletes all figures whose handles are not hidden. See `close` in the MATLAB Graphics function reference for more information.

- `clear all` removes all variables, functions, and MEX-files from memory, leaving the workspace empty. This command also clears all breakpoints.

  Note Remove the `clear all` command from the build scripts if you want to preserve breakpoints for debugging.

- `clc` clears all input and output from the Command Window display, giving you a "clean screen."
- `N = 73113` sets the value of the variable `N`, which represents the number of samples in each of the two input parameters for the function `lms_02`
- `fiaccel -report lms_02.m -args { zeros(N,1) zeros(N,1) }` calls `fiaccel` to accelerate simulation of the file `lms_02.m` using the following options:
  - `-report` generates a code generation report
  - `-args { zeros(N,1) zeros(N,1) }` specifies the properties of the function inputs as a cell array of example values. In this case, the input parameters are N-by-1 vectors of real doubles.

Using the MATLAB Code Analyzer to Check Code Interactively at Design Time

The code analyzer checks your code for problems and recommends modifications to maximize performance and maintainability. You can use the code analyzer to check your code continuously in the MATLAB Editor while you work.

To ensure that continuous code checking is enabled:

1. From the MATLAB menu, select **File > Preferences > Code Analyzer**.

   The list of code analyzer preferences appears.

2. Select the **Enable integrated warning and error messages** check box.

Separating Your Test Bench from Your Function Code

Separate your core algorithm from your test bench. Create a separate test script to do all the pre- and post-processing such as loading inputs, setting up input values, calling the function under test, and outputting test results. See the example on the `fiaccel` reference page.

Preserving Your Code

Preserve your code before making further modifications. This practice provides a fallback in case of error and a baseline for testing and validation. Use a consistent file naming convention, as described in "File Naming Conventions" on page 8-52. For example, add a 2-digit suffix to the file name for each file in a sequence. Alternatively, use a version control system.

File Naming Conventions

Use a consistent file naming convention to identify different types and versions of your MATLAB files. This approach keeps your files organized and minimizes the risk of overwriting existing files or creating two files with the same name in different folders.

For example, the file naming convention in the Generating MEX Functions getting started tutorial is:

- The suffix `_build` identifies a build script.
- The suffix `_test` identifies a test script.
- A numerical suffix, for example, `_01` identifies the version of a file. These numbers are typically two-digit sequential integers, beginning with 01, 02, 03, and so on.

For example:

- The file `build_01.m` is the first version of the build script for this tutorial.
- The file `test_03.m` is the third version of the test script for this tutorial.

Working with Fixed-Point Code Generation Reports

In this section...

"Generating the Code Generation Report" on page 8-53
"Opening the Code Generation Report" on page 8-54
"Viewing Your MATLAB Code" on page 8-54
"Viewing Variables in the Variables Tab" on page 8-56
"See Also" on page 8-57

Generating the Code Generation Report

When you compile your code with the `fiaccel` function or the MATLAB Coder `codegen` function, you can use the `-report` option to generate a code generation report. This report allows you to examine the data types of the variables and expressions in your code.

To see an example of the code generation report generated by the `fiaccel` function, compile `cordic_atan_kernel.m`. This file ships as a part of the Fixed-Point ATAN2 Calculation demo. You can open the file by typing the following at the MATLAB command line:

```
open cordic_atan_kernel
```

To compile the `cordic_atan_kernel` file, you must provide inputs `x`, `y`, `N`, and `angleLUT`. This example uses the following input values:

```
x = fi(0.23);
y = x;
N = 12;
Tz = numerictype(1,16,13);
angleLUT = fi(atan(2.^-(0:N-1)), 'NumericType', Tz);
```

After you define the input variables in the MATLAB workspace, change your working folder to a local folder and compile the file using `fiaccel`. Use the `-report` option to generate the code generation report:

```
fiaccel cordic_atan_kernel -args {x,y,N,angleLUT} -report
```

Opening the Code Generation Report

If the compilation is successful, you receive the following message:

```
Code generation successful: View report
```

Click the **View report** link to view the report.

If the compilation fails, a link to the error report appears:

```
Code generation failed: View report
```

Click the **View report** link to view the error report and debug your code. For more information on working with error reports, see "Code Generation Reports" in the MATLAB Coder documentation.

Viewing Your MATLAB Code

When the code generation report opens, you can hover your cursor over the variables and expressions in your MATLAB code to see their data type information. The code generation report provides color-coded data type information according to the following legend.

Color	Meaning
Green	Data type information is available for the selected variable at this location in the code.
Orange	There is a warning message associated with the selected variable or expression.
Pink	No data type information is available for the selected variable.
Purple	Data type information is available for the selected expression at this location in the code.
Red	There is an error message associated with the selected variable or expression.

Variables in your code that have data type information available appear highlighted in green, as shown in the following figure.

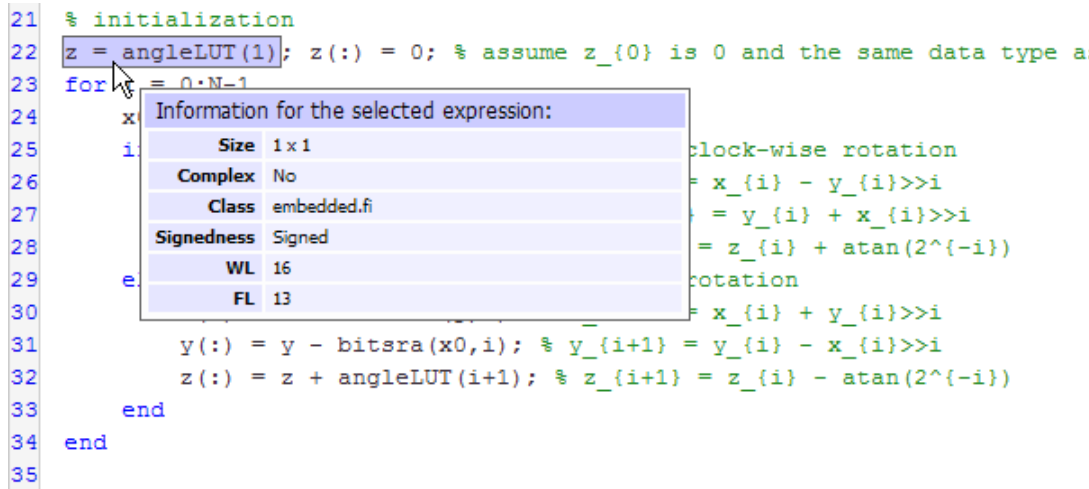
Function: cordic_atan_kernel Callers: Select a function call-site:

```
1  function [z,x,y] = cordic_atan_kernel(y,x,N,angleLUT) %#codegen
2  % Calculate arctangent in range [-pi/2, pi/2] using Vectoring mode CORDIC
3  % algorithm. Both x and y inputs must be real scalar, x must >= 0.
4  % Full precision Fimath is used in all fixed-point operations
5  %
6  % Inputs:
7  %  y   : y coordinate or imaginary part of the input vector
8  %  x   : x coordinate or real part of the input vector
9  %  N   : total number of iterations, must be a non-negative integer
10 % angleLUT : the angle look-up table, has same numerictype as the output
11 %             angle
12 % Output:
13 %  z   : angle that equals atan2(y,x), in radians
14 %        the output angle range is within [-pi/2, +pi/2]
15 %  x   : x coordinate of the last vector at the end of the iterations
16 %  y   : y coordinate of the last vector at the end of the iterations
17 %
18 %    Copyright 1984-2010 The MathWorks, Inc.
19 %    $Revision: 1.1.6.2 $  $Date: 2010/10/15 14:11:18 $
20
21 % initialization
22 z = angleLUT(1); z(:) = 0; % assume z_{0} is 0 and the same data type as angleLUT
23 for i = 0:N-1,
24     x0 = x;
25     if y < 0 % negative y leads to counter clock-wise rotation
26         x(:) = x0 - bitsra(y,i); % x_{i+1} = x_{i} - y_{i}>>i
27         y(   _{i} + x_{i}>>i
28         z(   {i} + atan(2^{-i})
29     else     ion
30         x(   i} + y_{i}>>i
31         y(   i} - x_{i}>>i
32         z(   {i} - atan(2^{-i})
33     end
34 end
35
```

Information for the selected variable:

Size	1 x 1
Complex	No
Class	embedded.fi
Signedness	Signed
WL	16
FL	17

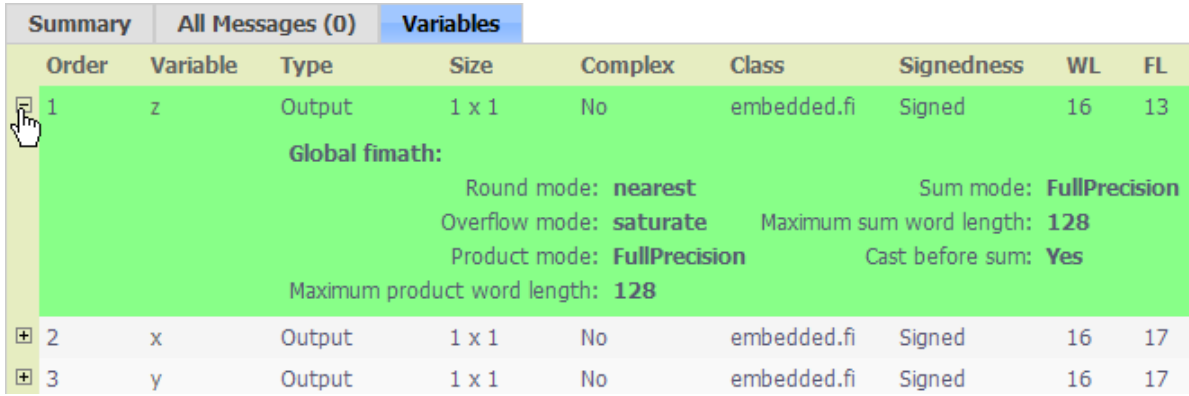
Expressions in your code that have data type information available appear highlighted in purple, as the next figure shows.



Viewing Variables in the Variables Tab

To see the data type information for all the variables in your file, click the **Variables** tab of the code generation report. You can expand all `fi` and `fimath` objects listed in the **Variables** tab to display the `fimath` properties. When you expand a `fi` object in the **Variables** tab, the report indicates whether the `fi` object has a local `fimath` object or is using default `fimath` values.

The following figure shows the information displayed for a `fi` object that is using default `fimath` values.



You can sort the variables by clicking the column headings in the **Variables** tab. To sort the variables by multiple columns, press the **Shift** key while clicking the column headings.

See Also

For more information about using the code generation report with the `fiaccel` function, see the `fiaccel` reference page.

For information about local and default `fimath`, see Chapter 4, "Working with fimath Objects".

For information about using the code generation report with the `codegen` function, see "Code Generation Reports" in the MATLAB Coder documentation.

Generating MEX Functions from MATLAB Code That Uses Global Data

In this section...

"Workflow Overview" on page 8-58
"Declaring Global Variables" on page 8-58
"Defining Global Data" on page 8-59
"Synchronizing Global Data with MATLAB" on page 8-60
"Limitations of Using Global Data" on page 8-63

Workflow Overview

To generate MEX functions from MATLAB code that uses global data:

1. Declare the variables as global in your code.
2. Define and initialize the global data before using it.

   For more information, see "Defining Global Data" on page 8-59.
3. Compile your code using `fiaccel`.

If you use global data, you must also specify whether you want to synchronize this data between MATLAB and the generated code. If there is no interaction between MATLAB and the generated code, it is safe to disable synchronization. Otherwise, you should enable synchronization. For more information, see "Synchronizing Global Data with MATLAB" on page 8-60.

Declaring Global Variables

For code generation, you must declare global variables before using them in your MATLAB code. Consider the `use_globals` function that uses two global variables `AR` and `B`.

```
function y = use_globals()
%#codegen
% Turn off inlining to make
```

```
% generated code easier to read
coder.inline('never');
% Declare AR and B as global variables
global AR;
global B;
AR(1) = B(1);
y = AR * 2;
```

Defining Global Data

You can define global data either in the MATLAB global workspace or at the command line. If you do not initialize global data at the command line, `fiaccel` looks for the variable in the MATLAB global workspace. If the variable does not exist, `fiaccel` generates an error.

Defining Global Data in the MATLAB Global Workspace

To compile the `use_globals` function described in "Declaring Global Variables" on page 8-58 using `fiaccel`:

1. Define the global data in the MATLAB workspace. At the MATLAB prompt, enter:

   ```
   global AR B;
   AR = fi(ones(4),1,16,14);
   B = fi([1 2 3],1,16,13);
   ```

2. Compile the function to generate a MEX file named `use_globalsx`.

   ```
   fiaccel -o use_globalsx use_globals
   ```

Defining Global Data at the Command Line

To define global data at the command line, use the `fiaccel -global` option. For example, to compile the `use_globals` function described in "Declaring Global Variables" on page 8-58, specify two global inputs `AR` and `B` at the command line.

```
fiaccel -o use_globalsx ...
   -global {'AR',fi(ones(4)),'B',fi([1 2 3])} use_globals
```

Alternatively, specify the type and initial value with the `-globals` flag using the format `-globals {'g', {type, initial_value}}`.

Defining Variable-Sized Global Data. To provide initial values for variable-sized global data, specify the type and initial value with the `-globals` flag using the format `-globals {'g', {type, initial_value}}`. For example, to specify a global variable `g1` that has an initial value `[1 1]` and upper bound `[2 2]`, enter:

```
fiaccel foo -globals {'g1',{coder.typeof(0,[2 2],1),[1 1]}}
```

For a detailed explanation of `coder.typeof` syntax, see `coder.typeof`.

Synchronizing Global Data with MATLAB

Why Synchronize Global Data?

The generated code and MATLAB each have their own copies of global data. To ensure consistency, you must synchronize their global data whenever the two interact. If you do not synchronize the data, their global variables might differ. The level of interaction determines when to synchronize global data.

When to Synchronize Global Data

By default, synchronization between global data in MATLAB and generated code occurs at MEX function entry and exit and for all *extrinsic* calls, which are calls to MATLAB functions on the MATLAB path that `fiaccel` dispatches to MATLAB for execution. This behavior ensures maximum consistency between generated code and MATLAB.

To improve performance, you can:

- Select to synchronize only at MEX function entry and exit points.
- Disable synchronization when the global data does not interact.
- Choose whether to synchronize before and after each extrinsic call.

The following table summarizes which global data synchronization options to use. To learn how to set these options, see “How to Synchronize Global Data” on page 8-61.

Global Data Synchronization Options

If you want to...	Set the global data synchronization mode to:	Synchronize before and after extrinsic calls?
Ensure maximum consistency when all extrinsic calls modify global data.	`At MEX-function entry, exit and extrinsic calls` (default)	Yes. Default behavior.
Ensure maximum consistency when most extrinsic calls modify global data, but a few do not.	`At MEX-function entry, exit and extrinsic calls` (default)	Yes. Use the `coder.extrinsic -sync:off` option to turn off synchronization for the extrinsic calls that do not affect global data.
Ensure maximum consistency when most extrinsic calls do not modify global data, but a few do.	`At MEX-function entry and exit`	Yes. Use the `coder.extrinsic -sync:on` option to synchronize only the calls that modify global data
Maximize performance when synchronizing global data, and none of your extrinsic calls modify global data.	`At MEX-function entry and exit`	No.
Communicate between generated code files only. No interaction between global data in MATLAB and generated code.	`Disabled`	No.

How to Synchronize Global Data

To control global data synchronization, set the global data synchronization mode and select whether to synchronize extrinsic functions. For guidelines on which options to use, see “When to Synchronize Global Data” on page 8-60.

You control the synchronization of global data with extrinsic functions using the `coder.extrinsic -sync:on` and `-sync:off` options.

Controlling the Global Data Synchronization Mode from the Command Line.

1. Define the compiler options object in the MATLAB workspace by issuing a constructor command:

   ```
   comp_cfg = coder.mexconfig
   ```

2. From the command line, set the `GlobalDataSyncMethod` property to `Always`, `SyncAtEntryAndExits` or `NoSync`, as applicable. For example:

   ```
   comp_cfg.GlobalDataSyncMethod = 'SyncAtEntryAndExits';
   ```

3. Use the `comp_cfg` configuration object when compiling your code by specifying it using the `-config` compilation option. For example,

   ```
   fiaccel -config comp_cfg myFile
   ```

Controlling Synchronization for Extrinsic Function Calls. You can control whether synchronization between global data in MATLAB and generated code occurs before and after you call an extrinsic function. To do so, use the `coder.extrinsic -sync:on` and `-sync:off` options.

By default, global data is:

- Synchronized before and after each extrinsic call if the global data synchronization mode is `At MEX-function entry, exit and extrinsic calls`. If you are sure that certain extrinsic calls do not affect global data, turn off synchronization for these calls using the `-sync:off` option. Turning off synchronization improves performance. For example, if functions `foo1` and `foo2` *do not* affect global data, turn off synchronization for these functions:

  ```
  coder.extrinsic('-sync:off', 'foo1', 'foo2');
  ```

- Not synchronized if the global data synchronization mode is `At MEX-function entry and exit`. If the code has a few extrinsic calls that affect global data, turn on synchronization for these calls using the

`-sync:on` option. For example, if functions `foo1` and `foo2` *do* affect global data, turn on synchronization for these functions:

```
coder.extrinsic('-sync:on', 'foo1', 'foo2');
```

- Not synchronized if the global data synchronization mode is `Disabled`. When synchronization is disabled, you cannot control the synchronization for specific extrinsic calls. The `-sync:on` option has no effect.

Limitations of Using Global Data

You cannot use global data with

- The `coder.cstructname` function. This function does not support global variables.
- The `coder.varsize` function. Instead, use a `coder.typeof` object to define variable-sized global data as described in "Defining Variable-Sized Global Data" on page 8-60.

Defining Input Properties Programmatically in the MATLAB File

In this section...

"How to Use `assert` with `fiaccel`" on page 8-64

"Rules for Using assert Function" on page 8-69

"Example: Specifying Properties of Primary Fixed-Point Inputs" on page 8-69

"Example: Specifying Class and Size of Scalar Structure" on page 8-70

"Example: Specifying Class and Size of Structure Array" on page 8-71

How to Use `assert` with `fiaccel`

You can use the MATLAB `assert` function to define properties of primary function inputs directly in your MATLAB file.

Use the `assert` function to invoke standard MATLAB functions for specifying the class, size, and complexity of primary function inputs.

Specify Any Class

```
assert ( isa ( param, 'class_name') )
```

Sets the input parameter *`param`* to the MATLAB class *class_name*. For example, to set the class of input `U` to a 32-bit signed integer, call:

```
...
assert(isa(U,'embedded.fi'));
...
```

Note If you set the class of an input parameter to `fi`, you must also set its `numerictype`, see "Specify numerictype of Fixed-Point Input" on page 8-67. You can also set its `fimath` properties, see "Specify fimath of Fixed-Point Input" on page 8-68. If you do not set the `fimath` properties, `fiaccel` uses the MATLAB default `fimath` value.

If you set the class of an input parameter to `struct`, you must specify the properties of each field in the structure in the order in which you define the fields in the structure definition.

Specify fi Class

```
assert ( isfi ( param ) )
assert ( isa ( param, 'embedded.fi' ) )
```

Sets the input parameter *`param`* to the MATLAB class `fi` (fixed-point numeric object). For example, to set the class of input `U` to `fi`, call:

```
...
assert(isfi(U));
...
```

or

```
...
assert(isa(U,'embedded.fi'));
...
```

Note If you set the class of an input parameter to `fi`, you must also set its `numerictype`, see "Specify numerictype of Fixed-Point Input" on page 8-67. You can also set its `fimath` properties, see "Specify fimath of Fixed-Point Input" on page 8-68. If you do not set the `fimath` properties, `fiaccel` uses the MATLAB default `fimath` value.

Specify Structure Class

```
assert ( isstruct ( param ) )
```

Sets the input parameter *param* to the MATLAB class `struct` (structure). For example, to set the class of input `U` to a `struct`, call:

```
...
assert(isstruct(U));
...
```

or

```
...
assert(isa(U,'struct'));
...
```

Note If you set the class of an input parameter to `struct`, you must specify the properties of each field in the structure in the order in which you define the fields in the structure definition.

Specify Any Size

```
assert ( all ( size (param) == [dims ] ) )
```

Sets the input parameter *param* to the size specified by dimensions *dims*. For example, to set the size of input `U` to a 3-by-2 matrix, call:

```
...
assert(all(size(U)== [3 2]));
...
```

Specify Scalar Size

```
assert ( isscalar (param ) )
assert ( all ( size (param) == [ 1 ] ) )
```

Sets the size of input parameter *param* to scalar. For example, to set the size of input `U` to scalar, call:

```
...
assert(isscalar(U));
...
```

or

```
...
assert(all(size(U)== [1]));
...
```

Specify Real Input

```
assert ( isreal (param ) )
```

Specifies that the input parameter *`param`* is real. For example, to specify that input `U` is real, call:

```
...
assert(isreal(U));
...
```

Specify Complex Input

```
assert ( ~isreal (param ) )
```

Specifies that the input parameter *`param`* is complex. For example, to specify that input `U` is complex, call:

```
...
assert(~isreal(U));
...
```

Specify numerictype of Fixed-Point Input

```
assert ( isequal ( numerictype ( fiparam ), T ) )
```

Sets the `numerictype` properties of `fi` input parameter *`fiparam`* to the `numerictype` object *`T`*. For example, to specify the `numerictype` property of

fixed-point input `U` as a signed `numerictype` object `T` with 32-bit word length and 30-bit fraction length, use the following code:

```
...
% Define the numerictype object.
T = numerictype(1, 32, 30);

% Set the numerictype property of input U to T.
assert(isequal(numerictype(U),T));
...
```

Specify fimath of Fixed-Point Input

```
assert ( isequal ( fimath ( fiparam ), F ) )
```

Sets the `fimath` properties of `fi` input parameter *`fiparam`* to the `fimath` object *`F`*. For example, to specify the `fimath` property of fixed-point input `U` so that it saturates on integer overflow, use the following code:

```
...
% Define the fimath object.
F = fimath('OverflowMode','saturate');

% Set the fimath property of input U to F.
assert(isequal(fimath(U),F));
...
```

Note If you do not specify the `fimath` properties using `assert`, `fiaccel` uses the MATLAB default `fimath` value.

Specify Multiple Properties of Input

```
assert ( function1 ( params ) && function2 ( params ) && function3 ( params ) && ... )
```

Specifies the class, size, and complexity of one or more inputs using a single `assert` function call. For example, the following code specifies that input `U` is a double, complex, 3-by-3 matrix, and input `V` is a 16-bit unsigned integer:

```
...
assert(isa(U,'double') && ~isreal(U) && all(size(U) == [3 3]) && isa(V,'uint16'));
...
```

Rules for Using assert Function

Follow these rules when using the `assert` function to specify the properties of primary function inputs:

- Call `assert` functions at the beginning of the primary function, before any flow-control operations such as `if` statements or subroutine calls.
- Do not call `assert` functions inside conditional constructs, such as `if`, `for`, `while`, and `switch` statements.
- Use the `assert` function with `fiaccel` only for specifying properties of primary function inputs before converting your MATLAB code to MEX code.
- If you set the class of an input parameter to `fi`:
  - You must also set its `numerictype`, see "Specify numerictype of Fixed-Point Input" on page 8-67.
  - You can also set its `fimath` properties, see "Specify fimath of Fixed-Point Input" on page 8-68. If you do not set the `fimath` properties, `fiaccel` uses the MATLAB default `fimath` value.
- If you set the class of an input parameter to `struct`, you must specify the class, size, and complexity of each field in the structure in the order in which you define the fields in the structure definition.

Example: Specifying Properties of Primary Fixed-Point Inputs

In the following example, the primary MATLAB function `emcsqrtfi` takes one fixed-point input: `x`. The code specifies the following properties for this input:

Property	Value
class	`fi`
`numerictype`	`numerictype` object `T`, as specified in the primary function

Property	Value
`fimath`	`fimath` object `F`, as specified in the primary function
size	`scalar` (by default)
complexity	`real` (by default)

```
function y = emcsqrtfi(x)
T = numerictype('WordLength',32,'FractionLength',23,...
      'Signed',true);
F = fimath('SumMode','SpecifyPrecision',...
      'SumWordLength',32,'SumFractionLength',23,...
      'ProductMode','SpecifyPrecision',...
      'ProductWordLength',32,'ProductFractionLength',23);
assert(isfi(x));
assert(isequal(numerictype(x),T));
assert(isequal(fimath(x),F));

y = sqrt(x);
```

Example: Specifying Class and Size of Scalar Structure

Assume you have defined `S` as the following scalar MATLAB structure:

```
S = struct('r',double(1),'i',fi(4,true,8,0));
```

This code specifies the class and size of `S` and its fields when passed as an input to your MATLAB function:

```
function y = fcn(S)

% Specify the class of the input as struct.
assert(isstruct(S));

% Specify the size of the fields r and i
% in the order in which you defined them.
T = numerictype('Wordlength', 8,'FractionLength', ...
   0,'signed',true);
assert(isa(S.r,'double'));
```

```
assert(isfi(S.i) && isequal(numerictype(S.i),T));

y = S;
```

Note In most cases, `fiaccel` uses defaults when you do not explicitly specify values for properties—except for structure fields. The only way to name a field in a structure is to set at least one of its properties. Therefore in the preceding example, an `assert` function specifies that field `S.r` is of type `double`, even though `double` is the default.

Example: Specifying Class and Size of Structure Array

For structure arrays, you must choose a representative element of the array for specifying the properties of each field. For example, assume you have defined `S` as the following 1-by-2 array of MATLAB structures:

```
S = struct('r',{double(1), double(2)},'i',...
   {fi(4,1,8,0), fi(5,1,8,0)});
```

The following code specifies the class and size of each field of structure input `S` using the first element of the array:

```
function y = fcn(S)

% Specify the class of the input S as struct.
assert(isstruct(S));
T = numerictype('Wordlength', 8,'FractionLength', ...
   0,'signed',true);

% Specify the size of the fields r and i
% based on the first element of the array.
assert(all(size(S) == [1 2]));
assert(isa(S(1).r,'double'));
assert(isfi(S(1).i) && isequal(numerictype(S(1).i),T));

y = S;
```

Note In most cases, `fiaccel` uses defaults when you don't explicitly specify values for properties — except for structure fields. The only way to name a field in a structure is to set at least one of its properties. Therefore in the example above, an `assert` function specifies that field `S(1).r` is of type `double`, even though `double` is the default.

Controlling Run-Time Checks

In this section...

"Types of Run-Time Checks" on page 8-73

"When to Disable Run-Time Checks" on page 8-74

"How to Disable Run-Time Checks" on page 8-74

Types of Run-Time Checks

In simulation, the code generated for your MATLAB functions includes the following run-time checks and external function calls.

- Memory integrity checks

  These checks detect violations of memory integrity in code generated for MATLAB functions and stop execution with a diagnostic message.

  Caution For safety, these checks are enabled by default. Without memory integrity checks, violations will result in unpredictable behavior.

- Responsiveness checks in code generated for MATLAB functions

  These checks enable periodic checks for Ctrl+C breaks in code generated for MATLAB functions. Enabling responsiveness checks also enables graphics refreshing.

  Caution For safety, these checks are enabled by default. Without these checks the only way to end a long-running execution might be to terminate MATLAB.

- Extrinsic calls to MATLAB functions

  Extrinsic calls to MATLAB functions, for example to display results, are enabled by default for debugging purposes. For more information

about extrinsic functions, see “Declaring MATLAB Functions as Extrinsic Functions”.

When to Disable Run-Time Checks

Generally, generating code with run-time checks enabled results in more generated code and slower simulation than generating code with the checks disabled. Similarly, extrinsic calls are time consuming and have an adverse effect on performance. Disabling run-time checks and extrinsic calls usually results in streamlined generated code and faster simulation, with these caveats:

Consider disabling...	Only if...
Memory integrity checks	You are sure that your code is safe and that all array bounds and dimension checking is unnecessary.
Responsiveness checks	You are sure that you will not need to stop execution of your application using **Ctrl+C**.
Extrinsic calls	You are only using extrinsic calls to functions that do not affect application results.

How to Disable Run-Time Checks

To disable run-time checks:

1. Define the compiler options object in the MATLAB workspace by issuing a constructor command:

   ```
   comp_cfg = coder.MEXConfig
   ```

2. From the command line set the `IntegrityChecks`, `ExtrinsicCalls`, or `ResponsivenessChecks` properties false, as applicable:

   ```
   comp_cfg.IntegrityChecks = false;
   comp_cfg.ExtrinsicCalls = false;
   ```

```
comp_cfg.ResponsivenessChecks = false;
```

MATLAB Coder

MATLAB Coder `codegen` automatically converts MATLAB code directly to C code. It generates standalone C code that is bit-true to fixed-point MATLAB code. Using Fixed-Point Toolbox software you can generate C code with algorithms containing integer math only (i.e., without any floating-point math). For more information, refer to the *MATLAB Coder User's Guide*.

MATLAB Function Block

In this section...

"Composing a MATLAB Language Function in a Simulink Model" on page 8-77

"Using the MATLAB Function Block with Data Type Override" on page 8-77

"Using Fixed-Point Data Types with the MATLAB Function Block" on page 8-79

"Example: Implementing a Fixed-Point Direct Form FIR Using the MATLAB Function Block" on page 8-85

Composing a MATLAB Language Function in a Simulink Model

The MATLAB Function block lets you compose a MATLAB language function in a Simulink model that generates embeddable code. When you simulate the model or generate code for a target environment, a function in a MATLAB Function block generates efficient C/C++ code. This code meets the strict memory and data type requirements of embedded target environments. In this way, the MATLAB Function blocks bring the power of MATLAB for the embedded environment into Simulink.

For more information about the MATLAB Function block and code generation, refer to the followingn:

- MATLAB Function block reference page in the Simulink documentation
- "Using the MATLAB Function Block" in the Simulink documentation
- "About Code Generation from MATLAB Algorithms" in the Code Generation from MATLAB documentation

Using the MATLAB Function Block with Data Type Override

When you use the MATLAB Function block in a Simulink model that specifies data type override, the block determines the data type override equivalents of the input signal and parameter types. The block then uses these equivalent

values to run the simulation. The following table shows how the MATLAB Function block determines the data type override equivalent using

- The data type of the input signal or parameter
- The data type override setting in the Simulink model

Note The MATLAB Function block does not support the `Scaled double` data type override setting.

Input Signal or Parameter Type	Data Type Override Setting	Data Type Override Equivalent
Inherited `single`	`Double`	`fi double`
	`Single`	`fi single`
Specified `single`	`Double`	Built-in `double`
	`Single`	Built-in `single`
Inherited `double`	`Double`	`fi double`
	`Single`	`fi single`
Specified `double`	`Double`	Built-in `double`
	`Single`	Built-in `single`
Inherited `Fixed`	`Double`	`fi double`
	`Single`	`fi single`
Specified `Fixed`	`Double`	`fi double`
	`Single`	`fi single`

For more information about using the MATLAB Function block with data type override, see the following section of the Simulink documentation:

"Using Data Type Override with the MATLAB Function Block"

Using Fixed-Point Data Types with the MATLAB Function Block

Code generation from MATLAB supports a significant number of Fixed-Point Toolbox functions. Refer to "Functions Supported for Code Acceleration and Code Generation from MATLAB" on page 8-5 for information about which Fixed-Point Toolbox functions are supported.

For more information on working with fixed-point MATLAB Function blocks, see:

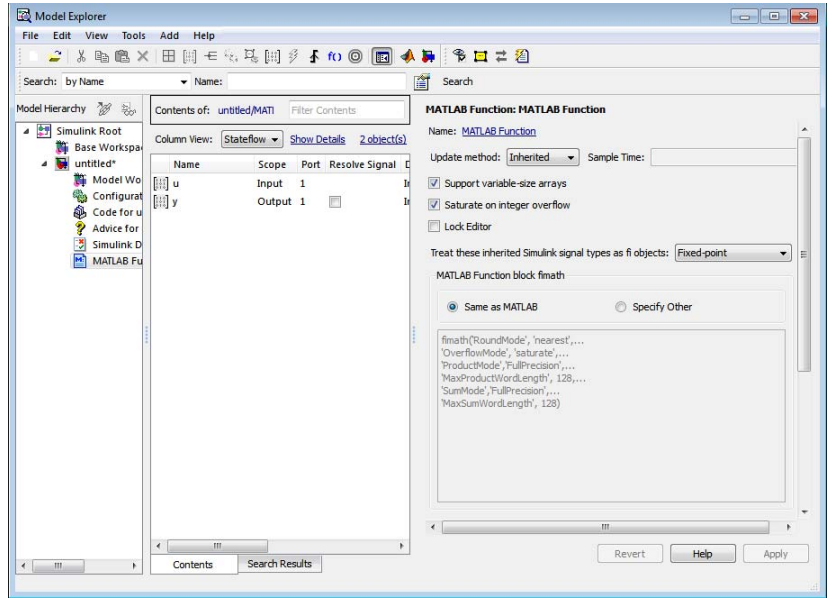
- "Specifying Fixed-Point Parameters in the Model Explorer" on page 8-79
- "Using fimath Objects in MATLAB Function Blocks" on page 8-81
- "Sharing Models with Fixed-Point MATLAB Function Blocks" on page 8-83

Note To simulate models using fixed-point data types in Simulink, you must have a Simulink Fixed Point license.

Specifying Fixed-Point Parameters in the Model Explorer

You can specify parameters for an MATLAB Function block in a fixed-point model using the Model Explorer. Try the following exercise:

1. Place a MATLAB Function block in a new model. You can find the block in the Simulink User-Defined Functions library.
2. Open the Model Explorer by selecting **View > Model Explorer** from your model.
3. Expand the **untitled*** node in the **Model Hierarchy** pane of the Model Explorer. Then, select the **MATLAB Function** node. The Model Explorer now appears as shown in the following figure.



The following parameters in the **Dialog** pane apply to MATLAB Function blocks in models that use fixed-point and integer data types:

Treat these inherited Simulink signal types as fi objects

Choose whether to treat inherited fixed-point and integer signals as `fi` objects.

- When you select `Fixed-point`, the MATLAB Function block treats all fixed-point inputs as Fixed-Point Toolbox `fi` objects.
- When you select `Fixed-Point & Integer`, the MATLAB Function block treats all fixed-point and integer inputs as Fixed-Point Toolbox `fi` objects.

MATLAB Function block fimath

Specify the `fimath` properties for the block to associate with the following objects:

- All fixed-point and integer input signals to the MATLAB Function block that you choose to treat as `fi` objects.
- All `fi` and `fimath` objects constructed in the MATLAB Function block.

You can select one of the following options for the **MATLAB Function block fimath**:

- **Same as MATLAB** — When you select this option, the block uses the same `fimath` properties as the current default fimath. The edit box appears dimmed and displays the current default fimath in read-only form.
- **Specify other** — When you select this option, you can specify your own `fimath` object in the edit box.

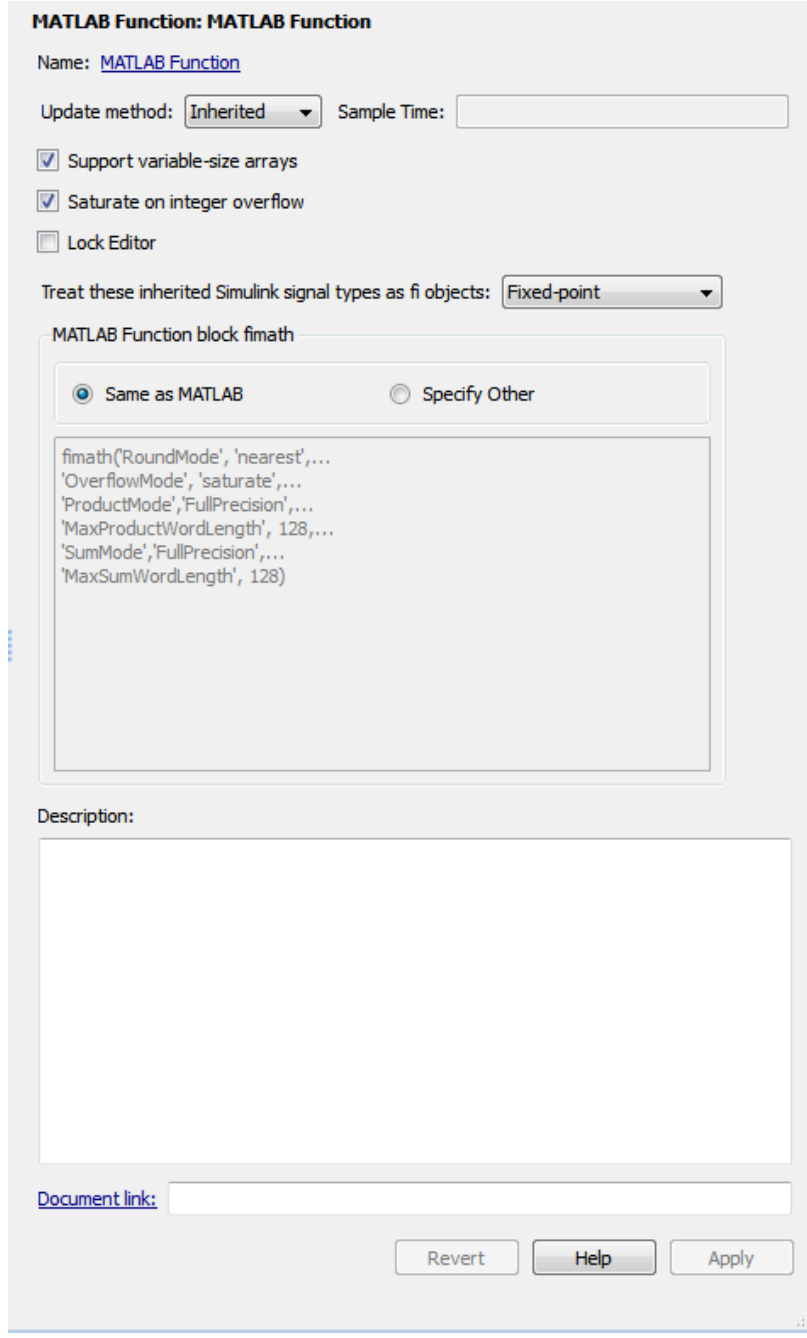
For more information on these parameters, see "Using fimath Objects in MATLAB Function Blocks" on page 8-81.

Using fimath Objects in MATLAB Function Blocks

The **MATLAB Function block fimath** parameter enables you to specify one set of `fimath` object properties for the MATLAB Function block. The block associates the `fimath` properties you specify with the following objects:

- All fixed-point and integer input signals to the MATLAB Function block that you choose to treat as `fi` objects.
- All `fi` and `fimath` objects constructed in the MATLAB Function block.

You can set these parameters on the following dialog box, which you can access through either the Model Explorer or the "Ports and Data Manager".


MATLAB Function: MATLAB Function
Name: MATLAB Function
Update method: Inherited
Sample Time:
Support variable-size arrays
Saturate on integer overflow
Lock Editor
Treat these inherited Simulink signal types as fi objects: Fixed-point
MATLAB Function block fimath
Same as MATLAB
Specify Other
fimath('RoundMode', 'nearest',...
'OverflowMode', 'saturate',...
'ProductMode','FullPrecision',...
'MaxProductWordLength', 128,...
'SumMode','FullPrecision',...
'MaxSumWordLength', 128)
Description:
Document link:
Revert
Help
Apply

- To access this pane through the Model Explorer:
  - Select **View** > **Model Explorer** from your model menu.
  - Then, select the MATLAB Function block from the Model Hierarchy pane on the left side of the Model Explorer.
- To access this pane through the Ports and Data Manager, select **Tools** > **Edit Data/Ports** from the MATLAB Editor menu.

When you select **Same as MATLAB** for the **MATLAB Function block fimath**, the MATLAB Function block uses the current default fimath. The current default fimath appears dimmed and in read-only form in the edit box.

When you select **Specify other** the block allows you to specify your own `fimath` object in the edit box. You can do so in one of two ways:

- Constructing the `fimath` object inside the edit box.
- Constructing the `fimath` object in the MATLAB or model workspace and then entering its variable name in the edit box.

Note If you use this option and plan to share your model with others, make sure you define the variable in the model workspace. See "Sharing Models with Fixed-Point MATLAB Function Blocks" on page 8-83 for more information on sharing models.

The Fixed-Point Toolbox `isfimathlocal` function supports code generation for MATLAB.

Sharing Models with Fixed-Point MATLAB Function Blocks

When you collaborate with a coworker, you can share a fixed-point model using the MATLAB Function block. To share a model, make sure that you move any variables you define in the MATLAB workspace, including `fimath` objects, to the model workspace. For example, try the following:

1 Place a MATLAB Function block in a new model. You can find the block in the Simulink User-Defined Functions library.

2 Define a `fimath` object in the MATLAB workspace that you want to use for any Simulink fixed-point signal entering the MATLAB Function block as an input:

```
F = fimath('RoundMode','Floor','OverflowMode','Wrap',...
    'ProductMode','KeepLSB','ProductWordLength',32,...
    'SumMode','KeepLSB','SumWordLength',32)

F =
              RoundMode: floor
           OverflowMode: wrap
            ProductMode: KeepLSB
       ProductWordLength: 32
                 SumMode: KeepLSB
           SumWordLength: 32
           CastBeforeSum: true
```

3 Open the Model Explorer by selecting **View** > **Model Explorer** from your model.

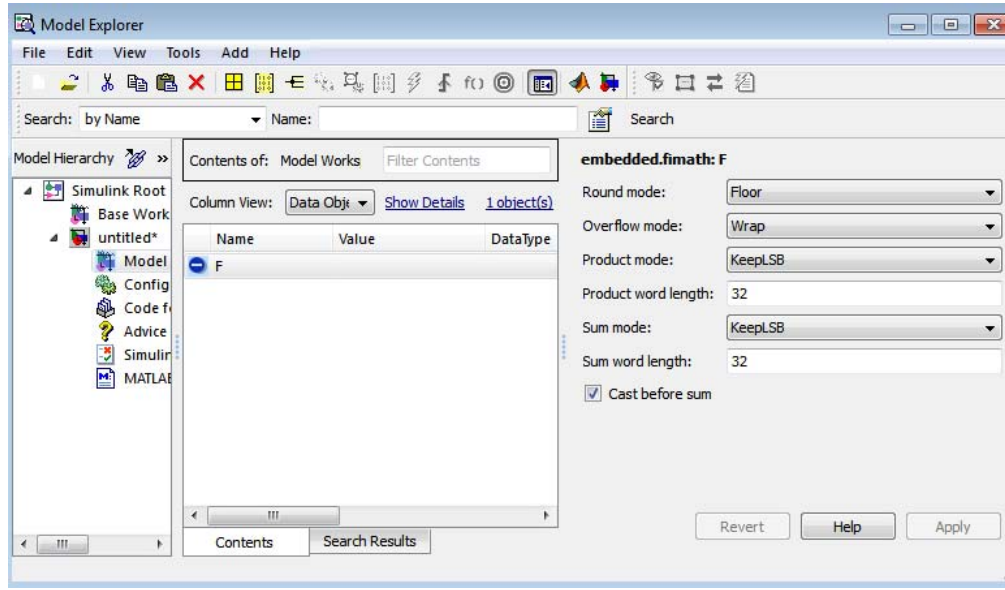
4 Expand the **untitled*** node in the **Model Hierarchy** pane of the Model Explorer, and select the **MATLAB Function** node.

5 Select **Specify other** for the **MATLAB Function block fimath** parameter and enter the variable `F` into the edit box on the **Dialog** pane. Click **Apply** to save your changes.

You have now defined the `fimath` properties to be associated with all Simulink fixed-point input signals and all `fi` and `fimath` objects constructed within the block.

6 Select the **Base Workspace** node in the **Model Hierarchy** pane. You can see the variable `F` that you have defined in the MATLAB workspace listed in the **Contents** pane. If you send this model to a coworker, that coworker must first define that same variable in the MATLAB workspace to get the same results.

7 Cut the variable `F` from the base workspace, and paste it into the model workspace listed under the node for your model, in this case, **untitled***. The Model Explorer now appears as shown in the following figure.



You can now email your model to a coworker. Because you included the required variables in the workspace of the model itself, your coworker can simply run the model and get the correct results. Receiving and running the model does not require any extra steps.

Example: Implementing a Fixed-Point Direct Form FIR Using the MATLAB Function Block

The following sections lead you through creating a fixed-point, low-pass, direct form FIR filter in Simulink. To create the FIR filter, you use Fixed-Point Toolbox software and the MATLAB Function block. In this example, you perform the following tasks in the sequence shown:

- "Program the MATLAB Function Block" on page 8-86
- "Prepare the Inputs" on page 8-86
- "Create the Model" on page 8-87
- "Define the fimath Object Using the Model Explorer" on page 8-92
- "Run the Simulation" on page 8-92

Program the MATLAB Function Block

1. Place a MATLAB Function block in a new model. You can find the block in the Simulink User-Defined Functions library.

2. Save your model as `cgen_fi.mdl`.

3. Double-click the MATLAB Function block in your model to open the MATLAB Function Block Editor. Type or copy and paste the following MATLAB code, including comments, into the Editor:

```
function [yout,zf] = dffirdemo(b, x, zi)
%codegen_fi doc model example
%Initialize the output signal yout and the final conditions zf
Ty = numerictype(1,12,8);
yout = fi(zeros(size(x)),'numerictype',Ty);
zf = zi;

% FIR filter code
for k=1:length(x);
  % Update the states: z = [x(k);z(1:end-1)]
  zf(:) = [x(k);zf(1:end-1)];
  % Form the output: y(k) = b*z
  yout(k) = b*zf;
end

% Plot the outputs only in simulation.
% This does not generate C code.
coder.extrinsic('figure');
coder.extrinsic('subplot');
coder.extrinsic('plot');
coder.extrinsic('title');
coder.extrinsic('grid');
figure;
subplot(211);plot(x); title('Noisy Signal');grid;
subplot(212);plot(yout); title('Filtered Signal');grid;
```

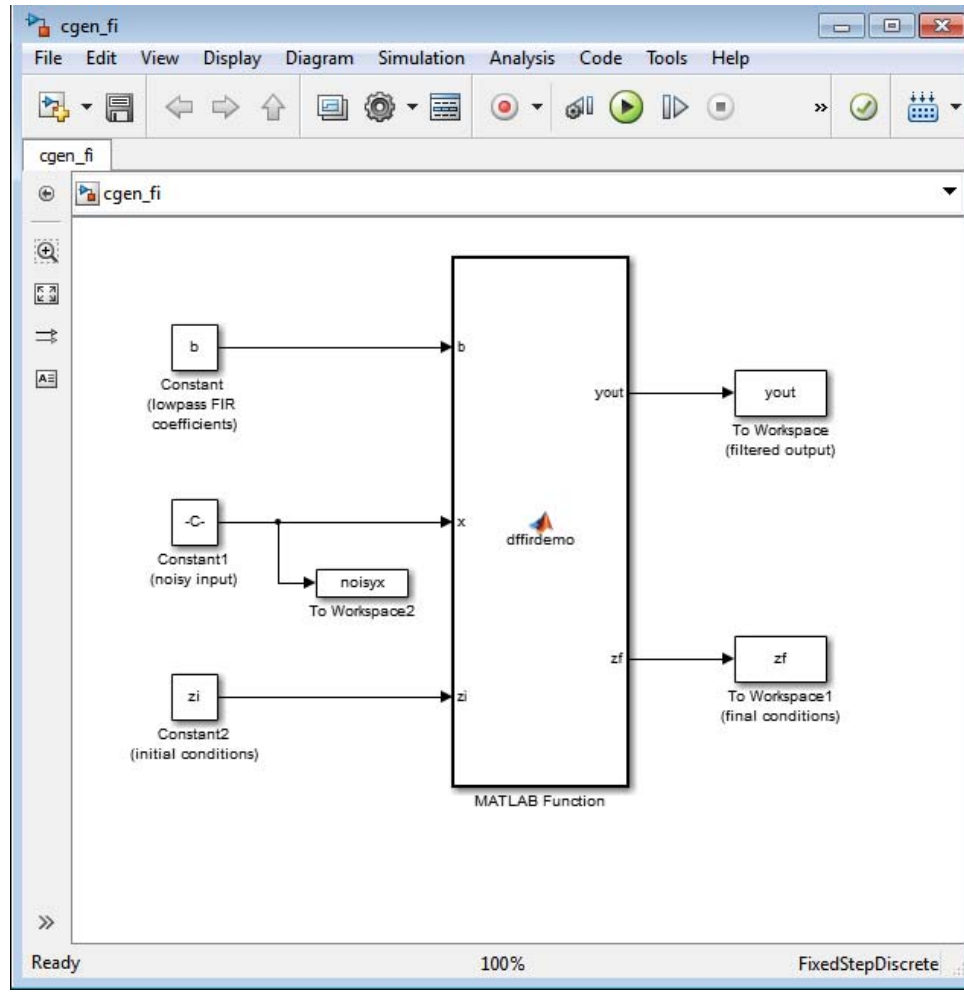
Prepare the Inputs

Define the filter coefficients *b*, noise *x*, and initial conditions *zi* by typing the following code at the MATLAB command line:

```
b=fidemo.fi_fir_coefficients;
load mtlb
x = mtlb;
n = length(x);
noise = sin(2*pi*2140*(0:n-1)'./Fs);
x = x + noise;
zi = zeros(length(b),1);
```

Create the Model

1 Add blocks to your model to create the following system.


cgen_fi
File Edit View Display Diagram Simulation Analysis Code Tools Help
cgen_fi
cgen_fi
b
Constant
(lowpass FIR
coefficients)
-C-
Constant1
(noisy input)
noisyx
To Workspace2
zi
Constant2
(initial conditions)
b
x
zi
dffirdemo
MATLAB Function
yout
yout
To Workspace
(filtered output)
zf
zf
To Workspace1
(final conditions)
Ready
100%
FixedStepDiscrete

2 Set the block parameters in the model to the following values.

Block	Parameter	Value
Constant	**Constant value**	`b`
	Interpret vector parameters as 1-D	Unselected
	Sampling mode	`Sample based`
	Sample time	`inf`
	Mode	`Fixed point`
	Signedness	`Signed`
	Scaling	`Slope and bias`
	Word length	`12`
	Slope	`2^-12`
	Bias	`0`
Constant1	**Constant value**	`x+noise`
	Interpret vector parameters as 1-D	Unselected
	Sampling mode	`Sample based`
	Sample time	`1`
	Mode	`Fixed point`
	Signedness	`Signed`
	Scaling	`Slope and bias`
	Word length	`12`
	Slope	`2^-8`
	Bias	`0`

Block	Parameter	Value
Constant2	**Constant value**	`zi`
	Interpret vector parameters as 1-D	Unselected
	Sampling mode	`Sample based`
	Sample time	`inf`
	Mode	`Fixed point`
	Signedness	`Signed`
	Scaling	`Slope and bias`
	Word length	`12`
	Slope	`2^-8`
	Bias	`0`
To Workspace	**Variable name**	`yout`
	Limit data points to last	`inf`
	Decimation	`1`
	Sample time	`-1`
	Save format	`Array`
	Log fixed-point data as a fi object	Selected

Block	Parameter	Value
To Workspace1	**Variable name**	`zf`
	Limit data points to last	`inf`
	Decimation	`1`
	Sample time	`-1`
	Save format	`Array`
	Log fixed-point data as a fi object	Selected
To Workspace2	**Variable name**	`noisyx`
	Limit data points to last	`inf`
	Decimation	`1`
	Sample time	`-1`
	Save format	`Array`
	Log fixed-point data as a fi object	Selected

3 From the model menu, select **Simulation > Configuration Parameters** and set the following parameters.

Parameter	Value
Stop time	`0`
Type	`Fixed-step`
Solver	`discrete (no continuous states)`

Click **Apply** to save your changes.

Define the fimath Object Using the Model Explorer

1. Open the Model Explorer for the model.
2. Click the **cgen_fi > MATLAB Function** node in the **Model Hierarchy** pane. The dialog box for the MATLAB Function block appears in the **Dialog** pane of the Model Explorer.
3. Select **Specify other** for the **MATLAB Function block fimath** parameter on the MATLAB Function block dialog box. You can then create the following `fimath` object in the edit box:

```
fimath('RoundMode','Floor','OverflowMode','Wrap',...
    'ProductMode','KeepLSB','ProductWordLength',32,...
    'SumMode','KeepLSB','SumWordLength',32)
```

The `fimath` object you define here is associated with fixed-point inputs to the MATLAB Function block as well as the `fi` object you construct within the block.

By selecting **Specify other** for the **MATLAB Function block fimath**, you ensure that your model always uses the `fimath` properties you specified.

Run the Simulation

1. Run the simulation by selecting your model and typing **Ctrl+T**. While the simulation is running, information outputs to the MATLAB command line. You can look at the plots of the noisy signal and the filtered signal.
2. Next, build embeddable C code for your model by selecting the model and typing **Ctrl+B**. While the code is building, information outputs to the MATLAB command line. A folder called `coder_fi_grt_rtw` is created in your current working folder.
3. Navigate to `coder_fi_grt_rtw` > `coder_fi.c`. In this file, you can see the code generated from your model. Search for the following comment in your code:

```
/* coder_fi doc model example */
```

This search brings you to the beginning of the section of the code that your MATLAB Function block generated.

9

Interoperability with Other Products

- "Using fi Objects with Simulink" on page 9-2
- "Using fi Objects with DSP System Toolbox " on page 9-7
- "Using fiaccel, MATLAB® Coder™, or Simulink to Generate Code" on page 9-12

Using fi Objects with Simulink

In this section...

"Reading Fixed-Point Data from the Workspace" on page 9-2

"Writing Fixed-Point Data to the Workspace" on page 9-2

"Setting the Value and Data Type of Block Parameters" on page 9-6

"Logging Fixed-Point Signals" on page 9-6

"Accessing Fixed-Point Block Data During Simulation" on page 9-6

Reading Fixed-Point Data from the Workspace

You can read fixed-point data from the MATLAB workspace into a Simulink model via the From Workspace block. To do so, the data must be in a structure format with a `fi` object in the `values` field. In array format, the From Workspace block only accepts real, double-precision data.

To read in `fi` data, the **Interpolate data** parameter of the From Workspace block must not be selected, and the **Form output after final data value by** parameter must be set to anything other than `Extrapolation`.

Writing Fixed-Point Data to the Workspace

You can write fixed-point output from a model to the MATLAB workspace via the To Workspace block in either array or structure format. Fixed-point data written by a To Workspace block to the workspace in structure format can be read back into a Simulink model in structure format by a From Workspace block.

Note To write fixed-point data to the MATLAB workspace as a `fi` object, select the **Log fixed-point data as a fi object** check box on the To Workspace block dialog. Otherwise, fixed-point data is converted to `double` and written to the workspace as `double`.

For example, you can use the following code to create a structure in the MATLAB workspace with a `fi` object in the `values` field. You can then use the From Workspace block to bring the data into a Simulink model.

```
a = fi([sin(0:10)' sin(10:-1:0)'])

a =

         0   -0.5440
    0.8415    0.4121
    0.9093    0.9893
    0.1411    0.6570
   -0.7568   -0.2794
   -0.9589   -0.9589
   -0.2794   -0.7568
    0.6570    0.1411
    0.9893    0.9093
    0.4121    0.8415
   -0.5440         0


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15

s.signals.values = a

s =

    signals: [1x1 struct]

s.signals.dimensions = 2

s =

    signals: [1x1 struct]

s.time = [0:10]'
```

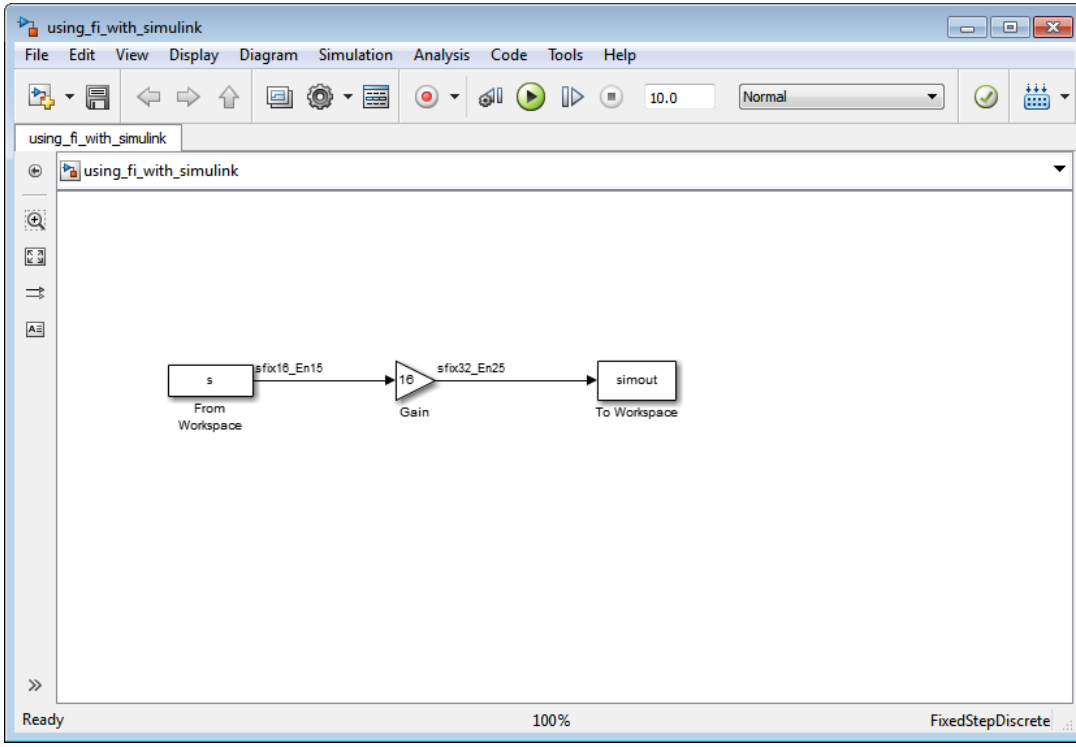
```
s =

    signals: [1x1 struct]
       time: [11x1 double]
```

The From Workspace block in the following model has the `fi` structure `s` in the **Data** parameter.

Remember, to write fixed-point data to the MATLAB workspace as a `fi` object, select the **Log fixed-point data as a fi object** check box on the To Workspace block dialog. Otherwise, fixed-point data is converted to `double` and written to the workspace as `double`.

In the model, the following parameters in the **Solver** pane of the **Configuration Parameters** dialog have the indicated settings:

- **Start time** — `0.0`
- **Stop time** — `10.0`
- **Type** — `Fixed-step`
- **Solver** — `Discrete (no continuous states)`
- **Fixed step size (fundamental sample time)** — `1.0`



The To Workspace block writes the result of the simulation to the MATLAB workspace as a `fi` structure.

```
simout.signals.values

ans =

         0   -8.7041
   13.4634    6.5938
   14.5488   15.8296
    2.2578   10.5117
  -12.1089   -4.4707
  -15.3428  -15.3428
   -4.4707  -12.1089
   10.5117    2.2578
   15.8296   14.5488
```

```
    6.5938   13.4634
   -8.7041         0


DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 32
        FractionLength: 25
```

Setting the Value and Data Type of Block Parameters

You can use Fixed-Point Toolbox expressions to specify the value and data type of block parameters in Simulink. Refer to "Block Support for Data and Numeric Signal Types" in the Simulink documentation for more information.

Logging Fixed-Point Signals

When fixed-point signals are logged to the MATLAB workspace via signal logging, they are always logged as `fi` objects. To enable signal logging for a signal, select the **Log signal data** option in the signal's **Signal Properties** dialog box. For more information, refer to "Exporting Signal Data Using Signal Logging" in the Simulink documentation.

When you log signals from a referenced model or Stateflow® chart in your model, the word lengths of `fi` objects may be larger than you expect. The word lengths of fixed-point signals in referenced models and Stateflow charts are logged as the next largest data storage container size.

Accessing Fixed-Point Block Data During Simulation

Simulink provides an application program interface (API) that enables programmatic access to block data, such as block inputs and outputs, parameters, states, and work vectors, while a simulation is running. You can use this interface to develop MATLAB programs capable of accessing block data while a simulation is running or to access the data from the MATLAB command line. Fixed-point signal information is returned to you via this API as `fi` objects. For more information on the API, refer to "Accessing Block Data During Simulation" in the Simulink documentation.

Using fi Objects with DSP System Toolbox

In this section...

"Reading Fixed-Point Signals from the Workspace" on page 9-7

"Writing Fixed-Point Signals to the Workspace" on page 9-7

"Using fi Objects with dfilt Objects" on page 9-11

Reading Fixed-Point Signals from the Workspace

You can read fixed-point data from the MATLAB workspace into a Simulink model using the Signal From Workspace and Triggered Signal From Workspace blocks from DSP System Toolbox™ software. Enter the name of the defined `fi` variable in the **Signal** parameter of the Signal From Workspace or Triggered Signal From Workspace block.

Writing Fixed-Point Signals to the Workspace

Fixed-point output from a model can be written to the MATLAB workspace via the Signal To Workspace or Triggered To Workspace block from the blockset. The fixed-point data is always written as a 2-D or 3-D array.

Note To write fixed-point data to the MATLAB workspace as a `fi` object, select the **Log fixed-point data as a fi object** check box on the Signal To Workspace or Triggered To Workspace block dialog. Otherwise, fixed-point data is converted to `double` and written to the workspace as `double`.

For example, you can use the following code to create a `fi` object in the MATLAB workspace. You can then use the Signal From Workspace block to bring the data into a Simulink model.

```
a = fi([sin(0:10)' sin(10:-1:0)'])

a =

         0   -0.5440
    0.8415    0.4121
    0.9093    0.9893
    0.1411    0.6570
   -0.7568   -0.2794
   -0.9589   -0.9589
   -0.2794   -0.7568
    0.6570    0.1411
    0.9893    0.9093
    0.4121    0.8415
   -0.5440         0


          DataTypeMode: Fixed-point: binary point scaling
            Signedness: Signed
            WordLength: 16
        FractionLength: 15
```

The Signal From Workspace block in the following model has these settings:

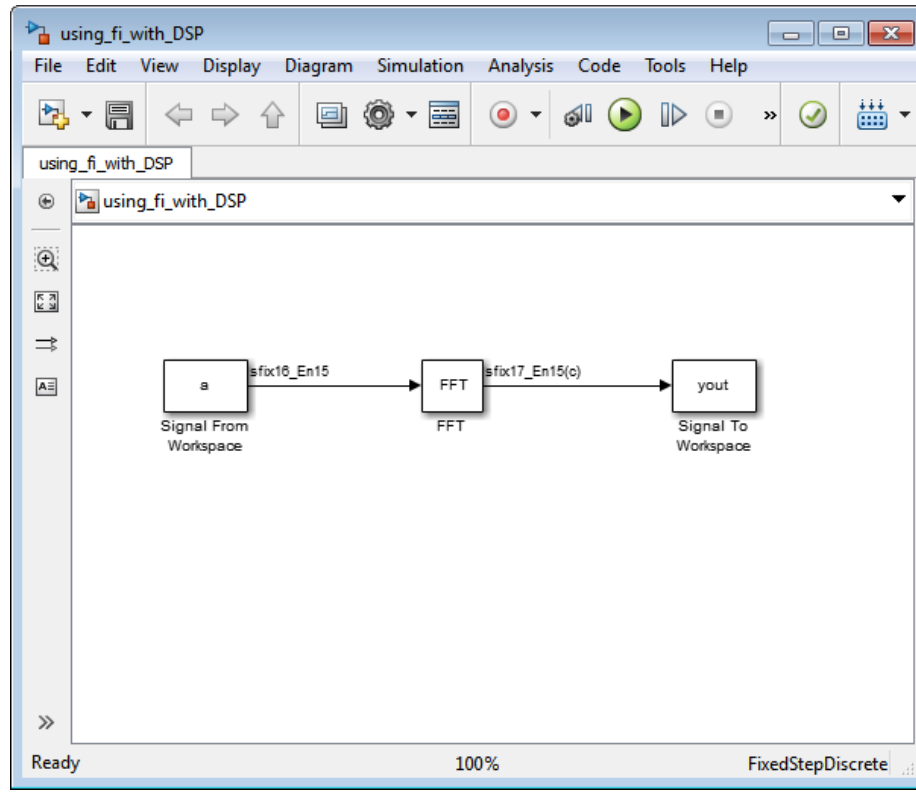
- **Signal** — `a`
- **Sample time** — `1`
- **Samples per frame** — `2`
- **Form output after final data value by** — `Setting to zero`

The following parameters in the **Solver** pane of the **Configuration Parameters** dialog have these settings:

- **Start time** — `0.0`

- **Stop time** — `10.0`
- **Type** — `Fixed-step`
- **Solver** — `Discrete (no continuous states)`
- **Fixed step size (fundamental sample time)** — `1.0`

Remember, to write fixed-point data to the MATLAB workspace as a `fi` object, select the **Log fixed-point data as a fi object** check box on the Signal To Workspace block dialog. Otherwise, fixed-point data is converted to `double` and written to the workspace as `double`.



The Signal To Workspace block writes the result of the simulation to the MATLAB workspace as a `fi` object.

```
yout =


(:,:,1) =

    0.8415   -0.1319
   -0.8415   -0.9561


(:,:,2) =

    1.0504    1.6463
    0.7682    0.3324


(:,:,3) =

   -1.7157   -1.2383
    0.2021    0.6795


(:,:,4) =

    0.3776   -0.6157
   -0.9364   -0.8979


(:,:,5) =

    1.4015    1.7508
    0.5772    0.0678


(:,:,6) =

   -0.5440         0
   -0.5440         0
```

```
    DataTypeMode: Fixed-point: binary point scaling
      Signedness: Signed
      WordLength: 17
  FractionLength: 15
```

Using fi Objects with dfilt Objects

When the `Arithmetic` property is set to `'fixed'`, you can use an existing `fi` object as the input, states, or coefficients of a `dfilt` object in DSP System Toolbox software. Also, fixed-point filters in the toolbox return `fi` objects as outputs. Refer to the DSP System Toolbox software documentation for more information.

Using fiaccel, MATLAB Coder, or Simulink to Generate Code

There are several ways to use Fixed-Point Toolbox software to generate code:

- The Fixed-Point Toolbox `fiaccel` function converts your fixed-point MATLAB code to a MEX function and can greatly accelerate the execution speed of your fixed-point algorithms.
- The MATLAB Coder `codegen` function automatically converts MATLAB code to C/C++ code. Using the MATLAB Coder software allows you to accelerate your MATLAB code that uses Fixed-Point Toolbox software. To use the `codegen` function with Fixed-Point Toolbox software, you also need to have a MATLAB Coder license. For more information, see "Generating C Code from MATLAB Code at the Command Line" in the MATLAB Coder documentation.
- The MATLAB Function block allows you to use MATLAB code in your Simulink models that generate embeddable C/C++ code. To use the MATLAB Function block with Fixed-Point Toolbox software, you also need a Simulink license. For more information on the MATLAB Function block, see "Using the MATLAB Function Block" in the Simulink documentation.

For more information on generating code with Fixed-Point Toolbox software, see Chapter 8, "Code Acceleration and Code Generation from MATLAB for Fixed-Point Algorithms".

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