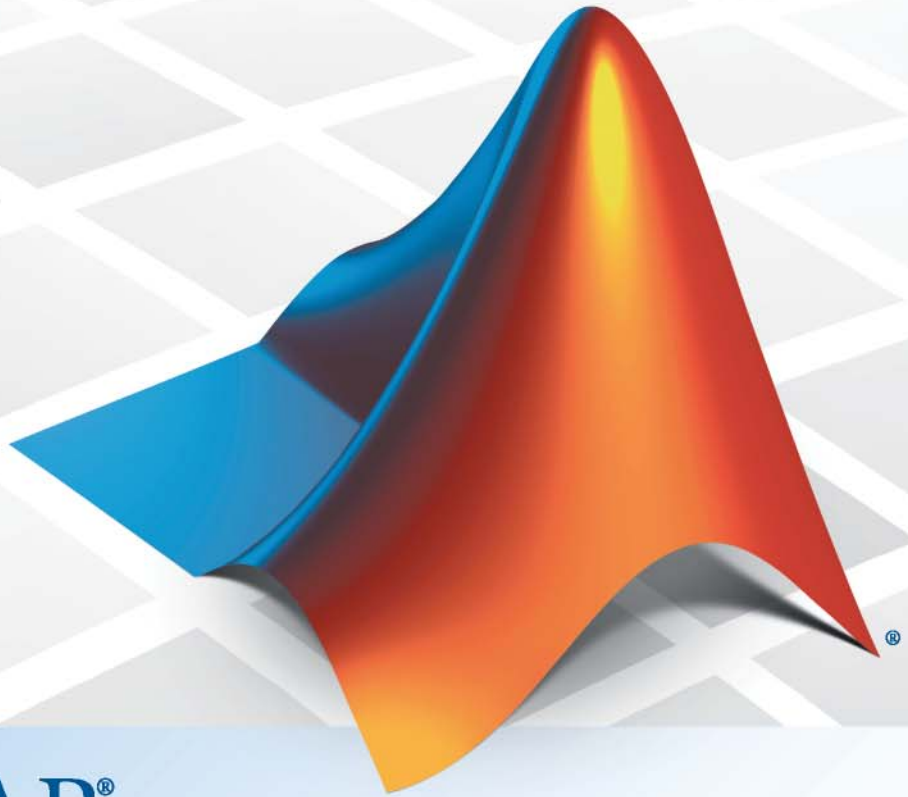


MATLAB® 7

Object-Oriented Programming



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Object-Oriented Programming

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- “Class Diagrams Used in This Documentation” on page 1-17

Where to Begin

In this section...
“Video Demo of MATLAB Classes” on page 1-2
“MATLAB Programmer Without Object-Oriented Programming Experience” on page 1-2
“MATLAB Programmer with Object-Oriented Programming Experience” on page 1-2

Video Demo of MATLAB Classes

You can watch a brief presentation on MATLAB® class development by clicking this link:

Play demo

MATLAB Programmer Without Object-Oriented Programming Experience

If you create MATLAB programs, but are not defining classes to accomplish your tasks, start with the following sections:

- “Why Use Object-Oriented Design” on page 1-4
- “MATLAB Classes” on page 2-2
- “Examples to Get Started” on page 2-6
- “Learning Object-Oriented Programming” on page 2-7

MATLAB Programmer with Object-Oriented Programming Experience

If have experience with both MATLAB programming and object-oriented techniques, start with the following sections:

- Chapter 3, “Class Definition—Syntax Reference”
- “Detailed Information and Examples” on page 2-8

- “Compatibility with Previous Versions ” on page 3-37
- “MATLAB Vs. Other OO Languages” on page 3-41

Why Use Object-Oriented Design

In this section...
“Approaches to Writing MATLAB Programs” on page 1-4
“When Should You Start Creating Object-Oriented Programs” on page 1-8

Approaches to Writing MATLAB Programs

Creating software applications typically involves designing how to represent the application data and determining how to implement operations performed on that data. Procedural programs pass data to functions, which perform the necessary operations on the data. Object-oriented software encapsulates data and operations in objects that interact with each other via the object’s interface.

The MATLAB language enables you to create programs using both procedural and object-oriented techniques and to use objects and ordinary functions in your programs.

Procedural Program Design

In procedural programming, your design focuses on steps that must be executed to achieve a desired state. You typically represent data as individual variables or fields of a structure and implement operations as functions that take the variables as arguments. Programs usually call a sequence of functions, each one of which is passed data, and then returns modified data. Each function performs an operation or perhaps many operations on the data.

Object-Oriented Program Design

The object-oriented program design involves:

- Identifying the components of the system or application that you want to build
- Analyzing and identifying patterns to determine what components are used repeatedly or share characteristics
- Classifying components based on similarities and differences

After performing this analysis, you define classes that describe the objects your application uses.

Classes and Objects

A class describes a set of objects with common characteristics. Objects are specific instances of a class. The values contained in an object's properties are what make an object different from other objects of the same class (an object of class `double` might have a value of 5). The functions defined by the class (called methods) are what implement object behaviors that are common to all objects of a class (you can add two doubles regardless of their values).

Using Objects in MATLAB Programs

The MATLAB language defines objects that are designed for use in any MATLAB code. For example, consider the `try-catch` programming construct.

If the code executed in the `try` block generates an error, program control passes to the code in the `catch` block. This behavior enables your program to provide special error handling that is more appropriate to your particular application. However, you must have enough information about the error to take the appropriate action.

MATLAB provides detailed information about the error by passing an `MException` object to functions executing the `try-catch` blocks.

The following `try-catch` blocks display the error message stored in an `MException` object when a function (`surf` in this case) is called without the necessary arguments:

```
try
    surf
catch ME
    disp(ME.message)
end
Not enough input arguments.
```

In this code, `ME` is an object of the `MException` class, which is returned by the `catch` statement to the function's workspace. Displaying the value of the object's `message` property returns information about the error (the `surf`

function requires input arguments). However, this is not all the information available in the MException object.

You can list the public properties of an object with the `properties` function:

```
properties(ME)
Properties for class MException:
    identifier
    message
    cause
    stack
```

Objects Organize Data

The information returned in an MException object is stored in properties, which are much like structure fields. You reference a property using dot notation, as in `ME.message`. This reference returns the value of the property. For example,

```
class(ME.message)
ans =
char
```

shows that the value of the `message` property is an array of class `char` (a text string). The `stack` property contains a MATLAB struct:

```
ME.stack
ans =
    file: 'U:\bat\A\perfect\matlab\toolbox\matlab\graph3d\surf.m'
    name: 'surf'
    line: 50
```

You can simply treat the property reference, `ME.stack` as a structure and reference its fields:

```
ME.stack.file
ans =
D:\myMATLAB\matlab\toolbox\matlab\graph3d\surf.m
```

The `file` field of the struct contained in the `stack` property is a character array:

```
class(ME.stack.file)
ans =
char
```

You could, for example, use a property reference in MATLAB functions:

```
strcmp(ME.stack.name, 'surf')
ans =
    1
```

Object properties can contain any class of value and can even determine their value dynamically. This provides more flexibility than a structure and is easier to investigate than a cell array, which lacks fieldnames and requires indexing into various cells using array dimensions.

Objects Manage Their Own Data

You could write a function that generates a report from the data returned by `MException` object properties. This function could become quite complicated because it would have to be able to handle all possible errors. Perhaps you would use different functions for different `try-catch` blocks in your program. If the data returned by the error object needed to change, you would have to update the functions you have written to use the new data.

Objects provide an advantage in that objects define their own operations. A requirement of the `MException` object is that it can generate its own report. The methods that implement an object's operations are part of the object definition (i.e., specified by the class that defines the object). The object definition might be modified many times, but the interface your program (and other programs) use does not change. Think of your program as a client of the object, which isolates your code from the object's code.

To see what methods exist for `MException` objects, use the `methods` function:

```
methods(ME)
Methods for class MException:

addCause    eq          isequal    rethrow    throwAsCaller
disp        getReport  ne         throw

Static methods:
```

```
last
```

You can use these methods like any other MATLAB statement when there is an MException object in the workspace. For example:

```
ME.getReport
ans =
??? Error using ==> surf at 50
Not enough input arguments.
```

Objects often have methods that overload (redefined for the particular object) MATLAB functions (e.g., `isequal`, `fieldnames`, etc.). This enables you to use objects just like other values. For example, MException objects have an `isequal` method. This method enables you to compare these objects in the same way you would compare variables containing doubles. If ME and ME2 are MException objects, you can compare them with this statement:

```
isequal(ME,ME2)
```

However, what really happens in this case is MATLAB calls the MException `isequal` method because you have passed MException objects to `isequal`.

Similarly, the `eq` method enables you to use the `==` operator with MException objects:

```
ME == ME2
```

Of course, objects should support only those methods that make sense. For example, it would probably not make sense to multiply MException objects so the MException class does not implement methods to do so.

When Should You Start Creating Object-Oriented Programs

Objects are well integrated into the MATLAB language, regardless of whether you are writing simple functions, working interactively in the command window, or creating large applications.

Simple programming tasks are easily implemented as simple functions, but as the magnitude and complexity of your tasks increase, functions become more complex and difficult to manage.

As functions become too large, you might break them into smaller functions and pass data from one to the other. However, as the number of functions becomes large, designing and managing the data passed to functions becomes difficult and error prone. At this point, you should consider moving your MATLAB programming tasks to object-oriented designs.

Understanding a Problem in Terms of Its Objects

Thinking in terms of things or objects is simpler and more natural for some problems. You might think of the nouns in your problem statement as the objects you need to define and the verbs as the operations you must perform.

For example, consider performing an analysis of economic institutions. It would be difficult to represent the various institutions as procedures even though they are all actors in the overall economy. Consider banks, mortgage companies, credit unions. You can represent each institution as an object that performs certain actions and contains certain data. The process of designing the objects involves identifying the characteristics of these institutions that are important to your application.

Identify Commonalities. All of these institutions belong in the general class of lending institutions, so all objects might provide a `loan` operation and have a `Rate` property that stores the current interest rate.

Identify Differences. You must also consider how each institution differs. A mortgage company might provide only home mortgage loans. Therefore, the `loan` operation might need be specialized for mortgage companies to provide `fixRateLoan` and `varRateLoan` methods to accommodate two loan types.

Consider Interactions. Institutions can interact, as well. For example, a mortgage company might sell a mortgage to a bank. To support this activity, the mortgage company object would support a `sellMortgage` operation and the bank object would support a `buyMortgage` operation.

You might also define a loan object, which would represent a particular loan. It might need `Amount`, `Rate`, and `Lender` properties. When the loan is sold to another institution, the `Lender` property could be changed, but all other information is neatly packaged within the loan object.

Add Only What Is Necessary. It is likely that these institutions engage in many activities that are not of interest to your application. During the design phase, you need to determine what operations and data an object needs to contain based on your problem definition.

Managing Data. Objects encapsulate the model of what the object represents. If the object represents a kind of lending institution, all the behaviors of lending institutions that are necessary for your application are contained by this object. This approach simplifies the management of data that is necessary in a typical procedural program.

Objects Manage Internal State

In the simplest sense, objects are data structures that encapsulate some internal state, which you access via its methods. When you invoke a method, it is the object that determines exactly what code to execute. In fact, two objects of the same class might execute different code paths for the same method invocation because their internal state is different. The internal workings of the object need not be of concern to your program — you simply use the interface the object provides.

Hiding the internal state from general access leads to more robust code. If a loan object's `Lender` property can be changed only by the object's `newLender` method, then inadvertent access is less likely than if the loan data were stored in a cell array where an indexing assignment statement could damage the data.

Objects provide a number of useful features not available from structures and cell arrays. For example, objects provide the ability to:

- Constrain the data assigned to any given property by executing a function to test values whenever an assignment is made
- Calculate the value of a property only when it is queried and thereby avoid storing data that might be dependent on the state of other data
- Broadcast notices when any property value is queried or changed, to which any number of listeners can respond by executing functions
- Restrict access to properties and methods

Reducing Redundancy

As the complexity of your program increases, the benefits of an object-oriented design become more apparent. For example, suppose you need to implement the following procedure as part of your application:

- 1 Check inputs
- 2 Perform computation on the first input argument
- 3 Transform the result of step 2 based on the second input argument
- 4 Check validity of outputs and return values

This simple procedure is easily implemented as an ordinary function. But now suppose you need to use this procedure again somewhere in your application, except that step 2 must perform a different computation. You could simply copy and paste the first implementation, and then rewrite step 2. Or you could create a function that accepted an option indicating which computation to make, and so on. However, these options lead to more and more complicated code.

An object-oriented design could result in a simpler solution by factoring out the common code into what is called a base class. The base class would define the algorithm used and implement whatever is common to all cases that use this code. Step 2 could be defined syntactically, but not implemented, leaving the specialized implementation to the classes that you then derive from this base class.

```
Step 1
function checkInputs()
    % actual implementation
end

Step 2
function results = computeOnFirstArg()
    % specify syntax only
end

Step 3
function transformResults()
```

```
        % actual implementation
    end

    Step 4
    function out = checkOutputs()
        % actual implementation
    end
```

The code in the base class is not copied or modified, it is inherited by the various classes you derive from the base class. This reduces the amount of code to be tested, and isolates your program from changes to the basic procedure.

Defining Consistent Interfaces

The use of a class as the basis for similar, but more specialized classes is a useful technique in object-oriented programming. This class is often called an interface class. Incorporating this kind of class into your program design enables you to:

- Identify the requirements of a particular objective
- Encode these requirements into your program as an interface class

For example, suppose you are creating an object to return information about errors that occur during the execution of specific blocks of code. There might be functions that return special types of information that you want to include in an error report only when the error is generated by these functions.

The interface class, from which all error objects are derived, could specify that all error objects must support a `getReport` method, but not specify how to implement that method. The class of error object created for the functions returning special information could implement its version of the `getReport` method to handle the different data.

The requirement defined by the interface class is that all error objects be able to display an error report. All programs that use this feature can rely on it being implemented in a consistent way.

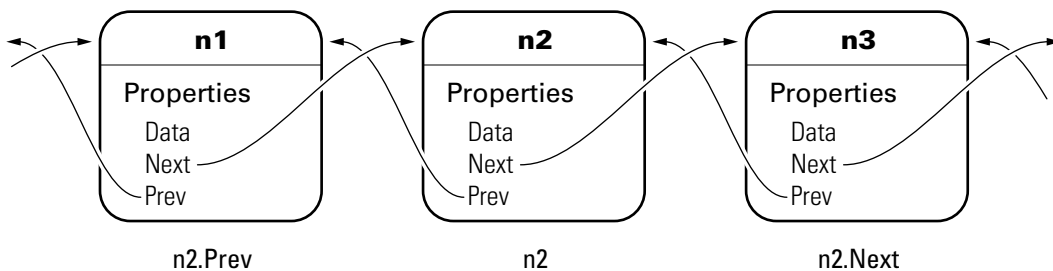
All of the classes derived from the interface class can create a method called `getReport` without any name conflicts because it is the class of the object that determines which `getReport` is called.

Reducing Complexity

Objects reduce complexity by reducing what you need to know to use a component or part of a system. This happens in a couple of ways:

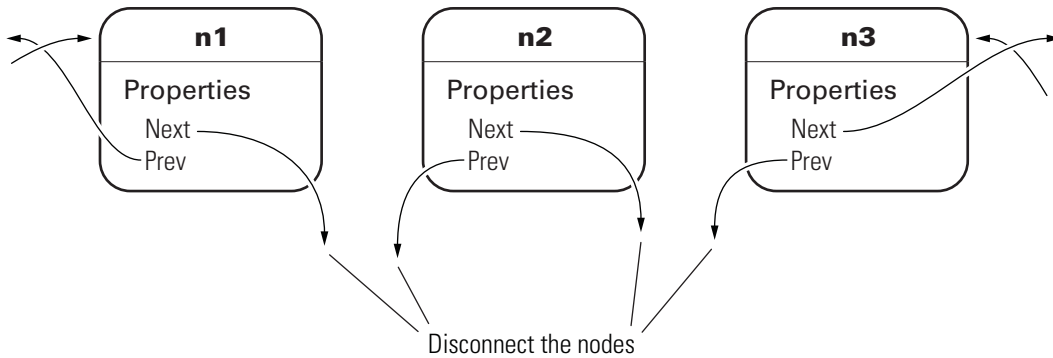
- Implementation details are hidden behind the interfaces defined by objects.
- Rules controlling how objects interact are enforced by object design and, therefore, not left to object users to enforce.

To illustrate these advantages, consider the implementation of a data structure called a doubly linked list.



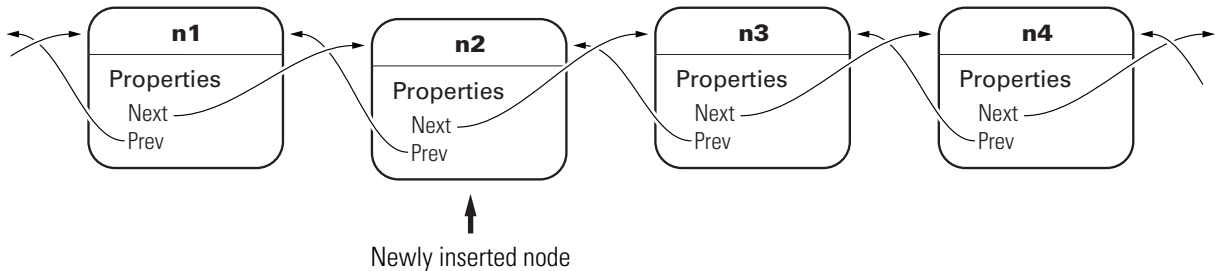
To add a new node to the list, the following steps must occur. First disconnect the nodes:

- 1 Unlink `n2.Prev` from `n1`
- 2 Unlink `n2.Next` from `n3`
- 3 Unlink `n3.Prev` from `n2`
- 4 Unlink `n1.Next` from `n2`



Now connect the new node and renumber:

- 5 Link new.Prev to n1
- 6 Link new.Next to n3 (was n2)
- 7 Link n1.Next to new (will be n2)
- 8 Link n3.Prev to new (will be n2)



The act of inserting a new node in an existing doubly linked list requires a number of steps. Any application code using a data structure like this can perform these operations. However, defining the linked list nodes as objects enables all the operations like adding, deleting, and rearranging nodes to be encapsulated in methods. The code that implements these operations can be well tested, implemented in an optimal way, always up to date with the current version of the class, and can even automatically update old-versions of the objects when they are loaded from MAT-files.

The objects enforce the rules for how the nodes interact by implementing methods to carry out these operations. A single `addNode` method would perform all the steps listed above. This removes the responsibility for enforcing constraints from the applications that use the objects. It also means the application is less likely to generate errors in its own implementation of the process.

This approach can reduce the complexity of your application code, provide greater consistency across applications, and reduce testing and maintenance requirements.

Fostering Modularity

As you decompose a system into objects (car → engine → fuel system → oxygen sensor), you form modules around natural boundaries. These objects provide interfaces by which they interact with other modules (which might be other objects or functions). Often the data and operations behind the interface are hidden from other modules to segregate implementation from interface.

Classes provide three levels of control over code modularity:

- **Public** — Any code can access this particular property or call this method.
- **Protected** — Only the object's own methods and those of the object's whose class has been derived from this object's class can access this property or call this method.
- **Private** — Only the object's own methods can access this property or call this method.

Overloaded Functions and Operators

When you define a class, you can overload existing MATLAB functions to work with your new object. For example, the MATLAB serial port class overloads the `fread` function to read data from the device connected to the port represented by this object. You can define various operations, such as equality (`eq`) or addition (`plus`), for a class you have defined to represent your data.

Reduce Code Redundancy

Suppose your application requires a number of dialog windows to interact with users. By defining a class containing all the common aspects of the

dialog windows, and then deriving the specific dialog classes from this base class, you can:


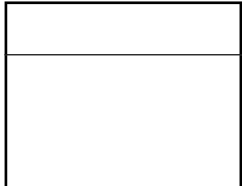
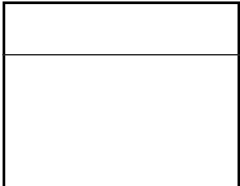


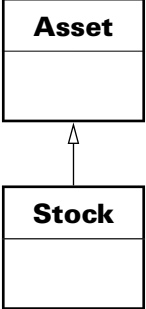

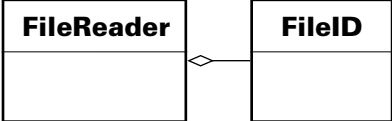

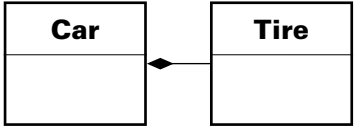
- Reuse code that is common to all dialog window implementations
- Reduce code testing effort due to common code
- Provide a common interface to dialog developers
- Enforce a consistent look and feel
- Apply global changes to all dialog windows more easily

Learning More

See “MATLAB Classes” on page 2-2 to learn more about writing object-oriented MATLAB programs.

Class Diagrams Used in This Documentation

The diagrams representing classes that appear in this documentation follow the conventions described in the following legend.

Concept	Graphical representation	Example
Object		
Class		
is_a		
has_a	 <p>(aggregation)</p>	
	 <p>(composition)</p>	

MATLAB Classes Overview

- “MATLAB Classes” on page 2-2
- “Detailed Information and Examples” on page 2-8
- “Developing Classes — Typical Workflow” on page 2-11
- “Using Objects to Write Data to a File” on page 2-18
- “Example — Representing Structured Data” on page 2-22
- “Example — Implementing Linked Lists” on page 2-31
- “Example — Class for Graphing Functions” on page 2-43

MATLAB Classes

In this section...

“Classes in the MATLAB Language” on page 2-2

“Some Basic Relationships” on page 2-4

“Examples to Get Started” on page 2-6

“Learning Object-Oriented Programming” on page 2-7

Classes in the MATLAB Language

In the MATLAB language, every value is assigned to a class. For example, creating a variable with an assignment statement constructs a variable of the appropriate class:

```
>> a = 7;
>> b = 'some string';
>> whos
```

Name	Size	Bytes	Class
a	1x1	8	double
b	1x11	22	char

Basic commands like `whos` display the class of each value in the workspace. This information helps MATLAB users recognize that some values are characters and display as text while other values might be double, single, or other types of numbers. Some variables can contain different classes of values like `cells`.

User-Defined Classes

You can create your own MATLAB classes. For example, you could define a class to represent polynomials. This class could define the operations typically associated with MATLAB classes, like addition, subtraction, indexing, displaying in the command window, and so on. However, these operations would need to perform the equivalent of polynomial addition, polynomial subtraction, and so on. For example, when you add two polynomial objects:

```
p1 + p2
```


the `plus` operation would know how to add polynomial objects because the polynomial class defines this operation.

When you define a class, you overload special MATLAB functions (`plus.m` for the addition operator) that are called by the MATLAB runtime when those operations are applied to an object of your class.

See “Example — A Polynomial Class” on page 16-2 for an example that creates just such a class.

MATLAB Classes — Key Terms

MATLAB classes use the following words to describe different parts of a class definition and related concepts.

- **Class definition** — Description of what is common to every instance of a class.
- **Properties** — Data storage for class instances
- **Methods** — Special functions that implement operations that are usually performed only on instances of the class
- **Events** — Messages that are defined by classes and broadcast by class instances when some specific action occurs
- **Attributes** — Values that modify the behavior of properties, methods, events, and classes
- **Listeners** — Objects that respond to a specific event by executing a callback function when the event notice is broadcast
- **Objects** — Instances of classes, which contain actual data values stored in the objects’ properties
- **Subclasses** — Classes that are derived from other classes and that inherit the methods, properties, and events from those classes (subclasses facilitate the reuse of code defined in the superclass from which they are derived).
- **Superclasses** — Classes that are used as a basis for the creation of more specifically defined classes (i.e., subclasses).
- **Packages** — Folders that define a scope for class and function naming

These are general descriptions of these components and concepts. This documentation describes all of these components in detail.

Some Basic Relationships

This section discusses some of the basic concepts used by MATLAB classes.

Classes

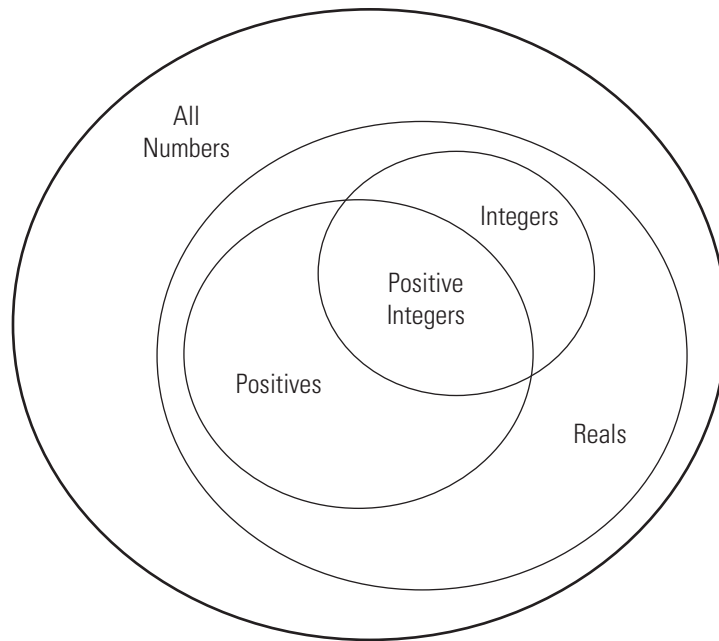
A class is a definition that specifies certain characteristics that all instances of the class share. These characteristics are determined by the properties, methods, and events that define the class and the values of attributes that modify the behavior of each of these class components. Class definitions describe how objects of the class are created and destroyed, what data the objects contain, and how you can manipulate this data.

Class Hierarchies

It sometimes makes sense to define a new class in terms of existing classes. This enables you to reuse the designs and techniques in a new class that represents a similar entity. You accomplish this reuse by creating a subclass. A subclass defines objects that are a subset of those defined by the superclass. A subclass is more specific than its superclass and might add new properties, methods, and events to those inherited from the superclass.

Mathematical sets can help illustrate the relationships among classes. In the following diagram, the set of Positive Integers is a subset of the set of Integers and a subset of Positive numbers. All three sets are subsets of Real numbers, which is a subset of All Numbers.

The definition of Positive Integers requires the additional specification that members of the set be greater than zero. Positive Integers combine the definitions from both Integers and Positives. The resulting subset is more specific, and therefore more narrowly defined, than the supersets, but still shares all the characteristics that define the supersets.



The “is a” relationship is a good way to determine if it is appropriate to define a particular subset in terms of existing supersets. For example, each of the following statements makes sense:

- A Positive Integer is an Integer
- A Positive Integer is a Positive number

If the “is a” relationship holds, then it is likely you can define a new class from a class or classes that represent some more general case.

Reusing Solutions

Classes are usually organized into taxonomies to foster code reuse. For example, if you define a class to implement an interface to the serial port of a computer, it would probably be very similar to a class designed to implement an interface to the parallel port. To reuse code, you could define a superclass that contains everything that is common to the two types of ports, and then

derive subclasses from the superclass in which you implement only what is unique to each specific port. Then the subclasses would inherit all of the common functionality from the superclass.

Objects

A class is like a template for the creation of a specific instance of the class. This instance or object contains actual data for a particular entity that is represented by the class. For example, an instance of a bank account class is an object that represents a specific bank account, with an actual account number and an actual balance. This object has built into it the ability to perform operations defined by the class, such as making deposits to and withdrawals from the account balance.

Objects are not just passive data containers. Objects actively manage the data contained by allowing only certain operations to be performed, by hiding data that does not need to be public, and by preventing external clients from misusing data by performing operations for which the object was not designed. Objects even control what happens when they are destroyed.

Encapsulating Information

An important aspect of objects is that you can write software that accesses the information stored in the object via its properties and methods without knowing anything about how that information is stored, or even whether it is stored or calculated when queried. The object isolates code that accesses the object from the internal implementation of methods and properties. You can define classes that hide both data and operations from any methods that are not part of the class. You can then implement whatever interface is most appropriate for the intended use.

Examples to Get Started

The following examples illustrate some basic features of MATLAB classes.

“Developing Classes — Typical Workflow” on page 2-11 — applies object-oriented thinking to a familiar concept to illustrate the process of designing classes.

“Using Objects to Write Data to a File” on page 2-18 — shows advantages of using objects to define certain operations and how smoothly object fit in a function-oriented workflow.

“Example — Representing Structured Data” on page 2-22 — shows the application of object-oriented techniques to managing data.

“Example — Implementing Linked Lists” on page 2-31 — using a handle class to implement a doubly linked list.

Learning Object-Oriented Programming

The following references can help you develop a basic understanding of object-oriented design and concepts.

- Shalloway, A., J. R. Trott, *Design Patterns Explained A New Perspective on Object-Oriented Design*. Boston, MA: Addison-Wesley 2002.
- Gamma, E., R. Helm, R. Johnson, J. Vlissides, *Design Patterns Elements of Reusable Object-Oriented Software*. Boston, MA: Addison-Wesley 1995.
- Freeman, E., Elisabeth Freeman, Kathy Sierra, Bert Bates, *Head First Design Patterns*. Sebastopol, CA 2004.
- See Wikipedia® :Object Oriented Programming

Detailed Information and Examples

Rapid Access to Information

This section provides a gateway to both conceptual information and example implementations. It enables you to scan the information available for broad topics

Topic	Background Information and Discussion	Code Examples
Attributes (all)	Attribute Tables	
Classes		
	<p>List of all class member attributes: Attribute Tables</p> <p>“MATLAB Classes” on page 2-2 for an introduction to object-oriented programming concepts.</p> <p>“Class Overview” on page 4-2 for an overview of classes features.</p>	<p>“Developing Classes — Typical Workflow” on page 2-11 for a simple example</p> <p>“Example — Representing Structured Data” on page 2-22</p> <p>“Example — Implementing Linked Lists” on page 2-31</p> <p>“Example — A Polynomial Class” on page 16-2</p> <p>“Example — A Simple Class Hierarchy” on page 17-2</p> <p>“Example — Containing Assets in a Portfolio” on page 17-19</p>
Attributes	“Class Attributes” on page 4-5 for a list of class attributes	
	“Hierarchies of Classes — Concepts” on page 10-2 describes how classes can be built on other classes	“Example — A Simple Class Hierarchy” on page 17-2

(Continued)

Topic	Background Information and Discussion	Code Examples
Attributes (all)	Attribute Tables	
	<p>“Creating Subclasses — Syntax and Techniques” on page 10-7</p> <p>“Modifying Superclass Methods and Properties” on page 10-13</p>	“Specializing the dlnode Class” on page 2-40
Kinds of classes	<p>“Comparing Handle and Value Classes” on page 5-2</p> <p>“The Handle Superclass” on page 5-11 — a detailed description of the abstract class.</p>	“Example — Implementing Linked Lists” on page 2-31
Properties		
	“Defining Properties” on page 6-5 for an overview of what properties are and how to use them	
	“Property Definition Block” on page 6-5 shows how to specify initial values	“Restricting Properties to Specific Values” on page 2-25
Attributes	“Specifying Property Attributes” on page 6-7 for a list of property attributes	“Dependent Properties” on page 2-27
	“Dynamic Properties — Adding Properties to an Instance” on page 6-21	“Assigning Data to the Dynamic Property” on page 6-22
Methods		
	“Class Methods” on page 7-2 for an overview of methods	
Attributes	“Method Attributes” on page 7-4 for a list of method attributes	

(Continued)

Topic	Background Information and Discussion	Code Examples
Attributes (all)	Attribute Tables	
	“Class Constructor Methods” on page 7-15 for information about constructor methods	“Simplifying the Interface with a Constructor” on page 2-26
	“Handle Class Delete Methods” on page 5-15	
	“Property Set and Get Access Methods” on page 6-12	“Restricting Properties to Specific Values” on page 2-25
	“Implementing a Set/Get Interface for Properties” on page 5-21	
Events		
	<p>“Events and Listeners — Concepts” on page 9-9 for an overview of how events work</p> <p>“Defining Events and Listeners — Syntax and Techniques” on page 9-15 for the syntax used to define events and listeners</p>	“Example — Using Events to Update Graphs” on page 9-30 for a complete example that uses events and listeners, including a property listener

Developing Classes — Typical Workflow

In this section...
“Formulating a Class” on page 2-11
“Implementing the BankAccount Class” on page 2-13
“Implementing the AccountManager Class” on page 2-15
“Using the BankAccount Class” on page 2-15

Formulating a Class

This example discusses the design and implementation of a simple class. To design a class that represents a bank account, first determine the elements of data and the operations that form your abstraction of a bank account. For example, a bank account has:

- An account number
- An account balance
- A current status (open, closed, etc.)

You need to perform certain operations on a bank account:

- Deposit money
- Withdraw money

You might also want the bank account to send a notice if the balance is too low and an attempt is made to withdraw money. When this event occurs, the bank account can broadcast a notice and other entities that are designed to listen for these notices, such as an account manager program, can take action. In this case, the status of all bank accounts is determined by an account manager program that looks at the account balance and assigns one of three values:

- `open` — Account balance is a positive value
- `overdrawn` — Account balance is overdrawn, but by \$200 or less.
- `closed` — Account balance is overdrawn by more than \$200.

In MATLAB classes, data is stored in properties, operations are implemented with methods, and notifications are supported with events and listeners. Therefore, the bank account class needs the components discussed in the following sections.

Defining Class Data

The class needs to define properties to store the account number and the account balance:

- `AccountNumber` — This property is assigned a value when you create an instance of the class.
- `AccountBalance` — This property is modified by the class operation of depositing and withdrawing money.
- `AccountStatus` — This property is set to an initial value when an instance of the class is created. It is then changed by methods from the `AccountManager` class whenever the value of the `AccountBalance` falls below 0.

The first two properties contain information that only the class should be able to change, so the `SetAccess` attribute should be set to `private` (only class methods can set these values). The `AccountStatus` is determined by an external program that needs access to the property, so its `SetAccess` attribute is left as the default, which is `public` (any code can access this property value).

Defining Class Operations

There are three operations that the class must be able to perform, so there needs to be three methods:

- `deposit` — Update the `AccountBalance` property when a deposit transaction occurs
- `withdraw` — Update the `AccountBalance` property when a withdrawal transaction occurs
- `BankAccount` — Create an initialized instance of the class

Defining Class Events

Bank accounts with negative balances have their status changed by the account manager program, as described above. To implement this action, the `BankAccount` class triggers an event when a withdrawal causes a negative balance to occur. Therefore, the triggering of the `InsufficientsFunds` event occurs from within the `withdraw` method.

To define an event, you simply define a name within an `events` block. The event is triggered by a call to the `notify` handle class method. Note that this is not a predefined event; it could be named with any string and you can trigger this event with any action you choose.

Implementing the BankAccount Class

It makes sense for there to be only one set of data associated with any instance of a `BankAccount` class. You would not want independent copies of the object that could have, for example, different values for the account balance. Therefore, the `BankAccount` class should be implemented as a handle class. All copies of a given handle object refer to the same data.

Display Fully Commented Example Code

You can display the code for this example in a popup window that contains detailed comments and links to related sections of the documentation:

[BankAccount class](#)

[AccountManager class](#)

You can open both class files in your editor by clicking this link:

[Open in editor](#)

Class Definition

```
classdef BankAccount < handle
    properties (Hidden)
        AccountStatus = 'open';
    end
    % The following properties can be set only by class methods
```

```
properties (SetAccess = private)
    AccountNumber
    AccountBalance = 0;
end
% Define an event called InsufficientFunds
events
    InsufficientFunds
end
methods
    function BA = BankAccount(AccountNumber,InitialBalance)
        BA.AccountNumber = AccountNumber;
        BA.AccountBalance = InitialBalance;
        % Calling a static method requires the class name
        % addAccount registers the InsufficientFunds listener on this instance
        AccountManager.addAccount(BA);
    end
    function deposit(BA,amt)
        BA.AccountBalance = BA.AccountBalance + amt;
        if BA.AccountBalance > 0
            BA.AccountStatus = 'open';
        end
    end
    function withdraw(BA,amt)
        if (strcmp(BA.AccountStatus,'closed')&& BA.AccountBalance < 0)
            disp(['Account ',num2str(BA.AccountNumber),' has been closed.'])
            return
        end
        newbal = BA.AccountBalance - amt;
        BA.AccountBalance = newbal;
        % If a withdrawal results in a negative balance,
        % trigger the InsufficientFunds event using notify
        if newbal < 0
            notify(BA,'InsufficientFunds')
        end
    end % withdraw
end % methods
end % classdef
```

Implementing the AccountManager Class

The AccountManager class provides two methods that implement and register a listener for the InsufficientFunds event, which is defined for all BankAccount objects. The BankAccount class constructor method calls addAccount to register the listener for the instance being created.

Class Definition

```
classdef AccountManager
    methods (Static)
        function assignStatus(BA)
            if BA.AccountBalance < 0
                if BA.AccountBalance < -200
                    BA.AccountStatus = 'closed';
                else
                    BA.AccountStatus = 'overdrawn';
                end
            end
        end
        function addAccount(BA)
            % Call the handle addlistener method
            % Object BA is a handle class
            addlistener(BA, 'InsufficientFunds', ...
                @(src, evnt)AccountManager.assignStatus(src));
        end
    end
end
```

Note that the AccountManager class is never instantiated. It serves as a container for the event listener used by all BankAccount objects.

Using the BankAccount Class

The BankAccount class, while overly simple, demonstrates how MATLAB classes behave. For example, create a BankAccount object with a serial number and an initial deposit of \$500:

```
BA = BankAccount(1234567,500);
BA.AccountNumber
ans =
```

```
1234567
BA.AccountBalance
ans =
    500
BA.AccountStatus
ans =
    open
```

Now suppose you make a withdrawal of \$600, which results in a negative account balance:

```
BA.withdraw(600)
BA.AccountBalance
ans =
   -100
BA.AccountStatus
ans =
    overdrawn
```

When the \$600 withdrawal occurred, the `InsufficientsFunds` event was triggered. Because the `AccountBalance` is not less than $-\$200$, the `AccountStatus` was set to `overdrawn`:

```
BA.withdraw(200)
BA.AccountBalance
ans =
   -300
BA.AccountStatus
ans =
    closed
```

Now the `AccountStatus` has been set to `closed` by the listener and further attempts to make withdrawals are blocked:

```
BA.withdraw(100)
Account 1234567 has been closed
```

If the `AccountBalance` is returned to a positive value by a deposit, then the `AccountStatus` is returned to `open` and withdrawals are allowed again:

```
BA.deposit(700)
```

```
BA.AccountStatus
ans =
open
BA.withdraw(100)
BA.AccountBalance
ans =
  300
```

Using Objects to Write Data to a File

In this section...

“Flexible Workflow” on page 2-18

“Performing a Task with an Object” on page 2-18

“Using Objects in Functions” on page 2-20

Flexible Workflow

The MATLAB language does not require you to define classes for all the code you write. You can use objects along with ordinary functions. This section illustrates the use of an object that implements the basic task of writing text to a file. Then this object is used in a function to write a text file template for a class definition.

Performing a Task with an Object

One of the advantages of defining a class instead of simply writing a function to perform a task is that classes provide better control over related data. For example, consider the task of writing data to a file. It involves the following steps:

- Opening a file for writing and saving the file identifier
- Using the file identifier to write data to the file
- Using the file identifier to close the file

The FileWriter Class

This simple class definition illustrates how you might create a class to write text to a file. It shows how you can use a class definition to advantage by:

- Hiding private data — The caller does not need to manage the file identifier.
- Ensuring only one file identifier is in use at any time — Copies of handle objects reference the same file identifier as the original.
- Providing automatic file closing when the object is deleted — the object’s `delete` method takes care of cleanup without needing to be called explicitly.

This class is derived from the `handle` class so that a `Filewriter` object is a handle object. All copies of handle objects reference the same internal data so there will be only one file identifier in use, even if you make copies of the object. Also, handle classes define a `delete` method which is called automatically when a handle object is destroyed. This example overrides the `delete` method to close the file before the file identifier is lost and the file is left open.

```
classdef Filewriter < handle
% Property data is private to the class
    properties (SetAccess = private, GetAccess = private)
        FileID
    end % properties

    methods
        % Construct an object and
        % save the file ID
        function obj = Filewriter(filename)
            obj.FileID = fopen(filename, 'a');
        end

        function writeToFile(obj, text_str)
            fprintf(obj.FileID, '%s\n', text_str);
        end
        % Delete methods are always called before a object
        % of the class is destroyed
        function delete(obj)
            fclose(obj.FileID);
        end
    end % methods
end % class
```

Using a Filewriter Object

Note that the user provides a file name to create a `Filewriter` object, and then uses the class `writeToFile` method to write text to the file. The following statements create a file named `mynewclass.m` and write one line to it. The `clear all` command deletes the `Filewriter` object, which causes its `delete` method to be called and the file is closed.

```
>> fw = Filewriter('mynewclass.m');
```

```
>> fw.writeToFile('classdef mynewclass < handle')
>> clear fw
>> type mynewclass
```

```
classdef mynewclass < handle
```

Using Objects in Functions

Filewriter objects provide functionality that you can use from functions and within other classes. You can create an ordinary function that uses this object, as the `writeClassFile` function does below.

This example creates only one simple class template, but another version might accept a cell array of attribute name/value pairs, method names, and so on.

```
function writeClassFile(classname,superclass)
% Use a Filewriter object to write text to a file
    fw = Filewriter([classname '.m']);
    if nargin > 1
        fw.writeToFile(['classdef ' classname ' < ' superclass])
    else
        fw.writeToFile(['classdef ' classname])
    end
    fw.writeToFile('    properties ')
    fw.writeToFile(' ')
    fw.writeToFile('    end % properties')
    fw.writeToFile(' ')
    fw.writeToFile('    methods ')
    fw.writeToFile(['        function obj = ' classname '()'])
    fw.writeToFile(' ')
    fw.writeToFile('        end')
    fw.writeToFile('    end % methods')
    fw.writeToFile('end % classdef')
    delete(fw) % Delete object, which closes file
end
```

To create a class file template, call `writeClassFile` with the name of the new class and its superclass. Use the `type` command to display the contents of the file:

```
>> writeClassFile('myNewClass','handle')
>> type myNewClass

classdef myNewClass < handle
    properties

        end % properties

    methods
        function obj = myNewClass()

            end
        end % methods
    end % classdef
```

More Information on These Techniques

“The Handle Superclass” on page 5-11

“Handle Class Delete Methods” on page 5-15

Example – Representing Structured Data

In this section...
“Display Fully Commented Example Code” on page 2-22
“Objects As Data Structures” on page 2-22
“Structure of the Data” on page 2-23
“Defining the TensileData Class” on page 2-23
“Creating an Instance and Assigning Data” on page 2-24
“Restricting Properties to Specific Values” on page 2-25
“Simplifying the Interface with a Constructor” on page 2-26
“Dependent Properties” on page 2-27
“Displaying TensileData Objects” on page 2-28
“A Method to Plot Stress vs. Strain” on page 2-29

Display Fully Commented Example Code

Open class code in a popup window — Use this link if you want to see the final code for this class annotated with links to descriptive sections.

Open class definition file in the MATLAB editor. — Use this link if you want to save and modify your version of the class.

To use the class, create a folder named @TensileData and save TensileData.m to this folder. The parent folder of @TensileData must be on the MATLAB path.

Objects As Data Structures

This example defines a class for storing data with a specific structure. Using a consistent structure for data storage makes it easier to create functions that operate on the data. While a MATLAB struct with field names describing the particular data element is a useful way to organize data, the use of a class to define both the data storage (properties) and operations you can perform on that data (methods) provides advantages, as this example illustrates.

Concepts on Which This Example Is Based.

For purposes of this example, the data represents tensile stress/strain measurements, which are used to calculate the elastic modulus of various materials. In simple terms, stress is the force applied to a material and strain is the resulting deformation. Their ratio defines a characteristic of the material. While this is an over simplification of the process, it suffices for this example.

Structure of the Data

The following table describes the structure of the data.

Data	Description
Material	Character string identifying the type of material tested
SampleNumber	Number of a particular test sample
Stress	Vector of doubles representing the stress applied to the sample during the test.
Strain	Vector of doubles representing the strain at the corresponding values of the applied stress.
Modulus	Double defining an elastic modulus of the material under test, which is calculated from the stress and strain data

Defining the TensileData Class

This class is designed to store data, so it defines a property for each of the data elements. The following class block defines five properties and specifies their initial values according to the type of data each will contain. Defining initial values is not required, but can be useful if a property value is not assigned during object creation.

Note that this example begins with a simple implementation of the class and builds on this implementation to illustrate how features enhance the usefulness of the class.

```
classdef TensileData
    properties
        Material = '';
        SampleNumber = 0;
        Stress
        Strain
        Modulus = 0;
    end
end
```

Creating an Instance and Assigning Data

Create a `TensileData` object and assign data to it with the following statements:

```
td = TensileData;
td.Material = 'Carbon Steel';
td.SampleNumber = 001;
td.Stress = [2e4 4e4 6e4 8e4];
td.Strain = [.12 .20 .31 .40];
td.Modulus = mean(td.Stress./td.Strain);
```

Advantages of a Class vs. a Structure Array

You can treat the `TensileData` object (`td` in the statements above) much as you would any MATLAB structure array. However, defining a specialized data structure as a class has advantages over using a general-purpose data structure, like a MATLAB `struct`:

- Users cannot accidentally misspell a field name without getting an error. For example, typing the following:

```
>>td.Modulis = ...
```

would simply add a new field to a structure array, but returns an error when `td` is an instance of the `TensileData` class.

- A class is easy to reuse. Once you have defined the class, you can easily extend it with subclasses that add new properties.

- A class is easy to identify. A class has a name so that you can identify objects with the `whos` and `class` functions and the Workspace browser. The class name makes it easy to refer to records with a meaningful name.
- A class can validate individual field values when assigned, including class or value.
- A class can restrict access to fields, for example, allowing a particular field to be read, but not changed.

The next section describes how to add type checking and how to restrict property access in the `TensileData` class.

Restricting Properties to Specific Values

You can restrict the values to which a property can be set by defining a property set access method. MATLAB software then calls this function whenever a value is set for a property, including when creating the object.

Defining the Material Property Set Function

The property set method restricts the assignment of the `Material` property to one of the following strings: `aluminum`, `stainless steel`, or `carbon steel`.

Add this function definition to the methods block.

```
classdef TensileData
    properties
        Material = 'carbon steel';
        SampleNumber = 0;
        Stress
        Strain
        Modulus
    end % properties
    methods
        function obj = set.Material(obj,material)
            if ~(strcmpi(material,'aluminum') ||...
                strcmpi(material,'stainless steel') ||...
                strcmpi(material,'carbon steel'))
                error('Material must be aluminum, stainless steel, or carbon steel')
            end
        end
    end
end
```

```
        obj.Material = material;
    end % set.Material
end% methods
end% classdef
```

When an attempt is made to set the `Material` property, the MATLAB runtime passes the object and the specified value to the property's `set.Material` function (the `obj` and the `material` input arguments). In this case, if the value does not match the acceptable values, the function returns an error. Otherwise, the specified value is used to set the property. Only the `set` method can directly access the property in the object (without calling the property `set` method).

For example:

```
>>td = TensileData;
>>td.Material = 'composite';
??? Error using ==> TensileData.TensileData>Material_set__
Material must be aluminum, stainless steel, or carbon steel
```

Simplifying the Interface with a Constructor

You can simplify the interface to the `TensileData` class by adding a constructor function that:

- Enables you to pass the data as arguments to the constructor
- Assigns values to properties

The constructor is a method having the same name as the class.

```
function td = TensileData(material,samplenum,stress,strain)
    if nargin > 0 % Support calling with 0 arguments
        td.Material = material;
        td.SampleNumber = samplenum;
        td.Stress = stress;
        td.Strain = strain;
    end
end % TensileData
```


Using the constructor, you can create a `TensileData` object fully populated with data using the following statement:

```
td = TensileData('carbon steel',1,[2e4 4e4 6e4 8e4],[.12 .20 .31 .40]);
```

Calculating Modulus

Note that the constructor function does not have an input argument for the value of the `Modulus` property. This is because the value of the `Modulus`:

- Is easy to calculate from the `Stress` and `Strain` property values
- Needs to change if the value of the `Stress` or `Strain` property changes

Therefore, it is better to calculate the value of the `Modulus` property only when its value is requested. You can do this with a property get access method, which is described in the next section.

Dependent Properties

`TensileData` objects do not store the value of the `Modulus` property; instead this value is calculated whenever it is requested. This approach enables you to update the `Stress` and `Strain` property data at any time without having to recalculate the value of the `Modulus` property.

Modulus Property Get Method

The `Modulus` property depends on `Stress` and `Strain`, so its `Dependent` attribute is set to logical true. To do this, create another `properties` block to set the `Dependent` attribute.

Also, because the `get.Modulus` method calculates and returns the value of the `Modulus` property, you should set the property's `SetAccess` attribute to `private`.

```
properties (Dependent = true, SetAccess = private)
    Modulus
end
```

Define the property's get method in a `methods` block.

```
methods
function modulus = get.Modulus(obj)
    ind = find(obj.Strain > 0); % Find nonzero strain
    modulus = mean(obj.Stress(ind)./obj.Strain(ind));
end % Modulus get method
end % methods
```

This function simply calculates the average ratio of stress to strain data after eliminating zeros in the denominator data.

The MATLAB runtime calls the `get.Modulus` method when the property is queried. For example,

```
td = TensileData('carbon steel',1,[2e4 4e4 6e4 8e4],[.12 .20 .31 .40]);
td.Modulus
ans =
    1.9005e+005
```

Modulus Property Set Method

To set the value of a Dependent property, the class must implement a property set method. There is no need to enable explicit setting of the Modulus property, but a set method enables you to provide a customized error message. The Modulus set method references the current property value and then returns an error:

```
methods
function obj = set.Modulus(obj,~)
    fprintf('%s%d\n','Modulus is: ',obj.Modulus)
    error('You cannot set Modulus explicitly');
end % Modulus get function
```

Displaying TensileData Objects

The `TensileData` class can implement a `disp` method that controls what is displayed when an object of this class is shown on the command line (for example, by an assignment statement not terminated by a semicolon).

The `TensileData` `disp` method displays the value of the `Material`, `SampleNumber`, and `Modulus` properties. It does not display the `Stress` and

Strain property data since these properties contain raw data that is not easily viewed in the command window. The `plot` method (described in the next section) provides a better way to display stress and strain data.

The `disp` method uses `fprintf` to display formatted text in the command window:

```
methods
function disp(td)
    fprintf(1,'Material: %s\nSample Number: %g\nModulus: %1.5g\n',...
        td.Material,td.SampleNumber,td.Modulus);
end % disp
end % methods
```

A Method to Plot Stress vs. Strain

It is useful to view a graph of the stress/strain data to determine the behavior of the material over a range of applied tension. A `TensileData` object contains the stress and strain data so it is useful to define a class method that is designed to plot this data.

The `TensileData` `plot` method creates a linear graph of the stress versus strain data and adds a title and axis labels to produce a standardized graph for the tensile data records:

```
function plot(td,varargin)
    plot(td.Strain,td.Stress,varargin{:})
    title(['Stress/Strain plot for Sample',...
        num2str(td.SampleNumber)])
    ylabel('Stress (psi)')
    xlabel('Strain %')
end % plot
```

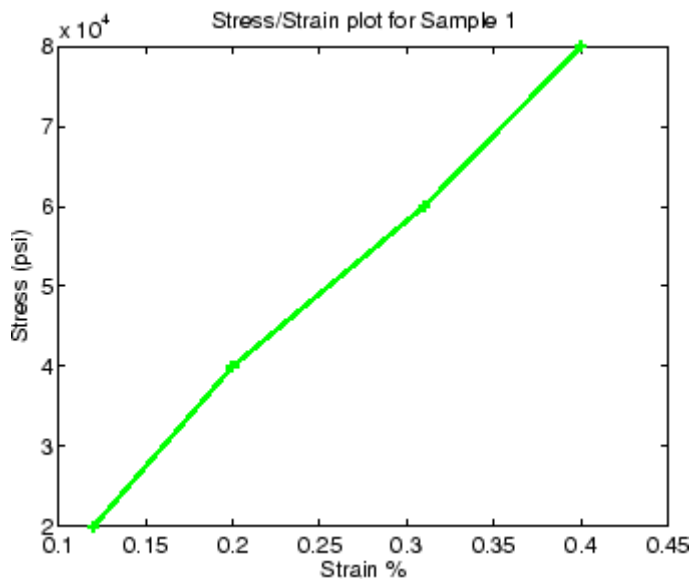
The first argument to this method is a `TensileData` object, which contains the data and is used by the MATLAB runtime to dispatch to the `TensileData` class `plot` method and not the built-in `plot` function.

The variable list of arguments that follow are passed directly to the built-in `plot` function from within the method. This enables the `TensileData` `plot` method to behave like the built-in `plot` function, which allows you to pass line specifier arguments or property name/value pairs along with the data.

For example, plotting the following object:

```
td = TensileData('carbon steel',1,[2e4 4e4 6e4  
8e4],[.12 .20 .31 .40]);  
plot(td,'-+g','LineWidth',2)
```

produces this graph.



Example — Implementing Linked Lists

In this section...

“Displaying Fully Commented Example Code” on page 2-31

“Important Concepts Demonstrated” on page 2-31

“dlnode Class Design” on page 2-32

“Creating Doubly Linked Lists” on page 2-33

“Why a Handle Class for Doubly Linked Lists?” on page 2-34

“Defining the dlnode Class” on page 2-35

“Specializing the dlnode Class” on page 2-40

Displaying Fully Commented Example Code

Open class code in a popup window — Use this link if you want to see the code for this class annotated with links to descriptive sections.

Open class definition file in the MATLAB editor. — Use this link if you want to save and modify your version of the class.

To use the class, create a folder named `@dlnode` and save `dlnode.m` to this folder. The parent folder of `@dlnode` must be on the MATLAB path. Alternatively, save `dlnode.m` to a path folder.

Important Concepts Demonstrated

This section discusses concepts that are important in object-oriented design, and which are illustrated in this example.

Encapsulation

This example shows how classes encapsulate the internal structure used to implement the class design (a doubly linked lists). Encapsulation conceals the internal workings of the class from other code and provides a stable interface to programs that use this class. It also prevents client code from misusing the class because only class methods can access certain class data.

Class methods define the operations that you can perform on nodes of this class. These methods hide the potentially confusing process of inserting and removing nodes, while at the same time providing an interface that performs operations simply:

- Creating a node by passing the constructor a data value
- Inserting nodes with respect to other nodes in the list (before or after)
- Removing nodes from the list

See “Defining the `dlnode` Class” on page 2-35 for the implementation details.

Handle Class Behavior

This example shows an application of a handle class and explains why this is the best choice for the class. See “Why a Handle Class for Doubly Linked Lists?” on page 2-34.

dlnode Class Design

This example defines a class for creating the nodes of doubly linked lists in which each node contains:

- Data array
- Link to the next node
- Link to the previous node

Each node has methods that enables the node to be:

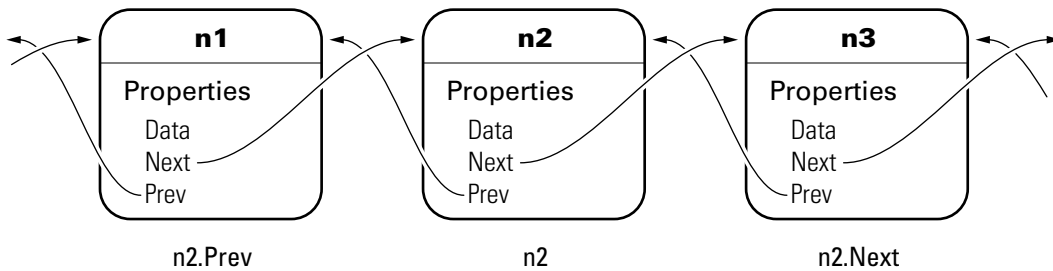
- Disconnected from a linked list
- Connected before a specified node in a linked list
- Connected after a specific node in a linked list

Class Properties

The `dlnode` class implements each node as a handle object with three properties:

- **Data** — Contains the data for this node
- **Next** — Contains the handle of the next node in the list (`SetAccess = private`)
- **Prev** — Contains the handle of the previous node in the list (`SetAccess = private`)

This diagram shows a three-node list `n1`, `n2`, and `n3`. It also shows how the nodes reference the next and previous nodes.



Class Methods

The `dlnode` class implements the following methods:

- `dlnode` — Constructs a node and assigns the value passed as input to the `Data` property
- `insertAfter` — Inserts this node after the specified node
- `insertBefore` — Inserts this node before the specified node
- `disconnect` — Removes this node from the list
- `disp` — Overloads default `disp` function so that the `Data` property displays on the command line for scalar objects and the dimension of the array displays for object arrays
- `delete` — Removes this node from the list before it is destroyed

Creating Doubly Linked Lists

You create a node by passing the node's data to the `dlnode` class constructor. For example, these statements create three nodes with sequential integer data just for simplicity:

```
n1=dlnode(1);  
n2=dlnode(2);  
n3=dlnode(3);
```

You build these nodes into a doubly linked list using the class methods:

```
n2.insertAfter(n1)  
n3.insertAfter(n2)
```

Now the three nodes are linked. The `dlnode disp` method returns the data for the node referred to:

```
n1.Next % Points to n2  
ans =  
Doubly-linked list node with data:  
    2  
n2.Next.Prev % Points back to n2  
ans =  
Doubly-linked list node with data:  
    2  
n1.Next.Next % Points to n3  
ans =  
Doubly-linked list node with data:  
    3  
n3.Prev.Prev % Points to n1  
ans =  
Doubly-linked list node with data:  
    1
```

Why a Handle Class for Doubly Linked Lists?

Each node is unique in that no two nodes can be previous to or next to the same node. Suppose a node object, `node`, contains in its `Next` property the handle of the next node object, `node.Next`. Similarly, the `Prev` property contains the handle of the previous node, `node.Prev`. Using the three-node linked list defined in the previous section, you can demonstrate that the following statements are true:

```
n1.Next == n2  
n2.Prev == n1
```


Now suppose you assign `n2` to `x`:

```
x = n2;
```

The following two equalities are then true:

```
x == n1.Next  
x.Prev == n1
```

But each instance of a node is unique so there is only one node in the list that can satisfy the conditions of being equal to `n1.Next` and having a `Prev` property that contains a handle to `n1`. Therefore, `x` must point to the same node as `n2`.

This means there has to be a way for multiple variables to refer to the same object. The MATLAB `handle` class provides a means for both `x` and `n2` to refer to the same node. All instances of the `handle` class are handles that exhibit the copy behavior described previously.

Notice that the `handle` class defines the `eq` method (use `methods('handle')` to list the `handle` class methods), which enables the use of the `==` operator with all `handle` objects.

See “Comparing Handle and Value Classes” on page 5-2 for more information on kinds of MATLAB classes.

See “The Handle Superclass” on page 5-11 for more information about the `handle` class.

Defining the `dlnode` Class

The following examples use this doubly linked list (see “Displaying Fully Commented Example Code” on page 2-31 before using this class):

```
n1 = dlnode(1);  
n2 = dlnode(2);  
n3 = dlnode(3);  
n2.insertAfter(n1)  
n3.insertAfter(n2)
```

Class Properties

The `dlnode` class is itself a handle class because it is derived from the `handle` class. Note that only class methods can set the `Next` and `Prev` properties (`SetAccess = private`). Using private set access prevents client code from performing any incorrect operation with these properties. The `dlnode` class defines methods that perform all the operations that are allowed on these nodes. Here are the property definition blocks:

```
classdef dlnode < handle
    properties
        Data
    end
    properties (SetAccess = private)
        Next
        Prev
    end
```

Creating a Node Object

To create a node object, you need to specify only the node's data.

```
function node = dlnode(Data)
    if nargin > 0
        node.Data = Data;
    end
end
```

When you add the node to a list, the class methods that perform the insertion set the `Next` and `Prev` properties. See “Inserting Nodes” on page 2-38.

Disconnecting Nodes

The `disconnect` method removes a node from a list and repairs the list by reconnecting the appropriate nodes. The `insertBefore` and `insertAfter` methods always call `disconnect` on the node to insert before attempting to connect it to a linked list. This ensures the node is in a known state before assigning it to the `Next` or `Prev` property:

```
function disconnect(node)
    if ~isscalar(node)
```

```

        error('Nodes must be scalar')
    end
    prevNode = node.Prev;
    nextNode = node.Next;
    if ~isempty(prevNode)
        prevNode.Next = nextNode;
    end
    if ~isempty(nextNode)
        nextNode.Prev = prevNode;
    end
    node.Next = [];
    node.Prev = [];
end

```

For example, suppose you remove `n2` from the three-node list discussed above (`n1 n2 n3`):

```
n2.disconnect;
```

`disconnect` removes `n2` from the list and repairs the list with the following steps:

```

n1 = n2.Prev;
n3 = n2.Next;
if n1 exists, then
    n1.Next = n3;
if n3 exists, then
    n3.Prev = n1

```

Now the list is rejoined because `n1` connects to `n3` and `n3` connects to `n1`. The final step is to ensure that `n2.Next` and `n2.Prev` are both empty (i.e., `n2` is not connected):

```

% These properties have private SetAccess
% so they can be set only within class methods
n2.Next = [];
n2.Prev = [];

```

Inserting Nodes

There are two methods for inserting nodes into the list—`insertAfter` and `insertBefore`. These methods perform similar operations, so this section describes only `insertAfter` in detail.

```
methods
function insertAfter(newNode,nodeBefore)
    disconnect(newNode);
    newNode.Next = nodeBefore.Next;
    newNode.Prev = nodeBefore;
    if ~isempty(nodeBefore.Next)
        nodeBefore.Next.Prev = newNode;
    end
    nodeBefore.Next = newNode;
end
```

How `insertAfter` Works. First `insertAfter` calls the `disconnect` method to ensure that the new node is not connected to any other nodes. Then, it assigns the `newNode` `Next` and `Prev` properties to the handles of the nodes that are after and before the `newNode` location in the list.

For example, suppose you want to insert a new node, `nnew`, after an existing node, `n1`, in a list containing `n1 n2`.

First, create `nnew`:

```
nnew = dlnode(rand(3));
```

Next, call `insertAfter` to insert `nnew` into the list after `n1`:

```
nnew.insertAfter(n1)
```

The `insertAfter` method performs the following steps to insert `nnew` in the list between `n1` and `n2`:

```
% n1.Next is currently n2, set nnew.Next to n1.Next (which is n2)
nnew.Next = n1.Next;
% nnew.Prev must be set to n1
nnew.Prev = n1;
% if n1.Next is not empty, then
% n1.Next is still n2, so n1.Next.Prev is n2.Prev, which is set to nnew
```

```

n1.Next.Prev = nnew;
% n1.Next is now set to nnew
n1.Next = nnew;

```

Displaying a Node on the Command Line

All objects call a default `disp` function, which displays information about the object on the command line (unless display is suppressed with a semicolon). The default `disp` function is not useful in this case because the `Next` and `Prev` properties contain other node objects. Therefore, the `dlnode` class overloads the default `disp` function by implementing its own `disp` class method. This `disp` method displays only a text message and the value of the `Data` property, when used with scalar objects, and array dimensions when used with object arrays.

```

function disp(node)
% DISP Display a link node
if (isscalar(node))
    disp('Doubly-linked list node with data:')
    disp(node.Data)
else
    % If node is an object array, display dimensions
    dims = size(node);
    ndims = length(dims);
    % Counting down in for loop avoids need to preallocate dimcell
    for k = ndims-1:-1:1
        dimcell{k} = [num2str(dims(k)) 'x'];
    end
    dimstr = [dimcell{:} num2str(dims(ndims))];
    disp([dimstr ' array of doubly-linked list nodes']);
end
end

```

Deleting a Node Object

MATLAB destroys a handle object when you reassign or delete its variable or when there are no longer any references to the object (see “Handle Class Delete Methods” on page 5-15 for more information). When you define a `delete` method for a handle class, MATLAB calls this method before destroying the object.

The `dlnode` class defines a `delete` method because each `dlnode` object is a node in a doubly linked list. If a node object is going to be destroyed, the `delete` method must disconnect the node and repair the list before allowing MATLAB to destroy the node.

The `disconnect` method already performs the necessary steps, so the `delete` method can simply call `disconnect`:

```
function delete(node)
    disconnect(node);
end
```

Specializing the `dlnode` Class

The `dlnode` class implements a doubly linked list and provides a convenient starting point for creating more specialized types of linked lists. For example, suppose you want to create a list in which each node has a name.

Rather than copying the code used to implement the `dlnode` class, and then expanding upon it, you can derive a new class from `dlnode` (i.e., subclass `dlnode`) to create a class that has all the features of `dlnode` and more. And because `dlnode` is a handle class, this new class is a handle class too.

NamedNode Class Definition

Open class definition file in the MATLAB editor. — Use this link if you want to save and modify your version of the class.

To use the class, create a folder named `@NamedNode` and save `NamedNode.m` to this folder. The parent folder of `@NamedNode.m` must be on the MATLAB path. Alternatively, save `NamedNode.m` to a path folder.

The following class definition shows how to derive the `NamedNode` class from the `dlnode` class:

```
classdef NamedNode < dlnode
    properties
        Name = ''; % property to contain node name
    end
    methods
        function n = NamedNode (name,data)
```

```

        if nargin == 0 % allow for the no argument case
            name = '';
            data = [];
        end
        n = n@dlnode(data); % Initialize a dlnode object
        n.Name = name;
    end
    function disp(node) % Extend the dlnode disp method
        if (isscalar(node))
            disp(['Node Name: ' node.Name])
            disp@dlnode(node); % Call dlnode disp method
        else
            disp@dlnode(node);
        end
    end
end % methods
end % classdef

```

The `NamedNode` class adds a `Name` property to store the node name and extends the `disp` method defined in the `dlnode` class.

The constructor calls the class constructor for the `dlnode` class, and then assigns a value to the `Name` property. The `NamedNode` class defines default values for the properties for cases when MATLAB calls the constructor with no arguments.

See “Basic Structure of Constructor Methods” on page 7-22 for more information on defining class constructor methods.

Using the `NamedNode` Class to Create a Doubly Linked List

Use the `NamedNode` class like the `dlnode` class, except you specify a name for each node object. For example:

```

n(1) = NamedNode('First Node',100);
n(2) = NamedNode('Second Node',200);
n(3) = NamedNode('Third Node',300);

```

Now use the insert methods inherited from `dlnode` to build the list:

```

n(2).insertAfter(n(1))

```

```
n(3).insertAfter(n(2))
```

A single node displays its name and data when you query its properties:

```
>> n(1).Next
ans =
Node Name: Second Node
Doubly-linked list node with data:
    200
>> n(1).Next.Next
ans =
Node Name: Third Node
Doubly-linked list node with data:
    300
>> n(3).Prev.Prev
ans =
Node Name: First Node
Doubly-linked list node with data:
    100
```

If you display an array of nodes, the `NamedNode disp` method displays only the dimensions of the array:

```
>> n
n =
1x3 array of doubly-linked list nodes
```


Example – Class for Graphing Functions

In this section...

“Display Fully Commented Example Code” on page 2-43

“Class Definition Block” on page 2-43

“Using the topo Class” on page 2-45

“Behavior of the Handle Class” on page 2-46

The *class block* is the code that starts with the `classdef` key word and terminates with the `end` key word. The following example illustrated a simple class definition that uses:

- Handle class
- Property set and get functions
- Use of a delete method for the handle object
- Static method syntax

Display Fully Commented Example Code

You can display this class definition in a separate window that contains links to related sections in the documentations by clicking this link:

Example with links

Open class definition file in the MATLAB editor. — Use this link if you want to save and modify your own version of the class.

Class Definition Block

The following code defines a class called `topo`. It is derived from `handle` so it is a handle class, which means it references the data it contains. See “Using the topo Class” on page 2-45 for information on how this class behaves.

```
classdef topo < handle
% topo is a subclass of handle
properties
    FigHandle % Store figure handle
```

```
FofXY % function handle
Lm = [-2*pi 2*pi]; % Initial limits
end % properties

properties (Dependent = true, SetAccess = private)
    Data
end % properties Dependent = true, SetAccess = private

methods

function obj = topo(fnc,limits)
% Constructor assigns property values
    obj.FofXY = fnc;
    obj.Lm = limits;
end % topo

function set.Lm(obj,lim)
% Lm property set function
    if ~(lim(1) < lim(2))
        error('Limits must be monotonically increasing')
    else
        obj.Lm = lim;
    end
end % set.Lm

function data = get.Data(obj)
% get function calculates Data
% Use class name to call static method
    [x,y] = topo.grid(obj.Lm);
    matrix = obj.FofXY(x,y);
    data.X = x;
    data.Y = y;
    data.Matrix = matrix;% Return value of property
end % get.Data

function surflight(obj)
% Graph function as surface
    obj.FigHandle = figure;
    surfc(obj.Data.X,obj.Data.Y,obj.Data.Matrix,...
        'FaceColor',[.8 .8 0], 'EdgeColor',[0 .2 0],...
        'FaceLighting','phong');
```

```

    camlight left; material shiny; grid off
    colormap copper
end % surfflight method

function delete(obj)
% Delete the figure
h = obj.FigHandle;
if ishandle(h)
    delete(h);
else
    return
end
end % delete
end % methods

methods (Static = true) % Define static method
function [x,y] = grid(lim)
    inc = (lim(2)-lim(1))/35;
    [x,y] = meshgrid(lim(1):inc:lim(2));
end % grid
end % methods Static = true
end % topo class

```

Using the topo Class

See “Display Fully Commented Example Code” on page 2-43 for information on using this class.

This class is designed to display a combination surface/contour graph of mathematical functions of two variables evaluated on a rectangular domain of x and y . For example, any of the following functions can be evaluated over the specified domain (note that x and y have the same range of values in this example just for simplicity).

```

x.*exp(-x.^2 - y.^2); [-2 2]
sin(x).*sin(y); [-2*pi 2*pi]
sqrt(x.^2 + y.^2); [-2*pi 2*pi]

```

To create an instance of the class, passing a function handle and a vector of limits to the constructor. The easiest way to create a function handle for these functions is to use an anonymous function:

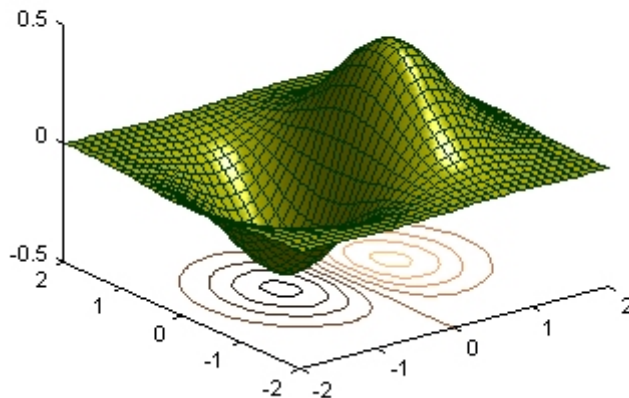
```
tobj = topo(@(x,y) x.*exp(-x.^2-y.^2),[-2 2]);
```

The class `surflight` method uses the object to create a graph of the function. The actual data required to create the graph is not stored. When the `surflight` method accesses the `Data` property, the property's `get` function performs the evaluation and returns the data in the `Data` property structure fields. This data is then plotted. The advantage of not storing the data is the reduced size of the object.

Behavior of the Handle Class

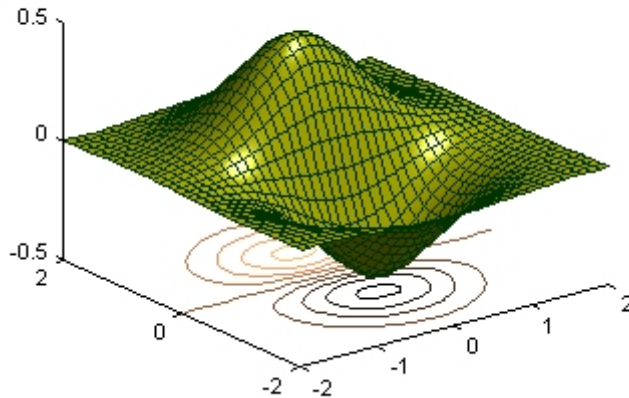
The `topo` class is defined as a handle class. This means that instances of this class are handle objects that reference the underlying data store created by constructing the object. For example, suppose you create an instance of the class and create a copy of the object:

```
tobj = topo(@(x,y) x.*exp(-x.^2-y.^2),[-2 2]);  
a = tobj;  
surflight(a) % Call class method to create a graph
```



Now suppose you change the `FofXY` property so that it contains a function handle that points to another function:

```
tobj.FofXY = @(x,y) y.*exp(-x.^2-y.^2); % now multiply  
exp by y instead of x  
surflight(a)
```



Because `a` is a copy of the handle object `tobj`, changes to the data referenced by `tobj` also change the data referenced by `a`.

How a Value Class Differs

If `topo` were a value class, the objects `tobj` and `a` would not share data; each would have its own copy of the property values.

Class Definition—Syntax Reference

- “Class Folders” on page 3-2
- “Class Components” on page 3-5
- “The Classdef Block” on page 3-6
- “Specifying Properties” on page 3-8
- “Specifying Methods and Functions” on page 3-13
- “Events and Listeners” on page 3-19
- “Specifying Attributes” on page 3-21
- “Calling Superclass Methods on Subclass Objects” on page 3-24
- “A Class Code Listing” on page 3-27
- “Understanding Code Analyzer Warnings” on page 3-29
- “Functions Used with Objects” on page 3-32
- “Using the Editor and Debugger with Classes” on page 3-33
- “Modifying and Reloading Classes” on page 3-34
- “Compatibility with Previous Versions ” on page 3-37
- “MATLAB Vs. Other OO Languages” on page 3-41

Class Folders

In this section...

- “Options for Class Folders” on page 3-2
- “Grouping Classes with Package Folders” on page 3-3
- “More Information on Class Folders” on page 3-4

Options for Class Folders

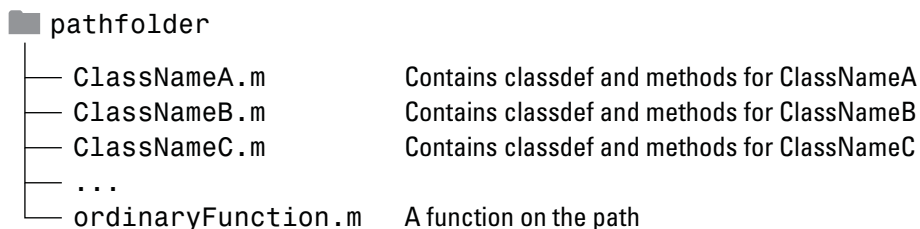
There are two basic ways to specify classes with respect to folders:

- Creating a single, self-contained class definition file in a folder on the MATLAB path.
- Distributing a class definition to multiple files in an @ folder inside a path folder.

Creating a Single, Self-Contained Class Definition File

Create a single, self-contained class definition file in a folder on the MATLAB® path. The name of the file must match the class (and constructor) name and must have the `.m` extension. Define the class entirely in this file. You can put other single-file classes in this folder.

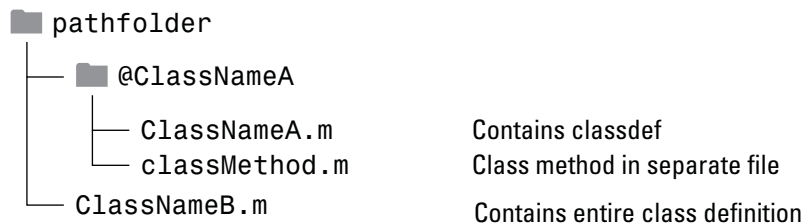
The following diagram shows an example of this folder organization. `pathfolder` is a folder on the MATLAB path.



See “Methods in Separate Files” on page 7-7 for more information on using multiple files to define classes.

Distributing the Class Definition to Multiple Files

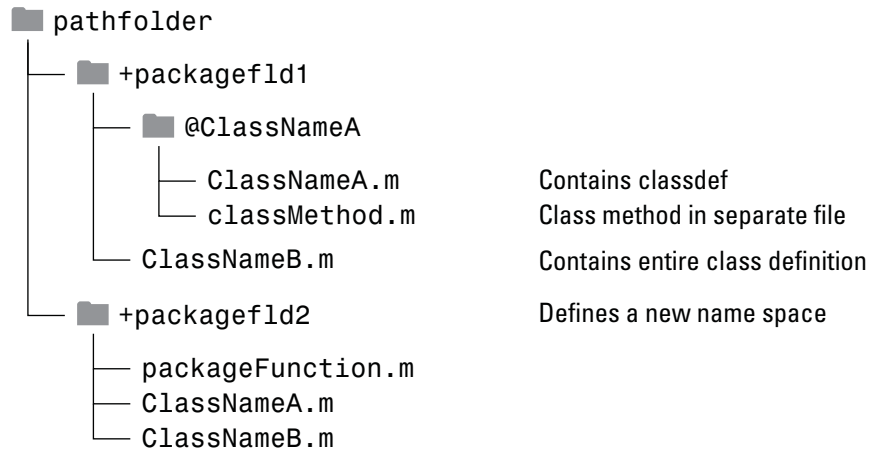
If you use multiple files to define a class, put all the class-definition files (the file containing the `classdef` and all class method files) in a single `@ClassName` folder. That `@`-folder must be inside a folder that is on the MATLAB path. You can define only one class in an `@`-folder.



A path folder can contain classes defined in both `@`-folders and single files without an `@`-folder.

Grouping Classes with Package Folders

The parent folder to a package folder is on the MATLAB path, but the package folder is not. Package folders (which always begin with a “+” character) can contain multiple class definitions, package-scoped functions, and other packages. A package folder defines a new name space in which you can reuse class names. Use the package name to refer to classes and functions defined in package folders (for example, `packagefld1.ClassNameA()`, `packagefld2.packageFunction()`).



More Information on Class Folders

See “Organizing Classes in Folders” on page 4-13 for more information on class folders and see “Scoping Classes with Packages” on page 4-19 for information on using classes contained in package folders.

See “Methods In Separate Files” on page 3-14 for the syntax used to define methods external to the clasdef file.

Class Components

In this section...

“Class Building Blocks” on page 3-5

“More In Depth Information” on page 3-6

Class Building Blocks

The basic components in the class definition are blocks describing the whole class and specific aspects of its definition:

- *classdef block* contains the class definition within a file that starts with the `classdef` keyword and terminates with the `end` keyword. See “The Classdef Block” on page 3-6 for more syntax information.

```
classdef ClassName
    ...
end
```

- *properties block* (one for each unique set of attribute specifications) contains property definitions, including optional initial values. The properties block starts with the `properties` keyword and terminates with the `end` keyword. See “Specifying Properties” on page 3-8 for more syntax information.

```
classdef ClassName
    properties
        ...
    end
    ...
end
```

- *methods block* (one for each unique set of attribute specifications) contains function definitions for the class methods. The methods block starts with the `methods` keyword and terminates with the `end` keyword. See “The Methods Block” on page 3-13 for more syntax information.

```
classdef ClassName
    methods
        ...
    end
end
```

```
        end
        ...
    end
```

- *events block* (one for each unique set of attribute specifications) contains the names of events that this class declares. The events blocks starts with the `events` keyword and terminates with the `end` keyword. See “Specifying Events” on page 3-19 for more syntax information.

```
classdef ClassName
    events
        ...
    end
    ...
end
```

properties, methods, and events are keywords only within a `classdef` block.

More In Depth Information

“Defining Classes — Syntax” on page 4-4 for more detail on class syntax.

“Defining Properties” on page 6-5 for information on specifying properties.

“Class Methods” on page 7-2 for information on specifying methods.

“Defining Events and Listeners — Syntax and Techniques” on page 9-15 for information on the use of events.

Attribute Tables for a list of all attributes.

The Classdef Block

In this section...
“Specifying Attributes and Superclasses” on page 3-7
“Assigning Class Attributes” on page 3-7
“Specifying Superclasses” on page 3-7

Specifying Attributes and Superclasses

The `classdef` block contains the class definition. The `classdef` line is where you specify:

- Class attributes
- Superclasses

The `classdef` block contains the properties, methods, and events subblocks.

Assigning Class Attributes

Class attributes modify class behavior in some way. Assign values to class attributes only when you want to change their default value.

No change to default attribute values:

```
classdef class_name
    ...
end
```

One or more attribute values assigned:

```
classdef (attribute1 = value,...)
    ...
end
```

See “Class Attributes” on page 4-5 for a list of attributes and a discussion of the behaviors they control.

Specifying Superclasses

To define a class in terms of one or more other classes by specifying the superclasses on the `classdef` line:

```
classdef class_name < superclass_name
    ...
end
```

See “Creating Subclasses — Syntax and Techniques” on page 10-7 for more information.

Specifying Properties

In this section...
“What You Can Define” on page 3-8
“How to Initialize Property Values” on page 3-8
“Defining Default Values” on page 3-9
“Assigning Property Values from Within the Constructor” on page 3-9
“Initializing Properties to Unique Values” on page 3-10
“Property Attributes” on page 3-10
“Property Access Methods” on page 3-11
“Referencing Object Properties Using Variables” on page 3-11

What You Can Define

You can control aspects of property definitions in the following ways:

- Specifying a default value for each property individually
- Assigning attribute values on a per block basis
- Defining methods that execute when the property is set or queried

Note Always use case sensitive property names in your MATLAB code.

How to Initialize Property Values

There are two basic approaches to initializing property values:

- In the property definition — MATLAB evaluates the expression only once and assigns the same value to the property of every instance. See “Defining Default Values” on page 3-9.
- In the class constructor — MATLAB evaluates the assignment expression for each instance, which ensures that each instance has a unique value. See “Assigning Property Values from Within the Constructor” on page 3-9.

Defining Default Values

Within a `properties` block, you can control an individual property's default value. Default values can be constant values or MATLAB expressions. Expressions cannot reference variables. For example:

```
classdef class_name
    properties
        PropertyName % No default value assigned
        PropertyName = 'some text';
        PropertyName = sin(pi/12); % Expression returns default value
    end
end
```

Evaluation of property default values occurs only when the value is first needed, and only once when MATLAB first initializes the class. MATLAB does not reevaluate the expression each time you create a class instance.

See “Using Expressions in Class Definitions” on page 4-7 for more information on how MATLAB evaluates expressions that you use to assign property default values.

MATLAB sets property values not specified in the class definition to empty (`[]`).

Assigning Property Values from Within the Constructor

To assign values to a property from within the class constructor, reference the object that the constructor returns (the output variable `obj`):

```
classdef MyClass
    properties
        PropertyOne
    end
    methods
        function obj = MyClass(intval)
            obj.PropertyOne = intval;
        end
    end
end
```

When you assign an object property from the class constructor, MATLAB evaluates the assignment statement for each instance created. Assign property values in the constructor if you want each object to contain a unique instance of a handle object.

See “Referencing the Object in a Constructor” on page 7-17 for more information on constructor methods.

Initializing Properties to Unique Values

MATLAB assigns properties to the specified default values only once when MATLAB loads the class definition. Therefore, if you initialize a property value with a handle-class constructor, MATLAB calls this constructor only once and every instance references the same handle object. If you want a property value to be initialized to a new instance of a handle object each time you create an object, assign the property value in the constructor.

Property Attributes

All properties have attributes that modify certain aspects of the property’s behavior. Specified attributes apply to all properties in a particular properties block. For example:

```
classdef class_name
    properties
        PropertyName % No default value assigned
        PropertyName = sin(pi/12); % Expression returns default value
    end
    properties (SetAccess = private, GetAccess = private)
        Stress
        Strain
    end
end
```

In this case, only methods in the same class definition can modify and query the `Stress` and `Strain` properties. This restriction exists because the class defines these properties in a `properties` block with `SetAccess` and `GetAccess` attributes set to `private`.

“Table of Property Attributes” on page 6-8 provides a description of property attributes.

Property Access Methods

You can define methods that MATLAB calls whenever setting or querying a property value. Define property set access or get access methods in `methods` blocks that specify no attributes and have the following syntax:

```

methods
    function value = get.PropertyName(object)
        ...
    end

    function obj = set.PropertyName(obj,value)
        ...
    end
end

```

MATLAB does not call the property set access method when assigning the default value specified in the property’s definition block.

If a handle class defines the property, the set access method does not need to return the modified object.

“Property Access Methods” on page 6-12 for more information on these methods.

“Defining Properties” on page 6-5 for information on properties.

Referencing Object Properties Using Variables

MATLAB can resolve a property name from a char variable using an expression of the form:

```
object.(PropertyNameVar)
```

where `PropertyNameVar` is a variable containing the name of a valid object property. Use this syntax when passing property names as arguments:

```
PropName = 'KeyType';
```

```
function o = getPropValue(obj,PropName)
    ...
    o = obj.(PropName); % Returns value of KeyType property
    ...
end
```

Specifying Methods and Functions

In this section...

“The Methods Block” on page 3-13
“Method Calling Syntax” on page 3-14
“Methods In Separate Files” on page 3-14
“Defining Private Methods” on page 3-16
“More Detailed Information On Methods” on page 3-16
“Defining Class-Related Functions” on page 3-16
“Overloading Functions and Operators” on page 3-17

The Methods Block

Define methods as MATLAB functions within a `methods` block, inside the `classdef` block. The constructor method has the same name as the class and returns an object. You can assign values to properties in the class constructor. Terminate all method functions with an `end` statement.

```
classdef ClassName
    methods
        function obj = ClassName(arg1,arg2,...)
            obj.Prop1 = arg1;
            ...
        end
        function normal_method(obj,arg1,...)
            ...
        end
    end
    methods (Static = true)
        function static_method(arg1,...)
            ...
        end
    end
end
```

Method Calling Syntax

MATLAB differs from languages like C++ and Java™ in that there is no special hidden class instance passed to all methods. You must pass an object of the class explicitly to the method. The left most argument does not need to be the class instance, and the argument list can have multiple objects.

See “Determining Which Method Is Invoked” on page 7-8 for more information.

See also “Static Methods” on page 7-24 for information on methods that do not require instances of their class.

Note Always use case sensitive method names in your MATLAB code.

Methods In Separate Files

You can define class methods in files that are separate from the class definition file, with certain exceptions (see “Methods That Must Be In the classdef File” on page 3-15). To use multiple files for a class definition, put the class files in a folder having a name beginning with the @ character followed by the name of the class. Ensure that the parent folder of the @-folder is on the MATLAB path.

For example, the folder @MyClass must contain the file MyClass.m (which contains the classdef block) and can contain other methods and function defined in files having a .m extension. For example, the folder @MyClass might contain a number of files:

```
@MyClass/MyClass.m
@MyClass/subsref.m
@MyClass/subsasgn.m
@MyClass/horzcat.m
@MyClass/vertcat.m
@MyClass/myFunc.m
```

Define the Method Like Any Function

To define a method in a separate file in the class @-folder, create the function in a separate file, but do not use a method block in that file. Name the file with the function name, as with any function.

Methods That Must Be in the `classdef` File

You must put the following methods in the `classdef` file, not in separate files:

- Class constructor
- Delete method
- All functions that use dots in their names, including:
 - Converter methods that convert to classes contained in packages, which must use the package name as part of the class name.
 - Property set and get access methods (“Property Access Methods” on page 6-12)

Specify Method Attributes in `classdef` File

If you specify method attributes for a method that you define in a separate file, include the method signature in a `methods` block in the `classdef` block. For example, the following code shows a method with `Access` set to `private` in the `methods` block. The method implementation resides in a separate file. Do not include the `function` or `end` keywords in the `methods` block, just the function signature showing input and output arguments.

```
classdef ClassName
% In a methods block, set the method attributes
% and add the function signature
    methods (Access = private)
        output = myFunc(obj, arg1, arg2)
    end
end
```

In a file named `myFunc.m`, in the `@ClassName` folder, define the function:

```
function output = myFunc(obj, arg1, arg2)
    ...
end
```

Include the method signature in the file with the `classdef` block only if you want to specify attributes for that method. Otherwise, you can implement the method as a function in a separate file in the `@-`folder.

Defining Static Methods in Separate Files

To create a static method, set the function's `Static` attribute to `true`. List any static methods that you define in separate files in the `@-class` folder. List these methods in the static methods block in the `classdef` file. Include the input and output arguments with the function name. For example:

```
classdef ClassName
...
    methods (Static)
        output = staticFunc1(arg1,arg2)
        staticFunc2
    end
```

You would then define the functions in separate files using the same function signature. For example:

```
function output = staticFunc1(arg1,arg2)
...
end
```

For an Example

The example, “Example — Using Events to Update Graphs” on page 9-30 uses multiple files for class definition.

Defining Private Methods

Use the `Access` method attribute to create a private method. You do not need to use a private folder.

See “Method Attributes” on page 7-4 for a list of method attributes.

More Detailed Information On Methods

See “Class Methods” on page 7-2 for more information about methods.

Defining Class-Related Functions

You can define functions that are not class methods in the file that contains the class definition (`classdef`). Define subfunctions outside of the `classdef`

- end block, but in the same file as the class definition. Subfunctions defined in `classdef` files work like subfunctions. You can call these subfunctions from anywhere in the same file, but they are not visible outside of the file in which you define them.

Subfunctions in `classdef` files are useful for utility functions that you use only within that file. These functions can take or return arguments that are instances of the class but, it is not necessary, as in the case of ordinary methods. For example, the following code defines `myUtilityFcn` outside the `classdef` block:

```
classdef MyClass
    properties
        PropName
    end
    methods
        function obj = MyClass(arg1)
            obj.PropName = arg1;
        end
    end % methods
end % classdef
function myUtilityFcn
    ...
end
```

You also can create package functions, which require you to use the package name when calling these functions. See “Scoping Classes with Packages” on page 4-19 for more information on packages

Overloading Functions and Operators

Overload MATLAB functions for your class by defining a class method with the same name as the function you want to overload. MATLAB dispatches to the class method when the function is called with an instance of the class. See “Overloading Functions for Your Class” on page 7-26 for more information.

You can also overload MATLAB arithmetic, logical, relational, and indexing operators by defining class methods with the appropriate names. See “Implementing Operators for Your Class” on page 15-35 for a list of the functions to overload.

See the `handle` class for a list of operations defined for that class, which are inherited by all classes deriving from `handle`.

Events and Listeners

In this section...

“Specifying Events” on page 3-19

“Listening for Events” on page 3-19

Specifying Events

To define an event, you declare a name for the event in the `events` block. Then one of the class methods triggers the event using the `notify` method, which is method inherited from the `handle` class. Only classes derived from the `handle` class can define events.

For example, the following class:

- Defines an event named `StateChange`
- Triggers the event using the inherited `notify` method.

```
classdef class_name < handle % Subclass handle
    events % Define an event called StateChange
        StateChange
    end
    ...
    methods
        function upDateGUI(obj)
            ...
            % Broadcast notice that StateChange event has occurred
            notify(obj, 'StateChange');
        end
    end
end
```

Listening for Events

Any number of objects can be listening for the `StateChange` event to occur. When `notify` executes, MATLAB calls all registered listener callbacks and passes the handle of the object generating the event and an event structure to

these functions. To register a listener callback, use the `addListener` method of the `handle` class.

```
addListener(event_obj, 'StateChange', @myCallback)
```

See “Defining Events and Listeners — Syntax and Techniques” on page 9-15

Specifying Attributes

In this section...

“Attribute Syntax” on page 3-21

“Attribute Descriptions” on page 3-21

“Specifying Attribute Values” on page 3-22

“Simpler Syntax for true/false Attributes” on page 3-22

Attribute Syntax

For a quick reference to all attributes, see Attribute Tables.

Attributes modify the behavior of classes and class components (properties, methods, and events). Attributes enable you to define useful behaviors without writing complicated code. For example, you can create a read-only property by setting its `SetAccess` attribute to `private`, but leaving its `GetAccess` attribute set to `public` (the default):

```
properties (SetAccess = private)
    ScreenSize = getScreenSize;
end
```

All class definition blocks (`classdef`, `properties`, `methods`, and `events`) support specific attributes and all attributes have default values. Specify attribute values only in cases where you want to change from the default value to another predefined value.

Attribute Descriptions

For lists of supported attributes, see:

- “Class Attributes” on page 4-5
- “Property Attributes” on page 6-8
- “Method Attributes” on page 7-4
- “Event Attributes” on page 9-14

Specifying Attribute Values

When you specify attribute values, these values affect all the components defined within the definition block. For example, the following property definition blocks set the:

- `AccountBalance` property `SetObservable` attribute to `true`
- `SSNumber` and `CreditCardNumber` properties' `Hidden` attribute to `true` and `SetAccess` attribute to `private`.

Defining properties with different attribute settings requires multiple `properties` blocks.

```
properties (SetObservable = true)
    AccountBalance
end
properties (SetAccess = private, Hidden = true)
    SSNumber
    CreditCardNumber
end
```

Specified multiple attributes in a comma-separated list, as shown in the previous example.

When specifying class attributes, place the attribute list directly after the `classdef` keyword:

```
classdef (Sealed = true) myclass
    ...
end
```

Simpler Syntax for true/false Attributes

You can use a simpler syntax for attributes whose values are `true` or `false` — the attribute name alone implies `true` and adding the not operator (`~`) to the name implies `false`. For example:

```
methods (Static)
    ...
end
```

is the same as:

```
methods (Static = true)
  ...
end
```

Use the not operator before an attribute name to define it as false:

```
methods (~Static)
  ...
end
```

is the same as:

```
methods (Static = false)
  ...
end
```

All attributes that take a logical value (that is, `true` or `false`) have a default value of `false`. Therefore, specify an attribute only if you want to set it to `true`.

Calling Superclass Methods on Subclass Objects

In this section...

“Calling a Superclass Constructor” on page 3-24

“Calling Superclass Methods” on page 3-25

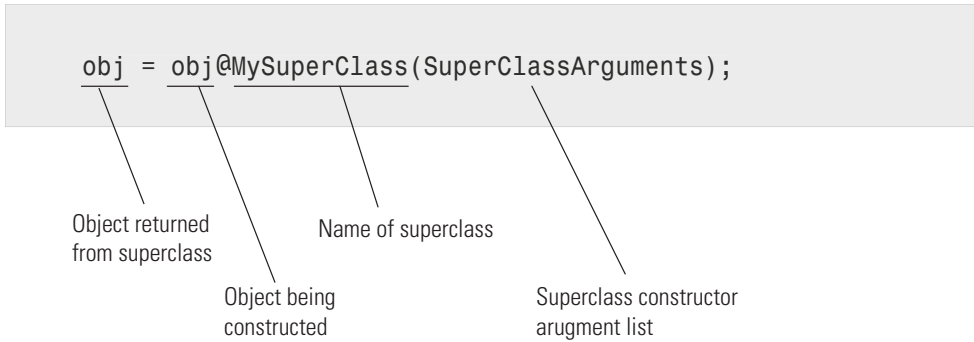
Calling a Superclass Constructor

If you create a subclass object, MATLAB calls the superclass constructor to initialize the superclass part of the subclass object. By default, MATLAB calls the superclass constructor without arguments. If you want the superclass constructor called with specific arguments, explicitly call the superclass constructor from the subclass constructor. The call to the superclass constructor must come before any other references to the object.

The syntax for calling the superclass constructor uses an @ symbol:

```
classdef MySub < MySuperClass
    function obj = MySub(arg1,arg2,...)
        obj = obj@MySuperClass(SuperClassArguments);
        ...
    end
end
```

Interpret this syntax as meaning, the MySub object arrives at the MySuperClass constructor , which constructs the MySuperClass part of the object using the specified arguments.



See “Constructing Subclasses” on page 7-19 for more information.

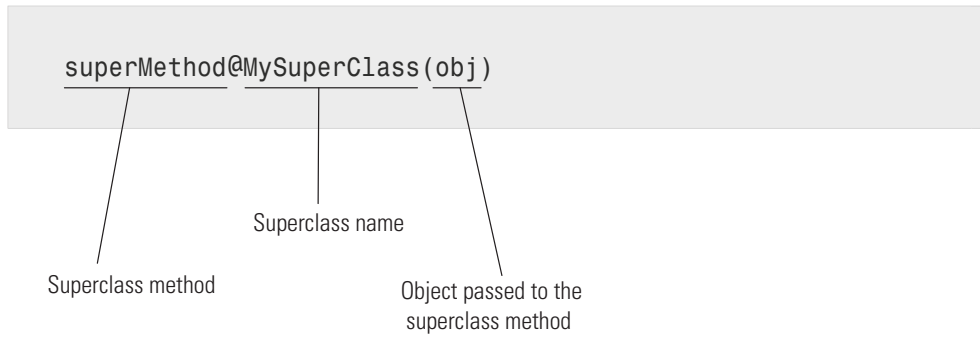
Calling Superclass Methods

You can call a superclass method from a subclass method if both methods have the same name. From the subclass, reference the method name and superclass name with the `@` symbol. See “Modifying Superclass Methods” on page 10-13 for more information on when to call superclass methods.

For example, a subclass can call a superclass `disp` method to implement the display of the superclass part of the object, and then add code to display the subclass part:

```
classdef MySub < MySuperClass
    function disp(obj)
        disp@MySuperClass(obj)
        ...
    endend
```

This diagram illustrates how to call the `superMethod` defined at `MySuperClass`.



A Class Code Listing

Example of Class Definition Syntax

The following code shows the syntax of a typical class definition. This example is not a functioning class because it references functions that it does not implement. The purpose of this section is to illustrate various syntactic constructions.

```
classdef (ConstructOnLoad) employee < handle
    % Class help goes here
    properties
        Name % Property help goes here
    end

    properties (Dependent)
        JobTitle
    end

    properties (Transient)
        OfficeNumber
    end

    properties (SetAccess = protected, GetAccess = private)
        EmpNumber
    end

    events
        BackgroundAlert
    end

    methods
        function Eobj = employee(name)
            % Method help here
            Eobj.Name = name;
            Eobj.EmpNumber = employee.getEmpNumber;
        end

        function result = backgroundCheck(obj)
            result = queryGovDB(obj.Name,obj.SSNumber);
        end
    end
end
```

```
        if result == false
            notify(obj, 'BackgroundAlert');
        end
    end

function jobt = get.JobTitle(obj)
    jobt = currentJT(obj.EmpNumber);
end

function set.OfficeNumber(obj, setvalue)
    if isInUse(setvalue)
        error('Not available')
    else
        obj.OfficeNumber = setvalue;
    end
end

methods (Static)
    function num = getEmpNumber
        num = queryDB('LastEmpNumber') + 1;
    end
end
end
```

Understanding Code Analyzer Warnings

In this section...

“Syntax Warnings and Property Names” on page 3-29

“Warnings Caused by Variable/Property Name Conflicts” on page 3-29

“Exception to Variable/Property Name Rule” on page 3-30

Syntax Warnings and Property Names

The MATLAB code analyzer helps you optimize your code and avoid syntax errors while you write code. It is useful to understand some of the rules that the Code Analyzer applies in its analysis of class definition code. This understanding helps you avoid situations in which MATLAB allows code that is undesirable.

Warnings Caused by Variable/Property Name Conflicts

The Code Analyzer warns about the use of variable names in methods that match the names of properties. For example, suppose a class defines a property called `EmployeeName` and in this class, there is a method that uses `EmployeeName` as a variable:

```
properties
    EmployeeName
end
methods
    function someMethod(obj,n)
        EmployeeName = n;
    end
end
```

While the previous function is legal MATLAB code, it results in Code Analyzer warnings for two reasons:

- The value of `EmployeeName` is never used
- `EmployeeName` is the name of a property that is used as a variable

If the function `someMethod` contained the following statement instead:

```
obj.EmployeeName = n;
```

The Code Analyzer generates no warnings.

If you change `someMethod` to:

```
function EN = someMethod(obj)
    EN = EmployeeName;
end
```

The Code Analyzer returns only one warning, suggesting that you might actually want to refer to the `EmployeeName` property.

While this version of `someMethod` is legal MATLAB code, it is confusing to give a property the same name as a function. Therefore, the Code Analyzer provides a warning suggesting that you might have intended the statement to be:

```
EN = obj.EmployeeName;
```

Exception to Variable/Property Name Rule

Suppose you define a method that returns a value of a property and uses the name of the property for the output variable name. For example:

```
function EmployeeName = someMethod(obj)
    EmployeeName = obj.EmployeeName;
end
```

M-Lint does not warn when a variable name is the same as a property name when the variable is:

- An input or output variable
- A global or persistent variable

In these particular cases, M-Lint does not warn you that you are using a variable name that is also a property name. Therefore, a coding error like the following:

```
function EmployeeName = someMethod(obj)
    EmployeeName = EmployeeName; % Forgot to include obj.
end
```

does not trigger a warning from M-Lint.

Functions Used with Objects

In this section...
“Functions to Query Class Members” on page 3-32
“Functions to Test Objects” on page 3-32

Functions to Query Class Members

These functions provide information about object class members.

Function	Purpose
<code>class</code>	Return class of object
<code>events</code>	List of event names defined by the class
<code>methods</code>	List of methods implemented by the class
<code>methodsview</code>	Information on class methods in separate window
<code>properties</code>	List of class property names

Functions to Test Objects

These functions provide logical tests, which are useful when using objects in ordinary functions.

Function	Purpose
<code>isa</code>	Determine whether argument is object of specific class
<code>isequal</code>	Determine if two objects are equal, which means both objects are of the same class and size and their corresponding property values are equal
<code>isobject</code>	Determine whether input is MATLAB object

Using the Editor and Debugger with Classes

Referring to Class Files

Define classes in files just like scripts and functions. To use the editor or debugger with a class file, use the full class name. For example, suppose the file for a class, `myclass.m` is in the following location:

```
+PackFld1/+PackFld2/@myclass/myclass.m
```

To open `myclass.m` in the MATLAB editor, you could reference the file using dot-separated package names:

```
edit PackFld1.PackFld2.myclass
```

You could also use path notation:

```
edit +PackFld1/+PackFld2/@myclass/myclass
```

If `myclass.m` is not in an @-folder, then enter:

```
edit +PackFld1/+PackFld2/myclass
```

To refer to functions inside a package folder, use dot or path separators:

```
edit PackFld1.PackFld2.packFunction  
edit +PackFld1/+PackFld2/packFunction
```

To refer to a function defined in its own file inside of a class @-folder, use:

```
edit +PackFld1/+PackFld2/@myclass/myMethod
```

Debugging Class Files

For debugging, `dbstop` accepts any of the file specifications used by the `edit` command.

See “Modifying and Reloading Classes” on page 3-34 for information about clearing class.

Modifying and Reloading Classes

Ensuring MATLAB Uses Your Changes

There is only one class definition for a given class in MATLAB at any given time. When you create an instance of a class, MATLAB loads the class definition. So as long as instances of that class exist, MATLAB does not reload the class definition.

Clear Class Instances

When you modify a class definition, the current MATLAB session continues to use the original class definition until you clear all objects of that class. For example, if `obj1` and `obj2` are instances of a class for which you have modified the class definition, clear those objects so MATLAB can use your changes. Use the `clear` command to remove only those instances:

```
clear obj1 obj2
```

Modifying a class definition includes doing any of the following:

- Changing class member attributes
- Adding, deleting, or changing the names of properties, methods, or events
- Changing class inheritance
- Changing the definition of a superclass (requires you to clear subclass objects)

If there are no class instances, MATLAB applies changes in the code immediately. If there are instances, you must clear those objects before MATLAB applies your changes.

Clear Classes

When you issue the `clear classes` command, MATLAB clears:

- The current workspace of all variables
- All functions, which can have persistent variables holding class instances (unless the function is locked)

- All classes that are not instantiated

However, it is possible that your MATLAB session is holding instances of the class that the `clear classes` command does not clear. For example, suppose you change the definition of `MyClass` after saving an instance of this class in a Handle Graphics® object's `UserData` property:

```
obj = MyClass; % User-defined class that you are editing
h = uicontrol('Style','pushbutton');
set(h,'UserData',obj)
clear classes
Warning: Objects of 'MyClass' class exist. Cannot clear this class or any of its
super-classes.
```

MATLAB issues a warning stating that it cannot apply your changes because it cannot clear the class. Clear the instance of `MyClass` before calling `clear classes`. For example, you can use the `close all` command to remove the object or reset the `UserData` property to another value:

```
% First, get the handle of the uicontrol, which was cleared
h = findobj('Type','uicontrol','Style','pushbutton');
set(h,'UserData',[])
```

Now you can issue the `clear classes` command.

Places That Can Hold Instances

You can remove class instances from your workspace using the `clear obj...` command. However, as the preceding example shows, objects can be held in various ways. Clear all instances before MATLAB applies your new class definition.

Here are some suggestions for finding and clearing class instances:

Persistent Variables. Persistent variables can hold objects. Clear persistent variables using `clear` functions. If the function containing the persistent variable is locked, then unlock the function (using `munlock`) before clearing it.

Locked Functions. Functions can contain objects in their workspace. If the function is locked (with `mlock`), unlock it (using `munlock`) so that MATLAB can clear the instance. Use `clear` functions once you have unlocked the function.

Default Property Values. When you specify a default value in a properties definition block, MATLAB evaluates the expression that defines the default value once when loading the class. Clear this value using the `clear classes` command.

Constant Properties. When you define a constant property (property Constant attribute set to `true`) whose value is an object, MATLAB creates the instance when loading the class. Clear this instance using the `clear classes` command.

Handle Graphics Objects. Handle Graphics objects can contain class instances in UserData properties, in Application Data, or created in callback functions. Issuing the `close all` command removes the Handle Graphics objects, unless these objects enable hidden handles. See the `close` command for more information. You can remove Application Data using the `rmappdata` function.

Simulink® Models. Models can contain class instances. Use `close_system` to close the model so that MATLAB can apply your changes.

Compatibility with Previous Versions

In this section...

“New Class-Definition Syntax Introduced with MATLAB Software Version 7.6” on page 3-37

“Changes to Class Constructors” on page 3-38

“New Features Introduced with Version 7.6” on page 3-39

“Examples of Old and New” on page 3-39

New Class-Definition Syntax Introduced with MATLAB Software Version 7.6

MATLAB software Version 7.6 introduces a new syntax for defining classes. This new syntax includes:

- The `classdef` keyword begins a block of class-definitions code. An `end` statement terminates the class definition.
- Within the `classdef` code block, `properties`, `methods`, and `events` are also keywords delineating where you define the respective class members.

Cannot Mix Class Hierarchy

It is not possible to create class hierarchies that mix classes defined before Version 7.6 and current class definitions that use `classdef`. Therefore, you cannot subclass an old class to create a version of the new class.

Only One @-Folder per Class

For classes defined using the new `classdef` keyword, an `@`-folder shadows all `@`-folders that occur after it on the MATLAB path. Classes defined in `@`-folders must locate all class files in that single folder. However, classes defined in `@`-folders continue to take precedence over functions and scripts having the same name, even those function and scripts that come before them on the path.

Private Methods

You do not need to define private folders in class folders in Version 7.6. You can set the method's `Access` attribute to `private` instead.

Changes to Class Constructors

Class constructor methods have two major differences. Class constructors:

- Do not use the `class` function.
- Must call the superclass constructor only if you want to pass arguments to its constructor. Otherwise, no call to the superclass constructor is necessary.

Example of Old and New Syntax

Compare the following two `Stock` constructor methods. The `Stock` class is a subclass of the `Asset` class, which requires arguments passed to its constructor.

Constructor Function Before Version 7.6

```
function s = Stock(description,num_shares,share_price)
    s.NumShares = num_shares;
    s.SharePrice = share_price;
% Construct Asset object
    a = Asset(description,'stock',share_price*num_shares);
% Use the class function to define the stock object
    s = class(s,'Stock',a);
```

Write the same `Stock` class constructor as shown here. Define the inheritance on the `classdef` line and define the constructor within a `methods` block.

Constructor Function for Version 7.6

```
classdef Stock < Asset
    ...
    methods

        function s = Stock(description,num_shares,share_price)
            % Call superclass constructor to pass arguments
```

```
        s = s@Asset(description, 'stock', share_price*num_shares);
        s.NumShares = num_shares;
        s.SharePrice = share_price;
    end % End of function

    end % End of methods block
end % End of classdef block
```

New Features Introduced with Version 7.6

- Properties: “How to Use Properties” on page 6-2
- Handle classes: “Comparing Handle and Value Classes” on page 5-2
- Events and listeners: “Events and Listeners — Concepts” on page 9-9
- Class member attributes: Attribute Tables
- Abstract classes: “Abstract Classes and Interfaces” on page 10-50
- Dynamic properties: “Dynamic Properties — Adding Properties to an Instance” on page 6-21
- Ability to subclass MATLAB built-in classes: “Creating Subclasses — Syntax and Techniques” on page 10-7
- Packages for scoping functions and classes: “Scoping Classes with Packages” on page 4-19. MATLAB does not support packages for classes created before MATLAB Version 7.6 (that is, classes that do not use `classdef`).
- The JIT/Accelerator supports objects defined only by classes using `classdef`.

Examples of Old and New

The MATLAB Version 7.6 implementation of classes uses different syntax from previous releases. However, classes written in previous versions continue to work. Most of the code you use to implement the methods is likely to remain the same, except where you take advantage of new features.

The following sections reimplement examples using the latest syntax. The original MATLAB Classes and Objects documentation implemented these same examples and provide a comparison of old and new syntax.

“Example — A Polynomial Class” on page 16-2

“Example — A Simple Class Hierarchy” on page 17-2

“Example — Containing Assets in a Portfolio” on page 17-19

Obsolete Documentation

Documentation for MATLAB Classes and Objects before Version 7.6 is available [here](#).

MATLAB Vs. Other OO Languages

In this section...

“Some Differences from C++ and Sun Java Code” on page 3-41

“Modifying Objects” on page 3-42

“Common Object-Oriented Techniques” on page 3-47

Some Differences from C++ and Sun Java Code

The MATLAB programming language differs from other object-oriented languages, such as C++ or Sun™ Java in some important ways.

Public Properties

Unlike fields in C++ or the Java language, you can use MATLAB properties to define a public interface separate from the implementation of data storage. You can provide public access to properties because you can define set and get access methods that execute automatically when assigning or querying property values. For example, the following statement:

```
myobj.Material = 'plastic';
```

assigns the string `plastic` to the `Material` property of `myobj`. Before making the actual assignment, `myobj` executes a method called `set.Material` (assuming the class of `myobj` defines this method), which can perform any necessary operations. See “Property Set and Get Access Methods” on page 6-12 for more information on property access methods.

You can also control access to properties by setting attributes, which enable public, protected, or private access. See “Property Attributes” on page 6-8 for a full list of property attributes.

No Implicit Parameters

In some languages, one object parameter to a method is always implicit. In MATLAB, objects are explicit parameters to the methods that act on them.

Dispatching

In MATLAB classes, method dispatching is not based on method signature, as it is in C++ and Java code. When the argument list contains objects of equal precedence, MATLAB software uses the left-most object to select the method to call. However, if the class of that argument is superior to the other arguments, MATLAB can dispatch to a method of an argument in any position within an argument list.

See “Specifying Class Precedence” on page 4-17 for more information.

Calling Superclass Method

- In C++, you call a superclass method using the scoping operator: `superclass::method`
- In Java code, you use: `superclass.method`

The equivalent MATLAB operation is `method@superclass`.

Other Differences

In MATLAB classes, there is no equivalent to C++ templates or Java generics. However, MATLAB is weakly typed and it is possible to write functions and classes that work with different types of data.

MATLAB classes do not support overloading functions using different signatures for the same function name.

Modifying Objects

MATLAB classes can define public properties, which you can modify by explicitly assigning values to those properties on a given instance of the class. However, only classes derived from the `handle` class exhibit reference behavior. Modifying a property value on an instance of a value classes (classes not derived from `handle`), changes the value only within the context in which the modification is made.

The sections that follow describe this behavior in more detail.

Passing Objects to Functions

MATLAB passes all variables by value. When you pass an object to a function, MATLAB copies the value from the caller into the parameter variable in the called function.

However, MATLAB supports two kinds of classes that behave differently when copied:

- Handle classes — a handle class instance variable refers to an object. A copy of a handle class instance variable refers to the same object as the original variable. If a function modifies a handle object passed as an input argument, the modification affects the object referenced by both the original and copied handles.
- Value classes — the property data in an instance of a value class are independent of the property data in copies of that instance (although, a value class property could contain a handle). A function can modify a value object that is passed as an input argument, but this modification does not affect the original object.

See “Comparing Handle and Value Classes” on page 5-2 for more information on the behavior and use of both kinds of classes.

Passing Value Objects. When you pass a value object to a function, the function creates a local copy of the argument variable. The function can modify only the copy. If you want to modify the original object, return the modified object and assign it to the original variable name. For example, consider the value class, `SimpleClass` :

```
classdef SimpleClass
    properties
        Color
    end
    methods
        function obj = SimpleClass(c)
            if nargin > 0
                obj.Color = c;
            end
        end
    end
end
```

```
end
```

Create an instance of `SimpleClass`, assigning a value of `red` to its `Color` property:

```
obj = SimpleClass('red');
```

Pass the object to the function `g`, which assigns `blue` to the `Color` property:

```
function y = g(x)
    x.Color = 'blue';
    y = x;
end
```

```
y = g(obj);
```

The function `g` modifies its copy of the input object and returns that copy, but does not change the original object.

```
y.Color
ans =
    blue
obj.Color
ans =
    red
```

If the function `g` did not return a value, the modification of the object `Color` property would have occurred only on the copy of `obj` within the function workspace. This copy would have gone out of scope when the function execution ended.

Overwriting the original variable actually replaces it with a new object:

```
obj = g(obj);
```

Passing Handle Objects. When you pass a handle to a function, the function makes a copy of the handle variable, just like when passing a value object. However, because a copy of a handle object refers to the same object as the original handle, the function can modify the object without having to return the modified object.

For example, suppose you modify the `SimpleClass` class definition to make a class derived from the handle class:

```
classdef SimpleHandleClass < handle
    properties
        Color
    end
    methods
        function obj = SimpleHandleClass(c)
            if nargin > 0
                obj.Color = c;
            end
        end
    end
end
```

Create an instance of `SimpleHandleClass`, assigning a value of red to its `Color` property:

```
obj = SimpleHandleClass('red');
```

Pass the object to the function `g`, which assigns blue to the `Color` property:

```
y = g(obj);
```

The function `g` sets the `Color` property of the object referred to by both the returned handle and the original handle:

```
y.Color
ans =
blue
obj.Color
```

```
ans =
```

```
blue
```

The variables `y` and `obj` refer to the same object:

```
y.Color = 'yellow';  
obj.Color
```

```
ans =
```

```
yellow
```

The function `g` modified the object referred to by the input argument (`obj`) and returned a handle to that object in `y`.

MATLAB Passes Handles by Value. A handle variable is a reference to an object. MATLAB passes this reference by value.

Handles do not behave like references in C++. If you pass an object handle to a function and that function assigns a different object to that handle variable, the variable in the caller is not affected. For example, suppose you define a function `g2`:

```
function y = g2(x)  
    x = SimpleHandleClass('green');  
    y = x;  
end
```

Pass a handle object to `g2`:

```
obj = SimpleHandleClass('red');  
y = g2(obj);  
y.Color
```

```
ans =
```

```
green  
obj.Color
```

```
ans =
```

red

The function overwrites the handle passed in as an argument, but does not overwrite the object referred to by the handle. The original handle `obj` still references the original object.

Common Object-Oriented Techniques

This table provides links to sections that discuss object-oriented techniques commonly used by other object-oriented languages.

If there are techniques that you would like to see added, respond with this form.

Technique	How to Use in MATLAB
Operator overloading	“Implementing Operators for Your Class” on page 15-35
Multiple inheritance	“Using Multiple Inheritance” on page 10-18
Subclassing	“Creating Subclasses — Syntax and Techniques” on page 10-7
Destructor	“Handle Class Delete Methods” on page 5-15
Data member scoping	“Property Attributes” on page 6-8
Packages (scoping classes)	“Scoping Classes with Packages” on page 4-19
Named constants	
Static methods	“Static Methods” on page 7-24
Static properties	Not supported. See persistent variables. For the equivalent of Java <code>static final</code> or C++ <code>static const</code> properties, use Constant properties. See
Constructor	“Class Constructor Methods” on page 7-15
Copy constructor	No direct equivalent

Technique	How to Use in MATLAB
Reference/reference classes	“Comparing Handle and Value Classes” on page 5-2
Abstract class/Interface	“Abstract Classes and Interfaces” on page 10-50
Garbage collection	“Object Lifecycle” on page 5-16
Instance properties	“Dynamic Properties — Adding Properties to an Instance” on page 6-21
Importing classes	“Importing Classes” on page 4-24
Events and Listeners	“Events and Listeners — Concepts” on page 9-9

Defining and Organizing Classes

- “Class Overview” on page 4-2
- “Defining Classes — Syntax” on page 4-4
- “Class Attributes” on page 4-5
- “Using Expressions in Class Definitions” on page 4-7
- “Organizing Classes in Folders” on page 4-13
- “Specifying Class Precedence” on page 4-17
- “Scoping Classes with Packages” on page 4-19
- “Importing Classes” on page 4-24

Class Overview

MATLAB User-Defined Classes

A MATLAB class definition is a template whose purpose is to provide a description of all the elements that are common to all instances of the class. Class members are the properties, methods, and events that define the class.

MATLAB classes are defined in code blocks, with sub-blocks delineating the definitions of various class members. See “`classdef` Syntax” on page 4-4 for details on the `classdef` block.

Attributes for Class Members

Attributes modify the behavior of classes and the members defined in the class-definition block. For example, you can specify that methods are static or that properties are abstract, and so on. The following sections describe these attributes:

- “Class Attributes” on page 4-5
- “Method Attributes” on page 7-4
- “Property Attributes” on page 6-8
- “Event Attributes” on page 9-14

Class definitions can provide information, such as inheritance relationships or the names of class members without actually constructing the class. See “Working with Meta-Classes” on page 14-2.

See “Specifying Attributes” on page 4-6 for more on attribute syntax.

Kinds of Classes

There are two kinds of MATLAB classes—handle and value classes.

- Handle classes create objects that reference the data contained. Copies refer to the same data.
- Value classes make copies of the data whenever the object is copied or passed to a function. MATLAB numeric types are value classes.

See “Comparing Handle and Value Classes” on page 5-2 for a more complete discussion.

Constructing Objects

For information on class constructors, see “Class Constructor Methods” on page 7-15

For information on creating arrays of objects, see “Creating Object Arrays” on page 8-3

Creating Class Hierarchies

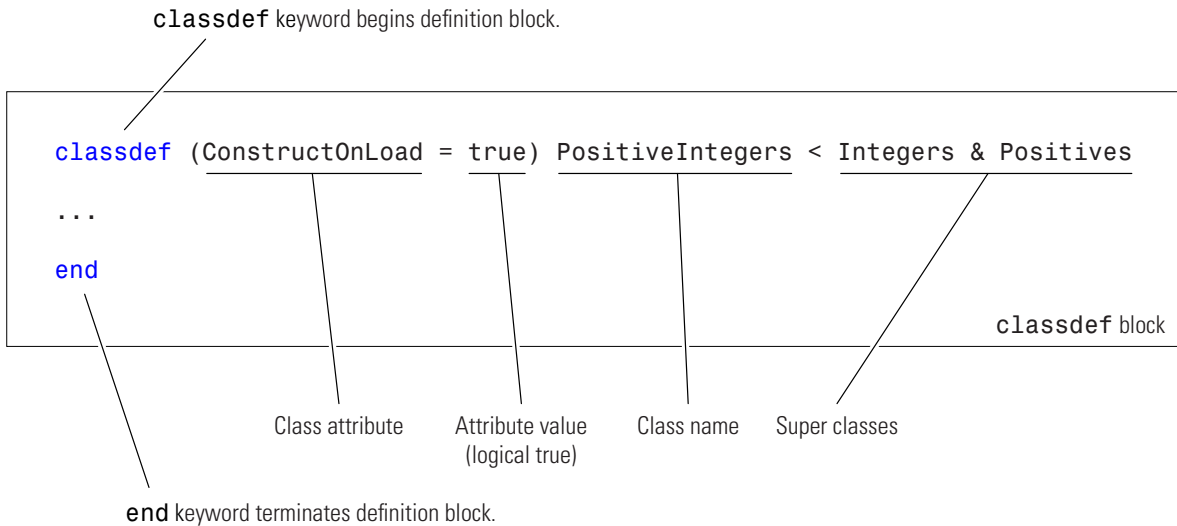
For more information on how to define class hierarchies, see Chapter 10, “Building on Other Classes”.

Defining Classes – Syntax

classdef Syntax

Class definitions are blocks of code that are delineated by the `classdef` keyword at the beginning and the `end` keyword at the end. Files can contain only one classes definition.

The following diagram shows the syntax of a `classdef` block. Only comments and blank lines can precede the `classdef` key word.



Examples of Class Definitions

See the following links for examples of class definitions:

- “Example — Representing Structured Data” on page 2-22
- “Example — Implementing Linked Lists” on page 2-31
- “Developing Classes — Typical Workflow” on page 2-11
- “Example — A Polynomial Class” on page 16-2

Class Attributes

In this section...

“Table of Class Attributes” on page 4-5

“Specifying Attributes” on page 4-6

Table of Class Attributes

All classes support the attributes listed in the following table. Attributes enable you to modify the behavior of class. Attribute values apply to the class defined within the `classdef` block.

Attribute Name	Class	Description
Hidden	logical (default = false)	If true, this class does not appear in the output of MATLAB commands or tools that display class names.
InferiorClasses	cell (default = {})	Use this attribute to establish a precedence relationship among classes. Specify a cell array of <code>meta.class</code> objects using the <code>?</code> operator. The built-in classes <code>double</code> , <code>single</code> , <code>char</code> , <code>logical</code> , <code>int64</code> , <code>uint64</code> , <code>int32</code> , <code>uint32</code> , <code>int16</code> , <code>uint16</code> , <code>int8</code> , <code>uint8</code> , <code>cell</code> , <code>struct</code> , and <code>function_handle</code> are always inferior to user-defined classes and do not show up in this list. See “Specifying Class Precedence” on page 4-17
ConstructOnLoad	logical (default = false)	If true, MATLAB calls the class constructor when loading an object from a MAT-file. Therefore, you must implement the constructor so it can be called with no arguments without producing an error. See “Calling Constructor When Loading” on page 11-25
Sealed	logical (default = false)	If true, this class can not be subclassed.

Specifying Attributes

Attributes are specified for class members in the `classdef`, `properties`, `methods`, and `events` definition blocks. The particular attribute setting applies to all members defined within that particular block. This means that, for example, you might use multiple `properties` definition blocks so you can apply different attribute setting to different properties.

Superclass Attributes Are Not Inherited

Class attributes are not inherited, so superclass attributes do not affect subclasses.

Attribute Syntax

Specify class attribute values in parentheses, separating each attribute name/attribute value pair with a comma. The attribute list always follows the `classdef` or class member key word, as shown below:

```
classdef (attribute-name = expression, ...) ClassName

    properties (attribute-name = expression, ...)
        ...
    end
    methods (attribute-name = expression, ...)
        ...
    end
    events (attribute-name = expression, ...)
        ...
    end
end
```

See “Expressions in Attribute Specifications” on page 4-8 for more information.

Using Expressions in Class Definitions

In this section...

“Basic Knowledge” on page 4-7

“Where Can You Use Expressions” on page 4-7

“How MATLAB Evaluates Expressions” on page 4-9

Basic Knowledge

“Expressions”, “Evaluating Expressions”, “Specifying Properties” on page 3-8, “Specifying Attributes” on page 3-21.

Where Can You Use Expressions

An expression used in a class definition can be any valid MATLAB statement that evaluates to a single array. Use expressions to define property default values and in attribute specifications. Here are some examples used in a class definition:

```

classdef MyClass (Sealed = true)
% Logical value sets attribute
properties (Constant = true)
    CnstProp = 2^.5;
end
properties
    Prop1 = MyClass.setupAccount;    % Static method of this class
    Prop2 = MyConstants.Minimum;    % Constant property from another class
    Prop3 = MyConstants.Rate*MyClass.CnstProp % Constant property from this class
    Prop4 = AccountManager;        % A class constructor
end
end

```

MATLAB does not call property set methods when assigning the result of default value expressions to properties. (See “Property Set and Get Access Methods” on page 6-12 for information about these special methods.)

Expressions in Attribute Specifications

Class definitions specify attribute values using an expression that assigns the desired value to the named attribute. For example, this assignment makes `MyClass` sealed (cannot be subclassed).

```
classdef MyClass (Sealed = true)
```

It is possible to use a MATLAB expression on the right side of the equals sign (=) as long as it evaluates to logical `true` or `false`. However, this expression *cannot* use any definitions in its own file, including any constant properties, static methods, and local functions.

While it is possible to use conditional expressions to specify attribute values, doing so can cause the class definition to change based on external conditions.

See “Specifying Attributes” on page 3-21 for more information on attribute syntax.

Expressions in Default Property Specifications

Property definitions allow you to specify default values for properties using any expression that has no reference to variables. For example, `MyClass` defines a constant property (`Deg2Rad`) and uses it in an expression that defines the default value of another property (`PropA`). The default value expression also uses a static method (`getAngle`) defined by the class:

```
classdef MyClass
    properties (Constant = true)
        Deg2Rad = pi/180;
    end
    properties
        PropA = sin(Deg2Rad*MyClass.getAngle[1 0],[0 1]);
    end
    ...
    methods (Static = true)
        r = getAngle(vx,vy)
        ...
    end
end
end
```

Expressions in Class Methods

Expression in class methods execute like expressions in any function — MATLAB evaluates an expression within the function’s workspace only when the method executes. Therefore, expressions used in class methods are not considered part of the class definition and are not discussed in this section.

How MATLAB Evaluates Expressions

MATLAB evaluates the expressions used in the class definition without any workspace. Therefore, these expressions cannot reference variables of any kind.

MATLAB evaluates expressions in the context of the class file, so these expressions can access any functions, static methods, and constant properties of other classes that are on your path at the time MATLAB initializes the class. Expressions defining property default values can access constant properties defined in their own class.

When Does MATLAB Evaluate These Expressions

MATLAB evaluates the expressions in class definitions only when the class is initialized, which occurs before the class is first used. After initialization, the values returned by these expressions are considered part of the class definition and are constant for all instances of the class. Each instance of the class uses the results of the initial evaluation of the expressions without reevaluation. If you clear a class (see “Modifying and Reloading Classes” on page 3-34), then MATLAB reinitializes the class by reevaluating the expressions that are part of the class definition.

The following example shows how value and handle object behave when assigned to properties as default values. Suppose you have the following classes. `ContClass` defines the object that is created as a default property value, and `ClassExp` has a property that contains a `ContClass` object:

```
classdef ContClass
    properties
        TimeProp = datestr(now); % Assign current date and time
    end
end
```

```
classdef ClassExp
    properties
        ObjProp = ContClass;
    end
end
```

MATLAB creates an instance of the `ContClass` class when the `ClassExp` class is first used. MATLAB initializes both classes at this time. All instances of `ClassExp` include a copy of this same instance of `ContClass`.

```
a = ClassExp;
a.ObjProp.TimeProp

ans =

08-Oct-2003 17:16:08
```

The `TimeProp` property of the `ContClass` object contains the date and time when MATLAB initialized the class. Creating additional instances of the `ClassExp` class shows that the date string has not changed:

```
b = ClassExp;
b.ObjProp.TimeProp

ans =

08-Oct-2003 17:16:08
```

Because this example uses a value class for the contained object, each instance of the `ClassExp` has its own copy of the object. For example, suppose you change the value of the `TimeProp` property on the object contained by `ClassExp` object `b`:

```
b.ObjProp.TimeProp = datestr(now)

ans =

08-Oct-2003 17:22:49
```

The copy of the object contained by object `a` is unchanged:


```
a.ObjProp.TimeProp

ans =

08-Oct-2003 17:16:08
```

Now consider the difference in behavior if the contained object is a handle object:

```
classdef ContClass < handle
    properties
        TimeProp = datestr(now);
    end
end
```

Creating two instances of the `ContClass` class shows that MATLAB created an object when it initialized the `ContClass` and used a copy of the object *handle* for each instance of the `ContClass` class. This means there is one `ContClass` object and the `ObjProp` property of each `ContClass` object contains a copy of its handle.

Create an instance of the `ContClass` class and note the time of creation:

```
a = ContClass;
a.ObjProp.TimeProp

ans =

08-Oct-2003 17:46:01
```

Create a second instance of the `ContClass` class. The `ObjProp` contains the handle of the same object:

```
b = ContClass;
b.ObjProp.TimeProp

ans =

08-Oct-2003 17:46:01
```

Reassign the value of the contained object's `TimeProp` property:

```
b.ObjProp.TimeProp = datestr(now);  
b.ObjProp.TimeProp
```

```
ans =
```

```
08-Oct-2003 17:47:34
```

Because the `ObjProp` property of object `b` contains a handle to the same object as the `ObjProp` property of object `a`, the value of the `TimeProp` property has changed on this object as well:

```
a.ObjProp.TimeProp
```

```
ans =
```

```
08-Oct-2003 17:47:34
```

See “Comparing Handle and Value Classes” on page 5-2 for more information on handle and value classes.

Organizing Classes in Folders

In this section...

“Options for Class Folders” on page 4-13

“@-Folders” on page 4-13

“Path Folders” on page 4-14

“Access to Functions Defined in Private Folders” on page 4-14

“Class Precedence and MATLAB Path” on page 4-14

Options for Class Folders

There are two types of folders that can contain class definitions. Each behave differently in a number of respects.

- @-folders — Folder name begins with “@” and is not on the MATLAB path, but its parent folder is on the path. Use this type of folder when you want to use multiple files for one class definition. You can define only one class per folder and the name of the class must match the name of the folder, without the “@” symbol (@MyClass/MyClass.m, @MyClass/MyMethod.m, and so on).
- path folders — Folder name does not use an @ character and is itself on the MATLAB path. Use this type of folder when you want multiple classes in one folder. Define each class in one file only (MyClass1.m, MyClass2.m, and so on)

See the path function for information about the MATLAB path.

@-Folders

An @-folder is contained by a path folder, but is not itself on the MATLAB path. Place the class definition file inside the @-folder, which can also contain method files. The class definition file must have the same name as the @-folder (without the @-sign) and the class definition (beginning with the `classdef` key word) must appear in the file before any other code (white space and comments do not constitute code). The name of the class must match the name of the file that contains the class definition.

You must use an @-folder if you want to use more than one file for your class definition. Methods defined in separate files match the file name to the function name. All files have a .m extension.

Path Folders

You can locate class definition files in folders that are on the MATLAB path. These classes are visible on the path like any ordinary function. Class definitions placed in path folders behave like any ordinary function with respect to precedence—the first occurrence of a name on the MATLAB path takes precedence over all subsequent occurrences.

The name of the file must match the name of the class, as specified with the `classdef` key word. Using a path folder eliminates the need to create a separate @-folder for each class. However, the entire class definition must be contained within a single file. All files have a .m extension.

Access to Functions Defined in Private Folders

Private folders contain functions that are accessible only from functions defined in folders immediately above the `private` folder (See “Private Functions” for more information). If a class folder contains a `private` folder, only the class (or classes) defined in that folder can access functions defined in the `private` folder. Subclasses do not have access to superclass private functions.

If you want a subclass to have access to the private functions of the superclass, define the private functions as protected methods of the superclass (that is, in a `methods` block with the `Access` attribute defined a `protected`).

No Class Definitions in Private Folders

You cannot put class definitions in private folders because doing so would not meet the requirements for @ or path folders.

Class Precedence and MATLAB Path

When multiple class definition files with the same name exist, the precedence of a given file is determined by its location on the MATLAB path. All class definition files before it on the path (whether in an @-folder or not) take

precedence and it takes precedence over all class definition files occurring later on the path.

For example, consider a path with the following folders, containing the files indicated:

```
fldr1/foo.m           % defines class foo
fldr2/foo.m           % defines function foo
fldr3/@foo/foo.m     % defines class foo
fldr4/@foo/bar.m     % defines method bar
fldr5/foo.m           % defines class foo
```

The MATLAB language applies the logic in the following list to determine which version of `foo` to call:

- Class `fldr1/foo.m` takes precedence over the class `fldr3/@foo` because it is before `fldr3/@foo` on the path.
- Class `fldr3/@foo` takes precedence over function `fldr2/foo.m` because it is a class in an `@`-folder and `fldr2/foo.m` is not a class (`@`-folder classes take precedence over functions).
- Function `fldr2/foo.m` takes precedence over class `fldr5/foo.m` because it comes before class `fldr5/foo.m` on the path and because class `fldr5/foo.m` is not in an `@`-folder. Classes not defined in `@`-folder abide by path order with respect to functions.
- Class `fldr3/@foo` takes precedence over class `fldr4/@foo`; therefore, the method `bar` is not recognized as part of the `foo` class (which is defined only by `fldr3/@foo`).
- If `fldr3/@foo/foo.m` does not contain a `classdef` keyword (i.e., it is a MATLAB class prior to Version 7.6), then `fldr4/@foo/bar.m` becomes a method of the `foo` class defined in `fldr3/@foo`.

Previous Behavior of Classes Defined in `@`-Folders

In MATLAB Versions 5 through 7, `@`-folders do not shadow other `@`-folders having the same name, but residing in later path folders. Instead, the class is defined by the combination of methods from all `@`-folders having the same name. This is no longer true.

Note that for backward compatibility, classes defined in @-folders always take precedence over functions and scripts having the same name, even those that come before them on the path.

Specifying Class Precedence

InferiorClasses Attribute

You can specify the relative precedence of user-defined classes using the class `InferiorClasses` attribute. Assign a cell array of class names (represented as `meta.class` objects) to this attribute to specify classes that are inferior to the class you are defining. For example, the following `classdef` declares that `myClass` is dominant over `class1` and `class2`.

```
classdef (InferiorClasses = {?class1,?class2}) myClass
    ...
end
```

The `?` operator combined with a class name creates a `meta.class` object. This syntax enables you to create a `meta.class` object without requiring you to construct an actual instance of the class.

MATLAB built-in classes are always inferior to user-defined classes and should not be used in this list.

The built-in classes include: `double`, `single`, `char`, `logical`, `int64`, `uint64`, `int32`, `uint32`, `int16`, `uint16`, `int8`, `uint8`, `cell`, `struct`, and `function_handle`.

Dominant Class

MATLAB uses class dominance when evaluating expressions involving objects of more than one class. The dominant class determines:

- The methods of which class MATLAB calls when more than one class defines methods with the same names.
- The class of arrays that are formed by combining objects of different classes, assuming MATLAB can convert the inferior objects to the dominant class.

See “Concatenating Objects of Different Classes” on page 8-13 for more information on creating object arrays.

More Information

See “Determining Which Method Is Invoked” on page 7-8 for more on how the MATLAB classes dispatch when evaluating expressions containing objects.

See “Class Precedence and MATLAB Path” on page 4-14 for information on how the location of a class definition on the MATLAB path determines its precedence.

See “Working with Meta-Classes” on page 14-2 for information on meta-class objects.

No Attribute Inheritance

Subclasses do not inherit a superclass `InferiorClasses` attribute. Only instances of the classes specified in the subclass `InferiorClasses` attribute are inferior to subclass objects.

Scoping Classes with Packages

In this section...

“Package Folders” on page 4-19

“Referencing Package Members Within Packages” on page 4-20

“Referencing Package Members from Outside the Package” on page 4-20

“Packages and the MATLAB Path” on page 4-22

Package Folders

Packages are special folders that can contain class folders, function and class definition files, and other packages. Packages define a scope (sometimes called a namespace) for the contents of the package folder. This means function and class names need to be unique only within the package. Using a package provides a means to organize classes and functions and to select names for these components that other packages can reuse.

Note Packages are not supported for classes created prior to MATLAB Version 7.6 (i.e., classes that do not use `classdef`).

Package folders always begin with the + character. For example,

```
+mypack
+mypack/pkfcn.m % a package function
+mypack/@myClass % class folder in a package
```

The top-level package folder’s parent folder must be on the MATLAB path.

Listing the Contents of a Package

List the contents of a package using the `what` command:

```
what event
```

```
Classes in directory Y:xxx\matlab\toolbox\matlab\lang\+event
```

```
EventData      PropertyEvent  listener      proplistener
```

Referencing Package Members Within Packages

All references to packages, functions, and classes in the package must use the package name prefix, unless you import the package. (See “Importing Classes” on page 4-24.) For example, call a package function with this syntax:

```
z = mypack.pkfcn(x,y);
```

Note that definitions do not use the package prefix. For example, the function definition line of the `pkfcn.m` function would include only the function name:

```
function z = pkfcn(x,y)
```

Similarly, a package class would be defined with only the class name:

```
classdef myClass
```

but would be called with the package prefix:

```
obj = mypack.myClass(arg1,arg2,...);
```

Calling class methods does not require the package name because you have an instance of the class:

```
obj.myMethod(arg) or  
myMethod(obj,arg)
```

A static method requires the full class name:

```
mypack.myClass.stMethod(arg)
```

Referencing Package Members from Outside the Package

Because functions, classes, and other packages contained in a package are scoped to that package, to reference any of the package members, you must prefix the package name to the member name, separated by a dot. For example, the following statement creates an instance of `myClass`, which is contained in `mypack` package.

```
obj = mypack.myClass;
```

Accessing Class Members – Various Scenarios

This section shows you how to access various package members from outside a package. Suppose you have a package `mypack` with the following contents:

```
+mypack
+mypack/myfcn.m
+mypack/@myfirstclass
+mypack/@myfirstclass/myfcn.m
+mypack/@myfirstclass/otherfcn.m
+mypack/@myfirstclass/myfirstclass.m
+mypack/@mysecondclass
+mypack/@mysecondclass/mysecondclass.m
+mypack/+mysubpack
+mypack/+mysubpack/myfcn.m
```

Invoke the `myfcn` function in `mypack`:

```
mypack.myfcn(arg)
```

Create an instance of each class in `mypack`:

```
obj1 = mypack.myfirstclass;
obj2 = mypack.mysecondclass(arg);
```

Invoke the `myfcn` function in `mysubpack`:

```
mypack.mysubpack.myfcn(arg1, arg2);
```

If `mypack.myfirstclass` has a method called `myfcn`, it is called as any method call on an object:

```
obj = mypack.myfirstclass;
myfcn(obj, arg);
```

If `mypack.myfirstclass` has a property called `MyProp`, it can be assigned using dot notation and the object:

```
obj = mypack.myfirstclass;
obj.MyProp = some_value;
```

Packages and the MATLAB Path

You cannot add package folders to the MATLAB path, but you must add the package's parent folder to the path. Even if a package folder is the current folder, its parent folder must still be on the MATLAB path or the package members are not accessible.

Package members remain scoped to the package even if the package folder is the current folder. You must, therefore, always refer to the package members using the package name.

Package folders do not shadow other package folders that are positioned later on the path, unlike classes, which do shadow other classes.

Resolving Redundant Names

Suppose a package and a class have the same name. For example:

```
fldr1/+foo
fldr2/@foo/foo.m
```

A call to `which foo` returns the path to the executable class constructor:

```
>> which foo
fldr2/@foo/foo.m
```

A function and a package can have the same name. However, a package name by itself is not an identifier so if a redundant name occurs alone, it identifies the function. Executing a package name alone returns an error.

Package Functions vs. Static Methods

In cases where a package and a class have the same name, a static method takes precedence over a package function. For example:

```
fldr1/+foo/bar.m % bar is a function in package foo
fldr2/@foo/bar.m % bar is a static method of class foo
```

A call to `which foo.bar` returns the path to the static method:

```
>> which foo.bar
fldr2/@foo/bar.m
```

In cases where a path folder contains both package and class folders with the same name, the class static method takes precedence over the package method:

```
fldr1/@foo/bar.m % bar is a static method of class foo  
fldr1/+foo/bar.m % bar is a function in package foo
```

A call to `which foo.bar` returns the path to the static method:

```
>> which foo.bar  
fldr1/@foo/bar.m
```

Importing Classes

In this section...
“Related Information” on page 4-24
“Syntax for Importing Classes” on page 4-24

Related Information

See “Scoping Classes with Packages” on page 4-19 for information about packages.

Syntax for Importing Classes

You can import classes into a function to simplify access to class members. For example, suppose there is a package that contains a number of classes, but you need to use only one of these classes in your function, or perhaps even just a static method from that class. You can use the `import` command as follows:

```
function myFunc
    import pkg.cls1
    obj = cls1(arg,...); % call cls1 constructor
    obj.Prop = cls1.StaticMethod(arg,...); % call cls1 static method
end
```

Note that you do not need to reference the package name (`pkg`) once you have imported the class (`cls1`). You can also import all classes in a package using the syntax `pkg.*`, where `*` indicates all classes in the package. For example,

```
function myFunc
    import pkg.*
    obj1 = cls1(arg,...); % call pkg.cls1 constructor
    obj2 = cls2(arg,...); % call pkg.cls2 constructor
    a = pkgFunction(); % call package function named pkgFunction
end
```

Importing Package Functions

You can use `import` with package functions:

```
function myFunc
    import pkg.pkfcn
    pkfcn(arg,...); % call imported package function
end
```

Package Function and Class Method Name Conflict

Suppose you have the following folder organization:

```
+pkg/timedata.m % package function
+pkg/@myclass/myclass.m % class definition file
+pkg/@myclass/timedata.m % class method
```

Now import the package and call `timedata` on an instance of `myclass`:

```
import pkg.*
myobj = pkg.myclass;
timedata(myobj)
```

A call to `timedata` finds the package function, not the class method because MATLAB applies the `import` and finds `pkg.timedata` first. Do not use a package in cases where you have name conflicts and plan to import the package.

Clearing Import List

You can *not* clear the import list from a function workspace. To clear the *base workspace only*, use:

```
clear import
```


Value or Handle Class — Which to Use

- “Comparing Handle and Value Classes” on page 5-2
- “Which Kind of Class to Use” on page 5-9
- “The Handle Superclass” on page 5-11
- “Finding Handle Objects and Properties” on page 5-19
- “Implementing a Set/Get Interface for Properties” on page 5-21
- “Controlling the Number of Instances” on page 5-25

Comparing Handle and Value Classes

In this section...
“Basic Difference” on page 5-2
“Why Select Handle or Value” on page 5-2
“Behavior of MATLAB Built-In Classes” on page 5-3
“Behavior of User-Defined Classes” on page 5-4

Basic Difference

A *value* class constructor returns an instance that is associated with the variable to which it is assigned. If you reassign this variable, MATLAB creates a copy of the original object. If you pass this variable to a function, the function must return the modified object.

A *handle* class constructor returns a handle object that is a reference to the object created. You can assign the handle object to multiple variables or pass it to functions without causing MATLAB to make a copy of the original object. A function that modifies a handle object passed as an input argument does not need to return the object.

Note All handle classes must subclass the abstract handle class.

compares handle and value object behavior when used as arguments to functions.

Why Select Handle or Value

MATLAB support two kinds of classes — handle classes and value classes. The kind of class you use depends on the desired behavior of the class instances and what features you want to use.

Use a handle class when you want to create a reference to the data contained in an object of the class, and do not want copies of the object to make copies of the object data. For example, use a handle class to implement an object that

contains information for a phone book entry. Multiple application programs can access a particular phone book entry, but there can be only one set of underlying data.

The reference behavior of handles enables these classes to support features like events, listeners, and dynamic properties.

Use value classes to represent entities that do not need to be unique, like numeric values. For example, use a value class to implement a polynomial data type. You can copy a polynomial object and then modify its coefficients to make a different polynomial without affecting the original polynomial.

“Which Kind of Class to Use” on page 5-9 describes how to select the kind of class to use for your application.

Behavior of MATLAB Built-In Classes

If you create an object of the class `int32` and make a copy of this object, the result is two independent objects having no data shared between them. The following code example creates an object of class `int32` and assigns it to variable `a`, and then copies it to `b`. When you raise `a` to the fourth power and assign the value again to the variable `a`, MATLAB creates an object with the new data and assigns it to the variable `a`, overwriting the previous assignment. The value of `b` does not change.

```
a = int32(7);  
b = a;  
a = a^4;  
b  
7
```

MATLAB copies the value of `a` to `b`, which results in two independent versions of the original object. This behavior is typical of MATLAB numeric classes.

Handle Graphics classes return a handle to the object created. A handle is a variable that references an instance of a class. If you copy the handle, you have another variable that refers to the same object. There is still only one version of the object data. For example, if you create a Handle Graphics line object and copy its handle to another variable, you can set the properties of the same line using either copy of the handle.

```
x = 1:10; y = sin(x);
h1 = line(x,y);
h2 = h1;

>>set(h2, 'Color', 'red') % line is red
>>set(h1, 'Color', 'green') % line is green
>>delete(h2)
>>set(h1, 'Color', 'blue')
??? Error using ==> set
Invalid handle object.
```

Note also, if you delete one handle, all copies are now invalid because you have deleted the single object that all copies point to.

Behavior of User-Defined Classes

Value class instances behave like built-in numeric classes and handle class instances behave like Handle Graphics objects, as illustrated in “Behavior of MATLAB Built-In Classes” on page 5-3.

Value Classes

MATLAB associates objects of value classes with the variables to which you assign them. When you copy a value object, MATLAB also copies the data contained by the object. The new object is independent of changes to the original object. Instances behave like standard MATLAB numeric and struct classes. Each property behaves essentially like a MATLAB array. See “Memory Allocation for Arrays” for more information.

Value Class Behavior

Use value classes when assigning an object to a variable and passing an object to a function must make a copy of the function. Value objects are always associated with one workspace or temporary variable and go out of scope when that variable goes out of scope or is cleared. There are no references to value objects, only copies which are themselves objects.

For example, suppose you define a polynomial class whose `Coefficients` property stores the coefficients of the polynomial. Note how copies of these value-class objects are independent of each other:

```
p = polynomial([1 0 -2 -5]);
p2 = p;
p.Coefficients = [2 3 -1 -2 -3];
p2.Coefficients
ans =
    1 0 -2 -5
```

Creating a Value Class

All classes that are not subclasses of the `handle` class are value classes. Therefore, the following `classdef` creates a value class named `myValueClass`:

```
classdef myValueClass
    ...
end
```

Handle Classes

Objects of handle classes use a handle to reference objects of the class. A handle is a variable that identifies an instance of a class. When you copy a handle object, MATLAB copies the handle, but not the data stored in the object properties. The copy refers to the same data as the original handle. If you change a property value on the original object, the copied object reflects the same change.

All handle classes are subclasses of the abstract `handle` class. In addition to providing handle copy semantics, deriving from the `handle` class enables your class to:

- Inherit a number of useful methods (“Handle Class Methods” on page 5-12)
- Define events and listeners (“Defining Events and Listeners — Syntax and Techniques” on page 9-15)
- Define dynamic properties (“Dynamic Properties — Adding Properties to an Instance” on page 6-21)
- Implement Handle Graphics type set and get methods (“Implementing a Set/Get Interface for Properties” on page 5-21)

Creating a Handle Class

Subclass the `handle` class explicitly to create a handle class:

```
classdef myClass < handle
    ...
end
```

See “The Handle Superclass” on page 5-11 for more information on the `handle` class and its methods.

Subclasses of Handle Classes

If you subclass a class that is itself a subclass of the `handle` class, your subclass is also a handle class. You do not need to specify the `handle` superclass explicitly in your class definition. For example, the `employee` class is a subclass of the `handle` class:

```
classdef employee < handle
    ...
end
```

Create a subclass of the `employee` class for engineer employees, which is also a handle class. You do not need to specify `handle` as a superclass in the `classdef`:

```
classdef engineer < employee
    ...
end
```

Handle Class Behavior

A `handle` is an object that references its data indirectly. When constructing a `handle`, the MATLAB runtime creates an object with storage for property values and the constructor function returns a `handle` to this object. When you assign the `handle` to a variable or when you pass the `handle` to a function, MATLAB copies the `handle`, but not the underlying data.

For example, suppose you have defined a `handle` class that stores data about company employees, such as the department in which they work:

```
classdef employee < handle
```

```

properties
    Name = ''
    Department = '';
end
methods
    function e = employee(name,dept)
        e.Name = name;
        e.Department = dept;
    end % employee
    function transfer(obj,newDepartment)
        obj.Department = newDepartment;
    end % transfer
end
end

```

The transfer method in the previous code changes the employee's department (the Department property of an employee object). In the following statements, e2 is a copy of the handle object e. Notice that when you change the Department property of object e, the property value also changes in object e2.

```

e = employee('Fred Smith','QE');
e2 = e; % Copy handle object
transfer(e,'Engineering')
e2.Department
ans =
    Engineering

```

The variable e2 is an alias for e and refers to the same property data storage as e.

Initializing Properties to Handle Objects

See “How to Initialize Property Values” on page 3-8 for information on the differences between initializing properties to default values in the properties block and initializing properties from within the constructor. Also, see “Arrays of Handle Objects” on page 8-7 for related information on working with handle classes.

employee as a Value Class

If the `employee` class was a value class, then the `transfer` method would modify only its local copy of the `employee` object. In value classes, methods like `transfer` that modify the object must return a modified object to copy over the existing object variable:

```
function obj = transfer(obj,newDepartment)
    obj.Department = newDepartment;
end
```

When you call `transfer`, assign the output argument to create the modified object.

```
e = transfer(e, 'Engineering');
```

In a value class, the `transfer` method does not affect the variable `e2`, which is a different `employee` object. In this example, having two independent copies of objects representing the same employee is not a good design. Hence, implement the `employee` class as a handle class.

Deleting Handles

You can destroy handle objects before they become unreachable by explicitly calling the `delete` function. Deleting the handle of a handle class object makes all handles invalid. For example:

```
delete(e2)
e.Department
??? Invalid or deleted object.
```

Calling the `delete` function on a handle object invokes the destructor function or functions for that object. See “Handle Class Delete Methods” on page 5-15 for more information.

Which Kind of Class to Use

In this section...
“Examples of Value and Handle Classes” on page 5-9
“When to Use Handle Classes” on page 5-9
“When to Use Value Classes” on page 5-10

Examples of Value and Handle Classes

Handle and value classes are useful in different situations. For example, value classes enable you to create new array classes that have the same semantics as MATLAB numeric classes.

“Example — A Polynomial Class” on page 16-2 and “Example — Representing Structured Data” on page 2-22 provides examples of value classes.

Handle classes enable you to create objects that more than one function or object can share. Handle objects allow more complex interactions among objects because they allow objects to reference each other.

“Example — Implementing Linked Lists” on page 2-31 and “Developing Classes — Typical Workflow” on page 2-11 provides examples of a handle class.

When to Use Handle Classes

Use a handle class when:

- No two instances of a class can have the same state, making it impossible to have exact copies. For example:
 - A copy of a graphics object (such as a line) has a different position in its parents list of children than the object from which it was copied. Therefore, the two objects are not identical.
 - Nodes in lists or trees having specific connectivity to other nodes—no two nodes can have the same connectivity.

- The class represents physical and unique objects like serial ports or printers, in which the entity or state cannot exist in a MATLAB variable. However, a handle to such entity can be a variable.
- The class defines events and notifies listeners when an event occurs (`notify` is a handle class method).
- The class creates listeners by calling the handle class `addlistener` method.
- The class subclasses the `dynamicprops` class (a subclass of `handle`) so that instances can define dynamic properties.
- The class subclasses the `hgsetget` class (a subclass of `handle`) so that it can implement a Handle Graphics™ style `set/get` interface.
- You want to create a singleton class or a class in which you track the number of instances from within the constructor. MATLAB software never creates a unique handle without calling the class constructor. A copy of a handle object is not unique because both original and copy reference the same data.

When to Use Value Classes

Value class instances behave like normal MATLAB variables. A typical use of value classes is to define data structures. For example, suppose you want to define a class to represent polynomials. This class can define a property to contain a list of coefficients for the polynomial. It can implement methods that enable you to perform various common operations on the polynomial object. For example, implement addition and multiplication without converting the object to another class.

A value class is suitable because you can copy a polynomial object and have two objects that are identical representations of the same polynomial. See “Subclassing MATLAB Built-In Classes” on page 10-19 for more information on value classes.

The Handle Superclass

In this section...

“Building on the Handle Class” on page 5-11

“Handle Class Methods” on page 5-12

“Relational Methods” on page 5-12

“Testing Handle Validity” on page 5-13

“Handle Class Delete Methods” on page 5-15

Building on the Handle Class

The `handle` class is an abstract class, which means you cannot create an instance of this class directly. Instead, you use this class as a superclass when you implement your own class. The `handle` class is the foundation of all classes that are themselves handle classes. When you define a class that is a subclass of `handle`, you have created a handle class. Therefore, all classes that follow handle semantics are subclasses of the `handle` class.

Handle Subclasses

There are two subclasses of the `handle` class that provide additional features when you derive your class from these subclasses:

- `hgsetget` — Provides `set` and `get` methods that enable you to implement a Handle Graphics™ style interface. See “Implementing a Set/Get Interface for Properties” on page 5-21 for information on subclassing `hgsetget`.
- `dynamicprops` — Provides the ability to define instance properties. See “Dynamic Properties — Adding Properties to an Instance” on page 6-21 for information on subclassing `dynamicprops`.

Deriving from subclasses of the `handle` class means that your class is a handle class. It inherits all the `handle` class methods, plus the special features provided by these subclasses.

Handle Class Methods

While the `handle` class defines no properties, it does define the methods discussed in this section. Whenever you create a `handle` class (that is, subclass the `handle` class), your subclass inherits these methods.

You can list the methods of a class by passing the class name to the `methods` function:

```
>> methods('handle')

Methods for class handle:

addlistener  findobj      gt          lt
delete      findprop    isvalid    ne
eq          ge          le          notify

Static Methods:

empty
```

“Defining Events and Listeners — Syntax and Techniques” on page 9-15 provides information on how to use the `notify` and `addlistener` methods, which are related to the use of events.

“Creating Subclasses — Syntax and Techniques” on page 10-7 provides general information on defining subclasses.

Relational Methods

```
function TF = eq(H1,H2)
function TF = ne(H1,H2)
function TF = lt(H1,H2)
function TF = le(H1,H2)
function TF = gt(H1,H2)
function TF = ge(H1,H2)
```

The `handle` class overloads these functions with implementations that allow for equality tests and sorting on handles. For each pair of input arrays, these functions return a logical array of the same size. Each element is an

element-wise equality or comparison test result. The input arrays must be the same size or one (or both) can be scalar. The method performs scalar expansion as required.

Testing Handle Validity

Use the `isvalid` handle class method to determine if you have a valid handle object. For example, in this statement:

```
B = isvalid(H)
```

B is a logical array in which each element is `true` if, and only if, the corresponding element of H is a valid handle. B is always the same size as H.

Handle Class or Graphics Object Handle

Use the `isa` function to determine if a handle is of class `handle`, or is a Sun Java or Handle Graphics handle. For example, consider the `button` class, which derives from the `handle` class:

```
classdef button < handle
    properties
        UiHandle
    end
    methods
        function obj = button(pos)
            if nargin > 0
                if length(pos) == 4
                    obj.UiHandle = uicontrol('Position',pos,'Style','pushbutton');
                else
                    error('Improper position')
                end
            end
        end
    end
end
```

Create a `button` object by passing a position vector to the `button` constructor:

```
h = button([50 20 50 20]);
```

Determine the difference between the graphics object handle (stored in the `UiHandle` property) and the handle class object, `h`. Use `ishandle` to test the validity of Handle Graphics object handles:

```
% h is a handle object
>> isa(h, 'handle')
ans =
     1

% The uicontrol object handle is not a handle object
>> isa(h.UiHandle, 'handle')
ans =
     0

% The button object is not a graphics object
>> ishandle(h)
ans =
     0

% The uicontrol is a graphics object handle
>> ishandle(h.UiHandle)
ans =
     1
```

If you close the figure, the `ishandle` function determines that the Handle Graphics handle is not valid:

```
>> close
>> ishandle(h.UiHandle)

ans =

     0
```

`h` is still of class `handle` and is still a valid handle object:

```
>> isa(h, 'handle')

ans =

     1
```

```
>> isvalid(h)
```

```
ans =
```

```
1
```

h is also of class `button`:

```
>> isa(h, 'button')
```

```
ans =
```

```
1
```

Handle Class Delete Methods

If you implement a `delete` method (the class destructor) for your handle class, MATLAB calls this delete method when destroying the object. MATLAB destroys objects in the workspace of a function when the function:

- Reassigns an object variable to a new value
- Does not use an object variable for the remainder of a function
- The function ends

When MATLAB destroys an object, it also destroys values stored in the properties of the object and returns any computer memory associated with the object to MATLAB or the operating system.

You do not need to free memory in handle classes. However, there can be other operations that you want to perform when destroying an object. For example, closing a file or shutting down an external program that the object constructor started.

Once deleted, any handles to that object in any workspace become invalid. Attempting to access the content of a deleted object produces an error. Variables previously referencing the deleted value become unassigned and inaccessible.

When to Define a Delete Method for Your Class

Perform any necessary cleanup operations in a special optional method having the name `delete` (sometimes called a destructor method). The `delete` method signature is,

```
function delete(h)
```

where `h` is a scalar handle.

For example, close a file that you have opened for writing in your object's `delete` method. This function calls `fclose` on a file identifier that the object's `FileID` property stores:

```
function delete(obj)
    fclose(obj.FileID);
end
```

“Using Objects to Write Data to a File” on page 2-18 presents an example that uses this `delete` method.

Object Lifecycle

The MATLAB runtime invokes the `delete` method only when the lifecycle of an object ends. The lifecycle of an object ends when the object is:

- No longer referenced anywhere
- Explicitly deleted by calling `delete` on the handle

Inside a Function. The lifecycle of an object referenced by a local variable or input argument exists from the time the variable is assigned until the time it is reassigned, cleared, or no longer referenced within that function or any handle array.

A variable goes out of scope when you explicitly cleared it or when its function ends. When a variable goes out of scope, if its value belongs to a class that defines a `delete` method, MATLAB calls that method. MATLAB defines no ordering among variables in a function. Do not assume that MATLAB destroys one value before another value when the same function contains both values.

Sequence During Handle Object Destruction

MATLAB invokes the `delete` methods in the following sequence when destroying an object:

- 1 The `delete` method for the class of the object
- 2 The `delete` method of each base class, starting with the immediate base classes and working up the hierarchy to the most general base classes

MATLAB invokes the `delete` methods of superclasses at the same level in the hierarchy as the order specified in the class definition. For example, the following class definition specifies `supclass1` before `supclass2` so MATLAB calls the `delete` function of `supclass1` before the `delete` function of `supclass2`.

```
classdef myClass < supclass1 & supclass2
```

Superclass `delete` methods cannot call methods or access properties belonging to a subclass.

After calling each `delete` method, MATLAB destroys the property values belonging exclusively to the class whose method was called. The destruction of property values that contain other handle objects causes MATLAB to call the `delete` methods for those objects.

Restricting Object Deletion

A class can prevent explicit destruction of objects by setting its `delete` method `Access` attribute to `private`. MATLAB issues an error if you call `delete` on a handle object whose `delete` method is `private`, unless one of its own class methods calls `delete`.

Similarly, if the class `delete` method `Access` attribute has a value of `protected`, only methods of the class and any subclasses can explicitly delete objects of that class.

Deleting Subclass Objects

Declaring a `private` `delete` method does not prevent MATLAB from explicitly destroying subclass objects. A subclass has its own `delete` method, which can be `public`, either declared explicitly or provided implicitly by MATLAB. When MATLAB destroys an object, it checks the `Access` attribute

of the `delete` method of only the direct class of the object. Therefore, a `private delete` method of a superclass does not prevent the destruction of an object of a subclass.

This behavior differs from the normal behavior of an overridden method. MATLAB executes each `delete` method of each base class of an object upon destruction, even if that `delete` method is not `public`.

Declaring a `private delete` method probably makes sense only for sealed classes (`Sealed` attribute set to `true`). If you design a class that you will subclass, declaring its `delete` method to be `protected` prevents objects of all subclasses from destruction by a call to `delete` from outside the class.

Even when you declare a `delete` method to be `protected`, MATLAB calls the `delete` method of each superclass when destroying the object.

Finding Handle Objects and Properties

In this section...

“Finding Handle Objects” on page 5-19

“Finding Handle Object Properties” on page 5-19

Finding Handle Objects

The `findobj` method enables you to locate handle objects that meet certain conditions.

```
function HM = findobj(H,<conditions>)
```

The `findobj` method returns an array of handles matching the conditions specified.

Finding Handle Object Properties

The `findprop` method returns the `meta.property` object for the specified object and property.

```
function mp = findprop(h, 'PropertyName')
```

The `findprop` method returns the `meta.property` object associated with the `PropertyName` property defined by the class of `h`. The property can also be a dynamic property created by the `addprop` method of the `dynamicprops` class.

You can use the returned `meta.property` object to obtain information about the property, such as querying the settings of any of its attributes. For example, the following statements determine that the setting of the `AccountStatus` property's `Dependent` attribute is `false`.

```
ba = BankAccount(007,50,'open');  
mp = findprop(ba,'AccountStatus'); % get meta.property object  
mp.Dependent  
ans =  
    0
```

“Working with Meta-Classes” on page 14-2 provides more information on meta-classes.

Implementing a Set/Get Interface for Properties

In this section...

“The Standard Set/Get Interface” on page 5-21

“Property Get Method” on page 5-21

“Property Set Method” on page 5-22

“Subclassing hgsetget” on page 5-22

The Standard Set/Get Interface

The MATLAB Handle Graphics system implements an interface based on `set` and `get` methods. These methods enable you to set or query the value of graphics object properties. The `hgsetget` subclass of the `handle` class provides implementations of these methods that your class can inherit to provide the same set and get functionality.

Note The `set` and `get` methods referred to in this section are different from the property set access and property get access methods. See “Property Set and Get Access Methods” on page 6-12 for information on property access methods.

Property Get Method

The `get` method returns property values from a handle array.

```
function SV = get(H)
function CV = get(H,prop)
```

- If you do not specify property names, `get` returns a struct array in which each element corresponds to the element in `H`. Each field in the struct corresponds to a property defined by the class of `H`. The value of each field is the value of the corresponding property.
- If you specify `prop` as a char array, then MATLAB interprets it as a property name. `get` returns the value of that property if `H` is scalar, or returns a cell array of property values if `H` is an array of handles. The cell array is always a column vector regardless of the shape of `H`. If `prop` is a

cell array of string property values, then `get` returns a cell array of values where each row in the cell corresponds to an element in `H` and each column in the cell corresponds to an element in `prop`.

Property Set Method

The `set` method assigns values to properties for handles in array `H`.

```
function S = set(H)
function info = set(H, prop)
function set(H, 'PropertyName', PropertyValue)
```

If you do not specify property values, `set` returns a cell array of possible values for each requested property when the property value is a finite enumeration of possible values.

- If you specify only `H`, `set` returns a `struct` with one field for each property in the class of `H`. Each field contains either an empty cell array or a cell array of possible property values (if such a finite set exists).
- If you specify `prop` as a string containing a property name, then `set` returns either a cell array of possible values or an empty cell.
- If you specify `prop` as a cell array of property names, then `set` returns a cell column vector. Each cell corresponds to a property in `prop` and each cell value is a cell array of possible values, or empty if there is no finite enumeration of possible values.

You can also pass property-value pairs to `set` using cell arrays and structures as described for the built-in `set` function.

Subclassing `hgsetget`

This example creates a class with the `set/get` interface and illustrates the behavior of the inherited methods:

```
classdef MyAccount < hgsetget % subclass hgsetget
    properties
        AccountNumber
        AccountBalance = 0;
        AccountStatus
    end % properties
```

```

methods
function obj = MyAccount(actnum,intamount,status)
    obj.AccountNumber = actnum;
    obj.AccountBalance = intamount;
    obj.AccountStatus = status;
end % MyAccount
function obj = set.AccountStatus(obj,val)
    if ~(strcmpi(val,'open') ||...
        strcmpi(val,'deficit') ||...
        strcmpi(val,'frozen'))
        error('Invalid value for AccountStatus ')
    end
    obj.AccountStatus = val;
end % set.AccountStatus
end % methods
end % classdef

```

Create an instance of the class and save its handle:

```
h = MyAccount(1234567,500,'open');
```

You can query the value of any object property using the inherited get method:

```
get(h,'AccountBalance')
ans =

    500
```

You can set the value of any property using the inherited set method:

```
set(h,'AccountStatus','frozen')
```

MATLAB calls the property set function (set.AccountStatus) when you use the set method:

```
set(h,'AccountStatus','closed')
??? Error using ==> MyAccount.MyAccount>MyAccount.set.AccountStatus at 19
Invalid value for AccountStatus
```

Listing All Properties

The standard `set/get` interface enables you to display all object properties and their current values using `get` with no output argument and only a handle as input. For example,

```
get(h)
  AccountNumber: 1234567
  AccountBalance: 500
  AccountStatus: 'open'
```

Similarly, you can list the settable properties of the object using `set`:

```
set(h)
  AccountNumber: {}
  AccountBalance: {}
  AccountStatus: {}
```

Customizing the Property List

You can customize the way property lists are displayed by redefining the following methods in your subclass:

- `setdisp` — Called by `set` when you call `set` with no output arguments and a single input parameter containing the handle array.
- `getdisp` — Called by `get` when you call `get` with no output arguments and a single input parameter containing the handle array.

Controlling the Number of Instances

Limiting Instances

You can limit the number of instances of a class that can exist at any one time. For example, a *singleton* class can have only one instance and provides a way to access this instance. You can create a singleton class using these elements:

- A persistent variable to contain the instance
- A sealed class (Sealed attribute set to true) to prevent subclassing
- A private constructor (Access attribute set to private)
- A static method to return the handle to the instance, if it exists, or to create the instance when needed.

Implementing a Singleton Class

The following skeletal class definition shows how you can approach the implementation of a class that allows you to create only one instance at a time:

```
classdef (Sealed) SingleInstance < handle
    methods (Access = private)
        function obj = SingleInstance
            end
        end
    methods (Static)
        function singleObj = getInstance
            persistent localObj
            if isempty(localObj) || ~isvalid(localObj)
                localObj = SingleInstance;
            end
            singleObj = localObj;
        end
    end
end
```

The `getInstance` static method returns a handle to the object created, which the class stores in a persistent variable. `getInstance` creates an instance only the first time called in a session or when the object becomes invalid. For example:

```
sobj = SingleInstance.getInstance
sobj =
  SingleInstance handle with no properties.
  Methods, Events, Superclasses
```

As long as `sobj` exists as a valid handle, calling `getInstance` returns a handle to the same object. If you delete `sobj`, then calling `getInstance` creates an object and returns the handle.

```
delete(sobj)
invalid(sobj)
ans =

    0
sobj = SingleInstance.getInstance;
invalid(sobj)
ans =

    1
```

Properties — Storing Class Data

- “How to Use Properties” on page 6-2
- “Defining Properties” on page 6-5
- “Property Attributes” on page 6-8
- “Property Set and Get Access Methods” on page 6-12
- “Dynamic Properties — Adding Properties to an Instance” on page 6-21

How to Use Properties

In this section...
“What Are Properties” on page 6-2
“Types of Properties” on page 6-3

What Are Properties

Properties encapsulate the data that belongs to instances of classes. Data contained in properties can be public, protected, or private. This data can be a fixed set of constant values, or it can be dependent on other values and calculated only when queried. You control these aspects of property behaviors by setting property attributes and by defining property-specific access methods.

See “Property Attributes” on page 6-8 for a summary of property attributes.

Flexibility of Object Properties

In some ways, properties are like fields of a `struct` object. However, storing data in an object property provides more flexibility. Properties can:

- Define a constant value that you cannot change outside the class definition. See
- Calculate its value based on the current value of other data. See “Property Get Methods” on page 6-16
- Execute a function to determine if an attempt to assign a value meets a certain criteria. See “Property Set Methods” on page 6-14
- Trigger an event notification when any attempt is made to get or set its value. See “Property-Set and Query Events” on page 9-12
- Restrict access by other code to the property value. See the `SetAccess` and `GetAccess` attributes “Property Attributes” on page 6-8
- Control whether its value is saved with the object in a MAT-file. See “The Default Save and Load Process” on page 11-2

Types of Properties

There are two types of properties:

- Stored properties — Use memory and are part of the object
- Dependent properties — No allocated memory and the get access method calculates the value when queried

Features of Stored Properties

- Can assign an initial value in the class definition
- Property value is stored when you save the object to a MAT-file
- Can use a set access method to control possible values, but you are not required to use such methods.

When to Use Stored Properties

- You want to be able to save the property value in a MAT-file
- The property value is not dependent on other property values

Features of Dependent Properties

Dependent properties save memory because property values that depend on other values are calculated only when needed.

When to Use Dependent Properties

Define properties as dependent when you want to:

- Compute the value of a property from other values (for example, you can compute area from `Width` and `Height` properties).
- Provide a value in different formats depending on other values. For example, the size of a push button in values determined by the current setting of its `Units` property.
- Provide a standard interface where a particular property is or is not used, depending on other values. For example, different computer platforms can have different components on a toolbar).

“Property Set and Get Access Methods” on page 6-12 provides information on defining property access methods.

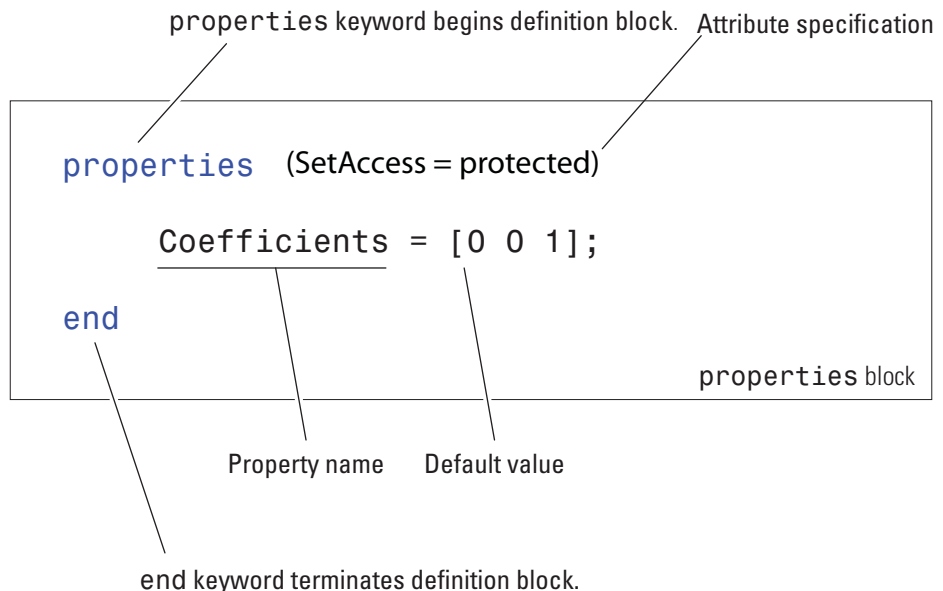
Defining Properties

In this section...

“Property Definition Block” on page 6-5
 “Accessing Property Values” on page 6-6
 “Inheritance of Properties” on page 6-6
 “Specifying Property Attributes” on page 6-7

Property Definition Block

The following illustration shows a typical property specification. The `properties` and `end` keywords delineate a block of code that defines properties having the same attribute settings.



Assigning a Default Value

The preceding example shows the `Coefficients` property specified as having a default value of `[0 0 1]`.

You can initialize property values with MATLAB expressions. However, these expressions cannot refer to the class that you are defining in any way, except to call class static methods. MATLAB executes expressions that create initial property values only when initializing the class, which occurs just before first using the class. See “Defining Default Values” on page 3-9 for more information about how MATLAB evaluates default value expressions.

Accessing Property Values

Property access syntax is like MATLAB structure field syntax. For example, assume there is a polynomial class called `polyno` that defines a `Coefficients` property. If you created a `polyno` object `p`:

```
p = polyno([1 0 -2 -3]); % Create an instance p (this  
code does not execute)
```

you can access this property as follows:

```
c = p.Coefficients; % Assign the current property value to c  
p.Coefficients = [4 0 -2 3 5]; % Assign new property values
```

When you access a property, MATLAB performs any operations that the property requires. For example, executing a property set or get access method and triggering property access events.

See “Implementing a Set/Get Interface for Properties” on page 5-21 for information on how to define set and get methods for properties.

Inheritance of Properties

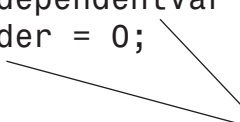
When you derive one class from another class, the derived (subclass) class inherits all the properties of the superclass. In general, subclasses define only properties that are unique to that particular class. Superclasses define properties that more than one subclass use.

Specifying Property Attributes

Attributes specified with the `properties` key word apply to all property definitions that follow in that block. If you want to apply attribute settings to certain properties only, reuse the `properties` keyword and create another property block for those properties.

For example, the following code shows the `SetAccess` attribute set to `private` for the `IndependentVar` and `Order` properties, but not for the `Coefficients` property:

```
properties
  Coefficients = [0 0 1];
end
properties (SetAccess = private)
  IndependentVar
  Order = 0;
end
```



These properties (and any others placed in this block) have private set access

Property Attributes

Table of Property Attributes

All properties support the attributes listed in the following table. Attributes enable you to modify the behavior of properties. Attribute values apply to all properties defined within the `properties` block that specifies the nondefault values.

Attribute Name	Class	Description
AbortSet	logical default = false	If true, and this property belongs to a handle class, then MATLAB does not set the property value if the new value is the same as the current value. This approach prevents the triggering of property <code>PreSet</code> and <code>PostSet</code> events.
Abstract	logical default = false	<p>If true, the property has no implementation, but a concrete subclass must redefine this property without <code>Abstract</code> being set to true.</p> <ul style="list-style-type: none"> • Abstract properties cannot define set or get access methods. See “Property Set and Get Access Methods” on page 6-12. • Abstract properties cannot define initial values. See “Assigning a Default Value” on page 6-6. • All subclasses must specify the same values as the superclass for the property <code>SetAccess</code> and <code>GetAccess</code> attributes. • <code>Abstract=true</code> use with the class attribute <code>Sealed=false</code> (the default).

(Continued)

Attribute Name	Class	Description
Access	char default = public	<p>public – unrestricted access</p> <p>protected – access from class or derived classes</p> <p>private – access by class members only</p> <p>Use <code>Access</code> to set both <code>SetAccess</code> and <code>GetAccess</code> to the same value. Query the values of <code>SetAccess</code> and <code>GetAccess</code> directly (not <code>Access</code>).</p>
Constant	logical default = false	<p>Set to true if you want only one value for this property in all instances of the class:</p> <ul style="list-style-type: none"> • Subclasses inherit constant properties, but cannot change them. • Constant properties cannot be Dependent. • <code>SetAccess</code> is ignored. <p>See for more information.</p>
Dependent	logical default = false	<p>If false, property value stored in object. If true, property value is not stored in object. The set and get functions cannot access the property by indexing into the object using the property name.</p> <p>MATLAB does not display in the command window the names and values of Dependent properties that do not define a get method (scalar object display only).</p> <p>See “Dependent Properties” on page 2-27, “Property Get Methods” on page</p>

(Continued)

Attribute Name	Class	Description
GetAccess	enumeration default = public	6-16, “Avoiding Property Initialization Order Dependency” on page 11-23 public — unrestricted access protected — access from class or derived classes private — access by class members only MATLAB does not display in the command window the names and values of properties having protected or private GetAccess or properties whose Hidden attribute is true.
GetObservable	logical default = false	If true, and it is a handle class property, then you can create listeners for access to this property. The listeners are called whenever property values are queried. See “Property-Set and Query Events” on page 9-12
Hidden	logical default = false	Determines whether the property should be shown in a property list (e.g., Property Inspector, call to set or get, etc.). MATLAB does not display in the command window the names and values of properties whose Hidden attribute is true or properties having protected or private GetAccess.
SetAccess	enumeration default = public	public — unrestricted access protected — access from class or derived classes private — access by class members only immutable — property can be set only in the constructor.

(Continued)

Attribute Name	Class	Description
SetObservable	logical default = false	If true, and it is a handle class property, then you can create listeners for access to this property. The listeners are called whenever property values are modified. See “Property-Set and Query Events” on page 9-12
Transient	logical default = false	If true, property value is not saved when object is saved to a file. See “The Save and Load Process” on page 11-2 for more about saving objects.

Property Set and Get Access Methods

In this section...
“Property Access Methods” on page 6-12
“Property Set Methods” on page 6-14
“Property Get Methods” on page 6-16
“Set and Get Method Execution and Property Events” on page 6-18
“Access Methods and Subscripted Reference and Assignment” on page 6-19
“Performing Additional Steps with Property Access Methods” on page 6-20

Property Access Methods

Property access methods execute specific code whenever the associated property’s value is referenced or assigned a new value. These methods enable you to perform a variety of operations:

- Execute code before assigning property values to perform actions such as:
 - Impose value range restrictions (“Restricting Properties to Specific Values” on page 2-25)
 - Check for proper types and dimensions
 - Provide error handling
- Execute code before returning the current values of properties to perform actions such as:
 - Calculate the value of properties that do not store values (for an example, see “Dependent Properties — Values Not Stored” on page 6-16)
 - Change the value of other properties
 - Trigger events (for an example, see “Defining and Triggering an Event” on page 9-4)

Property access methods execute automatically whenever you query or set the corresponding property values.

Restrictions on Access Methods

You can define property access methods only:

- For concrete properties (that is, properties that are not abstract)
- Within the class that defines the property (unless the property is abstract in that class, in which case the concrete subclass must define the access method).

MATLAB has no default set or get property access methods. Therefore, if you do not define property access methods, MATLAB software does not invoke any methods before assigning or returning property values.

Once defined, only the set and get methods can set and query the actual property values. See “Set Method Behavior” on page 6-15 for information on cases where MATLAB does not call property set methods.

Note Property set and get access methods are not equivalent to user-callable set and get methods used to access property values from an instance of the class. See “Implementing a Set/Get Interface for Properties” on page 5-21 for information on user-callable set and get methods.

Access Methods Cannot Call Other Functions to Access Property Values

You can set and get property values only from within your property set or get access method. You cannot call another function from the set or get method and attempt to access the property value from that function.

For example, an anonymous function that calls another function to do the actual work cannot access the property value. Similarly, an ordinary access function cannot call another function to access the property value.

Defining Access Methods

Access methods have special names that include the property’s name. Therefore, `get.PropertyName` executes whenever `PropertyName` is referenced and `set.PropertyName` executes whenever `PropertyName` is assigned a new value.

Define property access methods in a methods block that specifies no attributes. You cannot call these methods, MATLAB calls them when any code accesses the properties. Therefore, property access methods do not appear in the list of class methods returned by the `methods` command and are not included in the `meta.class` object's `Methods` property. However, the `meta.property` object's `SetMethod` property contains a function handle to the property's set method and the `GetMethod` property contains a function handle to the property's get method.

For example, if the class `myClass` defines a set function for its `Text` property, you can obtain a function handle to this method from the `meta.class` object:

```
m = ?myClass;
m.Properties{1}.SetMethod % Assuming Text is the first property in the cell array
ans =
    @\mydir\@myClass\myClass.m>myClass.set.Text % This is a function handle
```

The `meta.class` object (`m`) contains `meta.property` objects corresponding to each class property in its `Properties` property. This example assumes that the `Text` property corresponds to the first `meta.property` object in the cell array of `meta.property` objects. The order of the class properties in the `meta.class` `Properties` property is the same as the order in which the class definition defines the properties.

“Working with Meta-Classes” on page 14-2 provides more information on using meta-classes.

“Function Handles” discusses the use of function handles.

Property Set Methods

Property set methods have the following syntax, where *PropertyName* is the name of the property.

```
methods % No method attributes
function obj = set.PropertyName(obj,value) % Value class
end
```

Here `obj` is the object whose property is being assigned a value and `value` is the new value that is assigned to the property.

Value class set functions must return the object with the new value for the property assigned. Value classes replace the object whose property is being assigned with the object returned by the set method. Handle classes do not need to return the modified object.

```
methods % No method attributes
function set.PropertyName(obj,value) % Handle class
end
```

The property set method can perform actions like error checking on the input value before taking whatever action is necessary to store the new property value.

```
function obj = set.PropertyName(obj,value)
    if ~(value > 0)
        error('Property value must be positive')
    else
        obj.PropertyName = value;
    end
end
```

See “Restricting Properties to Specific Values” on page 2-25 for an example of a property set method.

Set Method Behavior

MATLAB software calls a property set method whenever a property value is assigned, if a set method for that property exists. However, property set methods are NOT called in the following cases:

- Assigning a value to a property from within its own property set method, to prevent recursive calling of the set method
- Assigning a property to its default initial value
- Initial values specified in class definitions do not invoke the set method
- Copying a value object (that is, not a handle object). Neither the set or get method is called when copying property values from one object to another.

It is possible for a set method from one property to assign values to other properties of the object. However, assignments made from property set methods cause the execution of any set methods defined for those properties.

When assigning a property value, the calling function's copy of the object that has been passed to the set method reflects the changed value.

Therefore, an assignment to even a single property is able to affect the whole object. This behavior enables a set method to change other properties in the object as well as its designated property. For example, a graphics window object can have a `Units` property and a `Size` property. Changing the `Units` property can also require a change to the values of the `Size` property to reflect the new units.

Property Get Methods

MATLAB calls a property's get method whenever the property value is queried. For example, passing a property value in the following statement causes the method `get.XYData` to execute, if it exists.

```
plot(obj.XYData)
```

Property get methods have the following syntax, where *PropertyName* is the name of the property. The function must return the property value.

```
methods % No method attributes
function value = get.PropertyName(obj)
end
```

Dependent Properties — Values Not Stored

One application of a property get method is to determine the value of a property only when it you need it, and avoid storing the value. To use this approach, set the property's `Dependent` attribute to `true`:

```
properties (Dependent = true)
    PropertyName
end
```

Now the get method for the *PropertyName* property determines the value of that property and assigns it to the object from within the method:

```

function value = get.PropertyName(obj)
    value = calculateValue;
    ...
end

```

The `get` method calls a function or static method `calculateValue` to calculate the property value and returns `value` to the code accessing the property. The property get method can take whatever action is necessary within the method to produce the output value.

“Dependent Properties” on page 2-27 provide an example of a property get method.

When to Use Set Methods with Dependent Properties

While a dependent property does not store its value, there are situations in which you might want to define a set method for a dependent property.

For example, suppose you have a class that changes the name of a property from `OldPropName` to `NewPropName`. You want to continue to allow the use of the old name without exposing it to new users. You can make `OldPropName` a dependent property with set and get methods as show in the following example:

```

properties
    NewPropName
end
properties (Dependent, Hidden)
    OldPropName
end
methods
    function obj = set.OldPropName(obj, val)
        obj.NewPropName = val;
    end
    function value = get.OldPropName(obj)
        value = obj.NewPropName;
    endend

```

There is no memory wasted by storing both old and new property values, and code that accesses `OldPropName` continues to work as expected.

When to Use Private Set Access with Dependent Properties

If you use a dependent property only to return a value, then do not define a set access method for the dependent property. Instead, set the `SetAccess` attribute of the dependent property to `private`. For example, consider the following get method for the `MaxValue` property:

```
methods
    function mval = get.MaxValue(obj)
        mval = max(obj.BigArray(:));
    end
end
```

This example uses the `MaxValue` property to return a value that it calculates only when queried. For this application, define the `MaxValue` property as dependent and private:

```
properties (Dependent, SetAccess = private)
    MaxValue
end
```

Set and Get Method Execution and Property Events

MATLAB software generates events before and after set and get operations. You can use these events to inform listeners that property values have been referenced or assigned. The timing of event generation is as follows:

- `PreGet` — Triggered before calling the property get method
- `PostGet` — Triggered after the property get method has returned its value

If a class computes a property value (`Dependent = true`), then the behaviors of its set events are like the get events:

- `PreSet` — Triggered before calling the property set method
- `PostSet` — Triggered after calling the property set method

If a property is not computed (`Dependent = false`, the default), then the assignment statement with the set method generates the events:

- `PreSet` — Triggered before assigning the new property value within the set method

- `PostSet` — Triggered after assigning the new property value within the `set` method

“Events and Listeners — Concepts” on page 9-9 provides general information about events and listeners.

“Creating Property Listeners” on page 9-23 provides information about using property events.

“Implementing the `PostSet` Property Event and Listener” on page 9-43 shows an example of a property listener.

“Responding to a Button Click” on page 9-6 is another example that uses property events.

Access Methods and Subscripted Reference and Assignment

You can use subscripting as a way to reference or assign property values (that is, `a = obj.prop(6)` or `obj.prop(6) = a`) without interfering with property set and get methods. When using subscripted reference, the `get` method returns the whole property value and MATLAB accesses the value referenced by subscripting that object.

For subscripted assignment, MATLAB:

- Invokes the `get` method to get the property value
- Performs the subscripted assignment into the returned property
- Passes the new property value to the `set` method

MATLAB always passes scalar objects to set and get methods. When reference or assignment occurs on an object array, the set and get methods are called in a loop.

Performing Additional Steps with Property Access Methods

Property access methods are useful in cases where you want to perform some additional steps before assigning or returning a property value. For example, the `Testpoint` class uses a property set method to check the range of a value. It then applies scaling if it is within a particular range, and set it to NaN if it is not.

The property get methods applies a scale factor before returning its current value:

```
classdef Testpoint
    properties (Dependent)
        expectedResult = [];
    end
    properties(Constant)
        scalingFactor = 0.001;
    end
    methods
        function obj = set.expectedResult(obj,erIn)
            if erIn >= 0 && erIn <= 100
                erIn = erIn.*obj.scalingFactor
                obj.expectedResult = erIn;
            else
                obj.expectedResult = NaN;
            end
        end
        function er = get.expectedResult(obj)
            er = obj.expectedResult/obj.scalingFactor;
        end
    end
end
```

Dynamic Properties — Adding Properties to an Instance

In this section...

“What Are Dynamic Properties” on page 6-21

“Defining Dynamic Properties” on page 6-22

“Responding to Dynamic-Property Events” on page 6-23

“Defining Property Access Methods for Dynamic Properties” on page 6-25

“Dynamic Properties and ConstructOnLoad” on page 6-27

What Are Dynamic Properties

You can attach properties to objects without defining these properties in the class definition. These dynamic properties are sometimes referred to as instance properties. Use dynamic properties to attach temporary data to objects or assign data that you want to associate with a particular instance of a class, but not all objects of that class.

It is possible for more than one program to define dynamic properties on the same object so you must take care to avoid name conflicts.

Characteristics of Dynamic Properties

Once defined, dynamic properties behave much like class-defined properties:

- Set and query the values of dynamic properties using dot notation (see “Assigning Data to the Dynamic Property” on page 6-22)
- MATLAB saves and loads dynamic properties when you save and load the objects to which they are attached (see “Saving and Loading Dynamic Properties” on page 11-20 and “Dynamic Properties and ConstructOnLoad” on page 6-27)
- Define attributes for dynamic property (see “Setting Dynamic Property Attributes” on page 6-22).
- Add property set and get access methods (see “Defining Property Access Methods for Dynamic Properties” on page 6-25)

- Listen for dynamic property events (see “Responding to Dynamic-Property Events” on page 6-23)
- Access dynamic property values from object arrays, with restricted syntax (see “Object Arrays with Dynamic Properties” on page 8-10)

Defining Dynamic Properties

Any class that is a subclass of the `dynamicprops` class (which is itself a subclass of the `handle` class) can define dynamic properties using the `addprop` method. The syntax is:

```
P = addprop(H, 'PropertyName')
```

where:

P is an array of `meta.DynamicProperty` objects

H is an array of handles

PropertyName is the name of the dynamic property you are adding to each object

Setting Dynamic Property Attributes

Use the `meta.DynamicProperty` object associated with the dynamic property to set property attributes. For example:

```
P.Hidden = true;
```

You can remove the dynamic property by deleting its `meta.DynamicProperty` object:

```
delete(P);
```

The property attributes `Constant` and `Abstract` have no meaning for dynamic properties and setting the value of these attributes to `true` has no effect.

Assigning Data to the Dynamic Property

Suppose, you are using a predefined set of GUI widget classes (buttons, sliders, check boxes, etc.) and you want to store the location on a grid of each instance of the widget class. Assume the widget classes are not designed to

store location data for your particular layout scheme and you want to avoid creating a map or hash table to maintain this information separately.

Assuming the `button` class is a subclass of `dynamicprops`, you could add a dynamic property to store your layout data. Here is a simple class to create a uicontrol button:

```
classdef button < dynamicprops
    properties
        UiHandle
    end
    methods
        function obj = button(pos)
            obj.UiHandle = uicontrol('Position',pos);
        end
    end
end
```

Create an instance of the `button` class, add a dynamic property, and set its value:

```
b1 = button([20 40 80 20]); % button class uses HG-type position layout
b1.addprop('myCoord'); % Add a dynamic property
b1.myCoord = [2,3]; % Set the property value
```

You can access the dynamic property just like any other property, but only on the instance on which you defined it:

```
>> b1.myCoord

ans =

     2     3
```

Responding to Dynamic-Property Events

You can attach listeners to `dynamicprops` objects to monitor the addition of dynamic properties to the object. You can also monitor the removal of dynamic properties, which occurs when you delete the object.

The `dynamicprops` class defines two events and inherits one from `handle`:

- `ObjectBeingDestroyed` — Inherited from the `handle` class.
- `PropertyAdded` — Triggered when you add a dynamic property to an object derived from the `dynamicprops` class.
- `PropertyRemoved` — Triggered when you delete the `meta.DynamicProperty` object associated with the dynamic property.

Suppose you define a `button` object, as described in the previous section:

```
b2 = button([20 40 80 20]);
```

Create a function to attach listeners to the `button` object, `b2`, and a listener callback function:

```
function listenDynoEvent(obj)
    addlistener(obj, 'PropertyAdded', @eventPR);
    addlistener(obj, 'PropertyRemoved', @eventPR);
    function eventPR(src, evnt)
        mc = metaclass(src);
        fprintf(1, '%s %s \n', mc.Name, 'object')
        fprintf(1, '%s %s \n', 'Event triggered:', evnt.EventName)
    end
end
```

Triggering the `PropertyAdded` Event

Add the listeners to the `button` object, `b2`. Then, add a dynamic property, `myCoord`.

```
% add listeners
listenDynoEvent(b2)
% add dynamic property and save meta.DynamicProperty object
mp = b2.addprop('myCoord');
```

The listener callback function, `eventPR`, executes and displays the object class and event name:

```
button object
Event triggered: PropertyAdded
```

Delete the dynamic property by deleting the `meta.DynamicProperty` object:

```
delete(mp)
button object
Event triggered: PropertyRemoved
```

Obtain the `meta.DynamicProperty` object for a dynamic property using the `handle.findprop` method. Use `findprop` if you do not have the object returned by `addprop`:

```
mp = findprop(b2, 'myCoord');
```

Dynamic Properties and Ordinary Property Events

Dynamic properties support property set and get events so you can define listeners for these properties. Listeners are bound to the particular dynamic property for which you define them. Therefore, if you delete a dynamic property, and then create another one with the same name, the listeners do not respond to events generated by the new property, even though the property has the same name as the property for which the event was defined.

Having a listener defined for a deleted dynamic property does not cause an error, but the listener callback is never executed.

“Property-Set and Query Events” on page 9-12 provides more information on how to define listeners for these events.

Defining Property Access Methods for Dynamic Properties

Dynamic properties enable you to add properties to class instances without modifying class definitions. You can also define property set access or get access methods without creating new class methods. See “Property Access Methods” on page 6-12 for more on the purpose and techniques of these methods.

Note You can set and get the property values only from within your property access methods. You cannot call another function from the set or get method and attempt to access the property value from that function.

Here are the steps for creating a property access method:

- Define a function that implements the desired operations you want to perform before the property set or get occurs. These methods must have the following signatures: `mySet(obj, val)` or `val = myGet(obj)`
- Obtain the dynamic property's corresponding `meta.DynamicProperty` object.
- Assign a function handle pointing to your set or get property function to the `meta.DynamicProperty` object's `GetMethod` or `SetMethod` property. This function does not need to be a method of the class and you cannot use a naming scheme like `set.PropertyName`. Instead, use any valid function name.

Suppose you want to create a property set function for the `button` class dynamic property `myCoord` created previously. Write the function as follows:

```
function set_myCoord(obj, val)
    if ~(length(val) == 2) % require two values
        error('myCoords require two values ')
    end
    obj.myCoord = val; % set property value
end
```

Because `button` is a handle class, the property set function does not need to return the object as an output argument. You simply assign the value to the property if the value is value is valid.

Use the handle class method `findprop` to get the `meta.DynamicProperty` object:

```
mb1 = b1.findprop('myCoord');
mb1.SetMethod = @set_myCoord;
```

The property set function is now called whenever you set this property:

```
b1.myCoord = [1 2 3] % length must be two
??? Error using ==> set_myCoord at 3
myCoords require two values
```

Dynamic Properties and ConstructOnLoad

Setting a class's `ConstructOnLoad` attribute to `true` causes MATLAB to call the class constructor when loading the class. Dynamic properties are saved and restored when loading an object. If you are creating dynamic properties from the class constructor, you can cause a conflict if you also set the class's `ConstructOnLoad` attribute to `true`. Here's the sequence:

- A saved object saves the names and values of properties, including dynamic properties
- When loaded, a new object is created and all properties are restored to the values at the time the object was saved
- Then, the `ConstructOnLoad` attribute causes a call to the class constructor, which would create another dynamic property with the same name as the loaded property (see “The Default Save and Load Process” on page 11-2 for more on the load sequence)
- MATLAB prevents a conflict by loading the saved dynamic property, and does not execute `addprop` when calling the constructor.

If it is necessary for you to use `ConstructOnLoad` and you add dynamic properties from the class constructor (and want the constructor's call to `addprop` to be executed at load time) then set the dynamic property's `Transient` attribute to `true`. This setting prevents the property from being saved. For example:

```
classdef (ConstructOnLoad) MyClass < dynamicprops
    function obj = MyClass
        P = addprop(obj, 'DynProp');
        P.Transient = true;
        ...
    end
end
```


Methods — Defining Class Operations

- “Class Methods” on page 7-2
- “Method Attributes” on page 7-4
- “Ordinary Methods” on page 7-6
- “Class Constructor Methods” on page 7-15
- “Static Methods” on page 7-24
- “Overloading Functions for Your Class” on page 7-26
- “Object Precedence in Expressions Using Operators” on page 7-29
- “Class Methods for Graphics Callbacks” on page 7-31

Class Methods

What Are Methods

Methods are functions that implement the operations performed on objects of a class. Methods, along with other class members support the concept of encapsulation—class instances contain data in properties and class methods operate on that data. This allows the internal workings of classes to be hidden from code outside of the class, and thereby enabling the class implementation to change without affecting code that is external to the class.

Methods have access to private members of their class including other methods and properties. This enables you to hide data and create special interfaces that must be used to access the data stored in objects.

See “Methods That Modify Default Behavior” on page 15-2 for a discussion of how to create classes that modify standard MATLAB behavior.

See “Class Folders” on page 3-2 for information on the use of @ and path directors and packages to organize your class files.

See “Methods In Separate Files” on page 3-14 for the syntax to use when defining classes in more than one file.

Kinds of Methods

There are specialized kinds of methods that perform certain functions or behave in particular ways:

- *Ordinary methods* are functions that act on one or more objects and return some new object or some computed value. These methods are like ordinary MATLAB functions that cannot modify input arguments. Ordinary methods enable classes to implement arithmetic operators and computational functions. These methods require an object of the class on which to operate. See “Ordinary Methods” on page 7-6.
- *Constructor methods* are specialized methods that create objects of the class. A constructor method must have the same name as the class and typically initializes property values with data obtained from input

arguments. The class constructor method must return the object it creates. See “Class Constructor Methods” on page 7-15

- *Destructor methods* are called automatically when the object is destroyed, for example if you call `delete(object)` or there are no longer any references to the object. See “Handle Class Delete Methods” on page 5-15
- *Property access methods* enable a class to define code to execute whenever a property value is queried or set. See “Property Access Methods” on page 6-12
- *Static methods* are functions that are associated with a class, but do not necessarily operate on class objects. These methods do not require an instance of the class to be referenced during invocation of the method, but typically perform operations in a way specific to the class. See “Static Methods” on page 7-24
- *Conversion methods* are overloaded constructor methods from other classes that enable your class to convert its own objects to the class of the overloaded constructor. For example, if your class implements a `double` method, then this method is called instead of the `double` class constructor to convert your class object to a MATLAB `double` object. See “Converting Objects to Another Class” on page 15-11 for more information.
- *Abstract methods* serve to define a class that cannot be instantiated itself, but serves as a way to define a common interface used by a number of subclasses. Classes that contain abstract methods are often referred to as interfaces. See “Abstract Classes and Interfaces” on page 10-50 for more information and examples.

Method Attributes

Table of Method Attributes

All methods support the attributes listed in the following table. Attributes enable you to modify the behavior of methods. For example, you can prevent access to a method from outside the class or enable the method to be invoked without a class instance.

Attribute values apply to all methods defined within the `methods` block that specifies the nondefault values.

```

methods (attribute1=value1,attribute2=value2,...)
  ...
end

```

Attribute Name	Class	Description
Abstract	logical Default=false	<p>If true, the method has no implementation. The method has a syntax line that can include arguments, which subclasses use when implementing the method:</p> <ul style="list-style-type: none"> • Subclasses are not required to define the same number of input and output arguments. However, subclasses generally use the same signature when implementing their version of the method. • The method can have comments after the function line. • The method does not contain <code>function</code> or <code>end</code> keywords, only the function syntax (e.g., <code>[a,b] = myMethod(x,y)</code>)
Access	enumeration Default = public	<p>Determines what code can call this method:</p> <ul style="list-style-type: none"> • <code>public</code> — Unrestricted access • <code>protected</code> — Access from methods in class or subclasses • <code>private</code> — Access by class methods only (not from subclasses)

(Continued)

Attribute Name	Class	Description
Hidden	logical Default=false	When <code>false</code> , the method name shows in the list of methods displayed using the <code>methods</code> or <code>methodsview</code> commands. If set to <code>true</code> , the method name is not included in these listings.
Sealed	logical Default=false	If <code>true</code> , the method cannot be redefined in a subclass. Attempting to define a method with the same name in a subclass causes an error.
Static	logical Default=false	Set to <code>true</code> to define a method that does not depend on an object of the class and does not require an object argument. You must use the class name to call the method: <i>classname.methodname</i> “Static Methods” on page 7-24 provides more information.

Ordinary Methods

In this section...

“Defining Methods” on page 7-6
“Determining Which Method Is Invoked” on page 7-8
“Specifying Precedence” on page 7-12
“Controlling Access to Methods” on page 7-12
“Invoking Superclass Methods in Subclass Methods” on page 7-13
“Invoking Built-In Methods” on page 7-14

Defining Methods

You can specify methods:

- Inside of a class definition block
- In a separate file in the class @-folder

Methods Inside classdef Block

This example shows the definition of a method (the compute function in this example) within the `classdef` and `methods` blocks:

```
classdef ClassName
    methods (AttributeName = value,...)
        function x = compute(obj,inc)
            x = obj.y + inc;
        end % compute method
    ...
end % methods block
...
end % classdef
```

Note Nonstatic methods must include an explicit object variable in the function definition. The MATLAB language does not support an implicit reference in the method function definition.

Either of the following statements is correct syntax for calling a method where `obj` is an object of the class defining the compute method:

```
obj.compute(inc)
compute(obj,inc)
```

See also “Dot Notation vs. Function Notation” on page 7-9.

Method attributes apply only to that particular methods block, which is terminated by the end statement.

Methods in Separate Files

You can define class methods in separate files within the class @-folder. In this case, create a function in a separate file having the same name as the function (i.e., *functionname.m*). If you want to specify attribute values for that method, you must declare the method signature within a methods block in the `classdef` block. For example:

```
classdef myClass
    methods (AttributeName = value,...)
        tdata = testdata(obj,arg1,arg2)
    ...
    end % methods
    ...
end % classdef
```

Do not use methods blocks in the separate files. Define the method as a function. Using the example above, the file `testdata.m`, must contain the definition of the `testdata` function. Note that the signatures must match.

```
function tdata = testdata(myClass_object,argument2,argument3)
    ...
end
```

The following limitations apply to methods defined in separate files:

- If you want to specify attributes for a method defined in a separate file, you must declare this method in a methods block (specifying attribute values) within the `classdef` block.
- The syntax declared in the methods block (if used) must match the method's function line.
- The separate file must be in the class @-folder.
- The constructor method must be defined within the `classdef` block and, therefore, cannot be in a separate file. (See “Class Constructor Methods” on page 7-15 for information on this method.)
- Set and get property access methods must be defined within the `classdef` block and, therefore, cannot be in separate files. (See “Property Set and Get Access Methods” on page 6-12 for information on these methods.)

Determining Which Method Is Invoked

When the MATLAB runtime invokes an ordinary method that has an argument list, it uses the following criteria to determine which method to call

- The class of the left-most argument whose class is not specified as inferior to any other argument's class is chosen as the dominant class and its method is invoked.
- If this class does not define the named method, then a function with that name on the MATLAB path is invoked.
- If no such function exists, MATLAB issues an error indicating that the dominant class does not define the named method.

Dominant Argument

The dominant argument in a method's argument list determines which version of the method or function that the MATLAB runtime calls. Dominance is determined by the relative precedences of the classes of the arguments. In general, user-defined classes take precedence over built-in MATLAB classes. Therefore, the left most argument determines which method to call. However, user-defined classes can specify the relative dominance of specific classes.

For example, suppose `classA` defines `classB` as inferior and suppose both classes define a method called `combine`.

Calling the method with an object of `classB` and `classA`:

```
combine(B,A)
```

actually calls the `combine` method of `classA` because `A` is the dominant argument.

See “Specifying Precedence” on page 7-12 for information on how to define class precedence.

Dot Notation vs. Function Notation

MATLAB classes support both function and dot notation syntax for calling methods. For example, if `setColor` is a method of the class of object `X`, then calling `setColor` with function notation would be:

```
X = setColor(X, 'red');
```

The equivalent method call using dot notation is:

```
X = X.setColor('red')
```

However, in certain cases, the results for dot notation can differ with respect to how MATLAB dispatching works:

- If there is an overloaded `subsref`, it is invoked whenever using dot-notation. That is, the statement is first tested to see if it is subscripted assignment.
- If there is no overloaded `subsref`, then `setColor` must be a method of `X`. An ordinary function or a class constructor is never called using this notation.
- Only the argument `X` (to the left of the dot) is used for dispatching. No other arguments, even if dominant, are considered. Therefore dot notation can call only methods of `X`; methods of other argument are never called.

A Case Where the Result is Different. Here is an example of a case where dot and function notation can give different results. Suppose you have the following classes:

- `classA` defines a method called `methodA` that requires an object of `classB` as one of its arguments
- `classB` defines `classA` as inferior to `classB`

```
classdef classB (InferiorClasses = {?classA})
    ...
end
```

The `methodA` method is defined with two input arguments, one of which is an object of `classB`:

```
classdef classA
methods
    function methodA(obj,obj_classB)
        ...
    end
end
```

`classB` does not define a method with the same name as `methodA`. Therefore, the following syntax causes the MATLAB runtime to search the path for a function with the same name as `methodA` because the second argument is an object of a dominant class. If a function with that name exists on the path, then MATLAB attempts to call this function instead of the method of `classA` and most likely returns a syntax error.

```
obj = classA(...);
methodA(obj,obj_classB)
```

Dot notation is stricter in its behavior. For example, this call to `methodA`:

```
obj = classA(...);
obj.methodA(obj_classB)
```

can call only `methodA` of the class of `obj`.

Referencing Names with Expressions—Dynamic Reference

You can reference an object's properties or methods using an expression in dot-parentheses syntax:

```
obj.(expression)
```


The expression must evaluate to a string that is the name of a property or a method. For example, the following statements are equivalent:

```
obj.Property1
obj.( 'Property1' )
```

In this case, `obj` is an object of a class that defines a property called `Property1`. Therefore, you can pass a string variable in the parentheses to reference to property:

```
propName = 'Property1';
obj.(propName)
```

You can call a method and pass input arguments to the method using another set of parentheses:

```
obj.(expression)(arg1,arg2,...)
```

Using this notation, you can make dynamic references to properties and methods in the same way you can create dynamic references to the fields of `structs` (see “Creating Field Names Dynamically” for information on MATLAB structures).

As an example, suppose an object has methods corresponding to each day of the week and these methods have the same names as the days of the week (Monday, Tuesday, and so on). Also, the methods take as string input arguments, the current day of the month (i.e., the date). Now suppose you write a function in which you want to call the correct method for the current day. You can do this using an expression created with the `date` and `datestr` functions:

```
obj.(datestr(date, 'dddd'))(datestr(date, 'dd'))
```

The expression `datestr(date, 'dddd')` returns the current day as a string. For example:

```
datestr(date, 'dddd')
ans =
Tuesday
```

The expression `datestr(date, 'dd')` returns the current date as a string. For example:

```
datestr(date, 'dd')  
  
ans =  
  
11
```

Therefore, the expression using dot-parentheses (called on Tuesday the 11th) is the equivalent of:

```
obj.Tuesday('11')
```

Specifying Precedence

“Specifying Class Precedence” on page 4-17 provides information on how you can specify the relative precedence of user-defined classes.

Controlling Access to Methods

There might be situations where you want to create methods for internal computation within the class, but do not want to publish these methods as part of the public interface to the class. In these cases, you can use the `Access` attribute to set the access to one of the following options:

- `public` — Any code having access to an object of the class can access this method (the default).
- `private` — Restricts method access to the defining class, excluding subclasses. Subclasses do not inherit private methods.
- `protected` — Restricts method access to the defining class and subclasses derived from the defining class. Subclasses inherit this method.

Local and nested functions inside the method files have the same access as the method. Note that local functions inside a class-definition file have private access to the class defined in the same file.

Invoking Superclass Methods in Subclass Methods

A subclass can override the implementation of a method defined in a superclass. In some cases, the subclass method might need to execute some additional code instead of completely replacing the superclass method. To do this, MATLAB classes can use a special syntax for invocation of superclass methods from a subclass implementation for the same-named method.

The syntax to call a superclass method in a subclass class uses the @ symbol:

MethodName@SuperclassName

For example, the following `disp` method is defined for a `Stock` class that is derived from an `Asset` class. The method first calls the `Asset` class `disp` method, passing the `Stock` object so that the `Asset` components of the `Stock` object can be displayed. After the `Asset` `disp` method returns, the `Stock` `disp` method displays the two `Stock` properties:

```
classdef Stock < Asset
    methods
        function disp(s)
            disp@Asset(s) % Call base class disp method first
            fprintf(1, 'Number of shares: %g\nShare price: %3.2f\n', ...
                s.NumShares, s.SharePrice);
        end % disp
    end
end
```

See “The `DocStock` `disp` Method” on page 17-10 for more information on this example.

Limitations of Use

The following restrictions apply to calling superclass methods. You can use this notation only within:

- A method having the same name as the superclass method you are invoking
- A class that is a subclass of the superclass whose method you are invoking

Invoking Built-In Methods

The MATLAB `builtin` function enables you call the built-in version of a function that has been overridden by a method. You should, therefore, not overload the `builtin` function in your class.

Class Constructor Methods

In this section...

“Rules for Constructors” on page 7-15

“Related Information” on page 7-16

“Examples of Class Constructors” on page 7-16

“Initializing the Object Within a Constructor” on page 7-17

“Constructing Subclasses” on page 7-19

“Errors During Class Construction” on page 7-21

“Basic Structure of Constructor Methods” on page 7-22

Rules for Constructors

A constructor method is a special function that creates an instance of the class. Typically, constructor methods accept input arguments to assign the data stored in properties and always return an initialized object.

- The constructor has the same name as the class.
- The only output argument from a constructor is the object constructed.
- The constructor can return only a single argument.
- Constructors must always return a valid instance of the class. Never return an empty object from a class constructor.
- If the class being created is a subclass, MATLAB calls the constructor of each superclass class to initialize the object. Implicit calls to the superclass constructor are made with no arguments. If superclass constructors require arguments, you must call them from the subclass constructor explicitly.
- If your constructor makes an explicit call to a superclass constructor, this call must occur before any other reference to the constructed object.
- A class does not need to define a constructor method unless it is a subclass of a superclass whose constructor requires arguments. In this case, you must explicitly call the superclass constructor with the required arguments. See “Constructing Subclasses” on page 7-19

- If a class does not define a constructor, MATLAB supplies a constructor that takes no arguments and returns a scalar object whose properties are initialized to empty or the values specified as defaults in the property definitions. The constructor supplied by MATLAB also calls all superclass constructors with no arguments.
- If you create a class constructor, you should implement class constructors so that they can be called with no input arguments, in addition to whatever arguments are normally required. See “Supporting the No Input Argument Case” on page 7-18 and “Basic Structure of Constructor Methods” on page 7-22.
- Constructors must always return objects of their own class. A superclass constructor cannot return an object of a subclass.
- Calls to superclass constructors cannot be conditional. This means superclass construction calls cannot be placed in loops, conditions, switches, try/catch, or nested functions. See “Make No Conditional Calls to Superclass Constructors” on page 7-19 for more information.
- You can restrict access to constructors using method attributes, as with any method.

Related Information

See “Creating Object Arrays” on page 8-3 for information on constructing arrays of objects.

See “Constructor Calling Sequence” on page 12-11 for information specific to constructing enumerations.

Examples of Class Constructors

The following links provide access to examples of class constructors:

- “Implementing the BankAccount Class” on page 2-13
- “The Filewriter Class” on page 2-18
- “Simplifying the Interface with a Constructor” on page 2-26
- “Specializing the dlnode Class” on page 2-40
- “Example — A Class to Manage uint8 Data” on page 10-28

- “Referencing Superclasses from Subclasses” on page 10-7
- “Constructor Arguments and Object Initialization” on page 10-9

Initializing the Object Within a Constructor

Constructor functions must return an initialized object as the only output argument. The output argument is created when the constructor executes, before executing the first line of code.

For example, the following constructor function can assign the value of the object’s property A as the first statement because the object `obj` has already been assigned to an instance of `myClass`.

```
function obj = myClass(a,b,c)
    obj.A = a;
    ...
end
```

You can call other class methods from the constructor because the object is already initialized.

The constructor also creates an object whose properties have their default values—either empty (`[]`) or the default value specified in the property definition block. See “Property Definition Block” on page 6-5 for a description of this syntax and see “Defining Default Values” on page 3-9 for a discussion of how best to define property values.

For example, the following code calls the class method `CalculateValue` to assign the value of the property `Value`.

```
function obj = myClass(a,b,c)
    obj.Value = obj.CalculateValue(a,b);
    ...
end
```

Referencing the Object in a Constructor

When initializing the object, for example, by assigning values to properties, you must use the name of the output argument to refer to the object within the constructor. For example, in the following code the output argument is `obj` and the object is reference as `obj`:

```
% obj is the object being constructed
function obj = myClass(arg)
    obj.property1 = arg*10;
    obj.method1;
    ...
end
```

Supporting the No Input Argument Case

There are cases where the constructor must be able to be called with no input argument:

- When loading objects into the workspace. If the class `ConstructOnLoad` attribute is set to `true`, the `load` function calls the class constructor with no arguments.
- When creating or expanding an object array such that not all elements are given specific values, the class constructor is called with no arguments to fill in unspecified elements, (for example, `x(10,1) = myClass(a,b,c);`). In this case, the constructor is called once with no arguments to populate the empty array elements with copies of this one object. See “Creating Empty Arrays” on page 8-6 for more information.

If there are no input arguments, the constructor creates an object using only default properties values. A good practice is to always add a check for zero arguments to the class constructor to prevent an error if either of the two cases above occur:

```
function obj = myClass(a,b,c)
    if nargin > 0
        obj.A = a;
        obj.B = b;
        obj.C = c;
        ...
    end
end
```

See “Basic Structure of Constructor Methods” on page 7-22 for ways to handle superclass constructors.

Constructing Subclasses

Subclass constructor functions must explicitly call superclass constructors if the superclass constructors require input arguments. The subclass constructor must specify these arguments in the call to the superclass constructor using the constructor output argument and the returned object must be assigned to the constructor output argument. Here is the syntax:

```
classdef MyClass < SuperClass
    function obj = MyClass(arg)
        obj = obj@SuperClass(ArgumentList);
        ...
    end
end
```

The class constructor must make all calls to superclass constructors before any other references to the object, such as assigning property values or calling ordinary class methods. Also, a subclass constructor can call a superclass constructor only once.

Reference Only Specified Superclasses

The constructor cannot call a superclass constructor with this syntax if the `classdef` does not specify the class as a superclass.

```
classdef MyClass < SuperClass
```

MATLAB calls any uncalled constructors in the left-to-right order in which they are specified in the `classdef` line. MATLAB passes no arguments these functions.

Make No Conditional Calls to Superclass Constructors

Calls to superclass constructors must be unconditional and you can have only one call for any given superclass. You must initialize the superclass portion of the object by calling the superclass constructors before you can use the object (for example, to assign property values or call class methods).

In cases where you need to call superclass constructors with different arguments depending on some condition, you can conditionally build a cell array of arguments and provide one call to the constructor.

For example, in the following example the superclass `shape` constructor is called using some default values when the `cube` constructor has been called with no arguments:

```
classdef cube < shape
    properties
        SideLength = 0;
        Color = [0 0 0];
    end
    methods
        function cube_obj = cube(length,color,upvector,viewangle)
            if nargin == 0 % Provide default values if called with no arguments
                super_args{1} = [0 0 1];
                super_args{2} = 10;
            else
                super_args{1} = upvector;
                super_args{2} = viewangle;
            end
            cube_obj = cube_obj@shape(super_args{:});
            if nargin > 0 % Use value if provided
                cube_obj.SideLength = length;
                cube_obj.Color = color;
            end
            ...
        end
        ...
    end
end
```

Zero or More Superclass Arguments

If you are calling the superclass constructor from the subclass constructor and you need to support the case where you call the superclass constructor with no arguments, you must explicitly provide for this syntax.

Suppose in the case of the `cube` class example above, all property values in the `shape` superclass and the `cube` subclass have initial values specified in the class definitions that create a default `cube`. Then you could create an instance of `cube` without specifying any arguments for the superclass or

subclass constructors. Here is how you can implement this behavior in the cube constructor:

```
function obj = cube(length,color,upvector,viewangle)
    if nargin == 0
        % Create empty cell array if no input arguments
        super_args = {};
    else
        % Use specified arguments
        super_args{1} = upvector;
        super_args{2} = viewangle;
    end
    % Call the superclass constructor with the
    % empty cell array (no arguments) if nargin == 0
    % otherwise cell array is not empty
    cube_obj = cube_obj@shape(super_args{:});
    if nargin > 0
        cube_obj.SideLength = length;
        cube_obj.Color = color;
    end
    ...
end
```

More on Subclasses

See “Creating Subclasses — Syntax and Techniques” on page 10-7 for information on creating subclasses.

Errors During Class Construction

If an error occurs during the construction of a handle class, the MATLAB class system calls the class destructor on the object along with the destructors for any objects contained in properties and any initialized base classes.

See “Handle Class Delete Methods” on page 5-15 for information on how objects are destroyed.

Basic Structure of Constructor Methods

It is important to consider the state of the object under construction when writing your constructor method. Constructor methods can be structured into three basic sections:

- Pre-initialization — Compute arguments for superclass constructors.
- Object initialization — Call superclass constructors.
- Post initialization — Perform any operations related to the subclass, including referencing and assigning to the object, call class methods, passing the object to functions, and so on.

This code illustrates the basic operations performed in each section:

```
classdef myClass < baseClass1
    properties
        ComputedValue
    end
    methods
        function obj = myClass(a,b,c)

            %%% Pre Initialization %%%
            % Any code not using output argument (obj)
            if nargin == 0
                % Provide values for superclass constructor
                % and initialize other inputs
                a = someDefaultValue;
                args{1} = someDefaultValue;
                args{2} = someDefaultValue;
            else
                % When nargin ~= 0, assign to cell array,
                % which is passed to supclass constructor
                args{1} = b;
                args{2} = c;
            end
            compvalue = myClass.staticMethod(a);

            %%% Object Initialization %%%
            % Call superclass constructor before accessing object
            % You cannot conditionalize this statement
```

```
        obj = obj@baseClass1( args{:} );

    %%% Post Initialization %%%
    % Any code, including access to object
        obj.classMethod(...);
        obj.ComputedValue = compvalue;
        ...
    end
    ...
end
...
end
```

See “Creating Object Arrays” on page 8-3 for information on creating object arrays in the constructor.

Static Methods

In this section...
“Why Define Static Methods” on page 7-24
“Calling Static Methods” on page 7-25

Why Define Static Methods

Static methods are associated with a class, but not with specific instances of that class. These methods do not perform operations on individual objects of a class and, therefore, do not require an instance of the class as an input argument, like ordinary methods.

Static methods are useful when you do not want to first create an instance of the class before executing some code. For example, you might want to set up the MATLAB environment or use the static method to calculate data needed to create class instances.

Suppose a class needs a value for π calculated to particular tolerances. The class could define its own version of the built-in `pi` function for use within the class. This approach maintains the encapsulation of the class’s internal workings, but does not require an instance of the class to return a value.

Defining a Static Method

To define a method as static, set the methods block `Static` attribute to `true`. For example:

```
classdef MyClass
    ...
    methods(Static)
        function p = pi(tol)
            [n d] = rat(pi,tol);
            p = n/d;
        end
    end
end
```

“Example — Using Events to Update Graphs” on page 9-30 provides an example that uses a static method to create a set of objects representing graphs.

Calling Static Methods

Invoke static methods using the name of the class followed by dot (`.`), then the name of the method:

```
classname.staticMethodName(args,...)
```

Calling the `pi` method of `MyClass` in the previous section would require this statement:

```
value = MyClass.pi(.001);
```

You can also invoke static methods using an instance of the class, like any method:

```
obj = MyClass;  
value = obj.pi(.001);
```

`createViews` static method provides an example of a static method.

Inheriting Static Methods

Subclasses can redefine static methods unless the method’s `Sealed` attribute is also set to `true` in the superclass.

Overloading Functions for Your Class

In this section...

“Overloading MATLAB Functions” on page 7-26

“Rules for Naming to Avoid Conflicts” on page 7-27

Overloading MATLAB Functions

Class methods can provide implementations of MATLAB functions that operate only on instances of the class. This is possible because MATLAB software can always identify which class an object belongs to. The dominant argument is used to determine which version of a function to call. If the argument is an object, then MATLAB calls the method defined by the object’s class, if there is one.

In cases where a class defines a function with the same name as a global function, the class’s implementation of the function is said to *overload* the original global implementation.

Using MATLAB Functions in Conversion Methods

You might want to overload a number of MATLAB functions to work with an object of your class. Often, a simple solution to providing a full set of MATLAB functionality for a class involves creating methods that convert the data contained in your object to a type that existing MATLAB functions can use.

For example, suppose you define a class to represent polynomials that can have only `single` precision coefficients. You want a `roots` method to work on objects of your new class, but want to use the existing MATLAB `roots` function, which accepts a row vector of doubles that are the coefficients of a polynomial, ordered in descending powers.

The following method accesses a class property, `coefficients`, that contains the polynomial’s coefficients, converts them to type `double`, and then passes the vector of doubles to the built-in version of the `roots` function.

```
methods
function rts = roots(polyobject)
    % Extract data for MATLAB version of roots function
```



```
        coef = double(polyobject.coefficients);  
        rts = roots(coef);  
    end  
end
```

“Overloading MATLAB Functions for the DocPolynom Class” on page 16-16 provides examples.

“Methods That Modify Default Behavior” on page 15-2 provides a discussion of methods that you might typically implement for MATLAB classes.

Implementing MATLAB Operators

Classes designed to implement new MATLAB data types typically overload certain operators, such as addition, indexed assignment, and so on.

For example, the addition + (plus) function cannot add two polynomials because this operation is not defined by simple addition. However, a polynomial class can define its own plus method that the MATLAB language calls to perform addition of polynomial objects when you use the + symbol:

```
p1 + p2
```

“Implementing Operators for Your Class” on page 15-35 provides information on methods to overload.

“Defining Arithmetic Operators for DocPolynom” on page 16-14 provides examples.

Rules for Naming to Avoid Conflicts

The names of methods, properties, and events are scoped to the class. Therefore, you should adhere to the following rules to avoid naming conflicts:

- You can reuse names that you have used in unrelated classes.
- You can reuse names in subclasses if the member does not have public or protected access. These names then refer to entirely different methods, properties, and events without affecting the superclass definitions

- Within a class, all names exist in the same name space and must be unique. A class cannot define two methods with the same name and a class cannot define a subfunction with the same name as a method.
- The name of a static method is considered without its class prefix. Thus, a static method name without its class prefix cannot match the name of any other method.

Object Precedence in Expressions Using Operators

Establishing an object precedence enables the MATLAB runtime to determine which of possibly many versions of an operator or function to call in a given situation.

For example, consider the expression

$$\text{objectA} + \text{objectB}$$

Ordinarily, objects have equal precedence and the method associated with the left-most object is called. However, there are two exceptions:

- User-defined classes have precedence over MATLAB built-in classes.
- User-defined classes can specify their relative precedence with respect to other user-defined classes using the `InferiorClasses` attribute.

In “Example — A Polynomial Class” on page 16-2, the `DocPolynom` class defines a `plus` method that enables the addition of `DocPolynom` objects. Given the object `p`:

```
p = DocPolynom([1 0 -2 -5])
p =
    x^3-2*x-5
```

the expression:

```
1 + p
ans =
    x^3-2*x-4
```

calls the `DocPolynom` `plus` method (which converts the `double`, `1`, to a `DocPolynom` object and then implements the addition of two polynomials). The user-defined `DocPolynom` class has precedence over the built-in `double` class.

Specifying Precedence of User-Defined Classes

You can specify the relative precedence of user-defined classes by listing inferior classes using a class attribute. The `InferiorClasses` property

places a class below other classes in the precedence hierarchy. Define the `InferiorClasses` property in the `classdef` statement:

```
classdef (InferiorClasses = {?class1,?class2}) myClass
```

This attribute establishes a relative priority of the class being defined with the order of the classes listed.

Location in the Hierarchy

If *objectA* is above *objectB* in the precedence hierarchy, then the expression

objectA + *objectB*

calls `@classA/plus.m`. Conversely, if *objectB* is above *objectA* in the precedence hierarchy, then the MATLAB runtime calls `@classB/plus.m`.

See “Rules for Naming to Avoid Conflicts” on page 7-27 for related information.

Class Methods for Graphics Callbacks

In this section...

“Callback Arguments” on page 7-31

“General Syntax for Callbacks” on page 7-31

“Object Scope and Anonymous Functions” on page 7-32

“Example — Class Method as a Slider Callback” on page 7-33

Callback Arguments

You can use class methods as callbacks for Handle Graphics objects by specifying the callback as an anonymous function. Anonymous functions enable you to pass the arguments required by methods (i.e., the first argument is a class object) and graphics object callbacks (i.e., the event source and the event data), as well as any other arguments you want to pass to the function.

The following links provide general information on graphics object callbacks and anonymous functions.

Background Information

- [Function Handle Callbacks](#) — Information on graphics object callbacks
- [Anonymous Functions](#) — Information about using anonymous functions

General Syntax for Callbacks

The basic syntax for a function handle that you assign to the graphic object’s `Callback` property includes the object as the first argument:

```
@(src,event)method_name(object,src,event,additional_arg,...)
```

You must define the callback method with the following signature:

```
method_name(object,src,event)
```

Object Scope and Anonymous Functions

Anonymous functions take a snapshot of the argument values when you define the function handle. You must, therefore, consider this scoping when assigning the `Callback` property. The following two sections provide examples.

Using Value Classes

Consider the following snippet of a value class definition:

```
classdef SeaLevelAdjuster
    properties
        Slider
    end
    methods
        function seal = SeaLevelAdjuster
            ...
            seal.Slider = uicontrol('Style','slider');
            set(seal.Slider,'Callback',@(src,event)slider_cb(seal,src,event))
        end
    end
end
```

This class assigns the `Callback` property in a separate `set` statement so that the value object's (`seal`) `Slider` property has been defined when you create the function handle. Otherwise, `Handle Graphics` freezes `seal` before the `uicontrol`'s handle is assigned to the `Slider` property.

Using Handle Classes

The difference in behavior between a handle object and a value object is important in this case. If you defined the class as a handle class, the object is a reference to the underlying data. Therefore, when the MATLAB runtime resolves the function handle, the contents of the object reflects assignments made after the function handle is defined:

```
classdef SeaLevelAdjuster < handle
    ...
    properties
        Slider
    end
end
```

```

    methods
        function seal = SeaLevelAdjuster
            ...
            seal.Slider = uicontrol('Style','slider',...
                'Callback',@(src,event)slider_cb(seal,src,event));
        end
    end
end

```

Example – Class Method as a Slider Callback

This example defines a slider that varies the color limits of an indexed image to give the illusion of varying the sea level.

Displaying the Class Files

Open the `SeaLevelAdjuster` class definition file in the MATLAB editor.

To use the class, create a folder named `@SeaLevelAdjuster` and save `SeaLevelAdjuster.m` to this folder. The parent folder of `@SeaLevelAdjuster` must be on the MATLAB path.

Class Properties

The class defines properties to store graphics object handles and the calculated color limits:

```

classdef SeaLevelAdjuster < handle
    properties
        Figure = [];
        Axes = [];
        Image = [];
        CLimit = [];
        Slider = [];
    end
end

```

Class Constructor

The class constructor creates the graphics objects and assigns the slider callback (last line in code snippet):

```

methods
function seal = SeaLevelAdjuster(x,map)
seal.Figure = figure('Colormap',map,...
    'Resize','off',...
    'Position',[100 100 560 580]);
seal.Axes = axes('DataAspectRatio',[1 1 1],...
    'XLimMode','manual',...
    'YLimMode','manual',...
    'DrawMode','fast',...
    'Parent',seal.Figure);
seal.Image = image(x,'CDataMapping','scaled','Parent',seal.Axes);
seal.CLimit = get(seal.Axes,'CLim');
seal.Slider = uicontrol('Style','slider',...
    'Parent',seal.Figure,...
    'Max',seal.CLimit(2),...
    'Min',seal.CLimit(1)-1,...
    'Value',seal.CLimit(1),...
    'Units','normalized',...
    'Position',[.9286 .1724 .0357 .6897],...
    'SliderStep',[.005 .002],...
    'Callback',@(src,event)slider_cb(seal));
end % SeaLevelAdjuster
end % methods

```

The callback function for the slider is defined to accept the three required arguments — a class instance, the handle of the event source, and the event data:

```

methods
function slider_cb(seal)
min_val = get(seal.Slider,'Value');
max_val = max(max(get(seal.Image,'CData')));
set(seal.Axes,'CLim',[min_val max_val])
drawnow
end % slider_cb
end % methods

```


Using the SeaLevelAdjuster Class

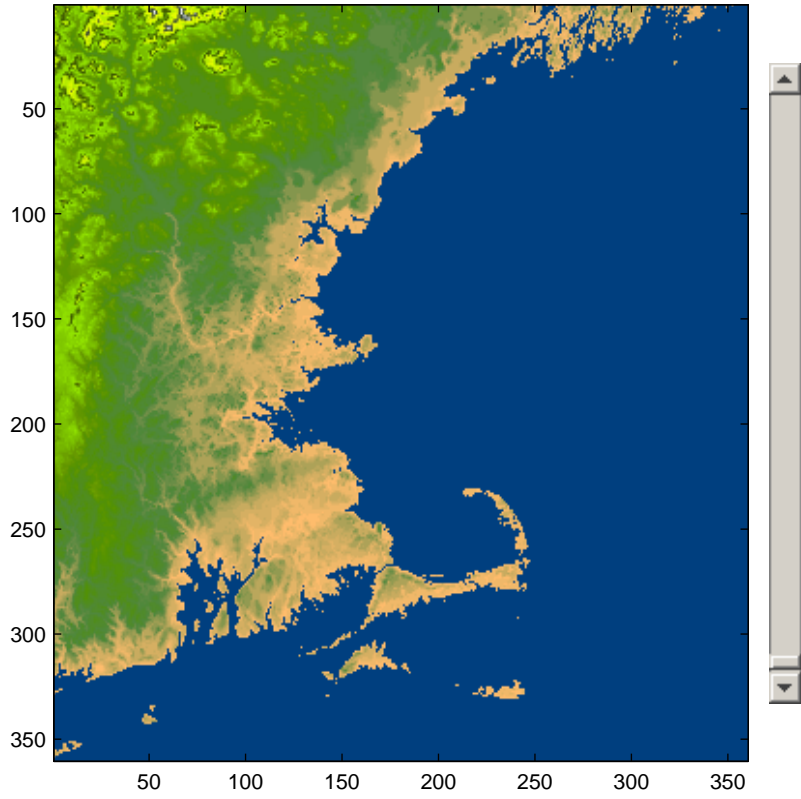
The class is designed to be used with the cape image that is included with the MATLAB product. To obtain the image data, use the `load` command:

```
load cape
```

After loading the data, create a `SeaLevelAdjuster` object for the image:

```
seal = SeaLevelAdjuster(X,map)
```

Move the slider to change the apparent sea level and visualize what would happen to Cape Cod if the sea level were to rise.



Object Arrays

- “Information About Arrays” on page 8-2
- “Creating Object Arrays” on page 8-3
- “Concatenating Objects of Different Classes” on page 8-13

Information About Arrays

Basic Knowledge

The material presented in this section builds on an understanding of the information presented in the following sections.

Chapter 3, “Class Definition—Syntax Reference”, “Class Constructor Methods” on page 7-15, “Matrix Indexing”, “Empty Matrices, Scalars, and Vectors”, “Multidimensional Arrays”

Creating Object Arrays

In this section...

“Building Arrays in the Constructor” on page 8-3

“Creating Empty Arrays” on page 8-6

“Arrays of Handle Objects” on page 8-7

“Referencing Property Values in Object Arrays” on page 8-10

“Object Arrays with Dynamic Properties” on page 8-10

Building Arrays in the Constructor

A constructor function can return an object array by making the necessary assignments when initializing the output argument. For example, the following `DocArrayExample` class creates an `m`-by-`n` object array and initializes the `Value` property of each object to the corresponding element in the input argument `F`:

```
classdef DocArrayExample
    properties
        Value
    end
    methods
        function obj = DocArrayExample(F)
            if nargin ~= 0 % Allow nargin == 0 syntax
                m = size(F,1);
                n = size(F,2);
                obj(m,n) = DocArrayExample; % Preallocate object array
                for i = 1:m
                    for j = 1:n
                        obj(i,j).Value = F(i,j);
                    end
                end
            end
        end
    end
end
```

Initializing Arrays of Value Objects

To initialize the object array in the previous example, the class constructor calls itself recursively with no arguments. MATLAB might need to call the constructor with no arguments even if the constructor does not build an object array. For example, suppose you have a class defined as follows:

```
classdef SimpleClass
    properties
        Value
    end
    methods
        function obj = SimpleClass(v)
            obj.Value = v;
        end
    end
end
```

Now suppose you execute the following statement (which is valid MATLAB code):

```
a(1,7) = SimpleClass(7)
??? Input argument "v" is undefined.

Error in ==> SimpleClass>SimpleClass.SimpleClass at 7
    obj.Value = v;
```

This error occurs because MATLAB is attempting to call the constructor with no arguments to initialize elements in the array `a(1,1:6)`.

Therefore, you must ensure the constructor function supports the no input argument syntax. The simplest solution is to test `nargin` and let the case when `nargin == 0` execute no code, but not error:

```
classdef SimpleClass
    properties
        Value
    end
    methods
        function obj = SimpleClass(v)
            if nargin > 0
                obj.Value = v;
            end
        end
    end
end
```

```

        end
    end
end
end

```

You can provide a default for the property in the `properties` definition block or assign a value to the input argument in the constructor, when calling the `SimpleClass` constructor with no arguments..

Using the revised class definition, the previous array assignment statement executes without error:

```

a(1,7) = SimpleClass(7)
a =
    1x7 SimpleClass
    Properties:
        Value

```

The object assigned to element `a(1,7)` used the input argument when MATLAB created it:

```

a(1,7)
ans =
    SimpleClass
    Properties:
        Value: 7

```

However, MATLAB created the objects contained in elements `a(1,1:6)` with no input argument and initialized the value of the `Value` property to empty `[]`. For example:

```

a(1,1)
ans =
    SimpleClass
    Properties:
        Value: []

```

MATLAB calls the `SimpleClass` constructor once and copies the value to the `Value` properties of each object.

Initial Values of Object Array Properties

When MATLAB calls a constructor with no arguments to initialize an object array, one of the following assignments occurs:

- If properties definitions specify default values, MATLAB assigns these values.
- If the constructor assigns values in the absence of input arguments, MATLAB assigns these values.
- If neither of the above situations apply, MATLAB assigns the value of empty double (i.e., []) to the property.

Creating Empty Arrays

Empty arrays have no elements, but are of a certain class. All nonabstract classes have a static method named `empty` that creates an empty array of the same class. The `empty` method enables you to specify the dimensions of the output array. However, at least one of the dimensions must be 0. For example:

```
ary = SimpleClass.empty(5,0);
```

creates a 5-by-0 empty array of class `SimpleClass`.

Calling `empty` with no arguments returns a 0-by-0 empty array.

Assigning Values to an Empty Array

An empty object defines the class of the array, however, to assign objects to the array, MATLAB must call the class constructor to create nonempty instances of the class to populate the array. Therefore, a class constructor never should return empty objects.

For example, using the `SimpleClass` defined in the previous section, create an empty array:

```
>> ary = SimpleClass.empty(5,0);  
>> class(ary)  
  
ans =  
  
SimpleClass
```


The array `ary` is an array of class `SimpleClass`. However, it is an empty array:

```
>> ary(1)
??? Index exceeds matrix dimensions.
```

If you make an assignment to a property value, MATLAB calls the `SimpleClass` constructor to grow the array to the required size:

```
>> ary(5).Value = 7;
>> ary(5).Value
```

```
ans =
```

```
7
```

```
>> ary(1).Value
```

```
ans =
```

```
[]
```

In this case, MATLAB populates array elements one through five with `SimpleClass` objects created by calling the class constructor with no arguments. Then MATLAB assigns the property value 7 to the object at `ary(5)`.

Arrays of Handle Objects

When MATLAB expands an array, it calls the class constructor once, and then creates unique handles for each element in the array. MATLAB copies the property values from the constructed object without calling the constructor for each additional element.

The following class illustrates this behavior.

```
classdef InitArray < handle
    properties
        RandNumb
    end
```

```
        methods
            function obj = InitArray
                obj.RandNumb = randi(100);
            end
        end
    end
```

The property `RandNumb` contains a random number that is assigned from the `InitArray` class constructor. The next section uses the `InitArray` class to show when MATLAB calls the class constructor when expanding an array.

Initializing a Handle Object Array

Consider what happens when MATLAB initialize an array by first assigning to the last element in the array. (The last element is the one with the highest index values). For example, suppose the value of the `RandNumb` property of the `InitArray` object assigned to the element `A(4,5)` is 59:

```
A(4,5) = InitArray;
A(4,5).RandNumb

ans =

    59
```

As expected, the element in the index location 4,5 is an instance of the `InitArray` class. Element 1,1 is also an instance of the `InitArray` class and its `RandNumb` property is set to the random number 91, in this case. MATLAB called the class constructor to create an object for the remaining array elements:

```
A(1,1).RandNumb

ans =

    91
```

However, MATLAB copies this second instance to create all remaining array elements:

```
A(2,2).RandNumb
```

```
ans =  
  
    91  
  
A(2,3).RandNumb  
  
ans =  
  
    91
```

When initializing an object array, MATLAB assigns a copy of a single default object to the empty elements in the array. MATLAB gives each object a unique handle so that later you can assign different property values to each object. This means that

```
A(1,1) == A(2,2)  
ans =  
  
    0
```

Therefore, the creation of an array with a statement such as:

```
A(4,5) = InitArray;
```

results in two calls to the class constructor. The first creates the object for array element A(4,5). The second creates a default object (no arguments passed to the constructor) that MATLAB copies to all remaining empty array elements.

See “Indexing Multidimensional Arrays” and “Reshaping Multidimensional Arrays” for information on array manipulation.

See “Initializing Properties to Unique Values” on page 3-10 for information on assigning values to properties.

See “Indexed Reference and Assignment” on page 15-13 for information on implementing subsasgn methods for your class.

Referencing Property Values in Object Arrays

You can reference all values of the same property in an object array using the syntax:

```
objarray.PropName
```

For example, given the ObjArray class:

```
classdef ObjArray
    properties
        RegProp
    end
    methods
        function obj = ObjArray
            % Assign property a random integer
            obj.RegProp = randi(100);
        end
    end
end
```

Create an array of ObjArray objects and assign all values of the RegProp property to the propvalues cell array:

```
for k = 1:5
    a(k) = ObjArray;
end
propvalues = {a.RegProp}

propvalues =

    [96]    [49]    [81]    [15]    [43]
```

Object Arrays with Dynamic Properties

See “Dynamic Properties — Adding Properties to an Instance” on page 6-21 for information about classes that can define dynamic properties.

You cannot reference all the dynamic properties in an object array using a single statement, as shown in the previous section for ordinary properties. For example, suppose the ObjArray class subclasses the dynamicprops class, which enables you to add properties to instances of the ObjArray class.

```
classdef ObjArray < dynamicprops
    properties
        RegProp
    end
    methods
        function obj = ObjArray
            % Assign property a random integer
            obj.RegProp = randi(100);
        end
    end
end
```

Create an object array and add dynamic properties to each member of the array:

```
% Define elements 1 and 2 as ObjArray objects
a(1) = ObjArray;
a(2) = ObjArray;
% Add dynamic properties to each object and assign a value
a(1).addprop('DynoProp');
a(1).DynoProp = 1;
a(2).addprop('DynoProp');
a(2).DynoProp = 2;
```

You can get the values of the ordinary properties, as with any array:

```
a.RegProp
```

```
ans =
```

```
4
```

```
ans =
```

```
85
```

MATLAB returns an error if you try to access the dynamic properties of all array elements using this syntax.

```
a.DynoProp
```

??? No appropriate method, property, or field DynoProp
for class ObjArray.

You must refer to each object individually to access dynamic property values:

```
a(1).DynoProp
```

```
ans =
```

```
1
```

```
a(2).DynoProp
```

```
ans =
```

```
2
```

Concatenating Objects of Different Classes

In this section...

“Basic Knowledge” on page 8-13

“MATLAB Concatenation Rules” on page 8-13

“Concatenating Objects” on page 8-13

“Converting to the Dominant Class” on page 8-14

“Implementing Converter Methods” on page 8-17

Basic Knowledge

The material presented in this section builds on an understanding of the information presented in the following sections.

“Specifying Class Precedence” on page 4-17, “Class Attributes” on page 4-5, “Creating Object Arrays” on page 8-3.

MATLAB Concatenation Rules

MATLAB follows these rules for concatenating objects:

- MATLAB always converts all objects to the dominant class.
- User-defined classes take precedence over built-in classes like `double`.
- If there is no defined dominance relationship between any two objects, then the left-most object dominates (see “Specifying Class Precedence” on page 4-17).
- MATLAB does not convert objects to a common superclass.

The following sections describe these rules in more detail. See “Combining Unlike Classes” for related information.

Concatenating Objects

Concatenation combines objects into arrays:

```
ary = [obj1,obj2,obj3,...,objn]; % size of ary is 1-by-n
```

```
ary = [obj1;obj2;obj3;...;objn]; % size of ary is n-by-1
```

The class of the resulting array, `ary`, is the same as the class of the objects being concatenated. Concatenating unlike objects is possible if MATLAB can convert objects to the dominant class. MATLAB attempts to convert unlike objects by:

- Calling the inferior object's converter method, if one exists (see “Implementing Converter Methods” on page 8-17 for an example).
- Passing an inferior object to the dominant class constructor to create an object of the dominant class.

If conversion of the inferior objects is successful, MATLAB returns an array that is of the dominant class. If conversion is not possible, MATLAB returns an error.

Modifying Default Concatenation

Classes can control how concatenation of its instances works by overloading `horzcat`, `vertcat`, `cat`. See “Redefining Concatenation for Your Class” on page 15-8 for more information.

Converting to the Dominant Class

MATLAB first attempts to find converter methods for objects of the inferior classes. If your class design requires object conversion, implement methods for this purpose. See “Converting Objects to Another Class” on page 15-11 for general information on converter methods.

Calling the Dominant-Class Constructor

When MATLAB calls the dominant class constructor to convert an object of an inferior class to the dominant class, the inferior object is passed to the constructor as an argument. If the class design enables the dominant class constructor to accept objects of inferior classes as input arguments, then concatenation is possible without implementing a separate converter method.

In cases where the constructor simply assigns this argument to a property, the result is an object of the dominant class with an object of an inferior class

stored in a property. If this is not a desired result, then ensure that class constructors include adequate error checking.

For example, consider the class `ColorClass` and two subclasses, `RGBColor` and `HSVColor`:

```
classdef ColorClass
    properties
        Color
    end
end
```

The class `RGBColor` inherits the `Color` property from `ColorClass`. `RGBColor` stores a color value defined as a three-element vector of red, green, and blue (RGB) values. The constructor does not restrict the value of the input argument. It assigns this value directly to the `Color` property.

```
classdef RGBColor < ColorClass
    % Class to contain RGB color specification
    methods
        function obj = RGBColor(rgb)
            if nargin > 0
                obj.Color = rgb;
            end
        end
    end
end
```

The class `HSVColor` also inherits the `Color` property from `ColorClass`. `HSVColor` stores a color value defined as a three-element vector of hue, saturation, value (HSV) values.

```
classdef HSVColor < ColorClass
    % Class to contain HSV color specification
    methods
        function obj = HSVColor(hsv)
            if nargin > 0
                obj.Color = hsv;
            end
        end
    end
end
```

```
end
```

Create an instance of each class and concatenate them into an array. The `RGBColor` object is dominant because it is the left most object and neither class defines a dominance relationship:

```
crgb = RGBColor([1 0 0]);  
chsv = HSVColor([0 1 1]);  
ary = [crgb,chsv];
```

```
class(ary)
```

```
ans =
```

```
RGBColor
```

MATLAB can combine these different objects into an array because it can pass the inferior object of class `HSVColor` to the constructor of the dominant class. However, notice that the `Color` property of the second `RGBColor` object in the array actually contains an `HSVColor` object, not an RGB color specification:

```
ary(2).Color
```

```
ans =
```

```
HSVColor
```

```
Properties:
```

```
Color: [0 1 1]
```

Avoid this undesirable behavior by:

- Implementing converter methods
- Performing argument checking in class constructors before assigning values to properties

The next section shows updates to these classes.

Implementing Converter Methods

Here is the `ColorClass` class with converter methods for `RGBColor` and `HSVColor` objects:

```
classdef ColorClass
    properties
        Color
    end
    methods
        function rgbObj = RGBColor(obj)
            % Convert HSVColor object to RGBColor object
            if strcmp(class(obj), 'HSVColor')
                rgbObj = RGBColor(hsv2rgb(obj.Color));
            end
        end
        function hsvObj = HSVColor(obj)
            % Convert RGBColor object to HSVColor object
            if strcmp(class(obj), 'RGBColor')
                hsvObj = HSVColor(rgb2hsv(obj.Color));
            end
        end
    end
end
```

Create an array of `RGBColor` and `HSVColor` objects with the revised superclass:

```
crgb = RGBColor([1 0 0]);
chsv = HSVColor([0 1 1]);
ary = [crgb, chsv];
class(ary)

ans =

RGBColor
```

MATLAB calls the converter method for the `HSVColor` object, which it inherits from the superclass. The second array element is now an `RGBColor` object with an RGB color specification assigned to the `Color` property:

```
ary(2)
```

```
ans =  
  
    RGBColor  
  
    Properties:  
        Color: [1 0 0]  
ary(2).Color  
  
ans =  
  
     1     0     0
```

If the left-most object is of class `HSVColor`, the array `ary` is also of class `HSVColor`, and MATLAB converts the `Color` property data to HSV color specification.

```
ary = [chsv crgb]  
ary =  
  
    1x2 HSVColor  
  
    Properties:  
        Color  
ary(2).Color  
  
ans =  
  
     0     1     1
```

Defining a converter method in the superclass and adding better argument checking in the subclass constructors produces more predicable results. Here is the `RGBColor` class constructor with argument checking:

```
classdef RGBColor < ColorClass2  
    methods  
        function obj = RGBColor(rgb)  
            if nargin == 0  
                rgb = [0 0 0];  
            else  
                if ~(strcmp(class(rgb), 'double'))...
```

```
        && size(rgb,2) == 3 && max(rgb) <= 1 && min(rgb) >= 0)
        error('Specify color as RGB values')
    end
end
obj.Color = rgb;
end
end
end
```

Your applications might require additional error checking and other coding techniques. The classes in these examples are designed only to demonstrate concepts.

See “Class Constructor Methods” on page 7-15 for more information on writing class constructors.

See Chapter 10, “Building on Other Classes” for more information on inheritance.

Events — Sending and Responding to Messages

- “Learning to Use Events and Listeners” on page 9-2
- “Events and Listeners — Concepts” on page 9-9
- “Event Attributes” on page 9-14
- “Defining Events and Listeners — Syntax and Techniques” on page 9-15
- “Listening for Changes to Property Values” on page 9-23
- “Example — Using Events to Update Graphs” on page 9-30

Learning to Use Events and Listeners

In this section...
“What You Can Do With Events and Listeners” on page 9-2
“Some Basic Examples” on page 9-2
“Simple Event Listener Example” on page 9-3
“Responding to a Button Click” on page 9-6

What You Can Do With Events and Listeners

Events are notices that objects broadcast in response to something that happens, such as a property value changing or a user interaction with an application program. Listeners execute functions when notification of the event of interest occurs. You can use events to communicate things that happen in your program to other objects, which then can respond to these events by executing the listener’s callback function.

See “Events and Listeners — Concepts” on page 9-9 for a more thorough discussion of the MATLAB event model.

Some Basic Examples

The following sections provide simple examples that show the basic techniques for using events and listeners. Subsequent sections provide more detailed descriptions and more complex examples.

Quick Overview

When using events and listeners:

- Only handle classes can define events and listeners (See “Naming Events” on page 9-15 for syntax).
- Call the handle notify method to trigger the event (See “Triggering Events” on page 9-15, and “Defining and Triggering an Event” on page 9-4, for examples). The event notification broadcasts the named event to all listeners registered for this event.

- Use the handle `addlistener` method to associate a listener with an object that will be the source of the event (“Listening to Events” on page 9-16, “Creating a Listener for the Overflow Event” on page 9-5, and “Creating a Listener for the Property Event” on page 9-8).
- When adding a listener, pass a function handle for the listener callback function using a syntax such as the following:
 - `addlistener(eventObject, 'EventName', @functionName)` — for an ordinary function.
 - `addlistener(eventObject, 'EventName', @Obj.methodName)` — for a method of *Obj*.
 - `addlistener(eventObject, 'EventName', @ClassName.methodName)` — for a static method of the class *ClassName*.
- Listener callback functions must define at least two input arguments — the event source object handle and the event data (See “Defining Listener Callback Functions” on page 9-21 for more information).
- You can modify the data passed to each listener callback by subclassing the `event.EventData` class (See “Defining Event-Specific Data” on page 9-18) and “Defining the Event Data” on page 9-5 for more information).

Simple Event Listener Example

Suppose you want to create a listener callback that has access to specific information when the event occurs. This example shows how to do this by creating custom event data.

Events provide information to listener callback functions by passing an event data argument to the specified function. By default, MATLAB passes an `event.EventData` object to the listener callback. This object has two properties:

- `EventName` — Name of the event triggered by this object.
- `Source` — Handle of the object triggering the event.

You can provide additional information to the listener callback by subclassing the `event.EventData` class. In your subclass, you define properties to contain the additional data and provide a constructor method that accepts the additional data as arguments. Typically, you use the subclass constructor

as an argument to the `notify` method, which is the method that you use to trigger the event.

See “Defining Event-Specific Data” on page 9-18 for another example of subclassing `event.EventData`.

Defining and Triggering an Event

The `SimpleEventClass` defines a property set method (see “Property Set Methods” on page 6-14) from which it triggers an event if the property is set to a value exceeding a certain limit. The property set method performs these operations:

- Saves the original property value
- Sets the property to the specified value
- If the specified value is greater than 10, the set method triggers an `Overflow` event
- Passes the original property value, as well as other event data, in a `SpecialEventDataClass` object to the `notify` method (see “Defining the Event Data” on page 9-5)

```
classdef SimpleEventClass < handle
% Must be a subclass of handle
    properties
        Prop1 = 0;
    end
    events
        Overflow
    end
    methods
        function set.Prop1(obj,value)
            orgvalue = obj.Prop1;
            obj.Prop1 = value;
            if (obj.Prop1 > 10)
                % Trigger the event using custom event data
                notify(obj,'Overflow',SpecialEventDataClass(orgvalue));
            end
        end
    end
end
```

```
end
```

Defining the Event Data

Event data is always contained in an `event.EventData` object. The `SpecialEventDataClass` adds the original property value to the event data by subclassing `event.EventData`:

```
classdef SpecialEventDataClass < event.EventData
    properties
        OrgValue = 0;
    end
    methods
        function eventData = SpecialEventDataClass(value)
            eventData.OrgValue = value;
        end
    end
end
```

Creating a Listener for the Overflow Event

To listen for the `Overflow` event, attach a listener to an instance of the `SimpleEventClass` class. Use the `addlistener` method to create the listener. You also need to define a callback function for the listener to execute when the event is triggered.

The function `setupSEC` instantiates the `SimpleEventClass` class and adds a listener to the object. In this example, the listener callback function displays information that is contained in the `eventData` argument (which is a `SpecialEventDataClass` object).

```
function sec = setupSEC
    % Create an object and attach the listener
    sec = SimpleEventClass;
    addlistener(sec, 'Overflow', @overflowHandler)
    % Define the listener callback function
    function overflowHandler(eventSrc, eventData)
        disp('The value of Prop1 is overflowing!')
        disp(['It's value was: ' num2str(eventData.OrgValue)])
        disp(['It's current value is: ' num2str(eventSrc.Prop1)])
    end
end
```

```
end
```

Create the `SimpleEventClass` object and add the listener:

```
>> sec = setupSEC;
>> sec.Prop1 = 5;
>> sec.Prop1 = 15; % listener triggers callback
The value of Prop1 is overflowing!
It's value was: 5
It's current value is: 15
```

Responding to a Button Click

This example shows how to respond to changes in the state of a push button by listening for changes in the value of a property. It uses the predefined property set events (see “Listening for Changes to Property Values” on page 9-23 for more on property events). The example defines the following components:

- `PushButton` — a class that defines a push button whose callback changes the value of its `State` property when the state of the push button changes. Changing this property value triggers a predefined set property event named `PostSet`.
- `AxesObj` — a class that defines a Handle Graphics axes in the same figure window as the push button. Clicking the push button turns the axes grid on and off via the listener.
- A listener that responds to a change in the push button state by listening for a change in the `PushButton` object’s `State` property. The listener callback function sets an `AxesObj` property, which changes the grid display via the `AxesObj` object property’s set method. See “Property Set Methods” on page 6-14 for more on defining property set methods.

The PushButton Class

The `PushButton` class uses a `uicontrol` to create a push button. The push button’s callback is a class method (named `pressed`) that changes the value of the class’s `State` property. Changing the `State` property generates a property set event because the property’s `SetObservable` attribute is enabled:

```
classdef PushButton < handle
% must be a subclass of handle
```

```

properties (SetObservable)
% Enable property events with SetObservable attribute
    State = false;
end
methods
    function buttonObj = PushButton
        uicontrol('Style','pushbutton',...
            'String','R/B',...
            'Callback',@buttonObj.pressed);
    end
end
methods (Access = private)
% Make push button callback private
    function pressed(buttonObj,src,event) % #ok<INUSD>
        % Setting value of State property triggers property set events
        buttonObj.State = ~buttonObj.State;
    end
end
end
end

```

The AxesObj Class

The AxesObj class contains an axes object that is displayed in the figure window containing the push button. Its Grid property contains a logical value that determines whether to display the grid.

The private PrivGrid property isolates the Grid property from load order dependencies if the object is loaded from a MAT-file. See “Avoiding Property Initialization Order Dependency” on page 11-23 for more information.

```

classdef AxesObj < handle
    properties (Access = private)
        % Keep the axes handle private
        MyAxes = axes;
        PrivGrid = true;
    end
    properties (Dependent)
        % Determines if the grid is on or off
        Grid
    end
end

```

```
methods
function set.Grid(axObj,newGrid)
% Set method for Grid property
% As push button State changes,
% listener sets AxesObj Grid property
axObj.PrivGrid = newGrid;
if axObj.Grid
    grid(axObj.MyAxes,'on');
else
    grid(axObj.MyAxes,'off');
end
end
function g = get.Grid(axObj)
g = axObj.PrivGrid;
end
end
end
```

Creating a Listener for the Property Event

The listener is the connection between the push button and the axes. The listener responds to the event that is triggered when the push button is clicked by executing its callback function. This function changes the display of the grid according to the state of the push button. The listener responds to the property `PostSet` event, which means the listener callback executes after the property has been set.

```
function setup
pb = PushButton;
axo = AxesObj;
% listener responds to the PostSet event triggered after
% the PushButton State property changes value
addlistener(pb,'State','PostSet',@mapper);
function mapper(src,event) % #ok<INUSD>
axo.Grid = pb.State;
end
end
```

Events and Listeners — Concepts

In this section...

- “The Event Model” on page 9-9
- “Default Event Data” on page 9-11
- “Events Only in Handle Classes” on page 9-11
- “Property-Set and Query Events” on page 9-12
- “Listeners” on page 9-13

The Event Model

Events represent changes or actions that occur within class instances. For example,

- Modification of class data
- Execution of a method
- Querying or setting a property value
- Destruction of an object

Basically, any activity that you can detect programmatically can generate an event and communicate information to other objects.

MATLAB classes define a process that communicates the occurrence of events to other objects that need to respond to the events. The event model works this way:

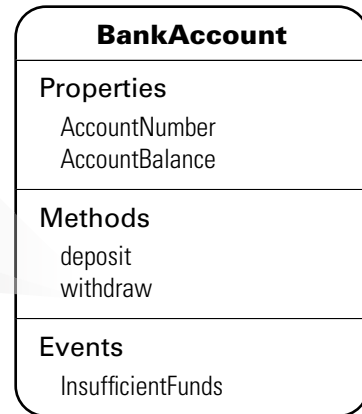
- A handle class declares a name used to represent an event. “Naming Events” on page 9-15
- After creating an instance of the event-declaring class, you can attach listener objects to it. “Ways to Create Listeners” on page 9-19
- A call to a class method broadcasts a notice of the event to listeners. The class user determines when to trigger the event. “Triggering Events” on page 9-15

- Listeners execute a callback function when notified that the event has occurred. “Defining Listener Callback Functions” on page 9-21
- You can bind listeners to the lifecycle of the object that defines the event, or limit listeners to the existence and scope of the listener object. “Ways to Create Listeners” on page 9-19

The following diagram illustrates the event model.

1. The **withdraw** method is called.

```
if AccountBalance <= 0
  notify(obj, 'InsufficientFunds');
end
```



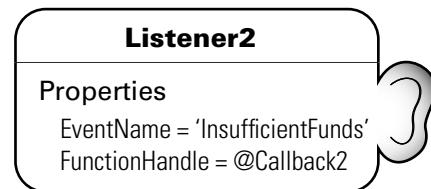
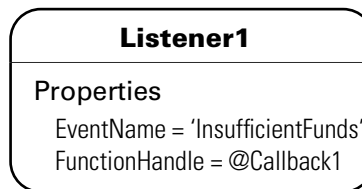
2. The **notify** method triggers an event, and a message is broadcast.

InsufficientFunds

InsufficientFunds

3. Listeners awaiting message execute their callbacks.

(The broadcasting object does not necessarily know who is listening.)



Default Event Data

Events provide information to listener callbacks by passing an event data argument to the callback function. By default, MATLAB passes an `event.EventData` object to the listener callback. This object has two properties:

- `EventName` — The event name as defined in the class event block
- `Source` — The object that is the source of the event

MATLAB passes the source object to the listener callback in the required event data argument. This enables you to access any of the object's public properties from within your listener callback function.

Customizing Event Data

You can create a subclass of the `event.EventData` class to provide additional information to listener callback functions. The subclass would define properties to contain the additional data and provide a method to construct the derived event data object so it can be passed to the `notify` method.

“Defining Event-Specific Data” on page 9-18 provides an example showing how to customize this data.

Events Only in Handle Classes

You can define events only in handle classes. This restriction exists because a value class is visible only in a single MATLAB workspace so no callback or listener can have access to the object that triggered the event. The callback could have access to a copy of the object. However, accessing a copy is not generally useful because the callback cannot access the current state of the object that triggered the event or effect any changes in that object.

“Comparing Handle and Value Classes” on page 5-2 provides general information on handle classes.

“Defining Events and Listeners — Syntax and Techniques” on page 9-15 shows the syntax for defining a handle class and events.

Property-Set and Query Events

There are four predefined events related to properties:

- `PreSet` — Triggered just before the property value is set, before calling its set access method
- `PostSet` — Triggered just after the property value is set
- `PreGet` — Triggered just before a property value query is serviced, before calling its get access method
- `PostGet` — Triggered just after returning the property value to the query

These events are predefined and do not need to be listed in the class events block.

When a property event occurs, the callback is passed an `event.PropertyEvent` object. This object has three properties:

- `EventName` — The name of the event described by this data object
- `Source` — The source object whose class defines the event described by the data object
- `AffectedObject` — The object whose property is the source for this event (that is, `AffectedObject` contains the object whose property was either accessed or modified).

You can define your own property-change event data by subclassing the `event.EventData` class. Note that the `event.PropertyEvent` class is a sealed subclass of `event.EventData`.

See “Listening for Changes to Property Values” on page 9-23 for a description of the process for creating property listeners.

See “Implementing the PostSet Property Event and Listener” on page 9-43 for an example.

See “Property Set and Get Access Methods” on page 6-12 for information on methods that control access to property values.

Listeners

Listeners encapsulate the response to an event. Listener objects belong to the `event.listener` class, which is a handle class that defines the following properties:

- **Source** — Handle or array of handles of the object that generated the event
- **EventName** — Name of the event
- **Callback** — Function to execute with an enabled listener receives event notification
- **Enabled** — Callback function executes only when `Enabled` is `true`. See “Enabling and Disabling the Listeners” on page 9-46 for an example.
- **Recursive** — Allow listener to cause the same event that triggered the execution of the callback

`Recursive` is `true` by default. It is possible to create a situation where infinite recursion reaches the recursion limit and eventually triggers an error. If you set `Recursive` to `false`, the listener cannot execute recursively if the callback triggers its own event.

“Ways to Create Listeners” on page 9-19 provides more specific information.

Listener Order of Execution

The order in which listeners execute after the firing of an event is undefined. However, all listener callbacks execute synchronously with the event firing.

Event Attributes

Table of Event Attributes

The following table lists the attributes you can set for events. To specify a value for an attribute, assign the attribute value on the same line as the event key word. For example, all the events defined in the following events block have private `ListenAccess` and `NotifyAccess` attributes.

```
events (ListenAccess = 'private', NotifyAccess = 'private')
  anEvent
  anotherEvent
end
```

To define other events in the same class definition that have different attribute settings, create another events block.

Attribute Name	Class	Description
Hidden	logical Default = false	If true, event does not appear in list of events returned by events function (or other event listing functions or viewers).
ListenAccess	enumeration Default = public	Determines where you can create listeners for the event. <ul style="list-style-type: none"> • <code>public</code> — Unrestricted access • <code>protected</code> — Access from methods in class or derived classes • <code>private</code> — Access by class methods only (not from derived classes)
NotifyAccess	enumeration Default = public	Determines where code can trigger the event <ul style="list-style-type: none"> • <code>public</code> — Any code can trigger event • <code>protected</code> — Can trigger event from methods in class or derived classes • <code>private</code> — Can trigger event by class methods only (not from derived classes)

Defining Events and Listeners — Syntax and Techniques

In this section...

“Naming Events” on page 9-15

“Triggering Events” on page 9-15

“Listening to Events” on page 9-16

“Defining Event-Specific Data” on page 9-18

“Ways to Create Listeners” on page 9-19

“Defining Listener Callback Functions” on page 9-21

Naming Events

Define an event by declaring an event name inside an `events` block, typically in the class that generates the event. For example, the following class creates an event called `ToggledState`, which might be triggered whenever a toggle button’s state changes.

```
classdef ToggleButton < handle
    properties
        State = false
    end
    events
        ToggledState
    end
end
```

Triggering Events

At this point, the `ToggleButton` class has defined a name that it will associate with the toggle button state changes—toggling on and toggling off. However, a class method controls the actual firing of the events. To accomplish this, the `ToggleButton` class adds a method to trigger the event:

```
classdef ToggleButton < handle
    properties
        State = false
    end
```

```
events
    ToggledState
end
methods
...
function OnStateChange(obj,newState)
% Call this method to check for state change
    if newState ~= obj.State
        obj.State = newState;
        notify(obj,'ToggledState'); % Broadcast notice of event
    end
end
end
end
end
```

The `OnStateChange` method calls `notify` to trigger the event, using the handle of the `ToggleButton` object that owns the event and the string name of the event.

Listening to Events

Once the call to `notify` triggers an event, MATLAB broadcasts a message to all registered listeners. To register a listener for a specific event, use the `addlistener` handle class method. For example, the following class defines objects that listen for the `ToggledState` event defined in the class `ToggleButton`.

```
classdef RespondToToggle < handle
methods
function obj = RespondToToggle(toggle_button_obj)
    addlistener(toggle_button_obj,'ToggledState',@RespondToToggle.handleEvt);
end
end
methods (Static)
function handleEvt(src,evtdata)
    if src.State
        disp('ToggledState is true') % Respond to true ToggleState here
    else
        disp('ToggledState is false') % Respond to false ToggleState here
    end
end
end
```

```

        end
    end
end

```

The class `RespondToToggle` adds the listener from within its constructor. The class defines the callback (`handleEvt`) as a static method that accepts the two standard arguments:

- `src` — the handle of the object triggering the event (i.e., a `ToggleButton` object)
- `evtdata` — an `event.EventData` object

The listener executes the callback when the specific `ToggleButton` object executes the `notify` method, which it inherits from the `handle` class.

For example, create instances of both classes:

```

tb = ToggleButton;
rtt = RespondToToggle(tb);

```

Whenever you call the `ToggleButton` object's `OnStateChange` method, `notify` triggers the event:

```

tb.OnStateChange(true)
ToggledState is true

tb.OnStateChange(false)
ToggledState is false

```

Removing Listeners

You can remove a listener object by calling `delete` on its handle. For example, if the class `RespondToToggle` above saved the listener handle as a property, you could delete the listener:

```

classdef RespondToToggle < handle
    properties
        ListenerHandle
    end
    methods

```

```
function obj = RespondToToggle(toggle_button_obj)
    h1 = addlistener(toggle_button_obj, 'ToggledState', @RespondToToggle.handleEvt);
    obj.ListenerHandle = h1;
end
end
...
end
```

With this code change, you can remove the listener from an instance of the `RespondToToggle` class. For example:

```
tb = ToggleButton;
rtt = RespondToToggle(tb);
```

At this point, the object `rtt` is listening for the `ToggleState` event triggered by object `tb`. To remove the listener, call `delete` on the property containing the listener handle:

```
delete(rtt.ListenerHandle)
```

You do not need to explicitly delete a listener. MATLAB automatically deletes the listener when the object's lifecycle ends (e.g., when the `rtt` object is deleted).

See “Limiting Listener Scope — Constructing event.listener Objects Directly” on page 9-20 for related information.

Defining Event-Specific Data

Suppose that you want to pass to the listener callback the state of the toggle button as a result of the event. You can add more data to the default event data by subclassing the `event.EventData` class and adding a property to contain this information. You then can pass this object to the `notify` method.

```
classdef ToggleEventData < event.EventData
    properties
        NewState
    end

    methods
        function data = ToggleEventData(newState)
```



```

        data.NewState = newState;
    end
end
end

```

The call to `notify` uses the `ToggleEventData` constructor to create the necessary argument.

```
notify(obj, 'ToggledState', ToggleEventData(newState));
```

Ways to Create Listeners

When you call the `notify` method, the MATLAB runtime sends the event data to all registered listener callbacks. There are two ways to create a listener:

- Use the `addlistener` method, which binds the listener to the lifecycle of the object(s) that will generate the event. The listener object persists until the object it is attached to is destroyed.
- Use the `event.listener` class constructor. In this case, the listeners you create are not tied to the lifecycle of the object(s) being listened to. Instead the listener is active so long as the listener object remains in scope and is not deleted.

Attach Listener to Event Source — Using `addlistener`

The following code defines a listener for the `ToggleState` event:

```
lh = addlistener(obj, 'ToggleState', @CallbackFunction)
```

The arguments are:

- `obj` — The object that is the source of the event
- `ToggleState` — The event name passed as a string
- `@CallbackFunction` — A function handle to the callback function

The listener callback function must accept at least two arguments, which are automatically passed by the MATLAB runtime to the callback. The arguments are:

- The source of the event (that is, `obj` in the call to `addlistener`)

- An `event.EventData` object, or a subclass of `event.EventData`, such as the `ToggleEventData` object described earlier “Defining Event-Specific Data” on page 9-18.

The callback function must be defined to accept these two arguments:

```
function CallbackFunction(src, evnt)
    ...
end
```

In cases where the event data (`evnt`) object is user defined, it must be constructed and passed as an argument to the `notify` method. For example, the following statement constructs a `ToggleEventData` object and passes it to `notify` as the third argument:

```
notify(obj, 'ToggledState', ToggleEventData(newState));
```

“Defining Listener Callback Functions” on page 9-21 provides more information on callback syntax.

Limiting Listener Scope — Constructing `event.listener` Objects Directly

You can also create listeners by calling the `event.listener` class constructor directly. When you call the constructor instead of using `addListener` to create a listener, the listener exists only while the listener object you create is in scope (e.g., within the workspace of an executing function). It is not tied to the event-generating object’s existence.

The `event.listener` constructor requires the same arguments as used by `addListener` — the event-naming object, the event name, and a function handle to the callback:

```
lh = event.listener(obj, 'ToggleState', @CallbackFunction)
```

If you want the listener to persist beyond the normal variable scope, you should use `addListener` to create it.

Temporarily Deactivating Listeners

The `addListener` method returns the listener object so that you can set its properties. For example, you can temporarily disable a listener by setting its `Enabled` property to `false`:

```
lh.Enabled = false;
```

To re-enable the listener, set `Enabled` to `true`.

“Enabling and Disabling the Listeners” on page 9-46 provides an example.

Permanently Deleting Listeners

Calling `delete` on a listener object destroys it and permanently removes the listener:

```
delete(lh) % Listener object is removed and destroyed
```

Defining Listener Callback Functions

Callbacks are functions that execute when the listener receives notification of an event. Typically, you define a method in the class that creates the listener as the callback function. Pass a function handle that references the method to `addListener` or the `event.listener` constructor when creating the listener.

`function_handle` provides more information on function handles.

All callback functions must accept at least two arguments:

- The handle of the object that is the source of the event
- An `event.EventData` object or an object that is derived from the `event.EventData` class (see “Defining Event-Specific Data” on page 9-18 for an example that extends this class).

Adding Arguments to a Callback Function

Ordinary class methods (i.e., not static methods) require a class object as an argument, so you need to add another argument to the callback function definition. If your listener callback is a method of the class of an object, `obj`, then your call to `addListener` would use this syntax:

```
hlistener = addlistener(eventSourceObj, 'MyEvent', @obj.listenMyEvent)
```

Another syntax uses an anonymous function.

See the “Anonymous Functions” section for general information on anonymous functions

For example, create a method to use as your callback function and reference this method as a function handle in a call to `addlistener` or the `event.listener` constructor:

```
hlistener =  
addlistener(eventSourceObj, 'MyEvent', @(src, evnt)listenMyEvent(obj, src, evnt))
```

Then define the method in a method block as usual:

```
methods  
function listenMyEvent(obj, src, evnt)  
    % obj - instance of this class  
    % src - object generating event  
    % evnt - the event data  
    ...  
end  
end
```

“Variables Used in the Expression” provides information on variables used in anonymous functions.

Listening for Changes to Property Values

In this section...

“Creating Property Listeners” on page 9-23

“Example Property Event and Listener Classes” on page 9-25

“Aborting Set When Value Does Not Change” on page 9-27

Creating Property Listeners

You can listen to the predeclared property events (named: `PreSet`, `PostSet`, `PreGet`, and `PostGet`) by creating a listener for those named events:

- Specify the `SetObservable` and/or `GetObservable` property attributes to add listeners for set or get events.
- Define a callback function
- Create a property listener by including the name of the property as well as the event in the call to `addListener` (see “Add a Listener to the Property” on page 9-24.)
- Optionally subclass `event.data` to create a specialized event data object to pass to the callback function

Set Property Attributes to Enable Property Events

In the properties block, enable the `SetObservable` attribute:

```
properties (SetObservable)
% Can define PreSet and PostSet property listeners
% for properties defined in this block
    PropOne
    PropTwo
    ...
end
```

Define a Callback Function for the Property Event

The listener executes the callback function when MATLAB triggers the property event. You must define the callback function to have two specific

arguments, which are passed to the function automatically when called by the listener:

- Event source — a `meta.property` object describing the object that is the source of the property event
- Event data — a `event.PropertyEvent` object containing information about the event

You can pass additional arguments if necessary. It is often simple to define this method as `Static` because these two arguments contain most necessary information in their properties.

For example, suppose the `handlePropEvents` function is a static method of the class creating listeners for two properties of an object of another class:

```
methods (Static)
  function handlePropEvents(src, evnt)
    switch src.Name % switch on the property name
      case 'PropOne'
        % PropOne has triggered an event
        ...
      case 'PropTwo'
        % PropTwo has triggered an event
        ...
    end
  end
end
```

Another possibility is to use the `event.PropertyEvent` object's `EventName` property in the `switch` statement to key off the event name (`PreSet` or `PostSet` in this case).

“Working with Meta-Classes” on page 14-2 provides more information about the `meta.property` class.

Add a Listener to the Property

The `addlistener` handle class method enables you to attach a listener to a property without storing the listener object as a persistent variable. For a property events, use the four-argument version of `addlistener`.

If the call

```
addListener(EventObject, 'PropOne', 'PostSet', @ClassName.handlePropertyEvents);
```

The arguments are:

- `EventObject` — handle of the object generating the event
- `PropOne` — name of the property to which you want to listen
- `PostSet` — name of the event for which you want to listen
- `@ClassName.handlePropertyEvents` — function handle referencing a static method, which requires the use of the class name

If your listener callback is an ordinary method and not a static method, the syntax is:

```
addListener(EventObject, 'PropOne', 'PostSet', @obj.handlePropertyEvents);
```

where *obj* is the handle of the object defining the callback method.

If the listener callback is a function that is not a class method, you pass a function handle to that function. Suppose the callback function is a package function:

```
addListener(EventObject, 'PropOne', 'PostSet', @package.handlePropertyEvents);
```

See `function_handle` for more information on passing functions as arguments.

Example Property Event and Listener Classes

The following two classes show how to create `PostSet` property listeners for two properties — `PropOne` and `PropTwo`.

Class Generating the Event

The `PropEvent` class enables property `PreSet` and `PostSet` event triggering by specifying the `SetObservable` property attribute. These properties also enable the `AbortSet` attribute, which prevents the triggering of the property events if the properties are set to a value that is the same as their current value (see “Aborting Set When Value Does Not Change” on page 9-27)

```
classdef PropEvent < handle
    % enable property events with the SetObservable attribute
    properties (SetObservable, AbortSet)
        PropOne
        PropTwo
    end
    methods
        function obj = PropEvent(p1,p2)
            if nargin > 0
                obj.PropOne = p1;
                obj.PropTwo = p2;
            end
        end
    end
end
```

Class Defining the Listeners

The PropListener class defines two listeners:

- Property PropOne PostSet event
- Property PropTwo PostSet event

You could define listeners for other events or other properties using a similar approach and it is not necessary to use the same callback function for each listener. See the `meta.property` and `event.PropertyEvent` reference pages for more on the information contained in the arguments passed to the listener callback function.

```
classdef PropListener < handle
    methods
        function obj = PropListener(evtobj)
            % Pass the object generating the event to the constructor
            % Add the listeners from the constructor
            if nargin > 0
                addlistener(evtobj, 'PropOne', 'PostSet', @PropListener.handlePropEvents);
                addlistener(evtobj, 'PropTwo', 'PostSet', @PropListener.handlePropEvents);
            end
        end
    end
end
```



```
methods (Static)
function handlePropEvents(src, evnt)
    switch src.Name
        case 'PropOne'
            fprintf(1, 'PropOne is %s\n', num2str(evnt.AffectedObject.PropOne))
        case 'PropTwo'
            fprintf(1, 'PropTwo is %s\n', num2str(evnt.AffectedObject.PropTwo))
    end
end
end
end
end
```

Aborting Set When Value Does Not Change

By default, MATLAB triggers the property PreSet and PostSet events and sets the property value, even when the current value of the property is the same as the new value. You can prevent this behavior by setting the property's AbortSet attribute to true. When AbortSet is true, MATLAB does not:

- Set the property value
- Trigger the PreSet and PostSet events

When AbortSet is true, MATLAB gets the current property value to compare it to the value you are assigning to the property. This causes the property get method (`get.Property`) to execute, if one is defined. However, MATLAB does not catch errors resulting from the execution of this method and these errors are visible to the user.

How AbortSet Works

The following example shows how the AbortSet attribute works. The AbortTheSet class defines a property, PropOne, that has listeners for the PreGet and PreSet events and enables the AbortSet attribute. The behavior of the post set/get events is equivalent so only the pre set/get events are used for simplicity:

Note Save the AbortTheSet class in a file with the same name in a folder on your MATLAB path.

```
classdef AbortTheSet < handle
    properties (SetObservable, GetObservable, AbortSet)
        PropOne = 7
    end
    methods
        function obj = AbortTheSet(val)
            obj.PropOne = val;
            addlistener(obj, 'PropOne', 'PreGet', @obj.getPropEvt);
            addlistener(obj, 'PropOne', 'PreSet', @obj.setPropEvt);
        end
        function propval = get.PropOne(obj)
            disp('get.PropOne called')
            propval = obj.PropOne;
        end
        function set.PropOne(obj, val)
            disp('set.PropOne called')
            obj.PropOne = val;
        end
        function getPropEvt(obj, src, evt)
            disp('Pre-get event triggered')
        end
        function setPropEvt(obj, src, evt)
            disp('Pre-set event triggered')
        end
        function disp(obj)
            % Override disp to avoid accessing property
            disp(class(obj))
        end
    end
end
```

The class specifies an initial value of 7 for the PropOne property. Therefore, if you create an object with the property value of 7, there is not need to trigger the PreSet event:

```
>> ats = AbortTheSet(7);
get.PropOne called
```

If you specify a value other than 7, then MATLAB triggers the PreSet event:

```
>> ats = AbortTheSet(9);  
get.PropOne called  
set.PropOne called
```

Similarly, if you set the PropOne property to the value 9, the AbortSet attribute prevents the property assignment and the triggering of the PreSet event. Notice also, that there is not PreGet event generated. Only the property get method is called:

```
>> ats.PropOne = 9;  
get.PropOne called
```

If you query the property value, the PreGet event is triggered:

```
>> a = ats.PropOne  
Pre-get event triggered  
get.PropOne called
```

If you set the PropOne property to a different value, MATLAB:

- Calls the property get method to determine if the value is changing
- Triggers the PreSet event
- Calls the property set method to set the new value

```
>> ats.PropOne = 11;  
get.PropOne called  
Pre-set event triggered  
set.PropOne called
```

Example — Using Events to Update Graphs

In this section...

- “Example Overview” on page 9-30
- “Access Fully Commented Example Code” on page 9-31
- “Techniques Demonstrated in This Example” on page 9-32
- “Summary of `fcneval` Class” on page 9-32
- “Summary of `fcnview` Class” on page 9-33
- “Methods Inherited from `HandleClass`” on page 9-35
- “Using the `fcneval` and `fcnview` Classes” on page 9-35
- “Implementing the `UpdateGraph` Event and Listener” on page 9-38
- “Implementing the `PostSet` Property Event and Listener” on page 9-43
- “Enabling and Disabling the Listeners” on page 9-46

Example Overview

This example defines two classes:

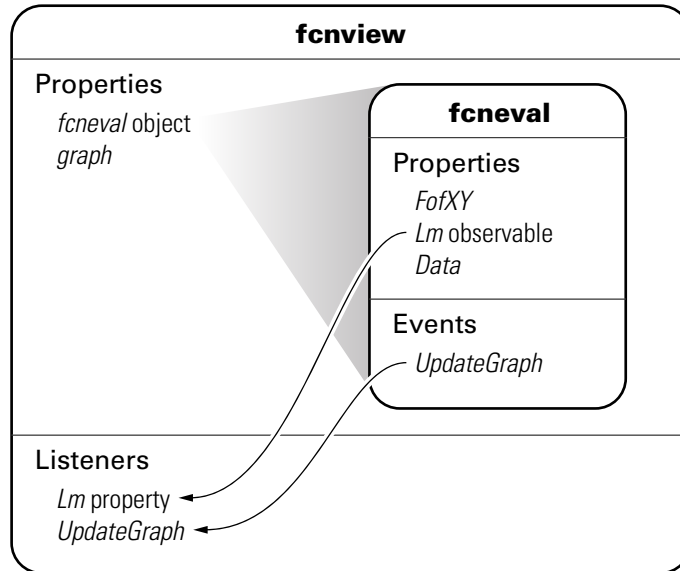
- `fcneval` — The function evaluator class contains a MATLAB expression and evaluates this expression over a specified range
- `fcnview` — The function viewer class contains a `fcneval` object and displays surface graphs of the evaluated expression using the data contained in `fcneval`.

This class defines two events:

- A class-defined event that occurs when a new value is specified for the MATLAB function
- A property event that occurs when the property containing the limits is changed

The following diagram shows the relationship between the two objects. The `fcnview` object contains a `fcneval` object and creates graphs from the data it

contains. `fcview` creates listeners to change the graphs if any of the data in the `fcneval` object change.



Access Fully Commented Example Code

You can display the code for this example in a popup window that contains detailed comments and links to related sections of the documentation by clicking these links:

[fcneval class](#)

[fcview class](#)

[createViews static method](#)

You can open all files in your editor by clicking this link:

[Open in editor](#)

To use the classes, save the files in folders with the following names:

- @fcneval/fcneval.m
- @fcnview/fcnview.m
- @fcnview/createViews.m

The @-folder's parent folder must be on the MATLAB path.

Techniques Demonstrated in This Example

- Naming an event in the class definition
- Triggering an event by calling `notify`
- Enabling a property event via the `SetObservable` attribute
- Creating listeners for class-defined events and property `PostSet` events
- Defining listener callback functions that accept additional arguments
- Enabling and disabling listeners

Summary of `fcneval` Class

The `fcneval` class is designed to evaluate a MATLAB expression over a specified range of two variables. It is the source of the data that is graphed as a surface by instances of the `fcnview` class. It is the source of the events used in this example.

Property	Value	Purpose
FofXY	function handle	MATLAB expression (function of two variables).
Lm	two-element vector	Limits over which function is evaluated in both variables. <code>SetObservable</code> attribute set to <code>true</code> to enable property event listeners.
Data	structure with <code>x</code> , <code>y</code> , and <code>z</code> matrices	Data resulting from evaluating the function. Used for surface graph. <code>Dependent</code> attribute set to <code>true</code> , which means the <code>get.Data</code> method is called to determine property value when queried and no data is stored.

Event	When Triggered
UpdateGraph	FofXY property set function (set.FofXY) calls the notify method when a new value is specified for the MATLAB expression on an object of this class.

Method	Purpose
fcneval	Class constructor. Inputs are function handle and two-element vector specifying the limits over which to evaluate the function.
set.FofXY	FofXY property set function. Called whenever property value is set, including during object construction.
set.Lm	Lm property set function. Used to test for valid limits.
get.Data	Data property get function. This method calculates the values for the Data property whenever that data is queried (by class members or externally).
grid	A static method (Static attribute set to true) used in the calculation of the data.

Summary of fcview Class

Instances of the fcview class contain fcneval objects as the source of data for the four surface graphs created in a function view. fcview creates the listeners and callback functions that respond to changes in the data contained in fcneval objects.

Property	Value	Purpose
FcnObject	fcneval object	This object contains the data that is used to create the function graphs.
HAxes	axes handle	Each instance of a fcview object stores the handle of the axes containing its subplot.

Property	Value	Purpose
HUpdateGraph	event.listener object for UpdateGraph event	Setting the event.listener object's Enabled property to true enables the listener; false disables listener.
HLLm	event.listener object for Lm property event	Setting the event.listener object's Enabled property to true enables the listener, false disables listener.
HEnableCm	uimenu handle	Item on context menu used to enable listeners (used to handle checked behavior)
HDisableCm	uimenu handle	Item on context menu used to disable listeners (used to manage checked behavior)
HSurface	surface handle	Used by event callbacks to update surface data.

Method	Purpose
fcnview	Class constructor. Input is fcneval object.
createLisn	Calls addlistener to create listeners for UpdateGraph and Lm property PostSet listeners.
lims	Sets axes limits to current value of fcneval object's Lm property. Used by event handlers.
updateSurfaceData	Updates the surface data without creating a new object. Used by event handlers.
listenUpdateGraph	Callback for UpdateGraph event.
listenLm	Callback for Lm property PostSet event
delete	Delete method for fcnview class.
createViews	Static method that creates an instance of the fcnview class for each subplot, defines the context menus that enable/disable listeners, and creates the subplots

Methods Inherited from Handle Class

Both the `fcneval` and `fcnview` classes inherit methods from the `handle` class. The following table lists only those inherited methods used in this example.

“Handle Class Methods” on page 5-12 provides a complete list of methods that are inherited when you subclass the `handle` class.

Methods Inherited from Handle Class	Purpose
<code>addlistener</code>	Register a listener for a specific event and attach listener to event-defining object.
<code>notify</code>	Trigger an event and notify all registered listeners.

Using the `fcneval` and `fcnview` Classes

This sections explains how to use the classes.

- Create an instance of the `fcneval` class to contain the MATLAB expression of a function of two variables and the range over which you want to evaluate this function
- Use the `fcnview` class static function `createViews` to visualize the function
- Change the MATLAB expression or the limits contained by the `fcneval` object and all the `fcnview` objects respond to the events generated.

You create a `fcneval` object by calling its constructor with two arguments—an anonymous function and a two-element, monotonically increasing vector.

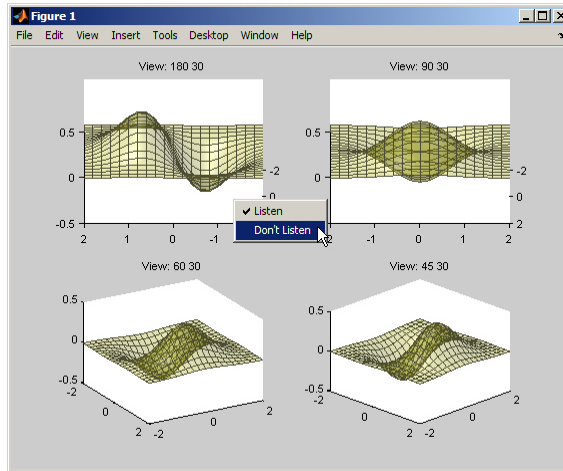
For example:

```
feobject = fcneval(@(x,y) x.*exp(-x.^2-y.^2), [-2 2]);
```

Use the `createViews` static method to create the graphs of the function. Note that you must use the class name to call a static function:

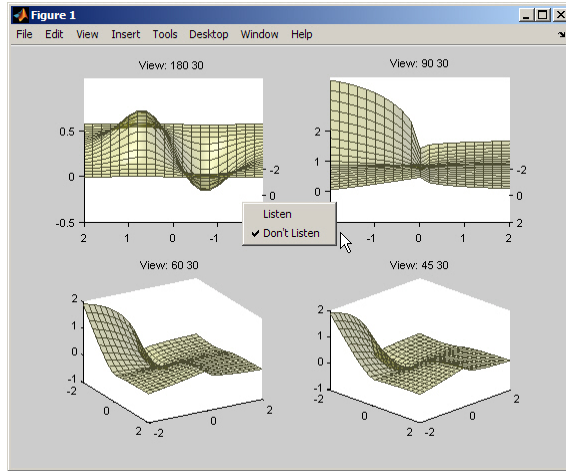
```
fcnview.createViews(feobject);
```

The `createView` method generates four views of the function contained in the `fcneval` object.



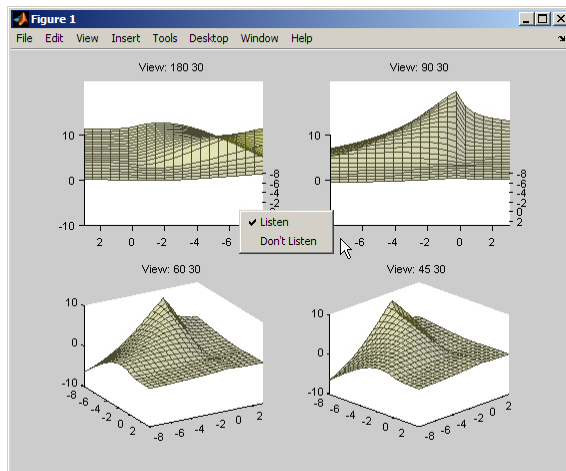
Each subplot defines a context menu that can enable and disable the listeners associated with that graph. For example, if you disable the listeners on subplot 221 (upper left) and change the MATLAB expression contained by the `fcneval` object, only the remaining three subplots update when the `UpdateGraph` event is triggered:

```
feobject.FofXY = @(x,y) x.*exp(-x.^.5-y.^.5);
```



Similarly, if you change the limits by assigning a value to the `feobject.Lm` property, the `feobject` triggers a `PostSet` property event and the listener callbacks update the graph.

```
feobject.Lm = [-8 3];
```



In this figure the listeners are re-enabled via the context menu for subplot 221. Because the listener callback for the property `PostSet` event also updates the surface data, all views are now synchronized

Implementing the UpdateGraph Event and Listener

The UpdateGraph event occurs when the MATLAB representation of the mathematical function contained in the `fcneval` object is changed. The `fcnview` objects that contain the surface graphs are listening for this event, so they can update the graphs to represent the new function.

Defining and Firing the UpdateGraph Event

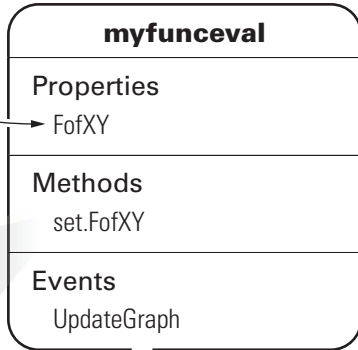
The UpdateGraph event is a class-defined event. The `fcneval` class names the event and calls `notify` when the event occurs.

1. A property is assigned a new value.

`obj.FofXY = @(x,y)x^2+y^2`

2. Setting the property runs a set access method, which, in turn, executes **notify**.

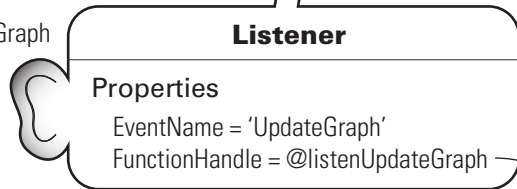
```
function set.FofXY(obj,func)
    obj.FofXY = func;
    notify(obj, 'UpdateGraph');
end
```



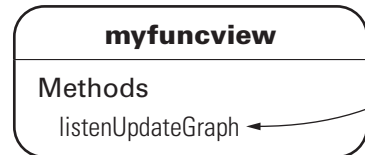
3. The **notify** method triggers an event, and a message is broadcast.

4. A listener awaiting the message executes its callback.

UpdateGraph



5. The callback function is executed.



The `fcnview` class defines a listener for this event. When `fcnview` triggers the event, the `fcnview` listener executes a callback function that performs the following actions:

- Determines if the handle of the surface object stored by the `fcnview` object is still valid (that is, does the object still exist)
- Updates the surface XData, YData, and ZData by querying the `fcnview` object's Data property.

The `fcneval` class defines an event name in an event block:

```
events
    UpdateGraph
end
```

Determining When to Trigger the Event

The `fcneval` class defines a property set method for the `FofXY` property. `FofXY` is the property that stores the MATLAB expression for the mathematical function. This expression must be a valid MATLAB expression for a function of two variables.

The `set.FofXY` method:

- Determines the suitability of the expression
- If the expression is suitable:
 - Assigns the expression to the `FofXY` property
 - Triggers the `UpdateGraph` event

If `fcneval.isSuitable` does not return an `MException` object, the `set.FofXY` method assigns the value to the property and triggers the `UpdateGraph` event.

```
function set.FofXY(obj,func)
% Determine if function is suitable to create a surface
me = fcneval.isSuitable(func);
if ~isempty(me)
    throw(me)
end
% Assign property value
obj.FofXY = func;
% Trigger UpdateGraph event
notify(obj, 'UpdateGraph');
end
```

Determining Suitability of the Expression

The `set.FofXY` method calls a static method (`fcneval.isSuitable`) to determine the suitability of the specified expression. `fcneval.isSuitable`

returns an `MException` object if it determines that the expression is unsuitable. `fcneval.isSuitable` calls the `MException` constructor directly to create more useful error messages for the user.

`set.FofXY` issues the exception using the `MException` `throw` method. Issuing the exception terminates execution of `set.FofXY` and prevents the method from making an assignment to the property or triggering the `UpdateGraph` event.

Here is the `fcneval.isSuitable` method:

```
function isOk = isSuitable(funcH)
    v = [1 1;1 1];
    % Can the expression except 2 numeric inputs
    try
        funcH(v,v);
    catch %#ok<CTCH>
        me = MException('DocExample:fcneval',...
            ['The function ',func2str(funcH),' Is not a suitable F(x,y)']);
        isOk = me;
        return
    end
    % Does the expression return non-scalar data
    if isscalar(funcH(v,v));
        me = MException('DocExample:fcneval',...
            ['The function ',func2str(funcH),' Returns a scalar when evaluated']);
        isOk = me;
        return
    end
    isOk = [];
end
```

The `fcneval.isSuitable` method could provide additional test to ensure that the expression assigned to the `FofXY` property meets the criteria required by the class design.

Other Approaches

The class could have implemented a property set event for the `FofXY` property and would, therefore, not need to call `notify` (see “Listening for Changes

to Property Values” on page 9-23). Defining a class event provides more flexibility in this case because you can better control event triggering.

For example, suppose you wanted to update the graph only if the new data is significantly different. If the new expression produced the same data within some tolerance, the `set.FofXY` method could not trigger the event and avoid updating the graph. However, the method could still set the property to the new value.

Defining the Listener and Callback for the UpdateGraph Event

The `fcnview` class creates a listener for the `UpdateGraph` event using the `addlistener` method:

```
obj.HLUpdateGraph =  
addlistener(obj.FcnObject, 'UpdateGraph', ...  
            @(src, evnt)listenUpdateGraph(obj, src, evnt));  
% Add obj to argument list
```

The `fcnview` object stores a handle to the `event.listener` object in its `HLUpdateGraph` property, which is used to enable/disable the listener by a context menu (see “Enabling and Disabling the Listeners” on page 9-46).

The `fcnview` object (`obj`) is added to the two default arguments (`src`, `evnt`) passed to the listener callback. Keep in mind, the source of the event (`src`) is the `fcneval` object, but the `fcnview` object contains the handle of the surface object that is updated by the callback.

The `listenUpdateGraph` function is defined as follows:

```
function listenUpdateGraph(obj, src, evnt)  
    if ishandle(obj.HSurface) % If surface exists  
        obj.updateSurfaceData % Update surface data  
    end  
end
```

The `updateSurfaceData` function is a class method that updates the surface data when a different mathematical function is assigned to the `fcneval` object. Updating a graphics object data is generally more efficient than creating a new object using the new data:


```
function updateSurfaceData(obj)
% Get data from fcneval object and set surface data
    set(obj.HSurface,...
        'XData',obj.FcnObject.Data.X,...
        'YData',obj.FcnObject.Data.Y,...
        'ZData',obj.FcnObject.Data.Matrix);
end
```

Implementing the PostSet Property Event and Listener

All properties support the predefined `PostSet` event (See “Property-Set and Query Events” on page 9-12 for more information on property events). This example uses the `PostSet` event for the `fcneval Lm` property. This property contains a two-element vector specifying the range over which the mathematical function is evaluated. Just after this property is changed (by a statement like `obj.Lm = [-3 5];`), the `fcnview` objects listening for this event update the graph to reflect the new data.

1. New limits are assigned.

```
obj.Lm = [-3 5];
```

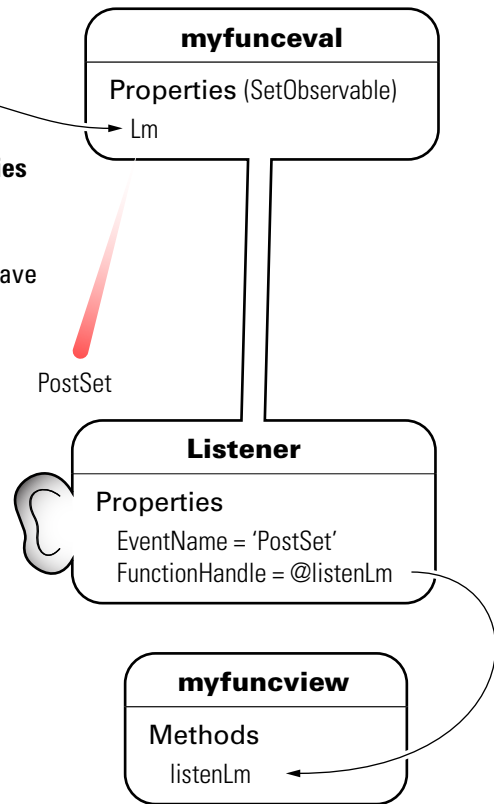
2. The **SetObservable** attribute of **Properties** is set to **True**, so setting the property automatically triggers a **PostSet** event.

Note that methods and events did not have to be declared in **myfuncval**.

3. A message is broadcast.

4. A listener awaiting the message executes its callback.

5. The callback function is executed.



Sequence During the Lm Property Assignment

The `fcneval` class defines a set function for the `Lm` property. When a value is assigned to this property during object construction or property reassignment, the following sequence occurs:

- 1 An attempt is made to assign argument value to `Lm` property.
- 2 The `set.Lm` method executes to check whether the value is in appropriate range — if yes, it makes assignment, if no, it generates an error.
- 3 If the value of `Lm` is set successfully, the MATLAB runtime triggers a `PostSet` event.

4 All listeners execute their callbacks, but the order is nondeterministic.

The `PostSet` event does not occur until an actual assignment of the property occurs. The property set function provides an opportunity to deal with potential assignment errors before the `PostSet` event occurs.

Enabling the `PostSet` Property Event

To create a listener for the `PostSet` event, you must set the property's `SetObservable` attribute to `true`:

```
properties (SetObservable = true)
    Lm = [-2*pi 2*pi]; % specifies default value
end
```

The MATLAB runtime automatically triggers the event so it is not necessary to call `notify`.

“Specifying Property Attributes” on page 6-7 provides a list of all property attributes.

Defining the Listener and Callback for the `PostSet` Event

The `fcnview` class creates a listener for the `PostSet` event using the `addlistener` method:

```
obj.HLLm = addlistener(obj.FcnObject, 'Lm', 'PostSet', ...
    @(src, evnt)listenLm(obj, src, evnt)); %
Add obj to argument list
```

The `fcnview` object stores a handle to the `event.listener` object in its `HLLm` property, which is used to enable/disable the listener by a context menu (see “Enabling and Disabling the Listeners” on page 9-46).

The `fcnview` object (`obj`) is added to the two default arguments (`src`, `evnt`) passed to the listener callback. Keep in mind, the source of the event (`src`) is the `fcneval` object, but the `fcnview` object contains the handle of the surface object that is updated by the callback.

The callback sets the axes limits and updates the surface data because changing the limits causes the mathematical function to be evaluated over a different range:

```
function listenLm(obj,src,evnt)
    if ishandle(obj.HAxes) % If there is an axes
        lims(obj); % Update its limits
        if ishandle(obj.HSurface) % If there is a surface
            obj.updateSurfaceData % Update its data
        end
    end
end
end
```

Enabling and Disabling the Listeners

Each `fcnview` object stores the handle of the listener objects it creates so that the listeners can be enabled or disabled via a context menu after the graphs are created. All listeners are instances of the `event.listener` class, which defines a property called `Enabled`. By default, this property has a value of `true`, which enables the listener. If you set this property to `false`, the listener still exists, but is disabled. This example creates a context menu active on the axes of each graph that provides a way to change the value of the `Enabled` property.

Context Menu Callback

There are two callbacks used by the context menu corresponding to the two items on the menu:

- **Listen** — Sets the `Enabled` property for both the `UpdateGraph` and `PostSet` listeners to `true` and adds a check mark next to the **Listen** menu item.
- **Don't Listen** — Sets the `Enabled` property for both the `UpdateGraph` and `PostSet` listeners to `false` and adds a check mark next to the **Don't Listen** menu item.

Both callbacks include the `fcnview` object as an argument (in addition to the required source and event data arguments) to provide access to the handle of the listener objects.

The `enableLisn` function is called when the user selects **Listen** from the context menu.

```
function enableLisn(obj,src,evnt)
    obj.HLUpdateGraph.Enabled = true; % Enable listener
    obj.HLLm.Enabled = true; % Enable listener
    set(obj.HEnableCm,'Checked','on') % Check Listen
    set(obj.HDisableCm,'Checked','off') % Uncheck Don't Listen
end
```

The disableLisn function is called when the user selects **Don't Listen** from the context menu.

```
function disableLisn(obj,src,evnt)
    obj.HLUpdateGraph.Enabled = false; % Disable listener
    obj.HLLm.Enabled = false; % Disable listener
    set(obj.HEnableCm,'Checked','off') % Uncheck Listen
    set(obj.HDisableCm,'Checked','on') % Check Don't Listen
end
```


Building on Other Classes

- “Hierarchies of Classes — Concepts” on page 10-2
- “Creating Subclasses — Syntax and Techniques” on page 10-7
- “Modifying Superclass Methods and Properties” on page 10-13
- “Subclassing Multiple Classes” on page 10-17
- “Subclassing MATLAB Built-In Classes” on page 10-19
- “Abstract Classes and Interfaces” on page 10-50

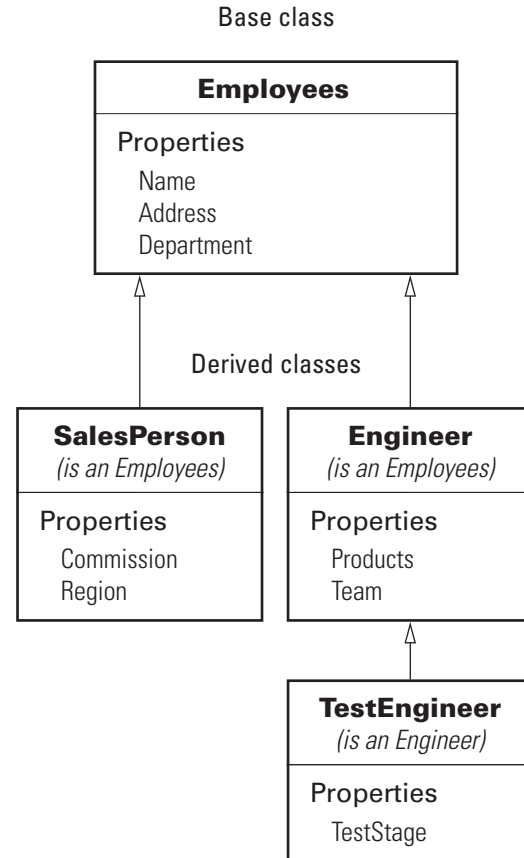
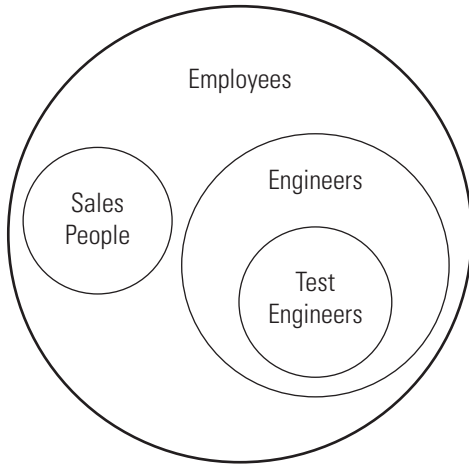
Hierarchies of Classes – Concepts

In this section...
“Classification ” on page 10-2
“Developing the Abstraction” on page 10-3
“Designing Class Hierarchies” on page 10-4
“Super and Subclass Behavior” on page 10-4
“Implementation and Interface Inheritance” on page 10-5

Classification

Organizing classes into hierarchies facilitates the reuse of code and the reuse of solutions to design problems that have already been solved. You can think of class hierarchies as sets — supersets (referred to as *superclasses* or *base classes*), and subsets (referred to as *subclasses* or *derived classes*). For example, the following picture shows how you could represent an employee database with classes.

Sales People and Engineers are subsets of Employees



At the root of the hierarchy is the **Employees** class. It contains data and operations that apply to the set of all employees. Contained in the set of employees are subsets whose members, while still employees, are also members of sets that more specifically define the type of employee. Subclasses like **TestEngineer** are examples of these subsets.

Developing the Abstraction

Classes are representations of real world concepts or things. When designing a class, form an abstraction of what the class represents. Consider an abstraction of an employee and what are the essential aspects of employees

for the intended use of the class. Name, address, and department can be what all employees have in common.

When designing classes, your abstraction must contain only those elements that are necessary. For example, the employee hair color and shoe size certainly characterize the employee, but are probably not relevant to the design of this employee class. Their sales region is relevant only to some employee so this characteristic belongs in a subclass.

Designing Class Hierarchies

As you design a system of classes, put common data and functionality in a superclass, which you can then use to derive subclasses. The subclasses inherit all the data and functionality of the superclass and contain only aspects that are unique to their particular purposes. This approach provides advantages:

- You avoid duplicating code that can be common to all classes.
- You can add or change subclasses at any time without modifying the superclass or affecting other derived classes.
- If the superclass changes (for example, all employees are assigned a badge number), then subclass automatically picks up these changes.

Super and Subclass Behavior

Subclass objects behave like objects of the superclass because they are specializations of the superclass. This fact facilitates the development of related classes that behave similarly, but are implemented differently.

A Subclass Object Is A Superclass Object

You usually can describe the relationship between an object of a subclass and an object of its superclass with a statement like:

The subclass is a superclass . For example: An Engineer is an Employee.

This relationship implies that objects belonging to a subclass have the same properties, methods, and events as the superclass, as well as any new features defined by the subclass.

Treat Subclass Objects Like Superclass Objects

You can pass a subclass object to a superclass method, but you can access only those properties that the superclass defines. This behavior enables you to modify the subclasses without affecting the superclass.

Two points about super and subclass behavior to keep in mind are:

- Methods defined in the superclass can operate on subclass objects.
- Methods defined in the subclass cannot operate on superclass objects.

Therefore, you can treat an `Engineer` object like any other `Employees` object, but an `Employee` object cannot pass for an `Engineer` object.

Limitations to Object Substitution

MATLAB determines the class of an object based on its most specific class. Therefore, an `Engineer` object is of class `Engineer`, while it is also an `Employees` object, as using the `isa` function reveals.

MATLAB does not allow you to create arrays containing a mix of superclass and subclass objects because an array can be of only one class. If you attempt to concatenate objects of different classes, MATLAB looks for a converter method defined by the less dominant class (generally, the left-most object in the expression is the dominant class).

See “Converting Objects to Another Class” on page 15-11 for information on defining converter methods.

See “Specifying Class Precedence” on page 4-17 for information on how to specify the precedence of one class to another.

Implementation and Interface Inheritance

MATLAB classes support both the inheritance of implemented methods from a superclass and the inheritance of interfaces defined by abstract methods in the superclass.

Implementation inheritance enables code reuse by subclasses. For example, an `employee` class can have a `submitStatus` method that all `employee`

subclasses can use. Subclasses can extend an inherited method to provide specialized functionality, while reusing the common aspects. See “Modifying Superclass Methods and Properties” on page 10-13 for more information on this process.

Interface inheritance is useful in cases where you want a group of classes to provide a common interface, but these classes create specialized implementations of methods and properties that define the interface. You create an

interface using an abstract class as the superclass. This class defines the methods and properties that you must implement in the subclasses, but does not provide an implementation, in contrast to implementation inheritance.

The subclasses must provide their own implementation of the abstract members of the superclass. To create an interface, define methods and properties as abstract using their `Abstract` attribute.

See “Abstract Classes and Interfaces” on page 10-50 for more information and an example.

Creating Subclasses — Syntax and Techniques

In this section...

“Defining a Subclass” on page 10-7

“Referencing Superclasses from Subclasses” on page 10-7

“Constructor Arguments and Object Initialization” on page 10-9

“Call Only Direct Superclass from Constructor” on page 10-10

“Sequence of Constructor Calls in a Class Hierarchy” on page 10-11

“Using a Subclass to Create an Alias for an Existing Class” on page 10-12

Defining a Subclass

To define a class that is a subclass of another class, add the superclass to the `classdef` line after a `<` character:

```
classdef classname < superclassname
```

When inheriting from multiple classes, use the `&` character to indicate the combination of the superclasses:

```
classdef classname < super1 & super2
```

See “Class Member Compatibility” on page 10-17 for more information on deriving from multiple superclasses.

Class Attributes

Subclasses do not inherit superclass attributes.

Referencing Superclasses from Subclasses

When you construct an instance of a subclass, use the `obj@baseclass1(args)` syntax to initialize the object for each superclass. For example, the following segment of a class definition shows a class called `stock` that is a subclass of a class called `asset`.

```
classdef stock < asset
    methods
```

```

        function s = stock(asset_args,...)
            if nargin == 0
                ...
            end
            s = s@asset(asset_args); % call asset constructor
            ...
        end
    end
end

```

“Constructing Subclasses” on page 7-19 provides more information on creating subclass constructor methods.

Referencing Superclasses Contained in Packages

If you are deriving a class from a superclass that is contained in a package and you want to initialize the object for the superclass, include the package name. For example:

```

classdef stock < financial.asset
    methods
        function s = stock(asset_args,...)
            if nargin == 0
                ...
            end
            s = s@financial.asset(asset_args); % call asset constructor
            ...
        end
    end
end

```

Initializing Objects When Using Multiple Superclasses

If you are deriving a class from multiple superclasses, initialize the subclass object with calls to each superclass constructor:

```

classdef stock < financial.asset & trust.member
    methods
        function s = stock(asset_args,member_args,...)
            if nargin == 0

```

```

        ...
        end
        s = s@financial.asset(asset_args) % call asset constructor
        s = s@trust.member(member_args) % call member constructor
        ...
    end
end
end

```

Explicitly calling each superclass constructor enables you to:

- Pass arguments to superclass constructors
- Control the order in which MATLAB calls the superclass constructors

If you do not explicitly call the superclass constructors from the subclass constructor, MATLAB implicitly calls these constructors with no arguments. Therefore, the superclass constructors must support no argument syntax. See “Supporting the No Input Argument Case” on page 7-18 for more information.

In the case of multiple superclasses, MATLAB does not guarantee any specific calling sequence. If the order in which MATLAB calls the superclass constructors is important, you must explicitly call the superclass constructors from the subclass constructor.

Constructor Arguments and Object Initialization

You cannot conditionalize calls to the superclass initialization of the object. However, always ensure that your class constructor supports the zero arguments syntax.

You can satisfy the need for a zero-argument syntax by assigning appropriate values to input argument variables before constructing the object:

```

classdef stock < financial.asset
    properties
        SharePrice
    end
    methods
        function s = stock(name,pps)
            if nargin == 0

```

```
        name = '';
        pps = 0;
    end
    s = s@financial.asset(name) % call superclass constructor
    s.SharePrice = pps;        % assign a property value
end
end
end
```

See “Supporting the No Input Argument Case” on page 7-18.

Call Only Direct Superclass from Constructor

You cannot call an indirect superclass constructor from a subclass constructor. For example, suppose class B derives from class A and class C derives from class B. The constructor for class C cannot call the constructor for class A to initialize properties. Class B must make the call to initialize class A properties.

The following implementations of classes A, B, and C show how to design this relationship among the classes.

Class A defines properties x and y, but assigns a value only to x:

```
classdef A
    properties
        x
        y
    end
    methods
        function obj = A(x)
            obj.x = x;
        end
    end
end
```

Class B inherits properties x and y from class A. The class B constructor calls the class A constructor to initialize x and then assigns a value to y.

```
classdef B < A
    methods
```



```

        function obj = B(x,y)
            obj = obj@A(x);
            obj.y = y;
        end
    end
end

```

Class C accepts values for the properties x and y and passes these values to the class B constructor, which in turn calls the class A constructor:

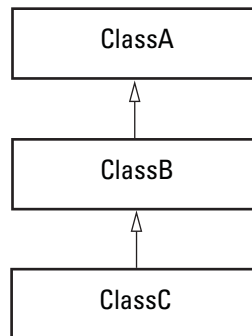
```

classdef C < B
    methods
        function obj = C(x,y)
            obj = obj@B(x,y);
        end
    end
end

```

Sequence of Constructor Calls in a Class Hierarchy

MATLAB always calls the most specific subclass constructor first to enable you to call superclass constructors explicitly. Suppose you have a hierarchy of class in which ClassC derives from ClassB, which derives from ClassA:



MATLAB always calls the most specific class constructor (ClassC in this case) first. This approach enables you to process input arguments and perform any necessary setup before calling the superclass constructors.

If you do not make an explicit call to a superclass constructor from the subclass constructor, MATLAB makes the implicit call before accessing the object. The order is always from most specific to least specific and all the superclass constructors must finish executing before the subclass can access the object.

You can change the order in which class constructors are called by calling superclass constructors explicitly from the subclass constructor.

Using a Subclass to Create an Alias for an Existing Class

You can refer to a class using a different name by creating an alias for that class. This technique is like the C++ `typedef` concept. To create an alias, create an empty subclass:

```
classdef newclassname < oldclassname
end
```

The old class constructor must be callable with zero input arguments. If not, see “Old Class Constructor Requires Arguments” on page 10-12.

This technique is useful when reloading objects that you saved using the old class name. However, the class of the object reflects the new name. For example,

```
class(obj)
```

returns the new class name.

Old Class Constructor Requires Arguments

If the old class constructor requires arguments, add a constructor to the new class:

```
classdef NewClass < OldClass
    methods
        function obj = NewClass(x,y)
            obj = obj@OldClass(x,y);
        end
    end
end
```

Modifying Superclass Methods and Properties

In this section...

“Modifying Superclass Methods” on page 10-13

“Modifying Superclass Properties” on page 10-15

“Private Local Property Takes Precedence in Method” on page 10-15

Modifying Superclass Methods

An important concept to keep in mind when designing classes is that a subclass object is also an object of its superclass. Therefore, you can pass a subclass object to a superclass method and have the method execute properly. At the same time, you can apply special processing to the unique aspects of the subclass. Some useful techniques include:

- Calling a superclass method from within a subclass method
- Redefining in the subclass protected methods called from within a public superclass method
- Defining the same named methods in both super and subclass, but using different implementations

Extending Superclass Methods

Subclass methods can call superclass methods of the same name. This fact enables you to extend a superclass method in a subclass without completely redefining the superclass method. For example, suppose that both superclass and subclass defines a method called `foo`. The method names are the same so the subclass method can call the superclass method. However, the subclass method can also perform other steps before and after the call to the superclass method. It can operate on the specialized parts to the subclass that are not part of the superclass.

For example, this subclass defines a `foo` method, which calls the superclass `foo` method

```
classdef sub < super
    methods
```

```
function foo(obj)
    preprocessing steps
    foo@super(obj); % Call superclass foo method
    postprocessing steps
end
end
end
```

See “Invoking Superclass Methods in Subclass Methods” on page 7-13 for more on this syntax.

Completing Superclass Methods

A superclass method can define a process that executes in a series of steps using a protected method for each step (`Access` attribute set to `protected`). Subclasses can then create their own versions of the protected methods that implement the individual steps in the process.

Implement this technique as shown here:

```
classdef super
    methods
        function foo(obj)
            step1(obj)
            step2(obj)
            step3(obj)
        end
    end
    methods (Access = protected)
        function step1(obj)
            superclass version
        end
        ...
    end
end
```

The subclass does not reimplement the `foo` method, it reimplements only the methods that carry out the series of steps (`step1(obj)`, `step2(obj)`, `step3(obj)`). That is, the subclass can specialize the actions taken by each step, but does not control the order of the steps in the process. When you pass

a subclass object to the superclass `foo` method, MATLAB calls the subclass step methods because of the dispatching rules.

```
classdef sub < super
    ...
    methods (Access = protected)
        function step1(obj)
            subclass version
        end
    end
    ...
end
end
```

Redefining Superclass Methods

You can completely redefine a superclass method. In this case, both the superclass and the subclass would define the same named method.

Modifying Superclass Properties

There are two separate conditions under which you can redefine superclass properties:

- The value of the superclass property `Abstract` attribute is `true`
- The values of the superclass property `SetAccess` and `GetAccess` attributes are `private`

In the first case, the superclass is just requesting that you define a concrete version of this property to ensure a consistent interface. In the second case, only the superclass can access the private property, so the subclass is free to reimplement it in any way.

Private Local Property Takes Precedence in Method

When a subclass property has the same name as a superclass private property, and a method of the superclass references the property name, MATLAB always accesses the property defined by the calling method's class. For example, given the following classes, `Sub` and `Super`:

```
classdef Super
```

```
        properties (Access = private)
            Prop = 2;
        end
        methods
            function p = superMethod(obj)
                p = obj.Prop;
            end
        end
    end

classdef Sub < Super
    properties
        Prop = 1;
    end
end
```

If you create an instance of the subclass and use it to call the superclass method, MATLAB access the private property of the method's class:

```
>> subObj = Sub
subObj =

    Sub

    Properties:
        Prop: 1

    Methods, Superclasses
>> obj.superMethod
ans =

     2
```

Subclassing Multiple Classes

Class Member Compatibility

When you create a subclass derived from multiple classes, the subclass inherits the properties, methods, and events defined by all specified superclasses. If more than one superclass defines a property, method, or event having the same name, there must be an unambiguous resolution to the multiple definitions. You cannot derive a subclass from any two or more classes that define incompatible class members.

There are various situations where you can resolve name and definition conflicts, as described in the following sections.

Property Conflicts

If two or more superclasses define a property with the same name, then at least one of the following must be true:

- All, or all but one of the properties must have their `SetAccess` and `GetAccess` attributes set to `private`
- The properties have the same definition in all superclasses (for example, when all superclasses inherited the property from a common base class)

Method Conflicts

If two or more superclasses define methods with the same name, then at least one of the following must be true:

- The method's `Access` attribute is `private` so only the defining superclass can access the method.
- The method has the same definition in all derived classes. This situation can occur when all superclasses inherit the method from a common base class and none of the superclasses override the inherited definition.
- The subclass redefines the method to disambiguate the multiple definitions across all superclasses. This means that the superclass methods must not have their `Sealed` attribute set to `true`.

- Only one superclass defines the method as `Sealed`, in which case, the subclass adopts the sealed method definition.
- The superclasses define the methods as `Abstract` and rely on the subclass to define the method.

Event Conflicts

If two or more superclasses define events with the same name, then at least one of the following must be true:

- The event's `ListenAccess` and `NotifyAccess` attributes must be `private`.
- The event has the same definition in all superclasses (for example, when all superclasses inherited the event from a common base class)

Using Multiple Inheritance

Resolving the potential conflicts involved when defining a subclass from multiple classes often reduces the value of this approach. For example, problems can arise when you enhance superclasses in future versions and introduce new conflicts.

Reduce potential problems by implementing only one unrestricted superclass. In all other superclasses, all methods are abstract and must be defined by a subclass or inherited from the unrestricted superclass.

In general, when using multiple inheritance, ensure that all superclasses remain free of conflicts in definition.

See “Defining a Subclass” on page 10-7 for the syntax used to derive a subclass from multiple superclasses.

Subclassing MATLAB Built-In Classes

In this section...

“MATLAB Built-In Classes” on page 10-19

“Why Subclass Built-In Classes” on page 10-19

“Behavior of Built-In Functions with Subclass Objects” on page 10-21

“Example — A Class to Manage uint8 Data” on page 10-28

“Example — Adding Properties to a Built-In Subclass” on page 10-35

“Understanding size and numel” on page 10-41

“Example — A Class to Represent Hardware” on page 10-46

MATLAB Built-In Classes

Built-in classes represent fundamental kinds of data such as numeric arrays, logical arrays, and character arrays. Other built-in classes combine data belonging to these fundamental classes. For example, `cell` and `struct` arrays contain instances of fundamental classes.

Built-in classes define methods that perform operations on objects of these classes. For example, you can perform operations on numeric arrays, such as, sorting, rounding values, and element-wise and matrix multiplication. You can create an object of class `double` using an assignment statement, indexing expressions, or using converter functions.

See “Classes (Data Types)” for more information on MATLAB built-in classes.

Note It is an error to define a class that has the same name as a built-in class.

Why Subclass Built-In Classes

Subclass a built-in class to extend the operations that you can perform on a particular class of data. For example, when you want to:

- Define unique operations to perform on class data. For example, subclass `double` and add methods to your subclass that restrict values to prime numbers.
- Be able to use methods of the built-in class and other built-in functions directly with objects of the subclass. For example, you do not need to reimplement all the mathematical and array manipulation operators if you derived from a class that has these operators already.

See “Built-In Classes You Cannot Subclass” on page 10-20 for a list of which MATLAB built-in classes you can subclass.

Which Functions Work With Subclasses of Built-Ins

Consider a class that defines enumerations. It can derive from an integer class and inherit methods that enable you to compare and sort values. For example, integer classes like `int32` support all the relational methods (`eq`, `ge`, `gt`, `le`, `lt`, `ne`).

To see a list of functions that the subclass has inherited as methods, use the `methods` function:

```
methods('SubclassName')
```

Generally, you can use an object of the subclass with any of the inherited methods and any functions coded in MATLAB that normally accept input arguments of the same class as the superclass.

See “Behavior of Built-In Functions with Subclass Objects” on page 10-21 for information on other required methods.

Built-In Classes You Cannot Subclass

You cannot subclass the following built-in MATLAB classes:

- `char`
- `cell`
- `struct`
- `function_handle`

Examples of Subclasses of Built-In Classes

“Example — A Class to Manage uint8 Data” on page 10-28

“Example — Adding Properties to a Built-In Subclass” on page 10-35

“Example — A Class to Represent Hardware” on page 10-46

Behavior of Built-In Functions with Subclass Objects

When you define a subclass of a built-in class, the subclass inherits all built-in class methods. In addition, MATLAB provide a number of built-in functions as subclass methods. However, built-in functions that work on built-in classes behave differently with subclasses, depending on which function you are using and whether your subclass defines properties.

Behavior Categories

When you call an inherited method on a subclass of a built-in class, the result of that call depends on the nature of the operation performed by the method. The behaviors of these methods fit into several categories.

- Operations on data values return objects of the superclass. For example, if you subclass `double` and perform addition on two subclass objects, MATLAB adds the numeric values and returns a value of class `double`.
- Operations on the orientation or structure of the data return objects of the subclass. Methods that perform these kinds of operations include, `reshape`, `permute`, `transpose`, and so on.
- Converting a subclass object to a built-in class returns an object of the specified class. Functions such as `uint32`, `double`, `char`, and so on, work with subclass objects the same as they work with superclass objects.
- Comparing objects or testing for inclusion in a specific set returns logical or built-in objects, depending on the function. Functions such as `isequal`, `ischar`, `isobject`, and so on.
- Indexing expressions return objects of the subclass. If the subclass defines properties, then default indexing no longer works and the subclass must define its own indexing methods. See “Subclasses That Define Properties” on page 10-22 for more information.

- Concatenation returns an object of the subclass. If the subclass defines properties, then default concatenation no longer works and the subclass must define its own concatenation methods. See “Subclasses That Define Properties” on page 10-22 for more information.

To list the built-in functions that work with a subclass of a built-in class, use the `methods` function.

Subclasses That Define Properties

When a subclass of a built-in class defines properties, MATLAB no longer provides support for indexing and concatenation operations. MATLAB cannot use the built-in functions normally called for these operations because subclass properties can contain any data. The subclass must define what indexing and concatenation mean for a class with properties. If your subclass needs indexing and concatenation functionality, then the subclass must implement the appropriate methods.

The sections that follow list the methods you must implement in the subclass to support indexing and concatenation. Also, the section “Example — Adding Properties to a Built-In Subclass” on page 10-35 provides an example of these methods.

Methods for Concatenation. To support concatenation, the subclass must implement the following methods:

- `horzcat` — Implement horizontal concatenation of objects
- `vertcat` — Implement vertical concatenation of objects
- `cat` — Implement concatenation of object arrays along specified dimension

“Concatenation Functions” on page 10-26

Methods for Indexing. To support indexing operations, the subclass must implement these methods:

- `subsasgn` — Implement dot notation and indexed assignments
- `subsref` — Implement dot notation and indexed references
- `subsindex` — Implement object as index value

“Indexing Methods” on page 10-26

More information on Built-In Methods

The following sections describe how different categories of methods behave with subclasses:

- “Extending the Operations of a Built-In Class” on page 10-23
- “Built-In Methods That Operate on Data Values” on page 10-25
- “Built-In Methods That Operate on Data Organization” on page 10-25

Extending the Operations of a Built-In Class

The MATLAB built-in class `double` defines a wide range of methods to perform arithmetic operations, indexing, matrix operation, and so on. Therefore, subclassing `double` enables you to add specific features without implementing many of the methods that a numeric class requires to function effectively in the MATLAB language.

The following class definition subclasses the built-in class `double`.

```
classdef DocSimpleDouble < double
    methods
        function obj = DocSimpleDouble(data)
            if nargin == 0
                data = 0;
            end
            obj = obj@double(data); % initialize the base class portion
        end
    end
end
```

You can create an instance of the class `DocSimpleDouble` and call any methods of the `double` class.

```
sc = DocSimpleDouble(1:10);
sc =
    DocSimpleDouble
    double data:
         1         2         3         4         5         6         7         8         9        10
```

Methods, Superclasses

Calling a method inherited from class `double` that operates on the data, like `sum`, returns a `double` and, therefore, uses the `display` method of class `double`:

```
sum(sc)
ans =
    55
```

You can index `sc` like an array of doubles. The returned value is the class of the subclass, not `double`:

```
a = sc(2:4)
a =
    DocSimpleDouble
double data:
     2     3     4
Methods, Superclasses
```

Indexed assignment also works:

```
sc(1:5) = 5:-1:1
sc =
    DocSimpleDouble
double data:
     5     4     3     2     1     6     7     8     9    10
Methods, Superclasses
```

Calling a method that modifies the order of the data elements operates on the data, but returns an object of the subclass:

```
sc = DocSimpleDouble(1:10);
sc(1:5) = 5:-1:1;
a = sort(sc)
a =
    DocSimpleDouble
double data:
     1     2     3     4     5     6     7     8     9    10
Methods, Superclasses
```

Extending the Subclass. You can extend the `DocSimpleDouble` with specialized methods to provide custom behavior. For example, see “Example — A Class to Manage uint8 Data” on page 10-28.

Built-In Methods That Operate on Data Values

Most built-in functions used with built-in classes are actually methods of the built-in class. For example, the `double` and `single` classes both have a `sin` method. All of these built-in class methods work with subclasses of the built-in class.

When you call a built-in method on a subclass object, MATLAB uses the superclass part of the subclass object as inputs to the method, and the value returned is same class as the built-in class. For example:

```
sc = DocSimpleDouble(1:10);  
a = sin(sc)  
class(a)  
  
ans =  
  
double
```

Built-In Methods That Operate on Data Organization

This group of built-in methods reorders or reshapes the input argument array. These methods operate on the superclass part of the subclass object, but return an object of the same type as the subclass. Methods in this group include:

- `reshape`
- `permute`
- `sort`
- `transpose`
- `ctranspose`

Indexing Methods

Built-in classes use specially implemented versions of the `subsref`, `subsasgn`, and `subsindex` methods to implement indexing (subscripted reference and assignment). When you index a subclass object, only the built-in data is referenced (not the properties defined by your subclass). For example, indexing element 2 in the `DocSimpleDouble` subclass object returns the second element in the vector:

```
sc = DocSimpleDouble(1:10);
a = sc(2)
a =
    DocSimpleDouble
    double data:
         2
    Methods, Superclasses
```

The value returned from an indexing operation is an object of the subclass. You cannot make subscripted references if your subclass defines properties unless your subclass overrides the default `subsref` method.

Assigning a new value to the second element in the `DocSimpleDouble` object operates only on the superclass data:

```
sc(2) = 12
sc =
    DocSimpleDouble
    double data:
         1    12     3     4     5     6     7     8     9    10
    Methods, Superclasses
```

The `subsref` method also implements dot notation for methods. See “Example — Adding Properties to a Built-In Subclass” on page 10-35 for an example of a `subsref` method.

Concatenation Functions

Built-in classes use the functions `horzcat`, `vertcat`, and `cat` to implement concatenation. When you use these functions with subclass objects of the same type, MATLAB concatenates the superclass data to form a new object. For example, you can concatenate objects of the `DocSimpleDouble` class:


```

sc1 = DocSimpleDouble(1:10);
sc2 = DocSimpleDouble(11:20);
[sc1 sc2]
ans =
    DocSimpleDouble
    double data:
    Columns 1 through 13
         1     2     3     4     5     6     7     8     9    10    11    12    13
    Columns 14 through 20
         14    15    16    17    18    19    20
    Methods, Superclasses
[sc1; sc2]
ans =
    DocSimpleDouble
    double data:
         1     2     3     4     5     6     7     8     9    10
        11    12    13    14    15    16    17    18    19    20
    Methods, Superclasses

```

Concatenate two objects along a third dimension:

```

c = cat(3,sc1,sc2)
c = cat(3,sc1,sc2)
c =
    DocSimpleDouble
    double data:
    (:,:,1) =
         1     2     3     4     5     6     7     8     9    10
    (:,:,2) =
        11    12    13    14    15    16    17    18    19    20
    Methods, Superclasses

```

If the subclass of built-in class defines properties, you cannot concatenate objects of the subclass. Such an operation does not make sense because there is no way to know how to combine properties of different objects. However, your subclass can define custom `horzcat` and `vertcat` methods to support concatenation in whatever way makes sense for your subclass. See “Concatenating DocExtendDouble Objects” on page 10-40 for an example.

Example – A Class to Manage uint8 Data

This example shows a class derived from the built-in `uint8` class. This class simplifies the process of maintaining a collection of intensity image data defined by `uint8` values. The basic operations of the class include:

- Capability to convert various classes of image data to `uint8` to reduce object data storage.
- A method to display the intensity images contained in the subclass objects.
- Ability to use all the methods that you can use on `uint8` data (for example, `size`, indexing (reference and assignment), `reshape`, `bitshift`, `cat`, `fft`, arithmetic operators, and so on).

The class data are matrices of intensity image data stored in the superclass part of the subclass object. This approach requires no properties.

The `DocUint8` class stores the image data, which converts the data, if necessary:

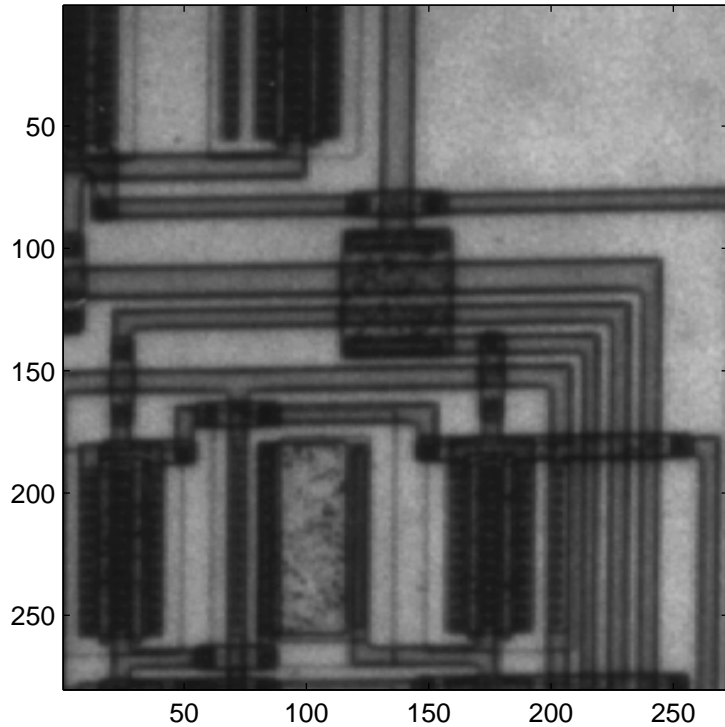
```
classdef DocUint8 < uint8
    methods
        function obj = DocUint8(data)
            % Support no argument case
            if nargin == 0
                data = uint8(0);
            % If image data is not uint8, convert to uint8
            elseif ~strcmp('uint8',class(data))
                switch class(data)
                    case 'uint16'
                        t = double(data)/65535;
                        data = uint8(round(t*255));
                    case 'double'
                        data = uint8(round(data*255));
                    otherwise
                        error('Not a supported image class')
                end
            end
            % assign data to superclass part of object
            obj = obj@uint8(data);
        end
    end
end
```

```
% Get uint8 data and setup call to imagesc
function h = showImage(obj)
    data = uint8(obj);
    figure; colormap(gray(256))
    h = imagesc(data,[0 255]);
    axis image
    brighten(.2)
end
end
end
```

Using the DocUint8 Class

The DocUint8 class contains its own conversion code and provides a method to display all images stored as DocUint8 objects in a consistent way. For example:

```
cir = imread('circuit.tif');
img1 = DocUint8(cir);
img1.showImage;
```



Because `DocUint8` subclasses `uint8`, you can use any of its methods. For example,

```
size(img1)
ans =
    280    272
```

returns the size of the image data.

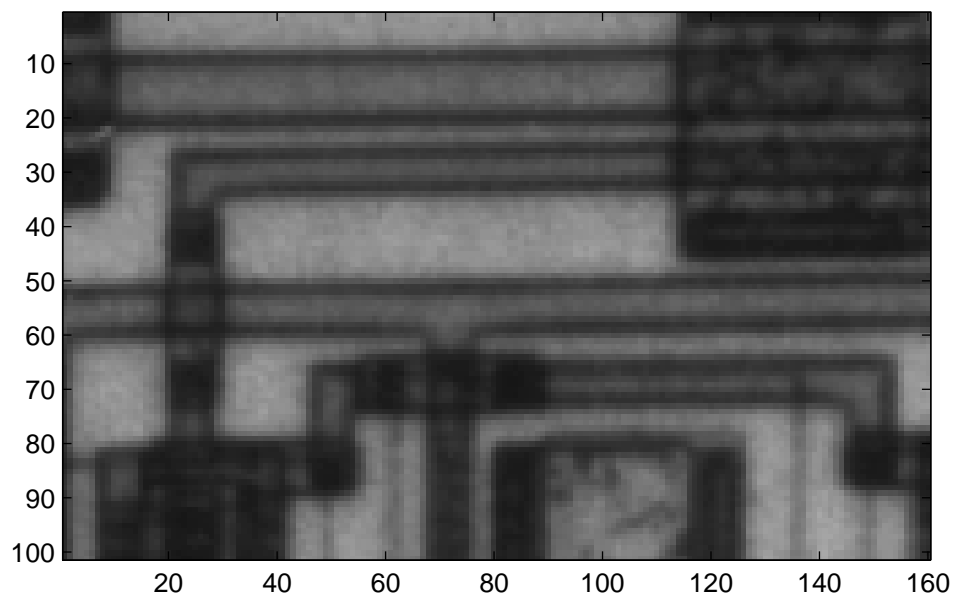
Indexing Operations

Inherited methods perform indexing operations, but return objects of the same class as the subclass.

Therefore, you can index into the image data and call a subclass method:

```
showImage(img1(100:200,1:160));
```

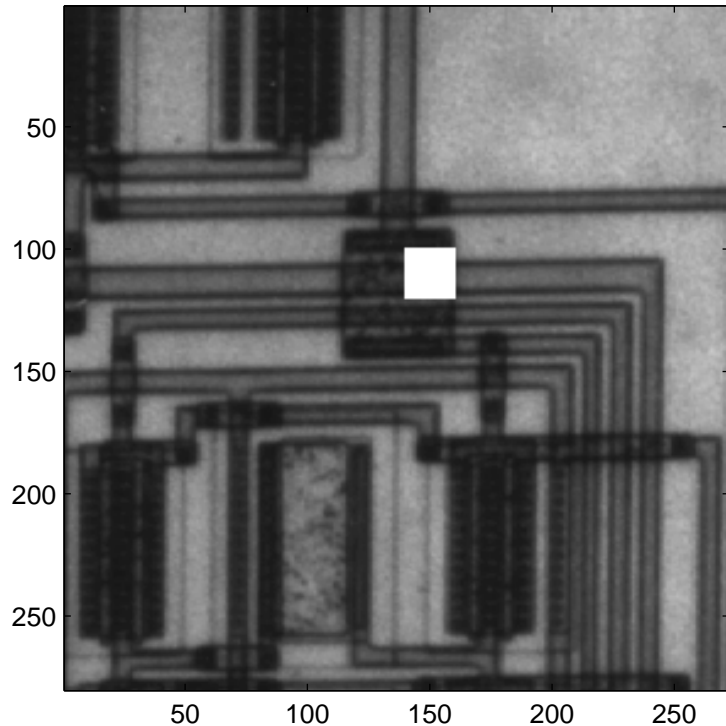
Subscripted reference operations (controlled by the inherited `subsref` method) return a `DocUint8` object.



You can assign values to indexed elements:

```
img1(100:120,140:160) = 255;  
img1.showImage;
```

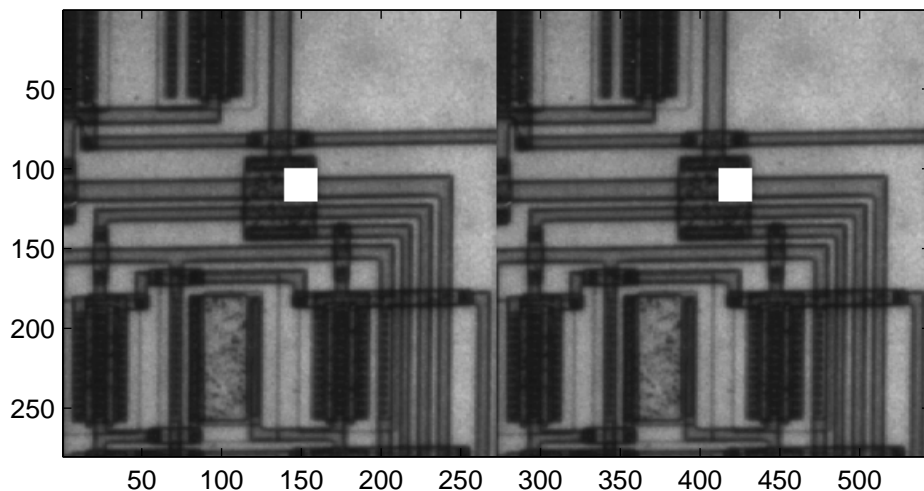
Subscripted assignment operations (controlled by the inherited `subsasgn` method) return a `DocUint8` object.



Concatenation Operations

Concatenation operations work on `DocUint8` objects because this class inherits the `uint8` `horzcat` and `vertcat` methods, which return a `DocUint8` object:

```
showImage([img1 img1]);
```



Data Operations

Methods that operate on data values, such as arithmetic operators, always return an object of the built-in type (not of the subclass type). For example, multiplying `DocUint8` objects returns a `uint8` object:

```
showImage(img1.*.8);  
??? Undefined function or method 'showImage' for input  
arguments of type 'uint8'.
```

If you must be able to perform operations of this type, implement a subclass method to override the inherited method. The `times` method implements

array (element-by-element) multiplication. See “Implementing Operators for Your Class” on page 15-35 for a list of operator method names.

For example:

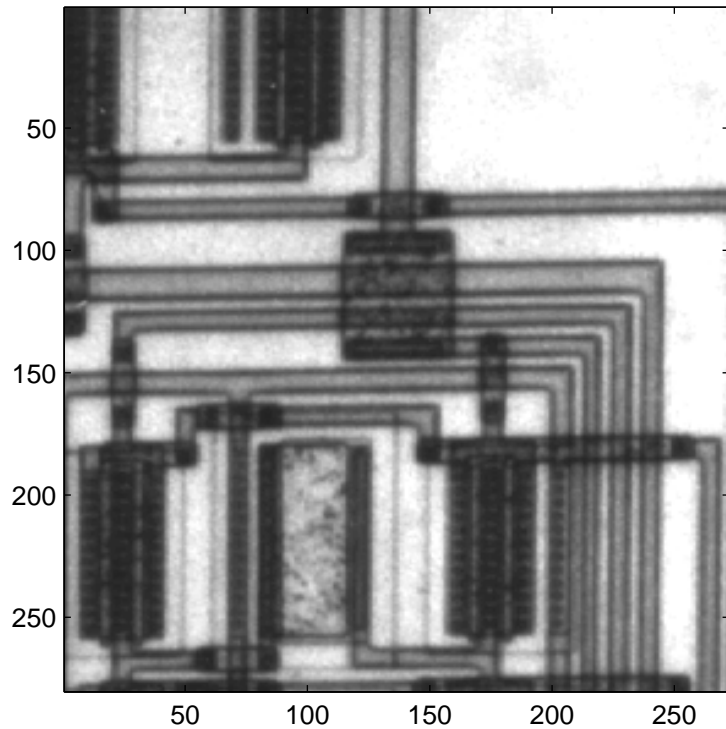
```
function o = times(obj,val)
    u8 = uint8(obj).*val; % Call uint8 times method
    o = DocUint8(u8);
end
```

Keep in mind that when you override a `uint8` method, MATLAB calls the subclass method and no longer dispatches to the base class method. Therefore, explicitly call the `uint8 times` method or an infinite recursion can occur. Make the explicit call in this statement of the `DocUint8 times` method:

```
u8 = uint8(obj).*val;
```

After adding the `times` method to `DocUint8`, you can use the `showImage` method in expressions like:

```
showImage(img1.*1.8);
```

Example – Adding Properties to a Built-In Subclass

When your subclass defines properties, indexing and concatenation do not work by default. There is really no way for the default `subsref`, `horzcat`, and `vertcat` methods to work with unknown property types and values. The following example subclasses the `double` class and defines a single property intended to contain a descriptive character string.

Methods Implemented

The following methods modify the behavior of the `DocExtendDouble` class:

- `DocExtendDouble` — The constructor supports a no argument syntax that initializes properties to empty values.
- `suboref` — Enables subscripted reference to the superclass part (`double`) of the subclass, dot notation reference to the `DataString` property, and dot notation reference the built-in data via the string `Data` (the `double` data property is hidden).
- `horzcat` — Defines horizontal concatenation of `DocExtendDouble` objects as the concatenation of the superclass part using the `double` class `horzcat` method and forms a cell array of the string properties.
- `vertcat` — The vertical concatenation equivalent of `horzcat` (both are required).
- `char` — A `DocExtendDouble` to `char` converter used by `horzcat` and `vertcat`.
- `disp` — `DocExtendDouble` implements a `disp` method to provide a custom display for the object.

Property Added

The `DocExtendDouble` class defines the `DataString` property to contain text that describes the data contained in instances of the `DocExtendDouble` class. Keep in mind that the superclass part (`double`) of the class contains the data.

Subclass with Properties

The `DocExtendDouble` class extends `double` and implements methods to support subscripted reference and concatenation.

```
classdef DocExtendDouble < double

    properties
        DataString
    end

    methods
        function obj = DocExtendDouble(data,str)
            % Support calling with zero arguments but do not return empty object
            if nargin == 0
                data = 0;
            end
        end
    end
end
```

```

        str = '';
    elseif nargin == 1
        str = '';
    end
    obj = obj@double(data);
    obj.DataString = str;
end

function sref = subsref(obj,s)
% Implements dot notation for DataString and Data
% as well as indexed reference
switch s(1).type
    case '.'
        switch s(1).subs
            case 'DataString'
                sref = obj.DataString;
            case 'Data'
                sref = double(obj);
                if length(s)>1 && strcmp(s(2).type, '()')
                    sref = subsref(sref,s(2:end));
                end
            end
        end
    case '()'
        sf = double(obj);
        if ~isempty(s(1).subs)
            sf = subsref(sf,s(1:end));
        else
            error('Not a supported subscripted reference')
        end
        sref = DocExtendDouble(sf,obj.DataString);
    end
end

function newobj = horzcat(varargin)
% Horizontal concatenation - cellfun calls double
% on all object to get superclass part. cellfun call local char
% to get DataString and the creates new object that combines
% doubles in vector and chars in cell array and creates new object
d1 = cellfun(@double,varargin,'UniformOutput',false );
data = horzcat(d1{:});

```

```

        str = horzcat(cellfun(@char,varargin,'UniformOutput',false));
        newobj = DocExtendDouble(data,str);
    end

function newobj = vertcat(varargin)
    % Need both horzcat and vertcat
    d1 = cellfun(@double,varargin,'UniformOutput',false );
    data = vertcat(d1{:});
    str = vertcat(cellfun(@char,varargin,'UniformOutput',false));
    newobj = DocExtendDouble(data,str);
end

function str = char(obj)
    % Used for cat functions to return DataString
    str = obj.DataString;
end

function disp(obj)
    % Change the default display
    disp(obj.DataString)
    disp(double(obj))
end
end
end
end

```

Create an instance of `DocExtendDouble` and notice that the display is different from the default:

```

ed = DocExtendDouble(1:10,'One to ten')
ed =
One to ten
     1     2     3     4     5     6     7     8     9    10

```

The `sum` function continues to operate on the superclass part of the object:

```

sum(ed)
ans =
    55

```

Subscripted assignment works on the superclass part of the object so there is no need to implement a `subsasgn` method; MATLAB uses the default

`subsasgn`. However, the following indexed assignment statement does cause a call to the `DocExtendDouble` constructor to convert the right-hand side of the assignment to a `DocExtendDouble` object. The expression `5:-1:1` results in values that are of class `double`. Therefore, the `DocExtendDouble` constructor must support a syntax requiring only one argument (there is no `str` argument).

```
ed(1:5) = 5:-1:1
ed =
One to ten
     5     4     3     2     1     6     7     8     9    10
```

The `sort` function works on the superclass part of the object:

```
sort(ed)
ans =
One to ten
     1     2     3     4     5     6     7     8     9    10
```

Indexed Reference of a `DocExtendDouble` Object

Subscripted assignment (performed by `subsasgn`) operates on the superclass part of the `DocExtendDouble` object by default. Subscripted reference (performed by `subsref`) requires the subclass to implement its own `subsref` method.

```
ed = DocExtendDouble(1:10, 'One to ten');
a = ed(2)
a =
One to ten
     2
whos
  Name      Size      Bytes  Class
  a         1x1         84   DocExtendDouble
  ed        1x10        156   DocExtendDouble
```

You can access the property data:

```
c = ed.DataString
c =
One to ten
```

```
whos
  Name      Size      Bytes  Class
  c         1x10      20     char
  ed        1x10     156    DocExtendDouble
```

You can access the superclass part of the object using dot notation with the `Data` property because the `DocExtendDouble` `subsref` method provides this capability:

```
d = ed.Data
d =
     1     2     3     4     5     6     7     8     9    10
whos
  Name      Size      Bytes  Class
  d         1x10      80     double
  ed        1x10     156    DocExtendDouble
```

Concatenating DocExtendDouble Objects

Given the following two objects:

```
ed1 = DocExtendDouble([1:10], 'One to ten');
ed2 = DocExtendDouble([10:-1:1], 'Ten to one');
```

You can concatenate these objects along the horizontal dimension:

```
hcat = [ed1 ed2]
hcat =
  'One to ten'  'Ten to one'
Columns 1 through 13
     1     2     3     4     5     6     7     8     9    10    10     9     8
Columns 14 through 20
     7     6     5     4     3     2     1
whos
  Name      Size      Bytes  Class
  ed1      1x10      156    DocExtendDouble
  ed2      1x10      156    DocExtendDouble
  hcat     1x20      376    DocExtendDouble
```

Vertical concatenation works in a similar way:

```

vcat = [ed1;ed2]
vcat =
    'One to ten'    'Ten to one'
     1     2     3     4     5     6     7     8     9    10
    10     9     8     7     6     5     4     3     2     1

```

Both `horzcat` and `vertcat` return a new object of the same class as the subclass.

Understanding `size` and `numel`

The `size` function returns the dimensions of an array. The `numel` function returns the number of elements in an array.

The default `size` and `numel` functions behave consistently with user-defined classes (see “Classes Not Derived from Built-In Classes” on page 10-43). Other MATLAB functions use `size` and `numel` to perform their operations and you usually do not need to overload them.

When used with subclasses of built-in classes, the `size` and `numel` functions behave the same as in the superclasses.

Consider the built-in class `double`:

```

d = 1:10;
size(d)

ans =

     1    10

numel(d)

ans =

    10

dsubref = d(7:end);

whos dsub

```

Name	Size	Bytes	Class	Attributes
dsubref	1x4	32	double	

The double class defines these behaviors, including parentheses indexing.

Subclass Inherited Behavior

Classes behave like the classes their superclasses, unless the subclass explicitly overrides any given behavior. For example, `DocSimpleDouble` subclasses `double`, but defines no properties:

```
classdef DocSimpleDouble < double
    methods
        function obj = DocSimpleDouble(data)
            if nargin == 0
                data = 0;
            end
            obj = obj@double(data);
        end
    end
end
```

Create an object and assign to the superclass part of the object the values 1:10:

```
sd = DocSimpleDouble(1:10);
```

The `size` function returns the size of the superclass part:

```
size(sd)

ans =

     1     10
```

The `numel` function returns the number of elements in the superclass part:

```
numel(sd)

ans =
```



```
10
```

Object arrays return the size of the built-in arrays also:

```
size([sd;sd])
```

```
ans =
```

```
2    10
```

```
numel([sd;sd])
```

```
ans =
```

```
20
```

The `DocSimpleDouble` class inherits the indexing behavior of the `double` class:

```
sdsubref = sd(7:end);
```

```
whos sdsubref
```

Name	Size	Bytes	Class	Attributes
sdsubref	1x4	88	DocSimpleDouble	

Classes Not Derived from Built-In Classes

Consider a simple value class. It does not inherit the array-like behaviors of the `double` class. For example:

```
classdef VerySimpleClass
    properties
        Value
    end
end
```

Create an instance of this class and assign a ten-element vector to the `Value` property:

```
vs = VerySimpleClass;
vs.Value = 1:10;
```

```
size(vs)

ans =

     1     1

numel(vs)

ans =

     1

size([vs;vs])

ans =

     2     1

numel([vs;vs])

ans =

     2
```

`vs` is a scalar object, as opposed to an array of `VerySimpleClass` objects. The `Value` property is an array of doubles:

```
size(vs.Value)

ans =

     1    10
```

Apply indexing expressions to the object property:

```
vssubref = vs.Value(7:end);
whos vssubref
```

Name	Size	Bytes	Class	Attributes
vssubref	1x4	32	double	

`vs.Value` is an array of class `double`:

```
class(vs.Value)

ans =

double
```

Creating an array of `VerySimpleClass` objects

```
vsArray(1:10) = VerySimpleClass;
```

MATLAB does not apply scalar expansion to object array property value assignment. Use the `deal` function for this purpose:

```
[vsArray.Value] = deal(1:10);
```

Indexing rules for object arrays are equivalent to those of `struct` arrays:

```
v1 = vsArray(1).Value;
>> whos v1
  Name      Size      Bytes  Class  Attributes

  v1        1x10        80    double

vsArray(1).Value(6)

ans =

    6
```

Overloading `size`

Subclasses of built-in classes inherit a `size` method, which operates on the superclass part of the subclass object. If you want `size` to behave in another way, you can override it by defining your own `size` method in your subclass.

Keep in mind that other MATLAB functions use the values returned by `size`. If you change the way `size` behaves, ensure that the values returned make sense for the intended use of your class.

Avoid Overloading numel

It is important to understand the significance of `numel` with respect to indexing. MATLAB calls `numel` to determine the number of elements returned by an indexed expression like:

```
A(index1,index2,...,indexn)
```

Both `subsref` and `subsasgn` use `numel`:

- `subsref` — `numel` computes the number of expected outputs (`nargout`) returned `subsref`
- `subsasgn` — `numel` computes the number of expected inputs (`nargin`) to that MATLAB assigns as a result of a call to `subsasgn`

Subclasses of built-in classes always return scalar objects as a result of subscripted reference and always use scalar objects for subscripted assignment. The `numel` function returns the correct value for these operations and there is, therefore, no reason to overload `numel`.

If you define a class in which `nargout` for `subsref` or `nargin` for `subsasgn` is different from the value returned by the default `numel`, then overload `numel` for that class to ensure that it returns the correct values.

Example — A Class to Represent Hardware

This example shows the implementation of a class to represent an optical multiplex card. These cards typically have a number of input ports, which this class represents by the port data rates and names. There is also an output port. The output rate of a multiplex card is the sum of the input port data rates.

The `DocMuxCard` class defines the output rate as a `Dependent` property, and then defines a `get` access method for this property. The `get.OutPutRate` method calculates the actual output rate whenever the `OutPutRate` property is queried. See “Property Get Methods” on page 6-16 for more information on this technique.

Why Derive from int32

The DocMuxCard class derives from the int32 class because 32-bit integers represent the input port data rates. The DocMuxCard class inherits the methods of the int32 class, which simplifies the implementation of this subclass.

Class Definition

Here is the definition of the DocMuxCard class. Notice that the input port rates initialize the int32 portion of class.

```
classdef DocMuxCard < int32
    properties
        InPutNames % cell array of strings
        OutPutName % a string
    end
    properties (Dependent = true)
        OutPutRate
    end
    methods
        function obj = DocMuxCard(inptnames, inptrates, outpname)
            obj = obj@int32(inptrates); % initial the int32 class portion
            obj.InPutNames = inptnames;
            obj.OutPutName = outpname;
        end
        function x = get.OutPutRate(obj)
            x = sum(obj); % calculate the value of the property
        end
        function x = subsref(card, s)
            if strcmp(s(1).type, '.')
                base = subsref@int32(card, s(1));
                if isscalar(s)
                    x = base;
                else
                    x = subsref(base, s(2:end));
                end
            else
                x = subsref(int32(card), s);
            end
        end
    end
end
```

```

        end
    end

```

Using the Class with Methods of int32

The constructor takes three arguments:

- `inptnames` — Cell array of input port names
- `inptrates` — Vector of input port rates
- `outpname` — Name for the output port

```

>> omx = DocMuxCard({'inp1','inp2','inp3','inp4'},[3 12 12 48],'outp')
omx =
    DocMuxCard
    Properties:
        InPutNames: {'inp1' 'inp2' 'inp3' 'inp4'}
        OutPutName: 'outp'
        OutPutRate: 75
    int32 data:
           3           12           12           48
    Methods, Superclasses

```

You can treat an `DocMuxCard` object like an `int32`. For example, this statement accesses the `int32` data in the object to determine the names of the input ports that have a rate of 12:

```

>> omx.InPutNames(omx==12)
ans =
    'inp2'    'inp3'

```

Indexing the `DocMuxCard` object accesses the `int32` vector of input port rates:

```

>> omx(1:2)
ans =
           3           12

```

The `OutPutRate` property get access method uses `sum` to sum the output port rates:

```

>> omx.OutPutRate

```

```
ans =  
    75
```

Abstract Classes and Interfaces

In this section...

“Abstract Classes” on page 10-50

“Interfaces and Abstract Classes” on page 10-51

“Example — Interface for Classes Implementing Graphs” on page 10-52

Abstract Classes

An *abstract* class serves as a basis (that is, a superclass) for a group of related subclasses. It forms the abstractions that are common to all subclasses by specifying the common properties and methods that all subclasses must implement. However, you cannot instantiate the abstract class. You can only create instances of the subclasses. These subclasses are sometimes referred to as *concrete* classes.

Abstract classes are useful for describing functionality that is common to a group of classes, but requires unique implementations within each class. This approach is often called an *interface* because the abstract class defines the interface of each subclass without specifying the actual implementation.

Defining Abstract Classes

Define an abstract class by setting the `Abstract` attribute on one or more methods of a class to `true`. You do not use a `function...end` block to define an abstract method, use only the method signature.

For example, the `group` abstract class defines two methods that take two input arguments and return a result:

```
classdef group
% Both methods must be implemented so that
% the operations are commutative
    methods (Abstract)
        result = add(numeric,polynomial)
        result = times(numeric,polynomial)
    end
end
```


The subclasses must implement methods with the same names. The names and number of arguments can be different. However, the abstract class typically conveys details about the expected implementation via its comments and argument naming.

Abstract Properties

For properties that have `Abstract` attributes set to `true`:

- Concrete subclasses must redefine abstract properties without the `Abstract` attribute set to `true` and must use the same values for `SetAccess` and `GetAccess` attributes as the base class.
- Abstract properties cannot define set or get access methods (see “Property Set and Get Access Methods” on page 6-12) and cannot specify initial values. The subclass must define the property and then can create set or get access methods and specify initial values.

Abstract Methods

For methods that have `Abstract` attributes set to `true`:

- Abstract methods have no implementation in the abstract class. The method has a normal function line (without the `function` or `end` key words) that can include input and output argument lists.
- Subclasses are not required to support the same number of input and output arguments and do not need to use the same argument names. However, subclasses generally use the same signature when implementing their version of the method.

Interfaces and Abstract Classes

The properties and methods defined by a class form the interface that determines how class users interact with objects of the class. When you are creating a group of related classes, define a common interface to all these classes, even though the actual implementations of this interface can differ from one class to another. Abstract properties and methods provide a mechanism to create interfaces for groups of classes.

For example, consider a set of classes designed to represent various graphs (for example, line plots, bar graphs, pie charts, and so on). Suppose all classes

must implement a `Data` property to contain the data used to generate the graph. However, the form of the data can differ considerably from one type of graph to another. Consequently, the way each class implements the `Data` property can be different.

The same differences apply to methods. All classes can have a `draw` method that creates the graph, but the implementation of this method changes with the type of graph.

The basic idea of an interface class is to specify the properties and methods that each subclass must implement without defining the actual implementation. This approach enables you to enforce a consistent interface to a group of related objects. As you add more classes in the future, the original interface remains.

Example – Interface for Classes Implementing Graphs

This example creates an interface for classes used to display specialized graphs. The interface is an abstract class that defines properties and methods that the subclasses must implement, but does not specify how to implement these components. This approach enforces the use of a consistent interface while providing the necessary flexibility to implement the internal workings of each specialized graph subclass differently.

In this example, the interface, derived subclasses, and a utility function are contained in a package folder:

```
+graphics/graph.m      % abstract interface class
+graphics/linegraph.m % concrete subclass
```

Interface Properties and Methods

The graph class specifies the following properties, which the subclasses must define:

- **Primitive** — Handle of the `Handle Graphics` object used to implement the specialized graph. The class user has no need to access these objects directly so this property has `protected SetAccess` and `GetAccess`.

- `AxesHandle` — Handle of the axes used for the graph. The specialized graph objects can set axes object properties and also limit this property's `SetAccess` and `GetAccess` to `protected`.
- `Data` — All specialized graph objects must store data, but the type of data varies so each subclass defines the storage mechanism. Subclass users can change the data so this property has public access rights.

The graph class names three abstract methods that subclasses must implement. The graph class also suggests in comments that each subclass constructor must accept the plot data and property name/property value pairs for all class properties.

- *subclass_constructor* — Accept data and P/V pairs and return an object.
- `draw` — Used to create a drawing primitive and render a graph of the data according to the type of graph implemented by the subclass.
- `zoom` — Implementation of a zoom method by changing the axes `CameraViewAngle` property. The interface suggests the use of the `camzoom` function for consistency among subclasses. The zoom buttons created by the `addButtons` static method use this method as a callback.
- `updateGraph` — Method called by the `set.Data` method to update the plotted data whenever the `Data` property changes.

Interface Guides Class Design

The package of classes that derive from the graph abstract class implement the following behaviors:

- Creating an instance of a specialized graph object (subclass object) without rendering the plot
- Specifying any or none of the object properties when you create a specialized graph object
- Changing any object property automatically updates the currently displayed plot
- Allowing each specialized graph object to implement whatever additional properties it requires to give class users control over those characteristics.

Defining the Interface

The graph class is an abstract class that defines the methods and properties used by the derived classes. Comments in the abstract class suggest the intended implementation:

```

classdef graph < handle
% Abstract class for creating data graphs
% Subclass constructor should accept
% the data that is to be plotted and
% property name/property value pairs
properties (SetAccess = protected, GetAccess = protected)
    Primitive % HG primitive handle
    AxesHandle % Axes handle
end
properties % Public access
    Data
end
methods (Abstract)
    draw(obj)
% Use a line, surface,
% or patch HG primitive
    zoom(obj, factor)
% Change the CameraViewAngle
% for 2D and 3D views
% use camzoom for consistency
    updateGraph(obj)
% Called by the set.Data method
% to update the drawing primitive
% whenever the Data property is changed
end
methods
    function set.Data(obj, newdata)
        obj.Data = newdata;
        updateGraph(obj)
    end
    function addButtons(gobj)
        hfig = get(gobj.AxesHandle, 'Parent');
        uicontrol(hfig, 'Style', 'pushbutton', 'String', 'Zoom Out', ...
            'Callback', @(src, evnt) zoom(gobj, .5));
        uicontrol(hfig, 'Style', 'pushbutton', 'String', 'Zoom In', ...

```

```

        'Callback',@(src,evt)zoom(gobj,2),...
        'Position',[100 20 60 20]);
    end
end
end

```

The graph class implements the property set method (`set.Data`) to monitor changes to the `Data` property. An alternative is to define the `Data` property as `Abstract` and enable the subclasses to determine whether to implement a set access method for this property. However, by defining the set access method that calls an abstract method (`updateGraph`, which each subclass must implement), the graph interface imposes a specific design on the whole package of classes, without limiting flexibility.

Method to Work with All Subclasses

The `addButtons` method adds push buttons for the zoom methods, which each subclass must implement. Using a method instead of an ordinary function enables `addButtons` to access the protected class data (the axes handle). Use the object's zoom method as the push button callback.

```

function addButtons(gobj)
    hfig = get(gobj.AxesHandle,'Parent');
    uicontrol(hfig,'Style','pushbutton','String','Zoom Out',...
        'Callback',@(src,evt)zoom(gobj,.5));
    uicontrol(hfig,'Style','pushbutton','String','Zoom In',...
        'Callback',@(src,evt)zoom(gobj,2),...
        'Position',[100 20 60 20]);
end

```

Deriving a Concrete Class – linegraph

Note Display the fully commented code for the `linegraph` class by clicking this link: [linegraph class](#).

This example defines only a single subclass used to represent a simple line graph. It derives from `graph`, but provides implementations for the abstract methods `draw`, `zoom`, `updateGraph`, and its own constructor. The base class

(graph) and subclass are all contained in a package (graphics), which you must use to reference the class name:

```
classdef linegraph < graphics.graph
```

Adding Properties

The linegraph class implements the interface defined in the graph class and adds two additional properties—LineColor and LineType. This class defines initial values for each property, so specifying property values in the constructor is optional. You can create a linegraph object with no data, but you cannot produce a graph from that object.

```
properties
    LineColor = [0 0 0];
    LineType = '-';
end
```

The linegraph Constructor

The constructor accepts a struct with x and y coordinate data, as well as property name/property value pairs:

```
function gobj = linegraph(data,varargin)
    if nargin > 0
        gobj.Data = data;
        if nargin > 2
            for k=1:2:length(varargin)
                gobj.(varargin{k}) = varargin{k+1};
            end
        end
    end
end
```

Implementing the draw Method

The linegraph draw method uses property values to create a line object. The linegraph class stores the line handle as protected class data. To support the use of no input arguments for the class constructor, draw checks the Data property to determine if it is empty before proceeding:

```
function gobj = draw(gobj)
```

```

if isempty(gobj.Data)
    error('The linegraph object contains no data')
end
h = line(gobj.Data.x,gobj.Data.y,...
        'Color',gobj.LineColor,...
        'LineStyle',gobj.LineType);
gobj.Primitive = h;
gobj.AxesHandle = get(h, 'Parent');
end

```

Implementing the zoom Method

The linegraph zoom method follows the comments in the graph class which suggest using the `camzoom` function. `camzoom` provides a convenient interface to zooming and operates correctly with the push buttons created by the `addButtons` method.

Defining the Property Set Methods

Property set methods provide a convenient way to execute code automatically when the value of a property changes for the first time in a constructor. (See “Property Set Methods” on page 6-14.) The `linegraph` class uses set methods to update the `line` primitive data (which causes a redraw of the plot) whenever a property value changes. The use of property set methods provides a way to update the data plot quickly without requiring a call to the `draw` method. The `draw` method updates the plot by resetting all values to match the current property values.

Three properties use set methods: `LineColor`, `LineStyle`, and `Data`. `LineColor` and `LineStyle` are properties added by the `linegraph` class and are specific to the `line` primitive used by this class. Other subclasses can define different properties unique to their specialization (for example., `FaceColor`).

The graph class implements the `Data` property set method. However, the graph class requires each subclass to define a method called `updateGraph`, which handles the update of plot data for the specific drawing primitive used.

Using the linegraph Class

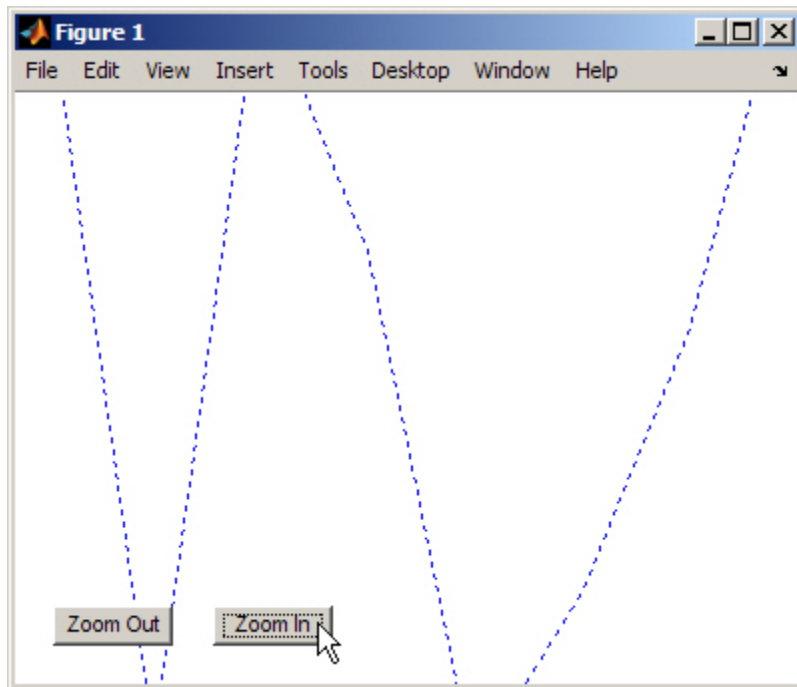
The `linegraph` class defines the simple API specified by the graph base class and implements its specialized type of graph:

```

d.x = 1:10;
d.y = rand(10,1);
lg = graphics.linegraph(d, 'LineColor', 'b', 'LineType', ':');
lg.draw;
graphics.graph.addButtons(lg);

```

Clicking the **Zoom In** button shows the `zoom` method providing the callback for the button.



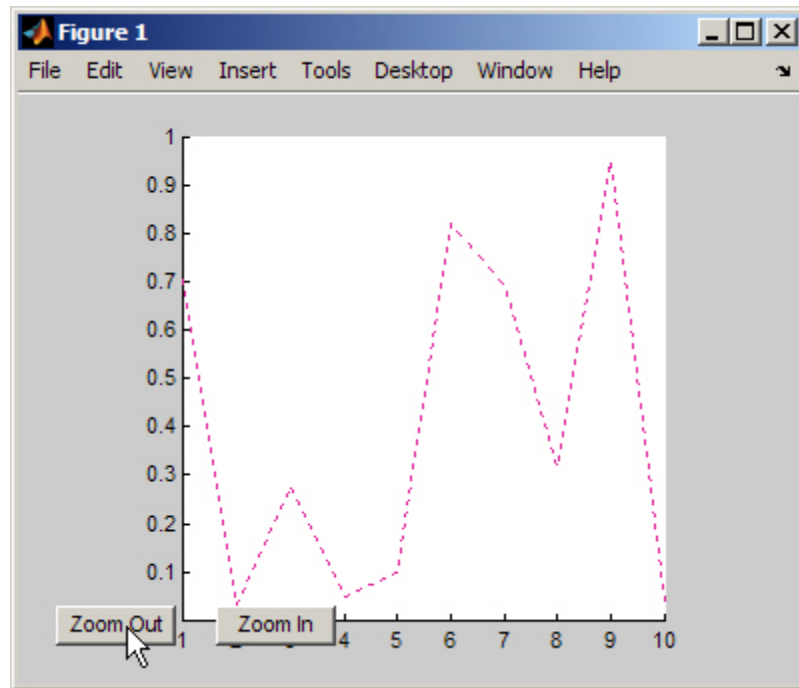
Changing properties updates the graph:

```

d.y = rand(10,1); % new set of random data for y
lg.Data = d;
lg.LineColor = [.9 .1 .6]; % LineColor can be char or double

```

Now click **Zoom Out** and see the new results:



Saving and Loading Objects

- “The Save and Load Process” on page 11-2
- “Modifying the Save and Load Process” on page 11-6
- “Example — Maintaining Class Compatibility” on page 11-9
- “Passing Arguments to Constructors During Load” on page 11-14
- “Saving and Loading Objects from Class Hierarchies” on page 11-17
- “Saving and Loading Dynamic Properties” on page 11-20
- “Tips for Saving and Loading” on page 11-22

The Save and Load Process

In this section...
“The Default Save and Load Process” on page 11-2
“When to Modify Object Saving and Loading” on page 11-4

The Default Save and Load Process

Use save and load to store objects:

```
save filename object
load filename object
```

What Information Is Saved

Saving objects in MAT-files saves:

- The full name of the object’s class, including any package qualifiers.
- Values of dynamic properties.
- The names and current values of all properties, *except*:
 - Properties that have their `Transient`, `Constant`, or `Dependent` attributes set to `true`. See “Specifying Property Attributes” on page 6-7 for a description of property attributes.

Loading Property Data

When loading objects from MAT-files the load function:

- Creates a new object.
- Calls the class constructor with no arguments *only* if the class’s `ConstructOnLoad` attribute is set to `true`.
- Assigns the saved values to the object’s properties. These assignments results in calls to property set methods defined by the class.

You can use property set methods to ensure property values are still valid in cases where the class definition has changed.

See “Property Set Methods” on page 6-14 for information on property set methods.

Errors During Load

It is possible for a default value to cause an error in a property set method (for example, the class definition might have changed). When an error occurs while an object is being loaded from a file, MATLAB returns the saved values in a `struct`. The field names correspond to the property names.

In cases where the saved object is derived from multiple superclasses that define private properties having the same name, the `struct` contains the property value of the most direct superclass only.

Saving and Loading Deleted Handle Objects

If you save a deleted handle, MATLAB load it as a deleted handle. For example:

```
% Create a handle object
>> a = containers.Map('Monday','sunny')
    invalid(a)

ans =

     1
% Delete the handle object
>> delete(a)
>> invalid(a)

ans =

     0

% Save the deleted handle
>> save savefile a

% Clear the variable a
>> clear a

% Load a back into the workspace
```

```
>> load savefile a
>> isvalid(a)
ans =

    0
```

See the handle class `delete` method and the `clear` command for more information on these operations.

saveobj and loadobj

The `save` and `load` functions call your class's `saveobj` and `loadobj` methods, respectively, if your class defines these methods. You use these methods to customize the save and load process.

When you issue a `save` command, MATLAB first calls your `saveobj` method and passes the output of `saveobj` to `save`. Similarly, when you call `load`, MATLAB passes the result of loading what you saved to `loadobj`. `loadobj` must then return a properly constructed object. Therefore, you must design `saveobj` and `loadobj` to work together.

When to Modify Object Saving and Loading

The following sections describe when and how to modify the process MATLAB uses to save and load objects. You modify this process by implementing `saveobj` and `loadobj` methods for your class.

Why Implement saveobj and loadobj

The primary reason for implementing `saveobj` and `loadobj` methods is to support backward and forward compatibility of classes. For example, you might have cases where:

- The class's properties have changed (just adding a new property does not necessarily require special code because it can be initialized to its default value when loaded).
- The order in which properties are initialized is important due to a circular reference to handle objects.

- You must call the object's constructor with arguments and, therefore, cannot support a default constructor (no arguments).

Information to Consider

If you decide to modify the default save and load process, keep the following points in mind:

- If your `loadobj` method generates an error, MATLAB still loads the objects in whatever state the object was in before the invocation of `loadobj`.
- Subclass objects inherit superclass `loadobj` and `saveobj` methods. Therefore, if you do not implement a `loadobj` or `saveobj` method in the most specific class, MATLAB calls only the inherited methods.

If a superclass implements a `loadobj` or `saveobj` method, then your subclass can also implement a `loadobj` or `saveobj` method that calls the superclass methods as necessary. See “Saving and Loading Objects from Class Hierarchies” on page 11-17 for more information.

- The `load` function does not call the default constructor by default. See “Calling Constructor When Loading” on page 11-25 for more information.
- If an error occurs while the object is loading from a file, the `load` function passes your `loadobj` method as much data as it can successfully load from the file. In case of an error, `load` passes `loadobj` a `struct` whose field names correspond to the property names extracted from the file. See “Reconstructing Objects with `loadobj`” on page 11-15 for an example of a `loadobj` method that processes a `struct`.

See “Tips for Saving and Loading” on page 11-22 for guidelines on saving and loading objects.

Modifying the Save and Load Process

In this section...

“Class saveobj and loadobj Methods” on page 11-6

“Processing Objects During Load” on page 11-7

“Save and Load Applications” on page 11-7

Class saveobj and loadobj Methods

You can define methods for your class that are executed when you call `save` or `load` on an object:

- The `save` function calls your class’s `saveobj` method before performing the save operation. The `save` function then saves the value returned by the object’s `saveobj` method. You can use the `saveobj` method to return a modified object or any other type of variable, such as a `struct` array.
- The `load` function calls your class’s `loadobj` method after loading the object. The `load` function loads into the workspace the value returned by the object’s `loadobj` method. If you define a `loadobj` method you can modify the object being returned or reconstruct an object from the data saved by your `saveobj` method.

If you implement a `saveobj` method that modifies the object being saved, implement a `loadobj` method to return the object to its proper state when reloading it. For example, you might want to store an object’s data in a `struct` array and reconstruct the object when reloaded to manage changes to the class definition.

Implement loadobj as a Static Method

You must implement the `loadobj` method as a `Static` method because `loadobj` can actually be called with a `struct` or other data instead of an object of the class. You can implement the `saveobj` method as an ordinary method (i.e., calling it requires an instance of the class).

MATLAB saves the object’s class name so that `load` can determine which `loadobj` method to call, even if your `saveobj` method saves only the object’s data in an array and not the object itself.

Processing Objects During Load

Implementing a `loadobj` method enables you to apply some processing to the object before it is loaded into the workspace. You might need to do this if:

- The class definition has changed since the object was saved and you need to modify the object before reloading.
- A `saveobj` method modified the object during the save operation, perhaps saving data in an array, and the `loadobj` method must reconstruct the object based on the output of `saveobj`.

Updating an Object Property When Loading

In the following example, the `loadobj` method checks if the object to be loaded has an old, shorter account number and calls a function to return an updated account number if necessary. After updating the object's `AccountNumber` property, `loadobj` returns the object to be loaded into the workspace.

```

methods (Static = true)
function obj = loadobj(a)
    accnb = a.AccountNumber;
    if length(num2str(accnb)) < 12
        a.AccountNumber = updateAccountNumber(accnb); % update object
    end
    obj = a; % return the updated object
end
end

```

In this case, you do not need to implement a `saveobj` method. You are using `loadobj` only to ensure older saved objects are brought up to date before loading.

The “Save and Load Applications” on page 11-7 section provides an example in which `loadobj` performs specific operations to recreate an object based on the data returned by `saveobj` during the save operation.

Save and Load Applications

The following sections describe some specific applications involving the saving and loading of objects.

- “Example — Maintaining Class Compatibility” on page 11-9 — how to maintain compatibility among progressive versions of an application.
- “Passing Arguments to Constructors During Load” on page 11-14 — using `loadobj` to call the class constructor of an object when you need to pass arguments to the constructor during load.
- “Saving and Loading Objects from Class Hierarchies” on page 11-17 — how inherited methods affect saving and loading objects.
- “Saving and Loading Dynamic Properties” on page 11-20 — how to handle dynamic properties when saving and loading objects.

Example – Maintaining Class Compatibility

Versions of a Phone Book Application Program

This section shows you how to use `saveobj` and `loadobj` methods to maintain compatibility among subsequent releases of an application program. Suppose you have created a program that implements a phone book application, which can be used to keep track of information about various people and companies.

One of the key elements of this program is that it uses a data structure to contain the information for each phone book entry. You save these data structures in MAT-files. This example shows ways to maintain the compatibility of subsequent versions of the data structures as you implement new versions of the program.

When the phone book application program loads a particular phone book entry by reading a variable from a Mat-file, it must ensure that the loaded data can be used by the current version of the application.

Version 1 – Stores Data in struct

Suppose in Version 1 of the phone book application program, you used an ordinary MATLAB struct to save phone book entries in the fields: `Name`, `Address`, and `PhoneNumber`. Your phone book application program saves these variables in a MAT-file. For example, here is a typical entry:

```
V1.Name = 'The MathWorks, Inc.';  
V1.Address = '3 Apple Hill Drive, Natick, MA, 01760';  
V1.PhoneNumber = '5086477000';
```

Version 2 – Maps struct Fields to Object Properties

With Version 2 of the phone book program, you change from a struct to a class having public properties with the same names as the fields in the struct. You want to save the new `PhoneBookEntry` objects and you want to load the old struct without causing any errors. To maintain this compatibility, the `PhoneBookEntry` class implements `loadobj` and `saveobj` methods:

```
classdef PhoneBookEntry  
    properties  
        Name
```

```
        Address
        PhoneNumber
    end
    methods (Static)
        function obj = loadobj(obj)
            if isstruct(obj)
                % Call default constructor
                newObj = PhoneBookEntry;
                % Assign property values from struct
                newObj.Name = obj.Name;
                newObj.Address = obj.Address;
                newObj.PhoneNumber = obj.PhoneNumber;
                obj = newObj;
            end
        end
    end
    methods
        function obj = saveobj(obj)
            s.Name = obj.Name;
            s.Address = obj.Address;
            s.PhoneNumber = obj.PhoneNumber;
            obj = s;
        end
    end
end
```

`saveobj` saves the object data in a struct that uses property names for field names. This struct is compatible with Version 1 of the product. When the struct is loaded into Version 2 of the phone book application program, the static `loadobj` method converts the struct to a `PhoneBookEntry` object. For example, given the previously defined struct `V1`:

```
V1 =

        Name: 'MathWorks, Inc.'
        Address: '3 Apple Hill Drive, Natick, MA, 01760'
        PhoneNumber: '5086477000'
```

The application program can use the `loadobj` static method to convert this Version 1 struct to a Version 2 object:

```

V2 = PhoneBookEntry.loadobj(V1)

V2 =

    PhoneBookEntry

    Properties:
        Name: 'MathWorks, Inc.'
        Address: '3 Apple Hill Drive, Natick, MA, 01760'
        PhoneNumber: '5086477000'

```

If a Version 2 `PhoneBookEntry` object is loaded, `load` automatically calls the object's `loadobj` method, which converts the struct to an object compatible with Version 2 of the phone book application program.

Version 3 — Adds More Properties to Class

In Version 3, you change the `PhoneBookEntry` class by splitting the `Address` property into `StreetAddress`, `City`, `State`, and `ZipCode` properties. With this version, you cannot load a Version 3 `PhoneBookEntry` object in previous releases by default. However, the `saveobj` method provides an option to save Version 3 objects as structs that you can load in Version 2. The `loadobj` method enables you to load both Version 3 objects and Version 2 structs.

Here is the new version of the `PhoneBookEntry` class.

```

classdef PhoneBookEntry
    properties
        Name
        StreetAddress
        City
        State
        ZipCode
        PhoneNumber
    end
    properties (Constant)
        Sep = ', ';
    end
    properties (Dependent, SetAccess=private)
        Address
    end
end

```

```
properties (Transient)
    SaveInOldFormat = 0;
end
methods (Static)
    function obj = loadobj(obj)
        if isstruct(obj)
            % Call default constructor
            newObj = PhoneBookEntry;
            % Assign property values from struct
            newObj.Name = obj.Name;
            newObj.Address = obj.Address;
            newObj.PhoneNumber = obj.PhoneNumber;
            obj = newObj;
        end
    end
end
methods
    function address = get.Address(obj)
        address=[obj.StreetAddress obj.Sep obj.City obj.Sep obj.State obj.Sep obj.ZipCode];
    end
    function obj = set.Address(obj,address)
        addressItems = regexp(address,obj.Sep,'split');
        if length(addressItems) == 4
            obj.StreetAddress = addressItems{1};
            obj.City = addressItems{2};
            obj.State = addressItems{3};
            obj.ZipCode = addressItems{4};
        else
            error('PhoneBookEntry:InvalidAddressFormat', ...
                'Invalid address format. ');
        end
    end
end
    function obj = saveobj(obj)
        % If set to true, save as a struct
        if obj.SaveInOldFormat
            s.Name = obj.Name;
            s.Address = obj.Address;
            s.PhoneNumber = obj.PhoneNumber;
            obj = s;
        end
    end
end
```

```
end  
end
```

To maintain compatibility among all versions, Version 3 of the `PhoneBookEntry` class applies the following techniques:

- Preserve the `Address` property (which is used in Version 2) as a `Dependent` property with private `SetAccess`.
- Define an `Address` property get method (`get.Address`) to build a string that is compatible with the Version 2 `Address` property.
- The `get.Address` method is invoked from the `saveobj` method to assign the object data to a `struct` that is compatible with previous versions. The `struct` continues to have only an `Address` field built from the data in the new `StreetAddress`, `City`, `State`, and `ZipCode` properties.
- As the `loadobj` method sets the object's `Address` property, it invokes the property set method (`set.Address`), which extracts the substrings required by the `StreetAddress`, `City`, `State`, and `ZipCode` properties.
- The `Transient` (not saved) property `SaveInOldFormat` enables you to specify whether to save the Version 3 object as a `struct` or an object.

See “Property Set and Get Access Methods” on page 6-12 for more on property set and get methods.

Passing Arguments to Constructors During Load

In this section...
“Calling Constructors When Loading Objects” on page 11-14
“Code for This Example” on page 11-14
“Example Overview” on page 11-14

Calling Constructors When Loading Objects

You can set the class `ConstructOnLoad` attribute when you need to call the default (no argument) class constructor on an object that is loaded from a MAT-file. Then `load` automatically calls the object’s class constructor, but cannot pass any arguments to it.

If the object you are loading requires a call to its class constructor and this call requires you to pass arguments to the constructor, you can implement a `loadobj` method that performs this task. For example, suppose the object’s constructor adds a listener and, therefore, must be passed a handle to the object triggering the event (required by the `addlistener` handle class method) to create this listener. Your `loadobj` method could call the constructor with the required argument.

Code for This Example

The following information on saving and loading objects refers to a `BankAccountSL` class. Click the following link to open the full code for this class in the MATLAB editor:

[Open class definition in editor](#)

Example Overview

This example shows how to use `loadobj` to call a class constructor with arguments at load time. Because the constructor requires arguments, you cannot use the `ConstructOnLoad` attribute to load the object, which causes a call to the default (no arguments) constructor.

This example uses `loadobj` to determine the status of a `BankAccountSL` object when the object data is loaded, and then calls the class constructor with the appropriate arguments to create the object. This approach provides a way to modify the criteria for determining status over time, while ensuring that all loaded objects are using the current criteria.

The `saveobj` method extracts the data from the object and writes this data into a `struct`, which `saveobj` returns to the `save` function.

Saving Only Object Data with `saveobj`

The following `saveobj` method saves the values of the `BankAccountSL` object's `AccountNumber` and `AccountBalance` properties in the `struct` variable `A`, which has field names that match the property names. `saveobj` then returns the variable `A` to be saved in the MAT-file by the `save` function.

```
methods
function A = saveobj(obj)
    A.AccountNumber = obj.AccountNumber;
    A.AccountBalance = obj.AccountBalance;
end
end
```

Reconstructing Objects with `loadobj`

The `BankAccountSL` class `AccountStatus` property is `Transient` because its value depends on the value of the `AccountBalance` property and the current criteria and possible status values. You can use the `loadobj` method to update all saved `BankAccount` objects when they are loaded into your system.

To create a valid object, `loadobj` calls the constructor using the data saved in the `struct` `A` and passes any other required arguments.

If the account balance is greater than zero, `AccountStatus` is set to `open`. If the account balance is zero or less, `AccountStatus` is set to `overdrawn` or to `frozen`.

The following `loadobj` method calls the class constructor with the appropriate values for the arguments:

```
methods (Static)
```

```
function obj = loadobj(A)
    if A.AccountBalance > 0
        obj = BankAccountSL(A.AccountNumber,A.AccountBalance,'open');
    elseif A.AccountBalance < 0) && (A.AccountBalance >= -100)
        obj = BankAccountSL(A.AccountNumber,A.AccountBalance,'overdrawn');
    else
        obj = BankAccountSL(A.AccountNumber,A.AccountBalance,'frozen');
    end
end
end
```

Saving and Loading Objects from Class Hierarchies

Saving and Loading Subclass Objects

When you modify the save operation of an object that is part of a class hierarchy, you must be sure that all classes in the hierarchy perform the correct operations in the save and load process. If the most specific class of an object does not define a `loadobj` or `saveobj` method, this class can inherit `loadobj` or `saveobj` methods from a superclass.

If any class in the hierarchy defines special save and load behavior:

- Define `saveobj` for all classes in the hierarchy.
- Call superclass `saveobj` methods from the subclass `saveobj` method because the `save` function calls only one `saveobj` method.
- If `saveobj` returns a `struct` instead of the object, then the subclass can implement a `loadobj` method to reconstruct the object.
- The subclass `loadobj` method can call the superclass `loadobj`, or other methods as required, to assign values to their properties.

Reconstructing the Subclass Object from a Saved Struct

Suppose you want to save a subclass object by first converting its property data to a `struct` in the class's `saveobj` method and then reconstruct the object when loaded using its `loadobj` method. This action requires that:

- Superclasses implement `saveobj` methods to save their property data in the `struct`.
- The subclass `saveobj` method calls each superclass `saveobj` method and then returns the completed `struct` to the `save` function, which writes the `struct` to the MAT-file.
- The subclass `loadobj` method creates a subclass object and then calls superclass methods to assign their property values in the subclass object.
- The subclass `loadobj` method returns the reconstructed object to the `load` function, which loads the object into the workspace.

The following superclass (MySuper) and subclass (MySub) definitions show how to code these methods. The MySuper class defines a loadobj method to enable an object of this class to be loaded directly. The subclass loadobj method calls a method named reload after it constructs the subclass object. reload first calls the superclass reload method to assign superclass property values and then assigns the subclass property value.

```
classdef MySuper
% Superclass definition
    properties
        X
        Y
    end
    methods
        function S = saveobj(obj)
            % Save property values in struct
            % Return struct for save function to write to MAT-file
            S.PointX = obj.X;
            S.PointY = obj.Y;
        end
        function obj = reload(obj,S)
            % Method used to assign values from struct to properties
            % Called by loadobj and subclass
            obj.X = S.PointX;
            obj.Y = S.PointY;
        end
    end
    methods (Static)
        function obj = loadobj(S)
            % Constructs a MySuper object
            % loadobj used when a superclass object is saved directly
            % Calls reload to assign property values retrived from struct
            % loadobj must be Static so it can be called without object
            obj = MySuper;
            obj = reload(obj,S);
        end
    end
end
```

Your subclass implements saveobj and loadobj methods that call superclass methods.

```
classdef MySub < MySuper
% Subclass definition
    properties
        Z
    end
    methods
        function S = saveobj(obj)
            % Call superclass saveobj
            % Save property values in struct
            S = saveobj@MySuper(obj);
            S.PointZ = obj.Z;
        end
        function obj = reload(obj,S)
            % Call superclass reload method
            % Assign subclass property value
            % Called by loadobj
            obj = reload@MySuper(obj,S);
            obj.Z = S.PointZ;
        end
    end
    methods (Static)
        function obj = loadobj(S)
            % Create object of MySub class
            % Assign property value retrived from struct
            % loadobj must be Static so it can be called without object
            obj = MySub;
            obj = reload(obj,S);
        end
    end
end
end
```

Saving and Loading Dynamic Properties

Reconstructing Objects That Have Dynamic Properties

If you use the `addprop` method to add dynamic properties to a MATLAB class derived from the `dynamicprops` class, those dynamic properties are saved along with the object to which they are attached when you save the object to a MAT-file. See “Dynamic Properties — Adding Properties to an Instance” on page 6-21 for more information about dynamic properties.

Why You Need `saveobj` and `loadobj` Methods

`save` saves dynamic properties and their values. However, `save` does not save dynamic property attributes because these attributes are not specified in the class definition. If you are saving an object that has dynamic properties, and these properties use nondefault attributes, you need to manage the saving and loading of attribute values using `saveobj` and `loadobj`.

If your class implements a `saveobj` method that converts the object to another type of MATLAB variable, such as a `struct`, you can save the dynamic property’s attribute values so that your `loadobj` method can reconstruct these properties. The attribute values of dynamic properties are not part of the class definition and might have been set after the properties were attached to the object, so these values might not be known to the `loadobj` method.

Implementing the `saveobj` and `loadobj` Methods

For example, your `saveobj` method can obtain the nondefault attribute values from the dynamic property’s `meta.DynamicProperty`. Suppose the object you are saving has a dynamic property called `DynoProp`, and your `saveobj` method creates a `struct` `s` to save the data that the `loadobj` method uses to reconstruct the object:

```
methods
function s = saveobj(obj)
...
% Obtain the meta.DynamicProperty object for the dynamic property
metaDynoProp = findprop(obj, 'DynoProp');
% Record name and value for the dynamic property
s.dynamicprops(1).name = metaDynoProp.Name;
```

```
s.dynamicprops(1).value = obj.DynoProp;
% Record additional dynamic property attributes so they can be
% restored at load time, for example SetAccess and GetAccess
s.dynamicprops(1).setAccess = metaDynoProp.SetAccess;
s.dynamicprops(1).getAccess = metaDynoProp.GetAccess;
...
end
end
```

Your loadobj method can add the dynamic property and set the attribute values:

```
methods (Static)
function obj = loadobj(s)
% first, create an instance of the class
obj = ClassConstructor;
...
% Add new dynamic property to object
metaDynoProp = addprop(obj,s.dynamicprops(1).name);
obj.(s.dynamicprops(1).name) = s.dynamicprops(1).value;
% Restore dynamic property attributes
metaDynoProp.SetAccess = s.dynamicprops(1).setAccess;
metaDynoProp.GetAccess = s.dynamicprops(1).getAccess;
end
end
```

Tips for Saving and Loading

In this section...
“Using Default Property Values to Reduce Storage” on page 11-22
“Avoiding Property Initialization Order Dependency” on page 11-23
“When to Use Transient Properties” on page 11-25
“Calling Constructor When Loading” on page 11-25

Using Default Property Values to Reduce Storage

When loading an object, MATLAB creates a new object and assigns the stored property values. For properties that had default values at the time you saved the object, MATLAB loads the saved default values, even if the class definition defines new default values for those properties.

See “Defining Default Values” on page 3-9 for more information on how MATLAB evaluates default value expressions.

Reducing Object Storage

If a property is often set to the same value, define a default value for that property. When the object is saved to a MAT-file, MATLAB does not save the default value, thereby, saving storage space.

Implementing Forward and Backward Compatibility

Default property values can help you implement version compatibility for saved objects. For example, if you add a new property to version 2 of your class, having a default value enables MATLAB to assign a value to the new property when loading a version 1 object.

Similarly, if version 2 of your class removes a property, then if a version 2 object is saved and loaded into version 1, your `loadobj` method can use the default value from version 1 for the version 2 object.

Avoiding Property Initialization Order Dependency

Use a Dependent property when the property value needs to be calculated at runtime. Whenever you can use a dependent property in your class definition you save storage for saved objects. Dependent is a property attribute (see “Property Attributes” on page 6-8 for a complete list.)

Controlling Property Loading

If your class design is such that setting one property value causes other property values to be updated, then you can use dependent properties to ensure objects load properly. For example, consider the following Odometer class. It defines two public properties: TotalDistance and Units. Whenever Units is modified, the TotalDistance is modified to reflect the change. There is also a private property, PrivateUnits, and a constant property ConversionFactor.

```
classdef Odometer
    properties(Constant)
        ConversionFactor = 1.6
    end
    properties
        TotalDistance = 0
    end
    properties(Dependent)
        Units
    end
    properties(Access=private)
        PrivateUnits = 'mi'
    end
    methods
        function unit = get.Units(obj)
            unit = obj.PrivateUnits;
        end
        function obj = set.Units(obj, newUnits)
            % validate newUnits to be a string
            switch(newUnits)
                case 'mi'
                    if strcmp(obj.Units, 'km')
                        obj.TotalDistance = obj.TotalDistance / ...
                            obj.ConversionFactor;
                    end
                end
            end
        end
    end
end
```

```
        obj.PrivateUnits = newUnits;
    end
    case 'km'
        if strcmp(obj.Units, 'mi')
            obj.TotalDistance = obj.TotalDistance * ...
                obj.ConversionFactor;
            obj.PrivateUnits = newUnits;
        end
    otherwise
        error('Odometer:InvalidUnits', ...
            'Units ''%s'' is not supported.', newUnits);
    end
end
end
end
end
```

Suppose you create an instance of `Odometer` with the following property values:

```
odObj = Odometer;
odObj.Units = 'km';
odObj.TotalDistance = 16;
```

When you save the object, the following happens to property values:

- `ConversionFactor` is not saved because it is a `Constant` property.
- `TotalDistance` is saved.
- `Units` is not saved because it is a `Dependent` property.
- `PrivateUnits` is saved and provides the storage for the current value of `Units`.

When you load the object, the following happens to property values:

- `ConversionFactor` is obtained from the class definition.
- `TotalDistance` is loaded from the saved object.
- `Units` is not loaded so its set method is not called.

- `PrivateUnits` is loaded and contains the value that is used if the `Units` get method is called.

If the `Units` property was not `Dependent`, loading it calls its set method and causes the `TotalDistance` property to be set again.

See “The `AxesObj` Class” on page 9-7 for another example of a class that uses a private, non-`Dependent` property to isolate a public, `Dependent` property from load-order side effects.

When to Use Transient Properties

The value of a `Transient` property is never stored when an object is saved to a file, but instances of the class do allocate storage to hold a value for this property. These two characteristics make a `Transient` property useful for cases where data needs to be stored in the object temporarily as an intermediate computation step, or for faster retrieval. (See “Property Attributes” on page 6-8 for a complete list of properties.)

You can use `Transient` properties to reduce storage space and simplify the load process in cases where:

- The property data can be easily reproduced at run-time.
- The property represent intermediate state that you can discard

Calling Constructor When Loading

MATLAB does not call the class constructor when loading an object from a MAT-file. However, if you set the `ConstructOnLoad` class attribute to `true`, `load` does call the constructor with no arguments.

Enabling `ConstructOnLoad` is useful when you do not want to implement a `loadobj` method, but do need to perform some actions at construction time, such as registering listeners for another object. You must be sure that the class constructor can be called with no arguments without generating an error. See “Supporting the No Input Argument Case” on page 7-18.

In cases where the class constructor sets only some property values based on input arguments, then using `ConstructOnLoad` is probably not useful.

See “Passing Arguments to Constructors During Load” on page 11-14 for an alternative.

Enumerations

- “Defining Named Values” on page 12-2
- “Enumerations” on page 12-4
- “Enumerations Derived from Built-In Classes” on page 12-15
- “Mutable (Handle) vs. Immutable (Value) Enumeration Members” on page 12-21
- “Enumerations That Encapsulate Data” on page 12-28
- “Saving and Loading Enumerations” on page 12-32

Defining Named Values

Kinds of Predefined Names

MATLAB supports two kinds of predefined names:

- Constant properties
- Enumerations

Constant Properties

Use constant properties when you want a collection of related constant values whose values can belong to different types (numeric values, character strings, and so on). Define properties with constant values by setting the property `Constant` attribute. Reference constant properties by name whenever you need access to that particular value.

See for more information.

Enumerations

Use enumerations when you want to create a fixed set of names representing a single type of value. You can derive enumeration classes from other classes to inherit the operations of the superclass. For example, if you define an enumeration class that subclasses a MATLAB numeric class like `double` or `int32`, the enumeration class inherits all of the mathematical and relational operations that MATLAB defines for those classes.

Using enumerations instead of character strings to represent a value, such as colors ('red'), can result in more readable code because:

- You can compare enumeration members with `==` instead of using `strcmp`
- Enumerations maintain type information, strings do not. For example, passing a string 'red' to functions means that every function must interpret what 'red' means. If you define red as an enumeration, the actual value of 'red' can change (from [1 0 0] to [.93 .14 .14], for example) without updating every function that accepts colors, as you would if you defined the color as a string 'red'.

Define enumerations by creating an enumeration block in the class definition.

See “Enumerations” on page 12-4 for more information.

Enumerations

In this section...

“Basic Knowledge” on page 12-4

“Using Enumeration Classes” on page 12-5

“Defining Methods in Enumeration Classes” on page 12-8

“Defining Properties in Enumeration Classes” on page 12-9

“Array Expansion Operations” on page 12-10

“Constructor Calling Sequence” on page 12-11

“Restrictions Applied to Enumeration Classes” on page 12-13

“Techniques for Defining Enumerations” on page 12-13

Basic Knowledge

The material presented in this section builds on an understanding of the information provided in the following sections.

Chapter 3, “Class Definition—Syntax Reference”, “Creating Subclasses — Syntax and Techniques” on page 10-7, Chapter 6, “Properties — Storing Class Data”, Chapter 7, “Methods — Defining Class Operations”

Terminology and Concepts

This documentation uses terminology as described in the following list:

- *Enumeration* or *Enumeration class* — A class that contains an enumeration block defining enumeration members.
- *Enumeration member* — A named instance of an enumeration class.
- *Enumeration member constructor arguments* — Values in parentheses next to the enumeration member name in the enumeration block. When you create an instance of an enumeration member, MATLAB passes the value or values in parenthesis to the class constructor.

- *Underlying value* — For enumerations derived from built-in classes, the value associated with an instance of an enumeration class (that is, an enumeration member).

Using Enumeration Classes

Create an enumeration class by adding an enumeration block to a class definition. For example, the `WeekDays` class enumerates a set of days of the week.

```
classdef WeekDays
    enumeration
        Monday, Tuesday, Wednesday, Thursday, Friday
    end
end
```

Constructing an Enumeration Member

Refer to an enumeration member using the class name and the member name:

```
ClassName.MemberName
```

For example, assign the enumeration member `WeekDays.Tuesday` to the variable `today`:

```
today = WeekDays.Tuesday;
```

`today` is a variable of class `WeekDays`:

```
>> whos
      Name      Size      Bytes  Class      Attributes
      today      1x1          56  WeekDays
>> today
today =
      Tuesday
```

Default Methods

Enumeration classes have four methods by default:

```
>> methods(today)
```

```
Methods for class WeekDays:
```

```
WeekDays      char      eq      ne
```

- Default constructor (WeekDays in this case)
- char — converts enumeration members to character strings
- eq — enables use of == in expressions
- ne — enables use of ~= in expressions

Equality and inequality methods enable you to use enumeration members in `if` and `switch` statements and other functions that test for equality.

Because you can define enumeration members with descriptive names, conversion to `char` is useful. For example:

```
today = WeekDays.Friday;  
['Today is ',char(today)]  
ans =
```

```
Today is Friday
```

Testing for Membership in a Set

Suppose you want to determine if today is a meeting day for your team.

```
today = WeekDays.Tuesday;  
teamMeetings = [WeekDays.Wednesday WeekDays.Friday];
```

Use the `ismember` function to determine if today is a meeting day:

```
ismember(today,teamMeetings)  
ans =  
    0
```

Using Enumerations in a Switch Statement

Enumerations work in switch statements:

```
function c = Reminder(day)
    % Add error checking here
    switch(day)
        case WeekDays.Monday
            c = 'Department meeting at 10:00';
        case WeekDays.Tuesday
            c = 'Meeting Free Day!';
        case {WeekDays.Wednesday WeekDays.Friday}
            c = 'Team meeting at 2:00';
        case WeekDays.Thursday
            c = 'Volley ball night';
    end
end
```

Pass a member of the WeekDays enumeration class to the Reminder function:

```
>> today = WeekDays.Wednesday;
>> Reminder (today)
```

```
ans =
```

```
Team meeting at 2:00
```

Getting Information About Enumerations

You can get information about enumeration classes using the enumeration function. For example:

```
enumeration WeekDays
```

```
Enumeration members for class 'WeekDays':
```

```
Monday
Tuesday
Wednesday
Thursday
Friday
```

See also “Meta-Class EnumeratedValues Property” on page 14-6

Converting to Superclass Value

If an enumeration class specifies a superclass, in many cases you can convert an enumeration object to the superclass by passing the object to the superclass constructor. However, the superclass must be able to accept its own class as input and return an instance of the superclass. MATLAB built-in numeric classes, like `double`, `single`, and so on allow this conversion.

For example, the `Bearing` class derives from the `uint32` built-in class:

```
classdef Bearing < uint32
    enumeration
        North (0)
        East  (90)
        South (180)
        West  (270)
    end
end
```

Assign the `Bearing.East` member to the variable `a`:

```
a = Bearing.East;
```

Pass `a` to the superclass constructor and return an object of the superclass, `b`:

```
b = uint32(a);
whos
```

Name	Size	Bytes	Class	Attributes
a	1x1	60	Bearing	
b	1x1	4	uint32	

The `uint32` constructor accepts an instance of the subclass `Bearing` and returns an object of class `uint32`.

Defining Methods in Enumeration Classes

Define methods in an enumeration class like any MATLAB class. For example, here is the `WeekDays` class with a method called `isMeetingDay` added:

```
classdef WeekDays
    enumeration
        Monday, Tuesday, Wednesday, Thursday, Friday
    end
    methods
        function tf = isMeetingDay(obj)
            tf = ~(WeekDays.Tuesday == obj);
        end
    end
end
```

Call `isMeetingDay` with an instance of the `WeekDays` class:

```
>> today = WeekDay.Tuesday;
>> today.isMeetingDay

ans =

    0
```

You can pass the enumeration member to the method directly:

```
>> isMeetingDay(WeekDays.Wednesday)

ans =

    1
```

Defining Properties in Enumeration Classes

Add properties to an enumeration class when you must store data related to the enumeration members. Set the property values in the class constructor. For example, the `SyntaxColors` class defines three properties whose values the constructor assigns to the values of the input arguments when you reference a class member.

```
classdef SyntaxColors
    properties
        R
        G
        B
    end
```

```
methods
    function c = SyntaxColors(r, g, b)
        c.R = r; c.G = g; c.B = b;
    end
end
enumeration
    Error    (1, 0, 0)
    Comment (0, 1, 0)
    Keyword  (0, 0, 1)
    String   (1, 0, 1)
end
end
```

When you refer to an enumeration member, the constructor initializes the property values:

```
e = SyntaxColors.Error;

e.R

ans =

    1
```

Because `SyntaxColors` is a value class (it does not derive from `handle`), only the class constructor can set property values:

```
e.R = 0
??? Setting the 'R' property of the 'SyntaxColors' class
is not allowed.
```

See “Mutable (Handle) vs. Immutable (Value) Enumeration Members” on page 12-21 for more information on enumeration classes that define properties.

Array Expansion Operations

MATLAB enables assignment to any element of an array, even if the array does not exist. For example, you can create an array of `WeekDays` objects:

```
classdef WeekDays
    enumeration
```

```

        Monday, Tuesday, Wednesday, Thursday, Friday
    end
end

clear
ary(5) = WeekDays.Tuesday;

```

MATLAB must initialize the values of array elements `ary(1:4)`. The default value of an enumeration class is the first enumeration member defined by the class in the enumeration block. The result of the assignment to the fifth element of the array `ary` is, therefore:

```

ary
ary =

    Monday    Monday    Monday    Monday    Tuesday

```

Constructor Calling Sequence

Each statement in an enumeration block is the name of an enumeration member, optionally followed by an argument list. If the enumeration class defines a constructor, MATLAB calls the constructor to create the enumerated instances.

MATLAB provides a default constructor for all enumeration classes that do not explicitly define a constructor. The default constructor creates an instance of the enumeration class:

- Using no input arguments, if the enumeration member defines no input arguments
- Using the input arguments defined in the enumeration class for that member

For example, the input arguments for the `Boolean` class are 0 for `Boolean.No` and 1 for `Boolean.Yes`.

```

classdef Boolean < logical
    enumeration
        No (0)
        Yes (1)
    end
end

```

```
end
```

The values of 0 and 1 are of class `logical` because the default constructor passes the argument to the first superclass. That is,

```
n = Boolean.No;
```

results in a call to `logical` that is equivalent to the following statement in a constructor:

```
function obj = Boolean(val)
    obj@logical(val)
end
```

MATLAB passes the member argument only to the first superclass. For example, suppose `Boolean` derived from another class:

```
classdef Boolean < logical & MyBool
    enumeration
        No (0)
        Yes (1)
    end
end
```

The `MyBool` class can add some specialized behavior:

```
classdef MyBool
    methods
        function boolValues = testBools(obj)
            ...
        end
    end
end
```

Now, the default `Boolean` constructor behaves as if defined like this function:

```
function obj = Boolean(val)
    obj@logical(val) % Argument passed to first superclass constructor
    obj@MyBool      % No arguments passed to subsequent constructors
end
```


Restrictions Applied to Enumeration Classes

Enumeration classes, which consist of a fixed set of possible values, restrict certain aspects of class use and definition:

- Enumeration classes are implicitly `Sealed`. You cannot define a subclass of an enumeration class because doing so would expand the set.
- You cannot call the constructor of an enumeration class directly. Only MATLAB can call enumeration class constructors to create the fixed set of members.
- The properties of value-based enumeration classes are immutable. Only the constructor can assign property values. MATLAB implicitly defines the `SetAccess` attributes of all properties defined by value-based enumeration classes as `immutable`. You cannot set the `SetAccess` attribute to any other value.
- All properties inherited by a value-based enumeration class that are not defined as `Constant` must have `immutable SetAccess`.
- The properties of handle-based enumeration classes are mutable. You can set property values on instances of the enumeration class. See “Mutable (Handle) vs. Immutable (Value) Enumeration Members” on page 12-21 for more information.
- An enumeration member cannot have the same name as a property, method, or event defined by the same class.
- Enumerations do not support colon (`a:b`) operations. For example, `FlowRate.Low:FlowRate.High` causes an error even if the `FlowRate` class derives from a numeric superclass.

Techniques for Defining Enumerations

Enumerations enable you to define names that represent entities useful to your application, without using numeric values or character strings. All enumerations support equality and inequality operations. Therefore, `switch`, `if`, and a number of comparison functions like `isequal` and `ismember` work with enumeration members.

You can define enumeration classes in ways that are most useful to your application, as described in the following sections.

Simple Enumerated Names

Simple enumeration classes have no superclasses and no properties. These classes define a set of related names that have no underlying values associated with them. Use this kind of enumeration when you want descriptive names, but your application does not require specific information associated with the name.

See the `WeekDays` class in the “Defining Methods in Enumeration Classes” on page 12-8 section.

Enumerations with Built-In Class Behaviors

Enumeration classes that subclass MATLAB built-in classes inherit most of the behaviors of those classes. For example, an enumeration class derived from the `double` class inherits the mathematical, relational, and set operations that work with variables of the class.

Enumerations do not support the colon (`:`) operator, even if the superclass does. See “Restrictions Applied to Enumeration Classes” on page 12-13 for more information.

See “Enumerations Derived from Built-In Classes” on page 12-15.

Enumerations with Properties for Member Data

Enumeration classes that do not subclass MATLAB built-in numeric and logical classes can define properties. These classes can define constructors that set each member’s unique property values.

The constructor can save input arguments in property values. For example, a `Color` class can specify a `Red` enumeration member color with three (Red, Green, Blue) values:

```
enumeration
    Red (1,0,0)
end
```

See “Enumerations That Encapsulate Data” on page 12-28

Enumerations Derived from Built-In Classes

In this section...

“Basic Knowledge” on page 12-15

“Why Derive Enumeration Class from Built-In Classes” on page 12-15

“Aliasing Enumeration Names ” on page 12-17

“Superclass Constructor Returns Underlying Value” on page 12-18

“Default Converter” on page 12-19

Basic Knowledge

See “Classes (Data Types)” for information on MATLAB built-in classes.

Why Derive Enumeration Class from Built-In Classes

Note Enumeration classes derived from built-in numeric and logical classes cannot define properties.

If an enumeration class subclasses a built-in numeric class, the subclass inherits ordering and arithmetic operations, which you can apply to the enumerated names.

For example, the `Results` class subclasses the `int32` built-in class and associates an integer value with each of the four enumeration members — `First`, `Second`, `Third`, and `NoPoints`.

```
classdef Results < int32
    enumeration
        First (100)
        Second (50)
        Third (10)
        NoPoints (0)
    end
end
```

Because the enumeration member inherits the methods of the `int32` class (not the colon operator), you can use these enumerations like numeric values (summed, sorted, averaged, and so on).

```
isa(Results.Second, 'int32')

ans =

    1
```

For example, use enumeration names instead of numbers to rank two teams:

```
Team1 = [Results.First, Results.NoPoints, Results.Third, Results.Second]
Team2 = [Results.Second, Results.Third, Results.First, Results.First];
```

Perform `int32` operations on these `Results` enumerations:

```
sum(Team1)
ans =

    160
mean(Team1)
ans =

    40
sort(Team2, 'descend')

ans =

    First    First    Second    Third
Team1 > Team2

ans =

    1    0    0    0
sum(Team1) < sum(Team2)

ans =

    1
```

Creating Enumeration Instances

When you first refer to an enumeration class that derives from a built-in class such as, `int32`, MATLAB passes the input arguments associated with the enumeration members to the superclass constructor. For example, referencing the `Second Results` member, defined as:

```
Second (50)
```

means that MATLAB calls:

```
int32(50)
```

to initialize the `int32` aspect of this `Results` object.

Aliasing Enumeration Names

Enumeration classes that derive from MATLAB built-in numeric and logical classes can define more than one name for an underlying value. The first name in the enumeration block with a given underlying value is the actual name for that underlying value and subsequent names are aliases.

Specify aliased names with the same superclass constructor argument as the actual name:

```
classdef Boolean < logical
    enumeration
        No (0)
        Yes (1)
        off (0)
        on (1)
    end
end
```

For example, the actual name of an instance of the `Boolean.off` enumeration member is `No`:

```
a = Boolean.No

a =

    No
```

```
b = Boolean.off
```

```
b =
```

```
No
```

Superclass Constructor Returns Underlying Value

The actual underlying value associated with an enumeration member is the value returned by the built-in superclass. For example, consider the `Boolean` class defined with constructor arguments that are of class `double`:

```
classdef Boolean < logical
  enumeration
    No (0)
    Yes (100)
  end
end
```

This class derives from the built-in `logical` class. Therefore, underlying values for an enumeration member depend only on what value `logical` returns when passed that value:

```
a = Boolean.Yes
```

```
a =
```

```
Yes
```

```
logical(a)
```

```
ans =
```

```
1
```

Subclassing a Numeric Built-In Class

The `FlowRate` enumeration class defines three members, `Low`, `Medium`, and `High`.

```
classdef FlowRate < int32
  enumeration
```

```

        Low    (10)
        Medium (50)
        High   (100)
    end
end

```

Referencing an instance of an enumeration member:

```
setFlow = FlowRate.Medium;
```

returns an instance that is the result of MATLAB calling the default constructor with the argument value of 50. MATLAB passes this argument to the first superclass constructor (`int32(50)` in this case), which results in an underlying value of 50 as a 32-bit integer for the `FlowRate.Medium` member.

Because `FlowRate` subclasses a MATLAB built-in numeric class (`int32`), it cannot define properties. However `FlowRate` inherits `int32` methods including a converter method, which programs can use to obtain the underlying value:

```

setFlow = FlowRate.Medium;
int32(setFlow)
ans =

```

```
50
```

Default Converter

All enumeration classes based on built-in classes have a default conversion method to convert built-in data to an enumeration member of that class. For example:

```

a = Boolean(1)

a =

    Yes

```

An enumerated class also accepts enumeration members of its own class as input arguments:

```
Boolean(a)
```

```
ans =
```

```
    Yes
```

Nonscalar inputs to the `converter` method return an object of the same size:

```
Boolean([0,1])
```

```
ans =
```

```
    No    Yes
```

Create an empty enumeration array using the `empty` static method:

```
Boolean.empty
```

```
ans =
```

```
0x0 empty Boolean enumeration.
```


Mutable (Handle) vs. Immutable (Value) Enumeration Members

In this section...

“Basic Knowledge” on page 12-21

“Selecting Handle- or Value-Based Enumerations” on page 12-21

“Value-Based Enumeration Classes” on page 12-21

“Handle-Based Enumeration Classes” on page 12-23

“Example – Using Enumerations to Represent a State” on page 12-26

Basic Knowledge

See “Comparing Handle and Value Classes” on page 5-2 for general information about these two kinds of classes.

Selecting Handle- or Value-Based Enumerations

Use a handle enumeration when you want to enumerate a set of objects whose state might change over time. Use a value enumeration to enumerate a set of abstract (and immutable) values.

Value-Based Enumeration Classes

A value-based enumeration class has a fixed set of specific values. You cannot modify these values by changing the values of properties because doing so expands or changes the fixed set of values for this enumeration class.

Inherited Property `SetAccess` Must Be Immutable

Value-based enumeration class implicitly define the `SetAccess` attributes of all properties as `immutable`. You cannot set the `SetAccess` attribute to any other value.

However, all superclass properties must explicitly define property `SetAccess` as `immutable`. See “Property Attributes” on page 6-8 for more information on property attributes.

Enumeration Members Remain Constant

When you create an instance of a value-based enumeration class, this instance is unique until the class is cleared and reloaded. For example, given the following class:

```
classdef WeekDays
    enumeration
        Monday, Tuesday, Wednesday, Thursday, Friday
    end
end
```

MATLAB considers a and b as equivalent:

```
a = WeekDays.Monday;
b = WeekDays.Monday;
isequal(a,b)
ans =

    1

a == b
ans =

    1
```

Enumeration Member Properties Remain Constant

Value-based enumeration classes that define properties are immutable. For example, the `Colors` enumeration class associates RGB values with color names.

```
classdef Colors
    properties
        R = 0;
        G = 0;
        B = 0;
    end
    methods
        function c = Colors(r, g, b)
            c.R = r; c.G = g; c.B = b;
        end
    end
end
```

```

        end
    end
    enumeration
        Red    (1, 0, 0)
        Green  (0, 1, 0)
        Blue   (0, 0, 1)
    end
end

```

The constructor assigns the input arguments to R, G, and B properties:

```
red = Colors.Red;
```

You cannot change a property value:

```
red.G = 1;
??? Setting the 'G' property of the 'Colors' class
is not allowed.
```

Handle-Based Enumeration Classes

Handle-based enumeration classes that define properties are mutable. Derive enumeration classes from the `handle` class when you must be able to change property values on instances of that class.

An Enumeration Member Remains Constant

Given a handle-based enumeration class with properties, changing the property value of an instance causes all references to that instance to reflect the changed value.

For example, the `HandleColors` enumeration class associates RGB values with color names, the same as the `Colors` class in the previous example. However, `HandleColors` derives from `handle`:

```

classdef HandleColors < handle
% Enumeration class derived from handle
    properties
        R = 0;
        G = 0;
        B = 0;
    end
end

```

```
    methods
        function c = HandleColors(r, g, b)
            c.R = r; c.G = g; c.B = b;
        end
    end

    enumeration
        Red (1, 0, 0)
    ... % Other colors omitted
    end
end
```

Create an instance of `HandleColors.Red` and return the value of the `R` property:

```
a = HandleColors.Red;
a.R

ans =

    1
```

MATLAB constructs the `HandleColors.Red` enumeration member, which sets the `R` property to 1, the `G` property to 0, and the `B` property to 0.

Change the value of the `R` property to `.8`:

```
a.R = .8;
```

After setting the value of the `R` property to `.8`, create another instance, `b`, of `HandleColors.Red`:

```
b = HandleColors.Red;

b.R

ans =

    0.8000
```

The value of the `R` property of the newly created instance is also `0.8000`. The MATLAB session has only one value for any enumeration member at any given time.

Clearing the workspace variables does not change the current definition of the enumeration member `HandleColors.Red`:

```
clear
a = HandleColors.Red;
a.R

ans =

    0.8000
```

Clear the class to reload the definition of the `HandleColors` class (see [clear classes](#)):

```
clear classes
a = HandleColors.Red;

a.R

ans =

    1
```

If you do not want to allow reassignment of a given property value, set that property's `SetAccess` attribute to `immutable`.

See “Property Attributes” on page 6-8 for more information about property attributes.

Equality of Handle-Based Enumerations

Suppose you assign two variables to a particular enumeration member:

```
a = HandleColors.Red;
b = HandleColors.Red;
```

You can compare `a` and `b` using `isequal`:

```
>> isequal(a,b)
```

```
ans =
```

```
1
```

The property values of `a` and `b` are the same, so `isequal` returns `true`. However, unlike nonenumeration handle classes, `a` and `b` are the same handle because there is only one enumeration member. Determine handle equality using `==` (the handle `eq` method).

```
>> a == b
```

```
ans =
```

```
1
```

See the `handle eq` method for information on how `isequal` and `==` differ when used with handles.

Example – Using Enumerations to Represent a State

The `MachineState` class defines two enumeration members to represent the state of a machine, either running or not running.

```
classdef MachineState
    enumeration
        Running
        NotRunning
    end
end
```

The `Machine` class represents a machine with start and stop operations. The `MachineState` enumerations are easy to work with because of their `eq` and `char` methods, and they result in code that is easy to read.

```
classdef Machine < handle
    properties (SetAccess = Private)
        State = MachineState.NotRunning;
    end
```

```
    methods
    function start(machine)
        if machine.State == MachineState.NotRunning
            machine.State = MachineState.Running;
        end
        disp (machine.State.char)
    end
    function stop(machine)
        if machine.State == MachineState.Running
            machine.State = MachineState.NotRunning;
        end
        disp (machine.State.char)
    end
end
end
```

Create a Machine object and call start and stop methods:

```
% Create a Machine object
>> m = Machine;
% Start the machine
>> m.start
Running
% Stop the machine
>> m.stop
NotRunning
```

Enumerations That Encapsulate Data

Store Data in Properties

Note Enumeration classes that subclass built-in numeric or logical classes cannot define or inherit properties. See “Enumerations Derived from Built-In Classes” on page 12-15 for more information on this kind of enumeration class.

Define properties in an enumeration class if you want to associate specific data with enumeration members, but do not need to inherit arithmetic, ordering, or other operations that MATLAB defines for specific built-in classes.

Representing Colors

Suppose you want to use a particular set of colors in all your graphs. You can define an enumeration class to represent the RGB values of the colors in your color set. The `Colors` class defines names for the colors, each of which uses the RGB values as arguments to the class constructor:

```
classdef Colors
    properties
        R = 0;
        G = 0;
        B = 0;
    end
    methods
        function c = Colors(r, g, b)
            c.R = r; c.G = g; c.B = b;
        end
    end
    enumeration
        Blueish (18/255,104/255,179/255)
        Reddish (237/255,36/255,38/255)
        Greenish (155/255,190/255,61/255)
        Purplish (123/255,45/255,116/255)
        Yellowish (1,199/255,0)
        LightBlue (77/255,190/255,238/255)
    end
end
```



```
end
```

Suppose you want to specify the new shade of red named `Reddish`:

```
a = Colors.Reddish;  
a.R
```

```
ans =  
  
    0.9294
```

```
a.G
```

```
ans =  
  
    0.1412
```

```
a.B
```

```
ans =  
  
    0.1490
```

Use these values by accessing the enumeration member's properties. For example, the `myPlot` function accepts a `Colors` enumeration member as an input argument and accesses the RGB values defining the color from the property values.

```
function h = myPlot(x,y,LineColor)  
    % Simple plotting function  
    h = line('XData',x,'YData',y);  
    r = LineColor.R;  
    g = LineColor.G;  
    b = LineColor.B;  
    set(h,'Color',[r g b])  
end
```

Create a plot using a reddish color line:

```
r = Colors.Reddish;  
h = myPlot(1:10,1:10,r);
```

The `Colors` class encapsulates the definitions of a standard set of colors. These definitions can change in the `Colors` class without affecting functions that use the `Colors` enumerations.

Enumerations Defining Categories

Suppose the `Cars` class defines categories used to inventory automobiles. The `Cars` class derives from the `CarPainter` class, which derives from `handle`. The abstract `CarPainter` class defines a `paint` method, which modifies the `Color` property if a car is painted another color.

The `Cars` class uses `Colors` enumerations to specify a finite set of available colors. The exact definition of any given color can change independently of the `Cars` class.

```
classdef Cars < CarPainter
    enumeration
        Hybrid (2, 'Manual', 55, Colors.Reddish)
        Compact(4, 'Manual', 32, Colors.Greenish)
        MiniVan(6, 'Automatic', 24, Colors.Blueish)
        SUV    (8, 'Automatic', 12, Colors.Yellowish)
    end
    properties (SetAccess = private)
        Cylinders
        Transmission
        MPG
        Color
    end
    methods
        function obj = Cars(cyl,trans,mpg,colr)
            obj.Cylinders = cyl;
            obj.Transmission = trans;
            obj.MPG = mpg;
            obj.Color = colr;
        end
        function paint(obj,colorobj)
            if isa(colorobj,'Colors')
                obj.Color = colorobj;
            else
                [~,cls] = enumeration('Colors');
            end
        end
    end
end
```

```

        disp('Not an available color')
        disp(cls)
    end
end
end
end

```

The CarPainter class requires its subclasses to define a method called paint:

```

classdef CarPainter < handle
    methods (Abstract)
        paint(carobj,colorobj)
    end
end

```

Suppose you define an instance of the Cars class:

```
c1 = Cars.Compact;
```

The color of this car is Greenish, as defined by the Colors.Greenish enumeration:

```

c1.Color

ans =

    Greenish

```

Use the paint method to change the car color:

```

c1.paint(Colors.Reddish)
c1.Color

ans =

    Reddish

```

Saving and Loading Enumerations

In this section...

“Basic Knowledge” on page 12-32

“Built-In and Value-Based Enumeration Classes” on page 12-32

“Simple and Handle-Based Enumeration Classes” on page 12-32

“What Causes Loading as a Struct Instead of an Object” on page 12-33

Basic Knowledge

See the `save` and `load` functions and “The Save and Load Process” on page 11-2 for general information on saving and loading objects.

Built-In and Value-Based Enumeration Classes

When you save enumerations that derive from built-in classes or that are value-based classes with properties, MATLAB saves the names of the enumeration members and the definition of each member.

When loading these types of enumerations, MATLAB preserves names over underlying values. If the saved named value is different from the current class definition, MATLAB uses the value defined in the current class, and then issues a warning.

Simple and Handle-Based Enumeration Classes

When you save simple enumerations (those having no properties, superclasses, or values associated with the member names) or those enumerations derived from the `handle` class, MATLAB saves the names and any underlying values.

However, when loading these types of enumerations, MATLAB does not check the values associated with the names in the current class definition. This behavior results from the fact that simple enumerations have no underlying values and handle-based enumerations can legally have values that are different than those defined by the class.

What Causes Loading as a Struct Instead of an Object

The addition of a new named value or a new property made to a class subsequent to saving an enumeration does not trigger a warning during load.

If there are changes to the enumeration class definition that do not prevent MATLAB from loading the object (that is, all of the named values in the MAT-File are present in the modified class definition), then MATLAB issues a warning that the class has changed and loads the enumeration.

In the following cases, MATLAB issues a warning and loads as much of the saved data as possible as a `struct`:

- MATLAB cannot find the class definition
- The class is no longer an enumeration class
- MATLAB cannot initialize the class
- There is one or more enumeration member in the loaded enumeration that is not in the class definition
- For value-based enumerations with properties, a property exists in the file, but is not present in the class definition

Struct Fields

The returned `struct` has the following fields:

- `ValueNames` — A cell array of strings, one per unique value in the enumeration array.
- `Values` — An array of the same dimension as `ValueNames` containing the corresponding values of the enumeration members named in `ValueNames`. Depending on the kind of enumeration class, `Values` can be one of the following:
 - If the enumeration class derives from a built-in class, the array is of the built-in class and the values in the array are the underlying values of each enumeration member.
 - Otherwise, a `struct` array representing the property name — property values pairs of each enumeration member. For simple and handle-based enumerations, the `struct` array has no fields.

- `ValueIndices` — a `uint32` array of the same size as the original enumeration. Each element is an index into the `ValueNames` and `Values` arrays. The content of `ValueIndices` represents the value of each object in the original enumeration array.

Constant Properties

Defining Named Constants

In this section...

“Defining Named Constants” on page 13-2

“Setting Constant Property Default” on page 13-4

Defining Named Constants

You can define a collection of constants and access these values by name. Create a class having properties with the `Constant` attribute set to `true`. Setting the `Constant` attribute to `true` effectively sets the `SetAccess` to `private`, so that the values of the properties cannot be changed outside of the class.

You can define a package of classes defining various sets of constants and import these classes into any function that needs them.

Assigning Values to Constant Properties

You can assign any value to a `Constant` property, including a MATLAB expression. For example:

```
classdef NamedConst
    properties (Constant)
        R = pi/180;
        D = 1/RadDeg.R;
        AccCode = '0145968740001110202NPQ';
        RN = rand(5);
    end
end
```

MATLAB evaluates the expressions when loading the class (when you first reference a constant property from that class). Therefore, the values MATLAB assigns to `RN` are the result to a single call to the `rand` function and do not change with subsequent references to `NamedConst.RN`. Calling `clear classes` causes MATLAB to reload the class.

Referencing Constant Properties

Refer to the constant using the class name and the property name:

```
ClassName.PropName
```

For example, to use the RadDeg class defined in the previous section, reference the constant for the degree to radian conversion, R:

```
radi = 45*RadDeg.R
```

```
radi =
```

```
0.7854
```

A Package for Constants

To create a library for constant values that you can access by name, first create a package folder, and then define the various classes to organize the constants you want to provide. For example, to implement a set of constants that are useful for making astronomical calculations, you can define a AstroConstants class in a package called Constants:

```
+Constants/@AstroConstants/AstroConstants.m
```

The class defines a set of Constant properties with initial values assigned:

```
classdef AstroConstants
    properties (Constant)
        C = 2.99792458e8;    % m/s
        G = 6.67259;        % m/kg*s
        Me = 5.976e24;      % Earth mass (kg)
        Re = 6.378e6;       % Earth radius (m)
    end
end
```

To use this set of constants, reference them with a fully qualified class name. For example, the following function uses some of the constants defined in AstroConstants:

```
function E = energyToOrbit(m,r)
    E = Constants.AstroConstants.G * Constants.AstroConstants.Me * m * ...
```

```
(1/Constants.AstroConstants.Re-0.5*r);  
end
```

You cannot import class properties. Therefore, use the fully qualified class name to reference constant properties.

Setting Constant Property Default

You can define a Constant property default value as the class that defines the property. MATLAB creates the instance assigned to the Constant property when loading the class. The MyCnstClass shows the behavior of Constant properties that contain an instance of the defining class:

```
classdef MyCnstClass  
    properties (Constant)  
        Instance = MyCnstClass;  
    end  
    properties  
        Date  
    end  
    methods (Access = private)  
        function obj = MyCnstClass  
            obj.Date = clock;  
        end  
    end  
end
```

Reference the class instance contained in the Constant property:

```
MyCnstClass.Instance.Date  
  
ans =  
  
    1.0e+003 *  
  
    2.0090    0.0070    0.0080    0.0110    0.0440    0.0331  
clear  
>> MyCnstClass.Instance.Date  
  
ans =
```

```
1.0e+003 *  
    2.0090    0.0070    0.0080    0.0110    0.0440    0.0331  
clear classes  
MyCnstClass.Instance.Date  
  
ans =  
  
1.0e+003 *  
    2.0090    0.0070    0.0080    0.0110    0.0450    0.0419
```

For properties that are not Constant, you cannot use a class instance for a default value.

Obtaining Information About Classes from Meta-Classes

- “Working with Meta-Classes” on page 14-2
- “Using Meta-Classes to Inspect Classes and Objects” on page 14-4
- “Finding Objects Having Specific Settings” on page 14-7
- “Getting Information About Properties” on page 14-10
- “Getting Property Default Values” on page 14-17

Working with Meta-Classes

What Are Meta-Classes?

Meta-classes contain information about class definitions. Use meta-classes to obtain information about class definitions without the need to create instances of the class. Each block in a class definition has an associated meta-class that defines the attributes for that block. Each attribute corresponds to a property in the meta-class. An instance of a meta-class has values assigned to each property that correspond to the values of the attributes of the associated class block.

Meta-classes enable programmatic inspection of classes. Tools such as property inspectors, debuggers, and so on, use these techniques.

The meta Package

The meta package contains meta-classes that MATLAB uses for the definition of classes and class components. The class name indicates the component described by the meta-class:

```
meta.package  
meta.class  
meta.property  
meta.method  
meta.event
```

Each meta-class has properties, methods, and events that contain information about the class or class component. See `meta.package`, `meta.class`, `meta.property`, `meta.method` and `meta.event` for more information on these meta-classes.

Creating Meta-Class Objects

You cannot instantiate meta-classes directly by calling the respective class constructor. You can create meta-class objects from class instances or from the class name.

- `?ClassName` — Returns a `meta.class` object for the named class. Use `meta.class.forName` with class names stored as characters in variables.

- `meta.class.fromName('ClassName')` — returns the `meta.class` object for the named class (`meta.class.fromName` is a `meta.class` method).
- `metaclass(obj)` — Returns a meta-class object for the class instance (`metaclass`)

```
% create meta-class object from class name
using the ? operator
mobj = ?classname;
% create meta-class object from class name using the fromName method
mobj = meta.class.fromName('classname');
% create meta-class object from class instance
obj = myClass;
mobj = metaclass(obj);
```

The `metaclass` function returns the `meta.class` object (that is, an object of the `meta.class` class). You can obtain other meta-class objects (`meta.property`, `meta.method`, and so on) from the `meta.class` object.

Note Meta-class is a term used here to describe a kind of class. `meta.class` is a class in the `meta` package whose instances contain information about MATLAB classes.

Using Meta-Class Objects

Here is how you can use meta-class objects:

- Obtain a `meta.class` object from a class definition (using `?`) or from a class instance (using `metaclass`).
- Use the `meta.class` properties, methods, and events to obtain information about the class or class instance from which you obtained the `meta.class` object. For example, get other meta-class objects, such as the `meta.properties` objects defined for each of the class properties.

The following examples show these techniques.

Using Meta-Classes to Inspect Classes and Objects

In this section...

“Inspecting a Class” on page 14-4

“Meta-Class EnumeratedValues Property” on page 14-6

Inspecting a Class

The `EmployeeData` class is a handle class with two properties, one of which has private Access and defines a set access method.

```
classdef EmployeeData < handle
    properties
        EmployeeName
    end
    properties (Access = private)
        EmployeeNumber
    end
    methods
        function obj = EmployeeData(name,ss)
            if nargin > 0
                obj.EmployeeName = name;
                obj.EmployeeNumber = ss;
            end
        end
        function set.EmployeeName(obj,name)
            if ischar(name)
                obj.EmployeeName = name;
            else
                error('Employee name must be a text string')
            end
        end
    end
end
end
```

Inspecting the Class Definition

Using the `EmployeeData` class, create a `meta.class` object using the `?` operator:


```
mc = ?EmployeeData;
```

Determine from what classes `EmployeeData` derives:

```
a = mc.SuperClasses; % a is cell array of meta.class objects
a{1}.Name
ans =
handle
```

Inspecting Properties

Find the names of the properties defined by this class. First obtain a cell array of `meta.properties` objects from the `meta.class Properties` property.

```
mpCell = mc.Properties;
```

The length of `mpCell` indicates there are two `meta.property` objects, one for each property defined by the `EmployeeData` class:

```
length(mpCell)
ans =
    2
```

Now get a `meta.property` object from the cell array:

```
prop1 = mpCell{1};
prop1.Name
ans =
EmployeeName
```

The `Name` property of the `meta.property` object identifies the class property represented by that `meta.property` object.

Query other `meta.property` object properties to determine the attributes of the `EmployeeName` property.

Inspecting an Instance of a Class

Create an `EmployeeData` object and determine property access settings:

```
EdObj = EmployeeData('My Name',1234567);
mcEdObj = metaclass(EdObj);
```

```
mpCell = mcEdObj.Properties;
EdObj.(mpCell{1}.Name) % Dynamic field names work with objects
ans =
    My Name
EdObj.(mpCell{2}.Name)
??? Getting the 'EmployeeNumber' property of the 'EmployeeData' class is
not allowed.
mpCell{2}.GetAccess
ans =
    private
```

Obtain a function handle to the property set access function:

```
mpCell{1}.SetMethod
ans =
    @D:\MyDir\@EmployeeData\EmployeeData.m>EmployeeData.set.EmployeeName
```

Meta-Class EnumeratedValues Property

The `meta.class EnumeratedValues` property contains a cell array of `meta.EnumeratedValue` objects, one for each enumeration member. Use the `meta.EnumeratedValue Name` property to obtain the enumeration member names defined by an enumeration class. For example, given the `FlowRate` enumeration class:

```
classdef WeekDays
    enumeration
        Monday, Tuesday, Wednesday, Thursday, Friday
    end
end
```

Query enumeration names from the `meta.class` object:

```
mc = ?WeekDays;
mc.EnumeratedValues{2}.Name

ans =

    Tuesday
```

Finding Objects Having Specific Settings

In this section...

“Finding Handle Objects” on page 14-7

“Perusing Meta-Classes with findobj” on page 14-8

Finding Handle Objects

Use the handle class `findobj` method to find objects that have properties with specific values. For example, the following class defines a `PhoneBook` object to represent a telephone book entry in a data base. The `PhoneBook` class subclasses the `dynamicprops` class, which derives from `handle`.

```
classdef PhoneBook < dynamicprops
    properties
        Name
        Address
        Number
    end
    methods
        function obj = PhoneBook(n,a,p)
            obj.Name = n;
            obj.Address = a;
            obj.Number = p;
        end
    end
end
```

Assume three of the `PhoneBook` entries in the database are:

```
PB(1) = PhoneBook('Nancy Vidal', '123 Washington Street', '5081234567');
PB(2) = PhoneBook('Nancy Vidal', '123 Main Street', '5081234568');
PB(3) = PhoneBook('Nancy Wong', '123 South Street', '5081234569');
```

One of these three `PhoneBook` objects has a dynamic property:

```
PB(2).addprop('HighSpeedInternet');
PB(2).HighSpeedInternet = '1M';
```

Finding Property/Value Pairs

Find the object representing employee Nancy Wong:

```
NW = findobj(PB, 'Name', 'Nancy Wong');
```

```
[NW.Name ' - ' NW.Number]
```

```
ans =
```

```
Nancy Wong - 5081234569
```

Finding Objects with Specific Property Names

Search for objects with specific property names using the `-property` option:

```
H = findobj(PB, '-property', 'HighSpeedInternet');
```

```
H.HighSpeedInternet
```

```
ans =
```

```
1M
```

The `-property` option enables you to omit the value of the property and search for objects using only the property name.

Using Logical Expressions

Search for specific combinations of property names and values:

```
H = findobj(PB, 'Name', 'Nancy Vidal', '-and', 'Address', '123 Main Street');
```

```
H.Number
```

```
ans =
```

```
5081234568
```

Perusing Meta-Classes with `findobj`

Find the names of all properties in the `containers.Map` class that have public `GetAccess`:

- Get the `meta.class` object

- Use `findobj` to search the array of `meta.property` objects

```
mc = ?containers.Map;
% findobj returns an array of meta.property objects
% use square brackets to convert the comma separated list to an array
mpArray = findobj([mc.Properties{:}], 'GetAccess', 'public');
% create cell array of property names
names = {mpArray.Name};
```

The cell array `names` contains the names of all `containers.Map` properties that have public `GetAccess`:

```
celldisp(names)
```

```
names{1} =
```

```
Count
```

```
names{2} =
```

```
KeyType
```

```
names{3} =
```

```
ValueType
```

Determine if any `containers.Map` class methods are static:

```
isempty(findobj([mc.Methods{:}], 'Static', true))
```

```
ans =
```

```
1
```

`findobj` returns an empty `meta.property` object indicating that there are no static methods.

Getting Information About Properties

In this section...

“Information Contained in the meta.property object” on page 14-10

“Example — Finding Properties with Specific Attributes” on page 14-14

Information Contained in the meta.property object

The `meta.property` class is useful for determining the settings of property attributes. The writable properties of a `meta.property` object correspond to the attributes of the associated property. The values of the writable `meta.property` properties correspond to the attribute setting specified in the class definition.

For example, create a default `containers.Map` object and use the `handle findprop` method to get the `meta.property` object for the `Count` property:

```
mp = findprop(containers.Map, 'Count')

mp =

meta.property handle
Package: meta

Properties:
      Name: 'Count'
      Description: 'Number of pairs in the collection'
      DetailedDescription: ''
      GetAccess: 'public'
      SetAccess: 'private'
      Dependent: 1
      Constant: 0
      Abstract: 0
      Transient: 1
      Hidden: 0
      GetObservable: 0
      SetObservable: 0
      AbortSet: 0
```

```

        GetMethod: []
        SetMethod: []
    DefiningClass: [1x1 meta.class]

```

The preceding `meta.property` display shows that the default `Map` object `Count` property has public `GetAccess` and private `SetAccess`, is `Dependent`, and `Transient`. See “Table of Property Attributes” on page 6-8 for a list of property attributes.

If you are working with a class that is not a handle class, get the `meta.property` objects from the `meta.class` object. All meta-classes are subclasses of the handle class. Use the `metaclass` function if you have an instance or the `?` operator with the class name:

```

mc = ?containers.Map

mc =

    meta.class handle
    Package: meta

    Properties:
        Name: 'containers.Map'
        Description: 'MATLAB Map Container'
        DetailedDescription: 'MATLAB Map Container'
        Hidden: 0
        Sealed: 0
        ConstructOnLoad: 1
        InferiorClasses: {0x1 cell}
        Properties: {4x1 cell}
        Methods: {33x1 cell}
        Events: {[1x1 meta.event]}
        EnumeratedValues: {0x1 cell}
        SuperClasses: {[1x1 meta.class]}
        ContainingPackage: [1x1 meta.package]

```

The `meta.class` object property named `Properties` contains a cell array of `meta.property` objects, one for each property defined by the `containers.Map` class. For example, the name of the property associated with the `meta.property` object in cell 1 is:

```
mc.Properties{1}.Name
```

```
ans =
```

```
Count
```

The `meta.class` object contains a `meta.property` object for hidden properties too. Compare the result with the `properties` function, which returns only public properties:

```
properties('containers.Map')
```

```
Properties for class containers.Map:
```

```
Count  
KeyType  
ValueType
```

The `serialization` property is `Hidden` and has its `GetAccess` and `SetAccess` attributes set to `private`. Therefore, the `properties` function does not list it. However, you can get information about this property from its associated `meta.property` object (which is the fourth element in the cell array of `meta.property` objects in this case):

```
mc.Properties{4}
```

```
ans =
```

```
meta.property handle  
Package: meta
```

```
Properties:
```

```
                Name: 'serialization'  
        Description: 'Serialization property.'  
DetailedDescription: ''  
        GetAccess: 'private'  
        SetAccess: 'private'  
        Dependent: 0  
        Constant: 0  
        Abstract: 0  
        Transient: 0
```



```

        Hidden: 1
    GetObservable: 0
    SetObservable: 0
        AbortSet: 0
        GetMethod: []
        SetMethod: []
    DefiningClass: [1x1 meta.class]

```

Methods, Events, Superclasses

Indexing Meta-Class Objects

You can access other meta-class objects directly from the `meta.class` object properties. For example, the statement:

```
mc = ?containers.Map;
```

returns a `meta.class` object:

```

class(mc)

ans =

meta.class

```

Referencing the `Properties` `meta.class` property returns a cell array with one cell for each property of the `containers.Map` class:

```

class(mc.Properties)

ans =

cell

```

Each cell contains a `meta.property` object:

```

class(mc.Properties{1})

ans =

meta.property

```

The `Name` property of the `meta.property` object contains a character string that is the name of the property:

```
class(mc.Properties{1}.Name)

ans =

char
```

Apply standard MATLAB indexing to access information in meta-class objects.

For example, the `meta.class Properties` property contains a cell array of `meta.property` objects. The following expression accesses the first `meta.property` object in this cell array and returns the first (C) and last (t) letters of the string contained in the `meta.property Name` property.

```
mc.Properties{1}.Name([1 end])

ans =

Ct
```

Example – Finding Properties with Specific Attributes

This example implements a function that finds properties with specific attribute settings. For example, you can find objects that define constant properties (Constant attribute set to true) or determine what properties are read-only (GetAccess = public, SetAccess = private). The `findAttrValue` function returns a cell array of property names that set the specified attribute.

This function access information from meta-classes using these techniques:

- If input argument, `obj`, is a string, use the `meta.class.fromName` static method to get the `meta.class` object.
- If input argument, `obj`, is an object, use the `metaclass` function to get the `meta.class` object.
- Every property has an associated `meta.property` object. Obtain these objects from the `meta.class Properties` property.

- Use the handle class `findprop` method to determine if the requested property attribute is a valid attribute name. All property attributes are properties of the `meta.property` object. The statement, `findobj(mp, 'PropertyName')` determines whether the `meta.property` object, `mp`, has a property called `PropertyName`.
- Reference `meta.property` object properties using dynamic field names. For example, if `attrName = 'Constant'`, then MATLAB converts the expression `mp.(attrName)` to `mp.Constant`
- The optional third argument enables you to specify the value of attributes whose values are not logical true or false (such as `GetAccess` and `SetAccess`).

```
function cl_out = findAttrValue(obj,attrName,varargin)

% Determine if first input is object or class name
if ischar(obj)
    mc = meta.class.fromName(obj);
elseif isobject(obj)
    mc = metaclass(obj);
end

% Initialize and preallocate
ii = 0; numb_props = length(mc.Properties);
cl_array = cell(1,numb_props);

% For each property, check the value of the queried attribute
for c = 1:numb_props

    % Get a meta.property object from the meta.class object
    mp = mc.Properties{c};

    % Determine if the specified attribute is valid on this object
    if isempty (findprop(mp,attrName))
        error('Not a valid attribute name')
    end
    attrValue = mp.(attrName);

    % If the attribute is set or has the specified value,
    % save its name in cell array
```

```
    if attrValue
        if islogical(attrValue) || strcmp(varargin{1},attrValue)
            ii = ii + 1;
            cl_array(ii) = {mp.Name};
        end
    end
end
% Return used portion of array
cl_out = cl_array(1:ii);
end
```

Finding Property Attributes

Suppose you have the following containers.Map object:

```
mapobj =
containers.Map({'rose', 'bicycle'}, {'flower', 'machine'});
```

Find properties with private SetAccess:

```
findAttrValue(mapobj, 'SetAccess', 'private')

ans =

    'Count'    'KeyType'    'ValueType'    'serialization'
```

Find properties with public GetAccess:

```
findAttrValue(mapobj, 'GetAccess', 'public')

ans =

    'Count'    'KeyType'    'ValueType'
```

Getting Property Default Values

Property Default Values

Class definitions can specify explicit default values for properties (see “Defining Default Values” on page 3-9). You can obtain the default value of a property from the property’s associated `meta.property` object. The `meta.class` object for a class contains a `meta.property` object for every property defined by the class, including properties with private and protected access. For example:

```
mc = ?MException;    % meta.class object for MException class
mp = mc.Properties;  % Cell array of meta.property objects
mp{1}                % meta.property object for 'type' property
ans =
```

```
meta.property handle
Package: meta
```

```
Properties:
```

```
      Name: 'type'
      Description: 'Type of error reporting'
DetailedDescription: ''
      GetAccess: 'private'
      SetAccess: 'private'
      Dependent: 0
      Constant: 0
      Abstract: 0
      Transient: 0
      Hidden: 0
      GetObservable: 1
      SetObservable: 1
      AbortSet: 0
      GetMethod: []
      SetMethod: []
      HasDefault: 1
      DefaultValue: {}
      DefiningClass: [1x1 meta.class]
```

Two `meta.property` object properties provide information on default values:

- `HasDefault` — True if class specifies a default value for the property, false if it does not.
- `DefaultValue` — Contains the default value, if the class defines a default value for the property.

These properties provide a programmatic way to obtain property default values without reading class definition files. Use these `meta.property` object properties to obtain property default values for built-in classes and classes defined in MATLAB code.

Querying a Default Value

The procedure for querying a default value involves:

- Getting the `meta.property` object for the property whose default value you want to query.
- Testing the logical value of the `meta.property` `HasDefault` property to determine if the property defines a default value. MATLAB returns an error when you query the `DefaultValue` property if the class does not define a default value for the property.
- Obtaining the default value from the `meta.property` `DefaultValue` property if the `HasDefault` value is true.

Use the `?` operator, the `metaclass` function, or the `meta.class.fromName` static method (works with string variable) to obtain a `meta.class` object. The `meta.class` object `Properties` property contains a cell array of `meta.property` objects. Identify which property corresponds to which `meta.property` object using the `meta.property` `Name` property.

For example, this class defines properties with default values:

```
classdef MyClass
    properties
        Material = 'acrylic';
        InitialValue = 0.0;
    end
end
```

Follow these steps to obtain the default value defined for the `Material` property. Include any error checking that is necessary for your application.

- Get the `meta.class` object for the class:

```
mc = ?MyClass;
```

- Get a cell array of `meta.property` objects from the `meta.class` `Properties` property:

```
mp = mc.Properties;
```

- The length of the cell array, `mp`, equals the number of properties. You can use the `meta.property` `Name` property to find the property of interest:

```
for k = 1:length(mp)
    if (strcmp(mp{k}.Name, 'Material')
```

- Before querying the default value of the `Material` property, test the `HasDefault` `meta.property` to determine if `MyClass` defines a default property for this property:

```
    if mp{k}.HasDefault
        dv = mp{k}.DefaultValue;
    end
end
end
```

The `DefaultValue` property is read only. Changing the default value in the class definition changes the value of `DefaultValue` property. You can query the default value of a property regardless of its access settings.

Abstract and dynamic properties cannot define default values. Therefore, MATLAB returns an error if you attempt to query the default value of properties with these attributes. Always test the logical value of the `meta.property` `HasDefault` property before querying the `DefaultValue` property to avoid generating an error.

Default Values Defined as Expressions

Class definitions can define property default values as MATLAB expressions (see “Using Expressions in Class Definitions” on page 4-7 for more

information). MATLAB evaluates these expressions the first time the default value is needed, such as the first time you create an instance of the class.

Querying the `meta.property.DefaultValue` property causes MATLAB to evaluate a default value expression, if it had not yet been evaluated. Therefore, querying a property default value can return an error or warning if errors or warnings occur when MATLAB evaluates the expression. See “Property With Expression That Errors” on page 14-21 for an example.

Property With No Explicit Default Value

`MyClass` does not explicitly define a default value for the `Foo` property:

```
classdef MyClass
    properties
        Foo
    end
end
```

The `meta.property` instance for property `Foo` has a value of `false` for `HasDefault`. The class does not explicitly define a default value for `Foo`. Therefore, attempting to access the `DefaultValue` property causes an error:

```
mc = ?MyClass;
mp = mc.Properties{1};
mp.HasDefault
ans =

    0

dv = mp.DefaultValue;
??? No default value has been defined for property Foo
```

Abstract Property

`MyClass` defines the `Foo` property as `Abstract`:

```
classdef MyClass
    properties (Abstract)
        Foo
    end
```



```
end
```

The `meta.property` instance for property `Foo` has a value of `false` for its `HasDefault` property because you cannot define a default value for an `Abstract` property. Attempting to access `DefaultValue` causes an error:

```
mc = ?MyClass;
mp = mc.Properties{1};
mp.HasDefault
ans =

    0

dv = mp.DefaultValue;
??? Property Foo is abstract and therefore cannot have a default value.
```

Property With Expression That Errors

`MyClass` defines the `Foo` property default value as an expression that errors.

```
classdef MyClass
    properties
        Foo = sin(pie/2);
    end
end
```

The `meta.property` instance for property `Foo` has a value of `true` for its `HasDefault` property because `Foo` does have a default value determined by the evaluation of the expression:

```
sin(pie/2)
```

However, this expression returns an error (`pie` is a function that creates a pie chart, not the value `pi`).

```
mc = ?MyClass;
mp = mc.Properties{1};
mp.HasDefault
ans =

    1
```

```
dv = mp.DefaultValue;  
??? Error using ==> pie at 30  
Not enough input arguments.
```

Querying the default value causes the evaluation of the expression and returns the error.

Property With Explicitly Defined Default Value

`MyClass` assigns a default to the `Foo` property:

```
classdef MyClass  
    properties  
        Foo = [];  
    end  
end
```

The `meta.property` instance for property `Foo` has a value of `true` for its `HasDefault` property. Accessing `DefaultValue` returns the value `[]`:

```
mc = ?MyClass;  
mp = mc.Properties{1};  
mp.HasDefault  
ans =  
  
    1  
  
dv = mp.DefaultValue;  
dv =  
  
    []
```

Specializing Object Behavior

- “Methods That Modify Default Behavior” on page 15-2
- “Redefining Concatenation for Your Class” on page 15-8
- “Displaying Objects in the Command Window” on page 15-9
- “Converting Objects to Another Class” on page 15-11
- “Indexed Reference and Assignment” on page 15-13
- “Implementing Operators for Your Class” on page 15-35

Methods That Modify Default Behavior

In this section...

“How to Modify Behavior” on page 15-2

“Which Methods Control Which Behaviors” on page 15-2

“Overloading and Overriding Functions and Methods” on page 15-4

“When to Overload MATLAB Functions” on page 15-5

“Caution When Overloading MATLAB Functions” on page 15-6

How to Modify Behavior

There are functions that MATLAB calls implicitly when you perform certain actions with objects. For example, a statement like `[B(1); A(3)]` involves indexed reference and vertical concatenation. These functions enable user-defined objects to behave like instances of MATLAB built-in classes.

You can change how user-defined objects behave by overloading the function that controls the particular behavior. To change a behavior, implement the appropriate method with the same name and signature as the MATLAB function. If an overloaded method exists, MATLAB calls this method whenever you perform that action on an object of the class.

Which Methods Control Which Behaviors

The following table lists MATLAB functions and describes the behaviors that they control. Your class can overload these functions as class methods if you want to specialize the behaviors described.

Class Method to Implement	Description
Concatenating Objects	
<code>cat</code> , <code>horzcat</code> , and <code>vertcat</code>	Customize behavior when concatenation objects See “Example — Adding Properties to a Built-In Subclass” on page 10-35
Displaying Objects	

Class Method to Implement	Description
<code>disp</code>	Called when you enter <code>disp(obj)</code> on the command line
<code>display</code>	Called when statements are not terminated by semicolons. <code>disp</code> is often used to implement <code>display</code> methods. See “Displaying Objects in the Command Window” on page 15-9
Converting Objects to Other Classes	
converters like <code>double</code> and <code>char</code>	Convert an object to a MATLAB built-in class See “The DocPolynom to Character Converter” on page 16-8 and “The DocPolynom to Double Converter” on page 16-7
Indexing Objects	
<code>subsref</code> and <code>subsasgn</code>	Enables you to create nonstandard indexed reference and indexed assignment See “Indexed Reference and Assignment” on page 15-13
<code>end</code>	Supports <code>end</code> syntax in indexing expressions using an object; e.g., <code>A(1:end)</code> See “Defining end Indexing for an Object” on page 15-31
<code>numel</code>	Determine the number of elements in an array See “Interactions with <code>numel</code> and Overloaded <code>subsref</code> and <code>subsasgn</code> ” on page 15-6
<code>size</code>	Determine the dimensions in an array

Class Method to Implement	Description
subsindex	Support using an object in indexing expressions See “Using Objects as Indices” on page 15-32
Saving and Loading Objects	
loadobj and saveobj	Customize behavior when loading and saving objects See Chapter 11, “Saving and Loading Objects”

See “Implementing Operators for Your Class” on page 15-35 for a list of functions that implement operators like +, >, ==, and so on.

Overloading and Overriding Functions and Methods

Overloading and overriding are ways to customize the behaviors of existing functions and methods. Both involve redefining how an existing function or method works by creating another one that MATLAB calls instead, under certain conditions. Which approach you use in any situation depends on the circumstances.

Here is how we use these terms in MATLAB. See “Specifying Class Precedence” on page 4-17 for information on how MATLAB determines argument dominance.

Overloading

Overloading means that there is more than one function or method that have the same name within the same scope. MATLAB dispatches to a particular function or method based on the dominant argument. For example, the `timeseries` class overloads the MATLAB `plot` function. When you call `plot` with a `timeseries` object as an input argument, MATLAB dispatches to the `timeseries` class method named `plot`. MATLAB

Overriding

Overriding means redefining a method inherited from a superclass. MATLAB dispatches to the most specific version of the method. That is, if the dominant argument is an instance of the subclass, then MATLAB calls the subclass method.

When to Overload MATLAB Functions

You do not need to overload the MATLAB functions if you do not want to modify the behavior of your class. However, you might need to overload certain functions when your class defines specialized behaviors that differ from the default.

Example of Modified Behavior

For example, MATLAB defines indexed reference of an array:

```
p(3)
```

as a reference to the third element in the array `p`.

However, suppose you define a class to represent polynomials and you want an indexed reference like:

```
polyobj(3)
```

to cause an evaluation of the scalar polynomial object with the value of the independent variable equal to the index value, 3. You overload the `subsref` function for the polynomial class to accomplish this.

See “The `DocPolynom subsref Method`” on page 16-11 for an example.

Select the appropriate function from the preceding table to change the behavior indicated. For example, MATLAB displays certain information about objects when you use the `disp` function or when you enter a statement that returns an object and is not terminated by a semicolon. Suppose you want your polynomial class to display the MATLAB expression for the polynomial represented by the object, instead of the default behavior. The display might look like this:

```
>> p
```

```
p =  
  
x^3 - 2*x - 5
```

for a polynomial with the coefficients [1 0 2 -5].

You can implement this specialized behavior by overloading the `disp` and `char` methods. See “The `DocPolynom disp Method`” on page 16-10 for an example that shows how to implement this change.

Caution When Overloading MATLAB Functions

Many built-in MATLAB functions depend on the behavior of other built-in functions, like `size`. Therefore, you must be careful to ensure that what is returned by an overloaded version of `size` is a correct and accurate representation of the size of an object.

You might need to overload `numel` to restore proper behavior when you have overloaded `size` to perform an action that is appropriate for your class design.

Interactions with `numel` and Overloaded `subsref` and `subsasgn`

You must ensure that the value returned by `numel` is appropriate for your class design when you overload `subsref` and `subsasgn`. `subsref` uses `numel` to compute the number of expected output arguments returned from `subsref` (i.e., `nargout`). Similarly, `subsasgn` uses `numel` to compute the expected number of input arguments to be assigned using `subsasgn` (i.e., `nargin`).

The value of `nargin` for an overloaded `subsasgn` function is determined by the value returned by `numel` plus two (one for the variable to which you are making an assignment and one for the `struct` array of subscripts).

If the MATLAB runtime produces errors when calling your class’s overloaded `subsref` or `subsasgn` methods because `nargout` is wrong for `subsref` or `nargin` is wrong for `subsasgn`, then you need to overload `numel` to return a value that is consistent with your implementation of these indexing functions.

See “Understanding size and numel” on page 10-41 and “Indexed Reference and Assignment” on page 15-13 for more information on implementing `subsref` and `subsasgn` methods.

Ensuring MATLAB Calls Your Overloaded Method

When invoking an overloaded method, be sure that the object passed is the dominant type in the argument list. To ensure that MATLAB dispatches to the correct function, use dot notation for method invocation:

```
obj.methodName(args)
```

See “Determining Which Method Is Invoked” on page 7-8 for more information.

Redefining Concatenation for Your Class

Default Concatenation

You can concatenate objects into arrays. For example, suppose you have three instances of the class `MyClass`, `obj1`, `obj2`, `obj3`. You can form various arrays with these objects using brackets. Horizontal concatenation calls `horzcat`:

```
HorArray = [obj1,obj2,obj3];
```

`HorArray` is a 1-by-3 array of class `MyClass`. You can concatenate the objects along the vertical dimension, which calls `vertcat`:

```
VertArray = [obj1;obj2;obj3]
```

`VertArray` is a 3-by-1 array of class `MyClass`. You can use the `cat` function to concatenate arrays along different dimensions. For example:

```
ndArray = cat(3,HorArray,HorArray);
```

`ndArray` is a 1-by-3-by-2 array.

You can overload `horzcat`, `vertcat`, and `cat` to produce specialized behaviors in your class. You must overload both `horzcat` and `vertcat` whenever you want to modify object concatenation because MATLAB uses both functions for any concatenation operation.

Example of `horzcat` and `vertcat`

“Example — Adding Properties to a Built-In Subclass” on page 10-35

Displaying Objects in the Command Window

Default Display

MATLAB software calls a method named `display` whenever an object is referred to in a statement that is not terminated by a semicolon. For example, the following statement creates the variable `a` and calls the MATLAB `display` method for class `double`. This method displays the value of `a` in the command line.

```
a = 5
a =
    5
```

All MATLAB objects use default `disp` and `display` functions. You do not need to overload the defaults, but you can overload in cases where you want objects to display in different ways.

You can define a `disp` method for your classes if you want MATLAB to display more useful information on the command line when referring to objects from your class. In many classes, `disp` can print the variable name, and then use the `char` converter method to print the contents of the variable. You need to define the `char` method to convert the object's data to a character string because MATLAB displays output as character strings.

You might also use `sprintf` or other data formatting functions to implement the `disp` method for your class.

Examples of disp Methods

For examples of overloaded `disp` methods, see the following sections:

“Displaying TensileData Objects” on page 2-28

“The DocPolynom `disp` Method” on page 16-10

“The DocAsset Display Method” on page 17-6

“The DocPortfolio `disp` Method” on page 17-23

Relationship Between disp and display

MATLAB invokes the built-in `display` function when:

- MATLAB executes a statement that returns a value and is not terminated with a semicolon.
- Code explicitly invokes the `display` function.

MATLAB invokes the built-in `disp` function in the following cases:

- The built-in `display` function calls `disp`.
- Code explicitly invokes `disp`.

Override disp Or disp and display

The built-in `display` function prints the name of the variable that is being displayed, if an assignment is made, or otherwise uses `ans` as the variable name. `display` then calls `disp` to handle the actual display of the values.

If the variable that is being displayed is an object of a class that overloads `disp`, then MATLAB always calls the overloaded method. Overload `disp` or `disp` and `display` to customize the display of objects. Overloading only `display` is not sufficient to properly implement a custom display for your class.

Converting Objects to Another Class

Why Implement a Converter

You can convert an object of one class to an object of another class. A converter method has the same name as the class it converts to, such as `char` or `double`. Think of a converter method as an overloaded constructor method of another class—it takes an instance of its own class and returns an object of a different class.

Converters enable you to:

- Use methods defined for another class
- Ensure that expressions involving objects of mixed class types execute properly
- Control how instances are interpreted in other contexts

For example, suppose you have defined a `polynomial` class, but you have not overloaded any of the MATLAB functions that operate on the coefficients of polynomials, which are doubles. If you create a `double` method for the `polynomial` class, you can use it to call other functions that require inputs of type `double`.

Use the `double` converter method to call other functions:

```
roots(double(p))
```

`p` is a polynomial object, `double` is a method of the `polynomial` class, and `roots` is a standard MATLAB function whose input arguments are the coefficients of a polynomial.

Converters and Subscripted Assignment

When you make a subscripted assignment statement such as:

```
A(1) = myobj;
```

MATLAB software compares the class of the Right-Hand-Side (RHS) variable to the class of the Left-Hand-Side (LHS) variable. If the classes are different, MATLAB attempts to convert the RHS variable to the class of the LHS

variable. To do this, MATLAB first searches for a method of the RHS class that has the same name as the LHS class. Such a method is a converter method, which is similar to a typecast operation in other languages.

If the RHS class does not define a method to convert from the RHS class to the LHS class, then MATLAB software calls the LHS class constructor and passes it to the RHS variable.

For example, suppose you make the following assignments:

```
A(1) = objA; % Object of class ClassA
A(2) = objB; % Object of class ClassB
```

MATLAB attempts to call a method of `ClassB` named `ClassA`. If no such converter method exists, MATLAB software calls the `ClassA` constructor, passing `objB` as an argument. If the `ClassA` constructor cannot accept `objB` as an argument, then MATLAB returns an error.

You can create arrays of objects of different classes using cell arrays (see `cell` for more information on cell arrays).

Examples of Converter Methods

See the following sections for examples of converter methods:

- “The DocPolynom to Double Converter” on page 16-7
- “The DocPolynom to Character Converter” on page 16-8
- “Example — Adding Properties to a Built-In Subclass” on page 10-35

Indexed Reference and Assignment

In this section...

“Overview” on page 15-13

“Default Indexed Reference and Assignment” on page 15-13

“What You Can Modify” on page 15-15

“subsref and subsasgn Within Class Methods — Built-In Called” on page 15-16

“Understanding Indexed Reference” on page 15-18

“Avoid Overriding Access Attributes” on page 15-21

“Understanding Indexed Assignment” on page 15-23

“A Class with Modified Indexing” on page 15-26

“Defining end Indexing for an Object” on page 15-31

“Using Objects as Indices” on page 15-32

Overview

This section describes how indexed reference and assignment work in MATLAB, and provides information on the behaviors you can modify. There are also examples of classes that modify the default indexing behavior.

MATLAB provides support for object array indexing by default and many class designs will require no modification to this behavior. The information in this section can help you determine if modifying object indexing is useful for your class design and can show you how to approach those modifications.

Default Indexed Reference and Assignment

MATLAB arrays enable you to reference and assign elements of the array using a subscripted notation that specifies the indices of specific array elements. For example, suppose you create two arrays of numbers (using `randi` and concatenation).

```
% Create a 3-by-4 array of integers between 1 and 9  
A = randi(9,3,4)
```

```
A =  
  
     4     8     5     7  
     4     2     6     3  
     7     5     7     7  
% Create a 1-by-3 array of the numbers 3, 6, 9  
B = [3 6 9];
```

You can reference and assign elements of either array using index values in parentheses:

```
B(2) = A(3,4);  
B  
B =  
     3     2     9
```

When you execute a statement that involves indexed reference:

```
C = A(3,4);
```

MATLAB calls the built-in `subsref` function to determine how to interpret the statement. Similarly, if you execute a statement that involves indexed assignment:

```
C(4) = 7;
```

MATLAB calls the built-in `subsasgn` function to determine how to interpret the statement.

The MATLAB default `subsref` and `subsasgn` functions also work with user-defined objects. For example, suppose you want to create an array of objects of the same class:

```
for k=1:3  
    objArray(k) = MyClass;  
end
```

Referencing the second element in the object array, `objArray`, returns the object constructed when `k = 2`:

```
D = objArray(2);
```



```
class(D)

ans =

MyClass
```

You also can assign an object to an array of objects of the same class, or an empty array (see “Creating Empty Arrays” on page 8-6 for related information):

```
emptyArray(3,4) = D;
```

Arrays of objects behave much like numeric arrays in MATLAB. You do not need to implement any special methods to provide this behavior with your class.

For general information about array indexing, see “Matrix Indexing”.

What You Can Modify

You can modify your class’s default indexed reference and/or assignment behavior by implementing class methods called `subsref` and `subsasgn`. For syntax description, see their respective reference pages. Keep in mind that once you add a `subsref` or `subsasgn` method to your class, then MATLAB calls only the class method, not the built-in function. Therefore, you must implement in your class method all of the indexed reference and assignment operations that you want your class to support. This includes:

- Dot notation calls to class methods
- Dot notation reference and assignment involving properties
- Any indexing using parentheses ' () '
- Any indexing using braces ' {} '

While implementing `subsref` and `subsasgn` methods gives you complete control over the interpretation of indexing expressions for objects of your class, it can be complicated to provide the same behavior that MATLAB provides by default.

When to Modify Indexing Behavior

The default indexing supported by MATLAB for object arrays and dot notation for access to properties and methods enables user-defined objects to behave like intrinsic classes, such as `double` and `struct`. For example, suppose you define a class with a property called `Data` that contains an array of numeric data. A statement like:

```
obj.Data(2,3)
```

returns the value contained in the second row, third column of the array. If you have an array of objects, you can use an expression like:

```
objArray(3).Data(4:end)
```

to return the fourth through last elements in the array contained in the `Data` property of the third object in the object array, `objArray`.

Modify the default indexing behavior when your class design requires behavior that is different from that provided by MATLAB by default.

subsref and subsasgn Within Class Methods — Built-In Called

MATLAB does not call class-defined `subsref` or `subsasgn` methods for indexed reference and assignment within the class's own methods. Within class methods, MATLAB always calls the built-in `subsref` and `subsasgn` functions regardless of whether the class defines its own methods. This is true within the class-defined `subsref` and `subsasgn` methods as well.

For example, within a class method, this dot reference:

```
% Calls built-in subsref  
obj.Prop
```

calls the built-in `subsref` function. To call the class-defined `subsref` method, use:

```
% Calls overloaded subsref  
subsref(obj,substruct('.', 'Prop'))
```

Whenever a class method requires the functionality of the class-defined `subsref` or `subsasgn` method, it must call the overloaded methods with function calls rather than using the operators, '()', '{}', or '.'

For example, suppose you define a polynomial class with a `subsref` method that causes the polynomial to be evaluated with the value of the independent variable equal to the subscript. This statement defines the polynomial with its coefficients:

```
p = polynom([1 0 -2 -5]);
```

The MATLAB expression for the resulting polynomial is:

$$x^3 - 2x - 5$$

The following subscripted expression returns the value of the polynomial at $x = 3$:

```
p(3)
ans =
    16
```

Suppose that you want to use this feature in another class method. To do so, call the `subsref` function directly. The `evalEqual` method accepts two `polynom` objects and a value at which to evaluate the polynomials:

```
methods
function ToF = evalEqual(p1,p2,x)
    % Create arguments for subsref
    subs.type = '()';
    subs.subs = {x};
    % Need to call subsref explicitly
    y1 = subsref(p1,subs);
    y2 = subsref(p2,subs);
    if y1 == y2
        ToF = true;
    else
        ToF = false;
    end
end
end
```

This behavior enables you to use standard MATLAB indexing to implement specialized behaviors. See “A Class with Modified Indexing” on page 15-26 for examples of how to use both built-in and class-modified indexing.

Understanding Indexed Reference

Object indexed references are in three forms — parentheses, braces, and name:

```
A(I)
A{I}
A.name
```

Each of these statements causes a call by MATLAB to the `subsref` method of the class of `A`, or a call to the built-in `subsref` function, if the class of `A` does not implement a `subsref` method.

MATLAB passes two arguments to `subsref`:

```
B = subsref(A,S)
```

The first argument is the object being referenced, `A`. The second argument, `S`, is a struct array with two fields:

- `S.type` is a string containing '()', '{}', or '.' specifying the indexing type used.
- `S.subs` is a cell array or string containing the actual index or name. A colon used as an index is passed in the cell array as the string ':'. Ranges specified using a colon (e.g., 2:5) are expanded to 2 3 4 5.

For example, the expression

```
A(1:4,:)
```

causes MATLAB to call `subsref(A,S)`, where `S` is a 1-by-1 structure with

```
S.type = '()'
S.subs = {1:4, ':'} % A 2-element cell array
                % containing the numbers 1 2 3 4 and ":"
```

Returning the contents of each cell of `S.subs` gives the index values for the first dimension and a string `' '` for the second dimension:

```
S.subs{:}
ans =

     1     2     3     4

ans =

:
```

The default `subsref` returns all array elements in rows 1 through 4 and all of the columns in the array.

Similarly, the expression

```
A{1:4}
```

uses

```
S.type = '{}'
```

```
S.subs = {1:4} % A cell array
           % containing the numbers 1 2 3 4
```

The default `subsref` returns the contents of all cell array elements in rows 1 through 4 and all of the columns in the array.

The expression

```
A.Name
```

calls `subsref(A,S)` where

```
S.type = '.'
S.subs = 'Name' % The string 'Name'
```

The default `subsref` returns the contents of the `Name` field in the struct array or the value of the property `Name` if `A` is an object with the specified property name.

Complex Indexed References

These simple calls are combined for more complicated indexing expressions. In such cases, `length(S)` is the number of indexing levels. For example,

```
A(1,2).PropertyName(1:4)
```

calls `subsref(A,S)`, where `S` is a 3-by-1 structure array with the values:

```
S(1).type = '()'      S(2).type = '.'      S(3).type = '()'
S(1).subs = {1,2}    S(2).subs = 'PropertyName'  S(3).subs = {1:4}
```

Writing `subsref`

Your class's `subsref` method must interpret the indexing expressions passed in by MATLAB. Any behavior you want your class to support must be implemented by your `subsref`. However, your method can call the built-in `subsref` to handle indexing types that you do not want to change.

You can use a `switch` statement to determine the type of indexing used and to obtain the actual indices. The following three code fragments illustrate how to interpret the input arguments. In each case, the function must return the value (`B`) that is returned by your `subsref` function.

For a parentheses index:

```
% Handle A(n)
switch S.type
case '()'
    B = A(S.subs{:});
end
```

For a brace index:

```
% Handle A{n}
switch S.type
case '{}'
    % Determine what this indexing means to your class
    % E.g., CellProperty contained a cell array
    B = A.CellProperty{S.subs{:}};
end
```

While braces are used for cell arrays in MATLAB, your `subsref` method is free to define its own meaning for this syntax.

For a name index, you might access property values. Method calls require a second level of indexing if there are arguments. The name can be an arbitrary string for which you take an arbitrary action:

```
switch S.type
case '.'
    switch S.subs
    case 'name1'
        B = A.name1;
    case 'name2'
        B = A.name2;
    end
end
```

Examples of `subsref`

These links show examples of classes that implement `subsref` methods:

“A Class with Modified Indexing” on page 15-26

“Example — Adding Properties to a Built-In Subclass” on page 10-35

“Example — A Class to Represent Hardware” on page 10-46

“The `DocPolynom` `subsref` Method” on page 16-11

See also, “Understanding `size` and `numel`” on page 10-41

Avoid Overriding Access Attributes

Because `subsref` is a class method, it has access to private class members. Avoid inadvertently giving access to private methods and properties as you handle various types of reference. Consider this `subsref` method defined for a class having private properties, `x` and `y`:

```
classdef MyPlot
```

```
properties (Access = private)
    x
    y
end
properties
    Maximum
    Minimum
    Average
end
methods
    function obj = MyPlot(x,y)
        obj.x = x;
        obj.y = y;
        obj.Maximum = max(y);
        obj.Minimum = min(y);
        obj.Average = mean(y);
    end
    function B = subsref(A,S)
        switch S(1).type
            case '.'
                switch S(1).subs
                    case 'plot'
                        % Reference to A.x and A.y call built-in subsref
                        B = plot(A.x,A.y);
                    otherwise
                        % Enable dot notation for all properties and methods
                        B = A.(S.subs);
                end
            end
        end
    end
end
end
```

This `subsref` enables users to use dot notation to perform an action (create a plot) using the name 'plot'. The statement:

```
obj = MyPlot(1:10,1:10);
h = obj.plot;
```

calls the `plot` function and returns the handle to the graphics object.

You do not need to explicitly code each method and property name because the otherwise code in the inner switch block handles any name reference that you do not explicitly specify in case statements. However, using this technique exposes any private and protected class members via dot notation. For example, you can reference the private property, `x`, with this statement:

```
obj.x
ans =
     1     2     3     4     5     6     7     8     9    10
```

The same issue applies to writing a `subsasgn` method that enables assignment to private or protected properties. Your `subsref` and `subsasgn` methods might need to code each specific property and method name explicitly to avoid violating the class design.

Understanding Indexed Assignment

Object indexed assignments are in three forms — parentheses, braces, and name:

```
A(I) = B
A{I} = B
A.name = B
```

Each of these statements causes a call by MATLAB to the `subsasgn` method of the class of `A`, or a call to the built-in function, if the class of `A` does not implement a `subsasgn` method.

MATLAB passes three arguments to `subsasgn`:

```
A = subsasgn(A,S,B)
```

The first argument, `A`, is the object being assigned the value in the third argument `B`.

The second argument, `S`, is a struct array with two fields:

- `S.type` is a string containing '()', '{}', or '.' specifying the indexing type used.
- `S.subs` is a cell array or string containing the actual index or name. A colon used as an index is passed in the cell array as the string ':'. Ranges specified using a colon (e.g., 2:5) are expanded to 2 3 4 5.

For example, the assignment statement:

```
A(2,3) = B;
```

generates a call to `subsasgn`: `A = subsasgn(A,S,B)` where `S` is:

```
S.type = '()'
S.subs = {2,3}
```

The default `subsasgn`:

- Determines the class of `A`. If `B` is not the same class as `A`, then MATLAB tries to construct an object of the same class as `A` using `B` as an input argument (e.g., by calling a converter method, if one exists). If this attempt fails, MATLAB returns an error.
- If `A` and `B` are, or can be made, into the same class, then MATLAB assigns the value of `B` to the array element at row 2, column 3.
- If `A` does not exist before you execute the assignment statement, then MATLAB initializes the five array elements that come before `A(2,3)` with a default object of the class of `A` and `B`. For example, empty elements are initialized to zero in the case of a numeric array or an empty cell (`[]`) in the case of cell arrays. See “Creating Empty Arrays” on page 8-6 for more information on how MATLAB initializes empty arrays.

Similarly, the expression

```
A{2,3} = B
```

uses

```
S.type = '{}'  
S.subs = {2,3} % A 2-element cell array containing the numbers 2 and 3
```

The default `subsasgn`:

- Assigns **B** to the cell array element at row 2, column 3.
- If **A** does not exist before you execute the assignment statement, MATLAB initializes the five cells that come before **A(2,3)** with **[]**. The result is a 2-by-3 cell array.

The expression

```
A.Name = B
```

calls `A = subsasgn(A,S,B)` where

```
S.type = '.'
S.subs = 'Name' % The string 'Name'
```

The default `subsasgn`:

- Assigns **B** to the struct field **Name**.
- If **A** does not exist before you execute the assignment statement, MATLAB creates a new struct variable, **A** with field **Name** and assigns the value of **B** to this field location.
- If struct **A** exists, but has no field **Name**, then MATLAB adds the field **Name** and assigns the value of **B** to the new field location.
- If struct **A** exists and has a **Name** field, then MATLAB assigns the value of **B** to **Name**.

You can redefine all or some of these assignment behaviors by implementing a `subsasgn` method for your class.

Indexed Assignment to Objects

If **A** is an object, the expression:

```
A.Name = B
```

calls `A = subsasgn(A,S,B)` where

```
S.type = '.'
S.subs = 'Name' % The string 'Name'
```

The default `subsasgn`:

- Attempts to assign `B` to the `Name` property.
- If the class of `A` does not have a `Name` property, MATLAB returns an error.
- If the `Name` property has restricted access (`private` or `protected`), MATLAB determines if the assignment is allowed based on the context in which the assignment is made.
- If the class of `A` defines a set method for property `Name`, MATLAB calls the set method.
- MATLAB applies all other property attributes before determining whether to assigning `B` to the property `Name`.

Complex Indexed Assignments

These simple calls are combined for more complicated indexing expressions. In such cases, `length(S)` is the number of indexing levels. For example,

```
A(1,2).PropertyName(1:4) = B
```

calls `subsasgn(A,S,B)`, where `S` is a 3-by-1 structure array with the values:

```
S(1).type = '()'      S(2).type = '.'      S(3).type = '()'
S(1).subs = {1,2}   S(2).subs = 'PropertyName' S(3).subs = {1:4}
```

For examples of `subsasgn` methods, see “Specialized Subscripted Assignment — `subsasgn`” on page 15-29 and .

A Class with Modified Indexing

This example defines a class that modifies the default indexing behavior. It uses a combination of default indexing and specialized indexing. The example shows some useful techniques for implement `subsref` and `subsasgn` methods, but does not implement a fully robust class. You cannot, for example, concatenate objects into an array without adding other methods, such as `horzcat`, `vertcat`, `cat`, `size`, and perhaps other methods.

See “Example — Adding Properties to a Built-In Subclass” on page 10-35 for another example of a class that modifies indexing and concatenation behavior.

Class Description

The class has three properties:

- **Data** — numeric test data
- **Description** — description of test data
- **Date** — date test was conducted

Assume you have the following data (`randi`):

```
d = randi(9,3,4)
d =

     8     9     3     9
     9     6     5     2
     2     1     9     9
```

Create an instance of the class:

```
obj = MyDataClass(d, 'Test001');
```

The constructor arguments pass the values for the **Data** and **Description** properties. The `clock` function assigns the value to the **Date** property from within the constructor. This approach captures the time and date information when the instance is created.

Here is the basic code listing without the `subsref` and `subsasgn` methods.

```
classdef MyDataClass
    properties
        Data
        Description
    end
    properties (SetAccess = private)
        Date
    end
    methods
        function obj = MyDataClass(data,desc)
            if nargin > 0
                obj.Data = data;
            end
        end
    end
end
```

```
        if nargin > 1
            obj.Description = desc;
        end
        obj.Date = clock;
    end
end
end
```

Specialized Subscripted Reference — subsref

Use the default indexed reference behavior for scalar objects, and add the ability to index into the Data property with an expression like:

```
obj(2,3)

ans =

    5
```

This statement is the equivalent of:

```
obj.Data(2,3)
```

which the class also supports.

Redefining '()' indexing as described here means you cannot create arrays of MyDataClass objects and use '()' indexing to access individual objects. Create only scalar objects.

To achieve the design goals, the subsref method calls the builtin subsref for indexing of type '.' and defines its own version of '()' type indexing.

```
function sref = subsref(obj,s)
% obj(i) is equivalent to obj.Data(i)
switch s(1).type
% Use the built-in subsref for dot notation
case '.'
    sref = builtin('subsref',obj,s);
case '()'
    if length(s)<2
        % Note that obj.Data is passed to subsref
```

```

        sref = builtin('subsref',obj.Data,s);
        return
    else
        sref = builtin('subsref',obj,s);
    end
% No support for indexing using '{}'
case '{}'
    error('MYDataClass:subsref',...
        'Not a supported subscripted reference')
end
end
end

```

Specialized Subscripted Assignment – subsasgn

The class supports the equivalent behavior in indexed assignment. You can assign values to the Data property by referencing only the object.

```
obj(2,3) = 9;
```

is equivalent to:

```
obj.Data(2,3) = 9;
```

Like the subsref method, the subsasgn method calls the builtin subsasgn for indexing of type '.' and defines its own version of '()' type indexing.

Another useful approach is the use of the substruct function to redefine the index type and index subscripts struct that MATLAB passes to subsref and subsasgn.

```

function obj = subsasgn(obj,s,val)
    if isempty(s) && strcmp(class(val),'MYDataClass')
        obj = MyDataClass(val.Data,val.Description);
    end
    switch s(1).type
        % Use the built-in subsasgn for dot notation
        case '.'
            obj = builtin('subsasgn',obj,s,val);
        case '()'
            if length(s)<2

```

```

        if strcmp(class(val), 'MYDataClass')
            error('MYDataClass:subsasgn',...
                'Object must be scalar')
        elseif strcmp(class(val), 'double')
            % Redefine the struct s to make the call: obj.Data(i)
            snew = substruct('.', 'Data', '()', s(1).subs(:));
            obj = subsasgn(obj, snew, val);
        end
    end
end
% No support for indexing using '{}'
case '{}'
    error('MYDataClass:subsasgn',...
        'Not a supported subscripted assignment')
end
end
end

```

Implementing Addition for Object Data – plus

Allow direct addition of the Data property data by implementing a plus method:

```

function a = double(obj)
    a = obj.Data;
end

function c = plus(obj,b)
    c = double(obj) + double(b);
end

```

For example, add a scalar to the object Data array:

```

% List Current value of Data
obj(:, :)

ans =

     8     9     3     9
     9     6     5     2
     2     1     9     9

% Add 7 to the array

```



```
obj + 7

ans =

    15    16    10    16
    16    13    12     9
     9     8    16    16
```

The `MyDataClass` `double` method provides a way to convert an object to an array of doubles. It is possible to add a `MyDataClass` object to another class of object, providing the other class implements a `double` method that also returns an array of doubles. MATLAB applies the rules of addition and returns errors for dimension mismatch, and so on.

Defining end Indexing for an Object

When you use `end` in an object indexing expression, such as `A(4:end)`, the `end` function returns the index value corresponding to the last element in that dimension.

Classes can overload the `end` function as a class method to implement specialized behavior. If your class defines an `end` method, MATLAB calls that method to determine how to interpret the expression.

The `end` has the calling syntax:

```
ind = end(A,k,n)
```

where

- `A` is the object
- `k` is the index in the expression using the `end` syntax
- `n` is the total number of indices in the expression
- `ind` is the index value to use in the expression

For example, consider the expression

```
A(end-1,:)
```

MATLAB calls the end method defined for the object A using the arguments

```
ind = end(A,1,2)
```

These arguments mean the end statement occurs in the first index element and there are two index elements. The end class method returns the index value for the last element of the first dimension (from which 1 is subtracted in this case). If your class implements an end method, ensure that it returns a value appropriate for the class.

The end Method for the MyDataClass Example

The end method for the MyDataClass example (see “A Class with Modified Indexing” on page 15-26) operates on the contents of the Data property. The objective of this method is to return a value that can replace end in any indexing expression, such as:

```
obj(4:end)  
obj.Data(2,3:end)
```

and so on.

The following end function determines a positive integer value for end and returns it so that MATLAB can plug it into the indexing expression.

```
function ind = end(obj,k,n)  
    szd = size(obj.Data);  
    if k < n  
        ind = szd(k);  
    else  
        ind = prod(szd(k:end));  
    end  
end
```

Using Objects as Indices

MATLAB can use objects as indices in indexed expressions. The rules of array indexing apply — indices must be positive integers. Therefore, MATLAB must be able to derive a value from the object that is a positive integer, which it uses in the indexed expression.

Indexing expressions like $X(A)$, where A is an object, cause MATLAB to call the default `subsindex` function, unless such an expression results in a call to an overloaded `subsref` or `subsasgn` method defined by the class of X . See “Scenarios for Implementing Objects as Indices” on page 15-33.

`subsindex` must return the value of the object as a zero-based integer index values in the range 0 to `prod(size(X)) - 1`.

Scenarios for Implementing Objects as Indices

If you want to enable indexing of one object by another object, such as $X(A)$, you can implement this behavior in various ways:

- Define a `subsindex` method in the class of A , which converts A to an integer. MATLAB calls A 's `subsindex` method to perform default indexing operations (when the class of X does not overload the default `subsref` or `subsasgn` method).
- If the class of X overloads `subsref` or `subsasgn`, these methods can explicitly call the `subsindex` method of A . In this case, ensure that A implements a `subsindex` method with appropriate error checking in your program.
- If the class of X overloads `subsref` or `subsasgn`, these methods can contain code that determines an integer index value without relying on the class of A to implement a `subsindex` method.

Implementing `subsindex`

MATLAB calls the `subsindex` method defined for the object used as the index. For example, suppose you want to use object A to index into object B . B can be a single object or an array, depending on your objectives.

```
C = B(A);
```

A `subsindex` method implemented by class A might do something as simple as convert the object to double format to be used as an index, as shown in this sample code.

```
function ind = subsindex(obj)
% Convert the object a to double format to be used
% as an index in an indexing expression
    ind = double(obj);
```

```
end
```

Or, your class might implement a special converter method that returns a numeric value representing an object based on particular values of object properties.

```
function ind = subsindex(obj)
% Return the value of an object property
    ind = obj.ElementPosition;
end
```

subsindex values are 0-based, not 1-based.

Implementing Operators for Your Class

In this section...

“Overloading Operators” on page 15-35

“MATLAB Operators and Associated Functions” on page 15-36

Overloading Operators

You can implement MATLAB operators (+, *, >, etc.) to work with objects of your class. Do this by defining the relevant functions as class methods.

Each built-in MATLAB operator has an associated function (e.g., the + operator has an associated `plus.m` function). You can overload any operator by creating a class method with the appropriate name.

Overloading enables operators to handle different types and numbers of input arguments and perform whatever operation is appropriate for the highest precedence object.

Object Precedence

User-defined classes have a higher precedence than built-in classes. For example, if `q` is an object of class `double` and `p` is a user-defined class, `MyClass`, both of these expressions:

```
q + p
p + q
```

generate a call to the `plus` method in the `MyClass`, if it exists. Whether this method can add objects of class `double` and class `MyClass` depends on how you implement it.

When `p` and `q` are objects of different classes, MATLAB applies the rules of precedence to determine which method to use.

“Object Precedence in Expressions Using Operators” on page 7-29 provides information on how MATLAB determines which overloaded method to call.

Examples of Overloaded Operators

“Defining Arithmetic Operators for DocPolynom” on page 16-14 provides examples of overloaded operators.

MATLAB Operators and Associated Functions

The following table lists the function names for common MATLAB operators.

Operation	Method to Define	Description
<code>a + b</code>	<code>plus(a,b)</code>	Binary addition
<code>a - b</code>	<code>minus(a,b)</code>	Binary subtraction
<code>-a</code>	<code>uminus(a)</code>	Unary minus
<code>+a</code>	<code>uplus(a)</code>	Unary plus
<code>a.*b</code>	<code>times(a,b)</code>	Element-wise multiplication
<code>a*b</code>	<code>mtimes(a,b)</code>	Matrix multiplication
<code>a./b</code>	<code>rdivide(a,b)</code>	Right element-wise division
<code>a.\b</code>	<code>ldivide(a,b)</code>	Left element-wise division
<code>a/b</code>	<code>mrdivide(a,b)</code>	Matrix right division
<code>a\b</code>	<code>mldivide(a,b)</code>	Matrix left division
<code>a.^b</code>	<code>power(a,b)</code>	Element-wise power
<code>a^b</code>	<code>mpower(a,b)</code>	Matrix power
<code>a < b</code>	<code>lt(a,b)</code>	Less than
<code>a > b</code>	<code>gt(a,b)</code>	Greater than
<code>a <= b</code>	<code>le(a,b)</code>	Less than or equal to
<code>a >= b</code>	<code>ge(a,b)</code>	Greater than or equal to
<code>a ~= b</code>	<code>ne(a,b)</code>	Not equal to
<code>a == b</code>	<code>eq(a,b)</code>	Equality

Operation	Method to Define	Description
<code>a & b</code>	<code>and(a,b)</code>	Logical AND
<code>a b</code>	<code>or(a,b)</code>	Logical OR
<code>~a</code>	<code>not(a)</code>	Logical NOT
<code>a:d:b</code>	<code>colon(a,d,b)</code>	Colon operator
<code>a:b</code>	<code>colon(a,b)</code>	
<code>a'</code>	<code>ctranspose(a)</code>	Complex conjugate transpose
<code>a.'</code>	<code>transpose(a)</code>	Matrix transpose
command window output	<code>display(a)</code>	Display method
<code>[a b]</code>	<code>horzcat(a,b,...)</code>	Horizontal concatenation
<code>[a; b]</code>	<code>vertcat(a,b,...)</code>	Vertical concatenation
<code>a(s1,s2,...sn)</code>	<code>subsref(a,s)</code>	Subscripted reference
<code>a(s1,...,sn) = b</code>	<code>subsasgn(a,s,b)</code>	Subscripted assignment
<code>b(a)</code>	<code>subsindex(a)</code>	Subscript index

Implementing a Class for Polynomials

Example – A Polynomial Class

In this section...

“Adding a Polynomial Object to the MATLAB Language” on page 16-2

“Displaying the Class Files” on page 16-2

“Summary of the DocPolynom Class” on page 16-3

“The DocPolynom Constructor Method” on page 16-5

“Removing Irrelevant Coefficients” on page 16-6

“Converting DocPolynom Objects to Other Types” on page 16-7

“The DocPolynom disp Method” on page 16-10

“The DocPolynom subsref Method” on page 16-11

“Defining Arithmetic Operators for DocPolynom” on page 16-14

“Overloading MATLAB Functions for the DocPolynom Class” on page 16-16

Adding a Polynomial Object to the MATLAB Language

This example implements a class to represent polynomials in the MATLAB language. A value class is used because the behavior of a polynomial object within the MATLAB environment should follow the copy semantics of other MATLAB variables. This example also implements for this class, methods to provide enhanced display and indexing, as well as arithmetic operations and graphing.

See “Comparing Handle and Value Classes” on page 5-2 for more information on value classes.

This class overloads a number of MATLAB functions, such as `roots`, `polyval`, `diff`, and `plot` so that these function can be used with the new polynomial object.

Displaying the Class Files

Open the DocPolynom class definition file in the MATLAB editor.

To use the class, create a folder named `@DocPolynom` and save `DocPolynom.m` to this folder. The parent folder of `@DocPolynom` must be on the MATLAB path.

Summary of the DocPolynom Class

The class definition specifies a property for data storage and defines a folder (`@DocPolynom`) that contains the class definition.

The following table summarizes the properties defined for the `DocPolynom` class.

DocPolynom Class Properties

Name	Class	Default	Description
<code>coef</code>	<code>double</code>	<code>[]</code>	Vector of polynomial coefficients [highest order ... lowest order]

The following table summarizes the methods for the `DocPolynom` class.

DocPolynom Class Methods

Name	Description
<code>DocPolynom</code>	Class constructor
<code>double</code>	Converts a <code>DocPolynom</code> object to a double (i.e., returns its coefficients in a vector)
<code>char</code>	Creates a formatted display of the <code>DocPolynom</code> object as powers of <code>x</code> and is used by the <code>disp</code> method
<code>disp</code>	Determines how MATLAB displays a <code>DocPolynom</code> objects on the command line
<code>subsref</code>	Enables you to specify a value for the independent variable as a subscript, access the <code>coef</code> property with dot notation, and call methods with dot notation.
<code>plus</code>	Implements addition of <code>DocPolynom</code> objects

DocPolynom Class Methods (Continued)

Name	Description
minus	Implements subtraction of DocPolynom objects
mtimes	Implements multiplication of DocPolynom objects
roots	Overloads the roots function to work with DocPolynom objects
polyval	Overloads the polyval function to work with DocPolynom objects
diff	Overloads the diff function to work with DocPolynom objects
plot	Overloads the plot function to work with DocPolynom objects

Using the DocPolynom Class

The following examples illustrate basic use of the DocPolynom class.

Create DocPolynom objects to represent the following polynomials. Note that the argument to the constructor function contains the polynomial coefficients

$$f(x) = x^3 - 2x - 5 \text{ and } f(x) = 2x^4 + 3x^2 + 2x - 7.$$

```
p1 = DocPolynom([1 0 -2 -5])
p1 =
    x^3 - 2*x - 5
p2 = DocPolynom([2 0 3 2 -7])
p2 =
    2*x^4 + 3*x^2 + 2*x - 7
```

The DocPolynom disp method displays the polynomial in MATLAB syntax.

Find the roots of the polynomial using the overloaded root method.

```
>> roots(p1)

ans =
```

```

2.0946
-1.0473 + 1.1359i
-1.0473 - 1.1359i

```

Add the two polynomials p1 and p2.

The MATLAB runtime calls the `plus` method defined for the `DocPolynom` class when you add two `DocPolynom` objects.

```

p1 + p2
ans =
    2*x^4 + x^3 + 3*x^2 - 12

```

The sections that follow describe the implementation of the methods illustrated here, as well as other methods and implementation details.

The DocPolynom Constructor Method

The following function is the `DocPolynom` class constructor, which is in the file `@DocPolynom/DocPolynom.m`:

```

function obj = DocPolynom(c)
    % Construct a DocPolynom object using the coefficients supplied
    if isa(c,'DocPolynom')
        obj.coef = c.coef;
    else
        obj.coef = c(:).';
    end
end

```

Constructor Calling Syntax

You can call the `DocPolynom` constructor method with two different arguments:

- Input argument is a `DocPolynom` object — If you call the constructor function with an input argument that is already a `DocPolynom` object, the constructor returns a new `DocPolynom` object with the same coefficients as the input argument. The `isa` function checks for this situation.

- Input argument is a coefficient vector — If the input argument is not a `DocPolynom` object, the constructor attempts to reshape the values into a vector and assign them to the `coef` property.

The `coef` property set method restricts property values to doubles. See “Removing Irrelevant Coefficients” on page 16-6 for a description of the property set method.

An example use of the `DocPolynom` constructor is the statement:

```
p = DocPolynom([1 0 -2 -5])
p =
    x^3 - 2*x -5
```

This statement creates an instance of the `DocPolynom` class with the specified coefficients. Note how class methods display the equivalent polynomial using MATLAB language syntax. The `DocPolynom` class implements this display using the `disp` and `char` class methods.

Removing Irrelevant Coefficients

MATLAB software represents polynomials as row vectors containing coefficients ordered by descending powers. Zeros in the coefficient vector represent terms that drop out of the polynomial. Leading zeros, therefore, can be ignored when forming the polynomial.

Some `DocPolynom` class methods use the length of the coefficient vector to determine the degree of the polynomial. It is useful, therefore, to remove leading zeros from the coefficient vector so that its length represents the true value.

The `DocPolynom` class stores the coefficient vector in a property that uses a set method to remove leading zeros from the specified coefficients before setting the property value.

```
function obj = set_coef(obj,val)
    % coef set method
    if ~isa(val,'double')
        error('Coefficients must be of class double')
    end
    ind = find(val(:).~=0);
```

```

    if ~isempty(ind);
        obj.coef = val(ind(1):end);
    else
        obj.coef = val;
    end
end
end

```

See “Property Set Methods” on page 6-14 for more information on controlling property values.

Converting DocPolynom Objects to Other Types

The DocPolynom class defines two methods to convert DocPolynom objects to other classes:

- `double` — Converts to standard MATLAB numeric type so you can perform mathematical operations on the coefficients.
- `char` — Converts to string; used to format output for display in the command window

The DocPolynom to Double Converter

The double converter method for the DocPolynom class simply returns the coefficient vector, which is a double by definition:

```

function c = double(obj)
    % DocPolynom/Double Converter
    c = obj.coef;
end

```

For the DocPolynom object `p`:

```
p = DocPolynom([1 0 -2 -5])
```

the statement:

```
c = double(p)
```

returns:

```
c=
```

```
1      0      -2      -5
```

which is of class double:

```
class(c)
ans =
    double
```

The DocPolynom to Character Converter

The `char` method produces a character string that represents the polynomial displayed as powers of an independent variable, x . Therefore, after you have specified a value for x , the string returned is a syntactically correct MATLAB expression, which you can evaluate.

The `char` method uses a cell array to collect the string components that make up the displayed polynomial.

The `disp` method uses `char` to format the `DocPolynom` object for display. Class users are not likely to call the `char` or `disp` methods directly, but these methods enable the `DocPolynom` class to behave like other data classes in MATLAB.

Here is the `char` method.

```
function str = char(obj)
    % Created a formatted display of the polynom
    % as powers of x
    if all(obj.coef == 0)
        s = '0';
    else
        d = length(obj.coef)-1;
        s = cell(1,d);
        ind = 1;
        for a = obj.coef;
            if a ~= 0;
                if ind ~= 1
                    if a > 0
                        s(ind) = {' + '};
                        ind = ind + 1;
                    end
                end
            end
        end
    end
end
```



```

else
    s(ind) = {' - '};
    a = -a;
    ind = ind + 1;
end
end
if a ~= 1 || d == 0
    if a == -1
        s(ind) = {' - '};
        ind = ind + 1;
    else
        s(ind) = {num2str(a)};
        ind = ind + 1;
        if d > 0
            s(ind) = {'*'};
            ind = ind + 1;
        end
    end
end
if d >= 2
    s(ind) = {'x^' int2str(d)};
    ind = ind + 1;
elseif d == 1
    s(ind) = {'x'};
    ind = ind + 1;
end
end
d = d - 1;
end
end
str = [s{:}];
end

```

Evaluating the Output

If you create the DocPolynom object p:

```
p = DocPolynom([1 0 -2 -5]);
```

and then call the char method on p:

```
char(p)
```

the result is:

```
ans =  
x^3 - 2*x - 5
```

The value returned by `char` is a string that you can pass to `eval` after you have defined a scalar value for `x`. For example:

```
x = 3;  
  
eval(char(p))  
ans =  
16
```

“The `DocPolynom` `subsref` Method” on page 16-11 describes a better way to evaluate the polynomial.

The `DocPolynom` `disp` Method

To provide a more useful display of `DocPolynom` objects, this class overloads `disp` in the class definition.

This `disp` method relies on the `char` method to produce a string representation of the polynomial, which it then displays on the screen.

```
function disp(obj)  
    % DISP Display object in MATLAB syntax  
    c = char(obj); % char returns a cell array  
    if iscell(c)  
        disp([' ' c{:}])  
    else  
        disp(c) % all coefficients are zero  
    end  
end
```

When MATLAB Calls the `disp` Method

The statement:

```
p = DocPolynom([1 0 -2 -5])
```

creates a `DocPolynom` object. Since the statement is not terminated with a semicolon, the resulting output is displayed on the command line:

```
p =
    x^3 - 2*x - 5
```

See “Displaying Objects in the Command Window” on page 15-9 for information about defining the display of objects.

The `DocPolynom` `subsref` Method

Normally, subscripted assignment is automatically defined by MATLAB. However, in this particular case, the design of the `DocPolynom` class specifies that a subscripted reference to a `DocPolynom` object causes an evaluation of the polynomial with the value of the independent variable equal to the subscript.

For example, given the following polynomial:

$$f(x) = x^3 - 2x - 5$$

a subscripted reference evaluates $f(x)$, where x is the value of the subscript.

Creating a `DocPolynom` object `p`:

```
p = DocPolynom([1 0 -2 -5])
p =
    x^3 - 2*x - 5
```

the following subscripted expression evaluates the value of the polynomial at $x = 3$ and $x = 4$ and returns a vector of resulting values:

```
p([3 4])
ans =
    16    51
```

Special Behavior Requires Specializing `subsref`

The `DocPolynom` class redefines the default subscripted reference behavior by implementing a `subsref` method. Once you define a `subsref` method, MATLAB software calls this method for objects of this class whenever a subscripted reference occurs. You must, therefore, define all the behaviors you want your class to exhibit in the local method.

The `DocPolynom` `subsref` method implements the following behaviors:

- The ability to pass a value for the independent variable as a subscripted reference (i.e., `p(3)` evaluates the polynomial at $x = 3$)
- Dot notation for accessing the `coef` property
- Dot notation for access to all class methods, which accept and return differing numbers of input and output arguments

`subsref` Implementation Details

See `subsref` for general information on implementing this method.

When you need to implement a `subsref` method to support calling methods with arguments using dot notation, both the `type` and `subs` structure fields contain multiple elements.

For example, consider a call to the class `polyval` method:

```
>> p = DocPolynom([1 0 -2 -5])
p =
      x^3 - 2*x - 5
>> p.polyval([3 5 7])
ans =
      16      110      324
```

This method requires an input argument of values at which to evaluate the polynomial and returns the value of $f(x)$ at these values. `subsref` performs the method call through the statements:

```
if length(s)>1
    b = a.(s(1).subs)(s(2).subs{:}); % method with arguments
else
    b = a.(s.subs); % method without input arguments
```

```
end
```

Where the contents of the structure `s`, which is passed to `subsref` contains:

```
s(1).type is '.'
```

```
s(2).type is '()'
```

```
s(1).subs is 'polyval'
```

```
s(2).subs is [3 5 7]
```

When you implement a `subsref` method for a class, you must implement all subscripted reference explicitly, as show in the following code listing.

```
function b = subsref(a,s)
    % Implement a special subscripted assignment
    switch s(1).type
    case '()'
        ind = s.subs{:};
        b = a.polyval(ind);
    case '.'
        switch s(1).subs
        case 'coef'
            b = a.coef;
        case 'plot'
            a.plot;
        otherwise
            if length(s)>1
                b = a.(s(1).subs)(s(2).subs{:});
            else
                b = a.(s.subs);
            end
        end
    end
    otherwise
        error('Specify value for x as obj(x)')
    end
end
```

Defining Arithmetic Operators for DocPolynom

Several arithmetic operations are meaningful on polynomials and should be implemented for the DocPolynom class. See “Implementing Operators for Your Class” on page 15-35 for information on overloading other operations that could be useful with this class, such as division, horizontal concatenation, etc.

This section shows how to implement the following methods:

Method and Syntax	Operator Implemented
plus(a,b)	Binary addition
minus(a,b)	Binary subtraction
mtimes(a,b)	Matrix multiplication

When overloading arithmetic operators, keep in mind what data types you want to operate on. In this section, the plus, minus, and mtimes methods are defined for the DocPolynom class to handle addition, subtraction, and multiplication on DocPolynom/DocPolynom and DocPolynom/double combinations of operands.

Defining the + Operator

If either p or q is a DocPolynom object, the expression

$$p + q$$

generates a call to a function @DocPolynom/plus, unless the other object is of a class of higher precedence. “Object Precedence in Expressions Using Operators” on page 7-29 provides more information.

The following function redefines the plus (+) operator for the DocPolynom class:

```
function r = plus(obj1,obj2)
% Plus Implement obj1 + obj2 for DocPolynom
obj1 = DocPolynom(obj1);
obj2 = DocPolynom(obj2);
k = length(obj2.coef) - length(obj1.coef);
r = DocPolynom([zeros(1,k) obj1.coef]+[zeros(1,-k) obj2.coef]);
```

```
end
```

Here is how the function works:

- Ensure that both input arguments are `DocPolynom` objects so that expressions such as

$$p + 1$$

that involve both a `DocPolynom` and a `double`, work correctly.

- Access the two coefficient vectors and, if necessary, pad one of them with zeros to make both the same length. The actual addition is simply the vector sum of the two coefficient vectors.
- Call the `DocPolynom` constructor to create a properly typed result.

Defining the - Operator

You can implement the minus operator (-) using the same approach as the plus (+) operator.

The MATLAB runtime calls the `DocPolynom` `minus` method to compute $p - q$, where p , q , or both are `DocPolynom` objects:

```
function r = minus(obj1,obj2)
    % MINUS Implement obj1 - obj2 for DocPolynom
    obj1 = DocPolynom(obj1);
    obj2 = DocPolynom(obj2);
    k = length(obj2.coef) - length(obj1.coef);
    r = DocPolynom([zeros(1,k) obj1.coef] - [zeros(1,-k) obj2.coef]);
end
```

Defining the * Operator

The MATLAB runtime calls the `DocPolynom` `mtimes` method to compute the product $p * q$. The `mtimes` method is used to overload *matrix* multiplication since the multiplication of two polynomials is simply the convolution (`conv`) of their coefficient vectors:

```
function r = mtimes(obj1,obj2)
```

```
% MTIMES Implement obj1 * obj2 for DocPolynoms
obj1 = DocPolynom(obj1);
obj2 = DocPolynom(obj2);
r = DocPolynom(conv(obj1.coef,obj2.coef));
end
```

Using the Arithmetic Operators

Given the DocPolynom object:

```
p = DocPolynom([1 0 -2 -5])
```

The following two arithmetic operations call the DocPolynom plus and mtimes methods:

```
q = p+1
r = p*q
```

to produce

```
q =
    x^3 - 2*x - 4
```

```
r =
    x^6 - 4*x^4 - 9*x^3 + 4*x^2 + 18*x + 20
```

Overloading MATLAB Functions for the DocPolynom Class

The MATLAB language already has several functions for working with polynomials that are represented by coefficient vectors. You can overload these functions to work with the new DocPolynom class.

In the case of DocPolynom objects, the overloaded methods can simply apply the original MATLAB function to the coefficients (i.e., the values returned by the coef property).

This section shows how to implement the following MATLAB functions.

MATLAB Function	Purpose
<code>root(obj)</code>	Calculates polynomial roots
<code>polyval(obj,x)</code>	Evaluates polynomial at specified points
<code>diff(obj)</code>	Finds difference and approximate derivative
<code>plot(obj)</code>	Creates a plot of the polynomial function

Defining the roots Function for the DocPolynom Class

The DocPolynom roots method finds the roots of DocPolynom objects by passing the coefficients to the overloaded roots function:

```
function r = roots(obj)
    % roots(obj) returns a vector containing the roots of obj
    r = roots(obj.coef);
end
```

If p is the following DocPolynom object:

```
p = DocPolynom([1 0 -2 -5]);
```

then the statement:

```
roots(p)
```

gives the following answer:

```
ans =
    2.0946
   -1.0473 + 1.1359i
   -1.0473 - 1.1359i
```

Defining the polyval Function for the DocPolynom Class

The MATLAB polyval function evaluates a polynomial at a given set of points. The DocPolynom polyval method simply extracts the coefficients from the coef property and then calls the MATLAB version to compute the various powers of x:

```
function y = polyval(obj,x)
    % polyval(obj,x) evaluates obj at the points x
    y = polyval(obj.coef,x);
end
```

Defining the diff Function for the DocPolynom Class

The MATLAB `diff` function finds the derivative of the polynomial. The `DocPolynom` `diff` method differentiates a polynomial by reducing the degree by 1 and multiplying each coefficient by its original degree:

```
function q = diff(obj)
    % diff(obj) is the derivative of the DocPolynom obj
    c = obj.coef;
    d = length(c) - 1; % degree
    q = DocPolynom(obj.coef(1:d).*(d:-1:1));
end
```

Defining the plot Function for the DocPolynom Class

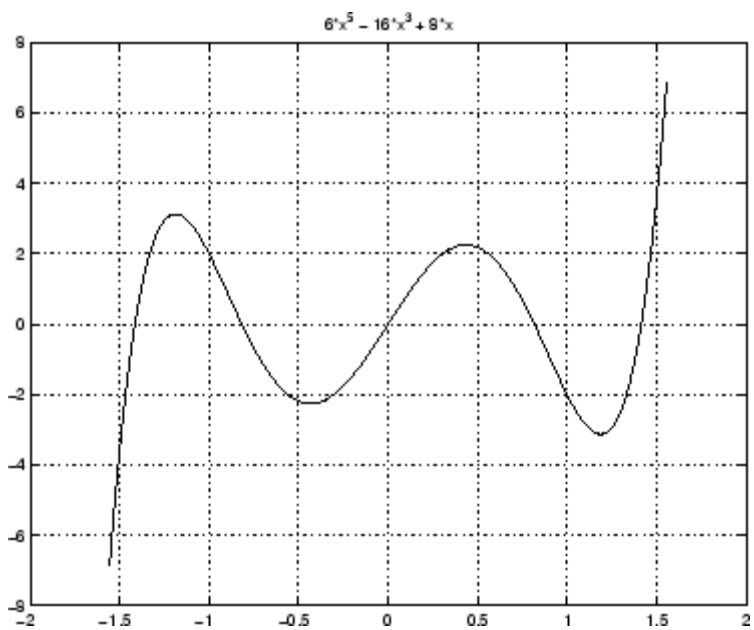
The MATLAB `plot` function creates line graphs. The overloaded `plot` function selects the domain of the independent variable to be slightly larger than an interval containing all real roots. Then the `polyval` method is used to evaluate the polynomial at a few hundred points in the domain:

```
function plot(obj)
    % plot(obj) plots the DocPolynom obj
    r = max(abs(roots(obj)));
    x = (-1.1:0.01:1.1)*r;
    y = polyval(obj,x);
    plot(x,y);
    title(['y = ' char(obj)])
    xlabel('X')
    ylabel('Y', 'Rotation', 0)
    grid on
end
```

Plotting the two `DocPolynom` objects `x` and `p` calls most of these methods:

```
x = DocPolynom([1 0]);
```

```
p = DocPolynom([1 0 -2 -5]);  
plot(diff(p*p + 10*p + 20*x) - 20)
```



Designing Related Classes

- “Example — A Simple Class Hierarchy” on page 17-2
- “Example — Containing Assets in a Portfolio” on page 17-19

Example – A Simple Class Hierarchy

In this section...

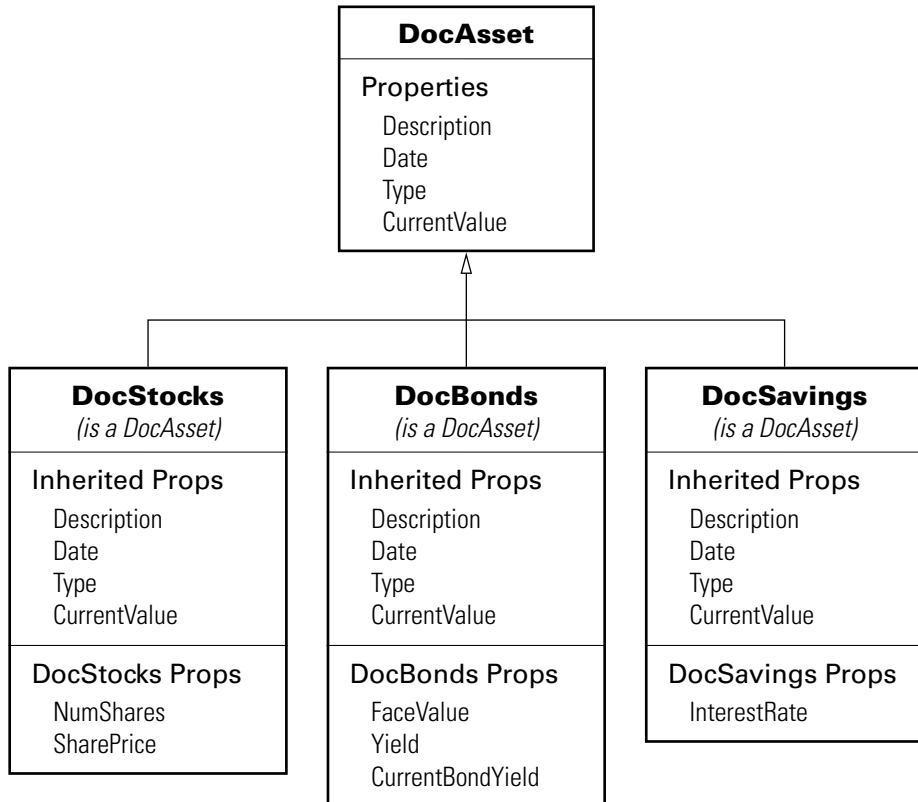
“Shared and Specialized Properties” on page 17-2
“Designing a Class for Financial Assets” on page 17-3
“Displaying the Class Files” on page 17-4
“Summary of the DocAsset Class” on page 17-4
“The DocAsset Constructor Method” on page 17-5
“The DocAsset Display Method” on page 17-6
“Designing a Class for Stock Assets” on page 17-7
“Displaying the Class Files” on page 17-7
“Summary of the DocStock Class” on page 17-7
“Designing a Class for Bond Assets” on page 17-10
“Displaying the Class Files” on page 17-10
“Summary of the DocBond Class” on page 17-11
“Designing a Class for Savings Assets” on page 17-15
“Displaying the Class Files” on page 17-15
“Summary of the DocSavings Class” on page 17-15

Shared and Specialized Properties

As an example of how subclasses are specializations of more general classes, consider an asset class that can be used to represent any item that has monetary value. Some examples of assets are stocks, bonds, and savings accounts. This example implements four classes — `DocAsset`, and the subclasses `DocStock`, `DocBond`, `DocSavings`.

The `DocAsset` class holds the data that is common to all of the specialized asset subclasses in class properties. The subclasses inherit the super class properties in addition to defining their own properties. The subclasses are all *kinds of* assets.

The following diagram shows the properties defined for the classes of assets.



The **DocStock**, **DocBond**, and **DocSavings** classes inherit properties from the **DocAsset** class. In this example, the **DocAsset** class provides storage for data common to all subclasses and shares methods with these subclasses.

Designing a Class for Financial Assets

This class provides storage and access for information common to all asset children. It is not intended to be instantiated directly, so it does not require an extensive set of methods. The class contains the following methods:

- Constructor

- A local setter function for one property

Displaying the Class Files

Open the DocAsset class definition file in the MATLAB Editor.

To use the class, create a folder named @DocAsset and save DocAsset.m to this folder. The parent folder of @DocAsset must be on the MATLAB path.

Summary of the DocAsset Class

The class is defined in one file, DocAsset.m, which you must place in an @ folder of the same name. The parent folder of the @DocAsset folder must be on the MATLAB path. See the addpath function for more information.

The following table summarizes the properties defined for the DocAsset class.

DocAsset Class Properties

Name	Class	Default	Description
Description	char	' '	Description of asset
CurrentValue	double	0	Current value of asset
Date	char	date	Date when record is created (set by date function)
Type	char	'savings'	Type of asset (stock, bond, savings)

The following table summarizes the methods for the DocAsset class.

DocAsset Class Methods

Name	Description
DocAsset	Class constructor
disp	Displays information about this object
set.Type	Set function for Type. Property tests for correct value when property is set.

The DocAsset Constructor Method

This class has four properties that store data common to all of the asset subclasses. All except `Date` are passed to the constructor by a subclass constructor. `Date` is a private property and is set by a call to the `date` function.

- `Description` — A character string that describes the particular asset (e.g., stock name, savings bank name, bond issuer, and so on).
- `Date` — The date the object was created. This property's set access is private so that only the constructor assigns the value using the `date` command when creating the object.
- `Type` — The type of asset (e.g., savings, bond, stock). A local set function provides error checking whenever an object is created.
- `CurrentValue` — The current value of the asset.

Property Definition Block

The following code block shows how the properties are defined. Note the `set` function defined for the `Type` property. It restricts the property's values to one of three strings: `bond`, `stock`, or `savings`.

```
properties
    Description = '';
    CurrentValue = 0;
end
properties(SetAccess = private)
    Date % Set value in constructor
    Type = 'savings'; % Provide a default value
end
```

Constructor Method Code

The `DocAsset` class is not derived from another class, so you do not need to call a superclass constructor. MATLAB constructs an object when you assign values to the specified output argument (`a` in the following code):

```
function a = DocAsset(description,type,current_value)
% DocAsset constructor
if nargin > 0
```

```
        a.Description = description;
        a.Date = date;
        a.Type = type;
        a.CurrentValue = current_value;
    end
end % DocAsset
```

Set Function for Type Property

In this class design, there are only three types of assets—bonds, stocks, and savings. Therefore, the possible values for the `Type` property are restricted to one of three possible strings by defining a set function as follows:

```
function obj = set.Type(obj,type)
    if ~(strcmpi(type,'bond') || strcmpi(type,'stock') || strcmpi(type,'savings'))
        error('Type must be either bond, stock, or savings')
    end
    obj.Type = type;
end %Type set function
```

The MATLAB runtime calls this function whenever an attempt is made to set the `Type` property, even from within the class constructor function or by assigning an initial value. Therefore, the following statement in the class definition would produce an error:

```
properties
    Type = 'cash';
end
```

The only exception is the `set.Type` function itself, where the statement:

```
obj.Type = type;
```

does not result in a recursive call to `set.Type`.

The DocAsset Display Method

The asset `disp` method is designed to be called from child-class `disp` methods. Its purpose is to display the data it stores for the child object. The method

simply formats the data for display in a way that is consistent with the formatting of the child's `disp` method:

```
function disp(a)
% Display a DocAsset object
    fprintf('Description: %s\nDate: %s\nType: %s\nCurrentValue:%9.2f\n',...
        a.Description,a.Date,a.Type,a.CurrentValue);
end % disp
```

The `DocAsset` subclass display methods can now call this method to display the data stored in the parent class. This approach isolates the subclass `disp` methods from changes to the `DocAsset` class.

Designing a Class for Stock Assets

Stocks are one type of asset. A class designed to store and manipulate information about stock holdings needs to contain the following information about the stock:

- The number of shares
- The price per share

In addition, the base class (`DocAsset`) maintains general information including a description of the particular asset, the date the record was created, the type of asset, and its current value.

Displaying the Class Files

Open the `DocStock` class definition file in the MATLAB Editor.

To use the class, create a folder named `@DocStock` and save `DocStock.m` to this folder. The parent folder of `@DocStock` must be on the MATLAB path.

Summary of the `DocStock` Class

This class is defined in one file, `DocStock.m`, which you must place in an `@` folder of the same name. The parent folder of the `@DocStock` folder must be on the MATLAB path. See the `addpath` function for more information.

`DocStock` is a subclass of the `DocAsset` class.

The following table summarizes the properties defined for the DocStock class.

DocStock Class Properties

Name	Class	Default	Description
NumShares	double	0	Number of shares of a particular stock
SharePrice	double	0	Current value of asset
Properties Inherited from the DocAsset Class			
Description	char	''	Description of asset
CurrentValue	double	0	Current value of asset
Date	char	date	Date when record is created (set by date function)
Type	char	''	Type of asset (stock, bond, savings)

The following table summarizes the methods for the DocStock class.

DocStock Class Methods

Name	Description
DocStock	Class constructor
disp	Displays information about the object

Specifying the Base Class

The < symbol specifies the DocAsset class as the base class for the DocStock class in the classdef line:

```
classdef DocStock < DocAsset
```

Property Definition Block

The following code shows how the properties are defined:

```
properties
    NumShares = 0;
    SharePrice = 0;
end
```

Using the DocStock Class

Suppose you want to create a record of a stock asset for 200 shares of a company called Xdotcom with a share price of \$23.47.

Call the DocStock constructor function with the following arguments:

- Stock name or description
- Number of shares
- Share price

For example, the following statement:

```
XdotcomStock = DocStock('Xdotcom',200,23.47);
```

creates a DocStock object, XdotcomStock, that contains information about a stock asset in Xdotcom Corp. The asset consists of 200 shares that have a per share value of \$23.47.

The DocStock Constructor Method

The constructor first creates an instance of a DocAsset object since the DocStock class is derived from the DocAsset class (see “The DocAsset Constructor Method” on page 17-5). The constructor returns the DocStock object after setting value for its two properties:

```
function s = DocStock(description,num_shares,share_price)
    if nargin ~= 3 % Support no argument constructor syntax
        description = '';
        num_shares = 0;
        share_price = 0;
    end
```

```
s = s@DocAsset(description,'stock',share_price*num_shares);
s.NumShares = num_shares;
s.SharePrice = share_price;
end % DocStock
```

The DocStock disp Method

When you issue the statement (without terminating with a semicolon):

```
XdotcomStock = DocStock('Xdotcom',100,25)
```

the MATLAB runtime looks for a method in the @DocStock folder called disp. The disp method for the DocStock class produces this output:

```
Description: Xdotcom
Date: 17-Nov-1998
Type: stock
Current Value: $2500.00
Number of shares: 100
Share price: $25.00
```

The following function is the DocStock disp method. When this function returns from the call to the DocAsset disp method, it uses fprintf to display the Numshares and SharePrice property values on the screen:

```
function disp(s)
disp@DocAsset(s)
fprintf('Number of shares: %g\nShare price: %3.2f\n',...
s.NumShares,s.SharePrice);
end % disp
```

Designing a Class for Bond Assets

The DocBond class is similar to the DocStock class in that it is derived from the DocAsset class to represent a specific type of asset.

Displaying the Class Files

Open the DocBond class definition file in the MATLAB Editor.

To use the class, create a folder named `@DocBond` and save `DocBond.m` to this folder. The parent folder of `@DocBond` must be on the MATLAB path. See the `addpath` function for more information.

Summary of the DocBond Class

This class is defined in one file, `DocBond.m`, which you must place in an `@` folder of the same name. The parent folder of the `@DocBond` folder must be on the MATLAB path.

`DocStock` is a subclass of the `DocAsset` class.

The following table summarizes the properties defined for the `DocBond` class

DocBond Class Properties

Name	Class	Default	Description
FaceValue	double	0	Face value of the bond
SharePrice	double	0	Current value of asset
Properties Inherited from the DocAsset Class			
Description	char	''	Description of asset
CurrentValue	double	0	Current value of asset
Date	char	date	Date when record is created (set by <code>date</code> function)
Type	char	''	Type of asset (stock, bond, savings)

The following table summarizes the methods for the `DocStock` class.

DocBond Class Methods

Name	Description
DocBond	Class constructor
disp	Displays information about this object and calls the DocAsset disp method
calc_value	Utility function to calculate the bond's current value

Specifying the Base Class

The < symbol specifies the DocAsset class as the base class for the DocBond class in the classdef line:

```
classdef DocBond < DocAsset
```

Property Definition Block

The following code block shows how the properties are defined:

```
properties
    FaceValue = 0;
    Yield = 0;
    CurrentBondYield = 0;
end
```

Using the DocBond Class

Suppose you want to create a record of an asset that consists of an xyzbond with a face value of \$100 and a current yield of 4.3%. The current yield for the equivalent bonds today is 6.2%, which means that the market value of this particular bond is less than its face value.

Call the DocBond constructor function with the following arguments:

- Bond name or description
- Bond's face value

- Bond's interest rate or yield
- Current interest rate being paid by equivalent bonds (used to calculate the current value of the asset)

For example, this statement:

```
b = DocBond('xyzbond',100,4.3,6.2);
```

creates a `DocBond` object, `b`, that contains information about a bond asset `xyzbond` with a face value of \$100, a yield of 4.3%, and also contains information about the current yield of such bonds (6.2% in this case) that is used to calculate the current value.

Note The calculations performed in this example are intended only to illustrate the use of MATLAB classes and do not represent a way to determine the actual value of any monetary investment.

The `DocBond` Constructor Method

The `DocBond` constructor method requires four arguments. It also supports the no argument syntax by defining default values for the missing input arguments:

```
function b =
DocBond(description,face_value,yield,current_yield)
    if nargin ~= 4
        description = '';
        face_value = 0;
        yield = 0;
        current_yield = 0;
    end
    market_value = DocBond.calc_value(face_value,yield,current_yield);
    b = b@DocAsset(description,'bond',market_value);
    b.FaceValue = face_value;
    b.Yield = yield;
    b.CurrentBondYield = current_yield;
end % DocBond
```

The `calc_value` Method

The `DocBond` class determines the market value of bond assets using a simple formula that scales the face value by the ratio of the bond's interest yield to the current yield for equivalent bonds.

Calculation of the asset's market value requires that the yields be nonzero, and should be positive just to make sense. While the `calc_value` method issues no errors for bad yield values, it does ensure bad values are not used in the calculation of market value.

The asset's market value is passed to the `DocAsset` base-class constructor when it is called within the `DocBond` constructor. `calc_value` has its `Static` attribute set to true because it does not accept a `DocBond` object as an input argument. The output of `calc_value` is used by the base-class (`DocAsset`) constructor:

```
methods (Static)
    function market_value = calc_value(face_value,yield,current_yield)
        if current_yield <= 0 || yield <= 0
            market_value = face_value;
        else
            market_value = face_value*yield/current_yield;
        end
    end % calc_value
end % methods
```

The `DocBond disp` Method

When you issue this statement (without terminating it with a semicolon):

```
b = DocBond('xyzbond',100,4.3,6.2)
```

the MATLAB runtime looks for a method in the `@DocBond` folder called `disp`. The `disp` method for the `DocBond` class produces this output:

```
Description: xyzbond
Date: 17-Nov-1998
Type: bond
Current Value: $69.35
Face value of bonds: $100
Yield: 4.30%
```

The following function is the DocBond disp method. When this function returns from the call to the DocAsset disp method, it uses fprintf to display the FaceValue, Yield, and CurrentValue property values on the screen:

```
function disp(b)
    disp@DocAsset(b) % Call DocAsset disp method
    fprintf('Face value of bonds: %g\nYield: %3.2f%%\n',...
        b.FaceValue,b.Yield);
end % disp
```

Designing a Class for Savings Assets

The DocSavings class is similar to the DocStock and DocBond class in that it is derived from the DocAsset class to represent a specific type of asset.

Displaying the Class Files

Open the DocSavings class definition file in the MATLAB Editor.

To use the class, create a folder named @DocSavings and save DocSavings.m to this folder. The parent folder of @DocSavings must be on the MATLAB path.

Summary of the DocSavings Class

This class is defined in one file, DocSavings.m, which you must place in an @ folder of the same name. The parent folder of the @DocSavings folder must be on the MATLAB path. See the addpath function for more information.

The following table summarizes the properties defined for the DocSavings class.

DocSavings Class Properties

Name	Class	Default	Description
InterestRate	double	''	Current interest rate paid on the savings account
Properties Inherited from the DocAsset Class			
Description	char	''	Description of asset
CurrentValue	double	0	Current value of asset
Date	char	date	Date when record is created (set by date function)
Type	char	''	The type of asset (stock, bond, savings)

The following table summarizes the methods for the DocSavings class.

DocSavings Class Methods

Name	Description
DocSavings	Class constructor
disp	Displays information about this object and calls the DocAsset disp method

Specifying the Base Class

The < symbol specifies the DocAsset class as the base class for the DocBond class in the classdef line:

```
classdef DocSavings < DocAsset
```

Property Definition Block

The following code shows how the property is defined:

```
properties
    InterestRate = 0;
end
```

Using the DocSavings Class

Suppose you want to create a record of an asset that consists of a savings account with a current balance of \$1000 and an interest rate of 2.9%.

Call the `DocSavings` constructor function with the following arguments:

- Bank account description
- Account balance
- Interest rate paid on savings account

For example, this statement:

```
sv = DocSavings('MyBank',1000,2.9);
```

creates a `DocSavings` object, `sv`, that contains information about an account in `MyBank` with a balance of \$1000 and an interest rate of 2.9%.

The DocSavings Constructor Method

The savings account interest rate is saved in the `DocSavings` class `InterestRate` property. The asset description and the current value (account balance) are saved in the inherited `DocAsset` object properties.

The constructor calls the base class constructor (`DocAsset.m`) to create an instance of the object. It then assigns a value to the `InterestRate` property. The constructor supports the no argument syntax by providing default values for the missing arguments.

```
function s = DocSavings(description,balance,interest_rate)
    if nargin ~= 3
        description = '';
        balance = 0;
```

```
        interest_rate = 0;
    end
    s = s@DocAsset(description,'savings',balance);
    s.InterestRate = interest_rate;
end % DocSavings
```

The DocSavings disp Method

When you issue this statement (without terminating it with a semicolon):

```
sv = DocSavings('MyBank',1000,2.9)
```

the MATLAB runtime looks for a method in the @DocSavings folder called `disp`. The `disp` method for the `DocSavings` class produces this output:

```
Description: MyBank
Date: 17-Nov-1998
Type: savings
Current Value: $1000.00
Interest Rate: 2.90%
```

The following function is the `DocSavings disp` method. When this function returns from the call to the `DocAsset disp` method, it uses `fprintf` to display the `Numshares` and `SharePrice` property values on the screen:

```
function disp(b)
    disp@DocAsset(b) % Call DocAsset disp method
    fprintf('%s%3.2f%\n','Interest Rate: ',s.InterestRate);
end % disp
```

Example — Containing Assets in a Portfolio

Kinds of Containment

Aggregation is the containment of objects by other objects. The basic relationship is that each contained object "is a part of" the container object. Composition is a more strict form of aggregation in which the contained objects are parts of the containing object and are not associated with any other objects. Portfolio objects form a composition with asset objects because the asset objects are value classes, which are copied when the constructor method creates the DocPortfolio object.

For example, consider a financial portfolio class as a container for a set of assets (stocks, bonds, savings, and so on). It can group, analyze, and return useful information about the individual assets. The contained objects are not accessible directly, but only via the portfolio class methods.

“Example — A Simple Class Hierarchy” on page 17-2 provides information about the assets collected by this portfolio class.

Designing the DocPortfolio Class

The DocPortfolio class is designed to contain the various assets owned by an individual client and to provide information about the status of his or her investment portfolio. This example implements a somewhat over-simplified portfolio class that:

- Contains an individual's assets
- Displays information about the portfolio contents
- Displays a 3-D pie chart showing the relative mix of asset types in the portfolio

Displaying the Class Files

Open the DocPortfolio class definition file in the MATLAB Editor.

To use the class, create a folder named @DocPortfolio and save DocPortfolio.m to this folder. The parent folder of @DocPortfolio must be on the MATLAB path.

Summary of the DocPortfolio Class

This class is defined in one file, `DocPortfolio.m`, which you must place in an @ folder of the same name. The parent folder of the @DocPortfolio folder must be on the MATLAB path. See the `addpath` function for more information.

The following table summarizes the properties defined for the `DocPortfolio` class.

DocPortfolio Class Properties

Name	Class	Default	Description
Name	char	''	Name of client owning the portfolio
IndAssets	cell	{}	A cell array containing individual asset objects
TotalValue	double	0	Value of all assets (calculated in the constructor method)

The following table summarizes the methods for the `DocPortfolio` class.

DocBond Class Methods

Name	Description
<code>DocPortfolio</code>	Class constructor
<code>disp</code>	Displays information about this object and calls the <code>DocAsset disp</code> method
<code>pie3</code>	Overloaded version of <code>pie3</code> function designed to take a single portfolio object as an argument

Property Definition Block

The following code block shows how the properties are defined:

```
properties
    Name = '';
end
```



```

properties (SetAccess = private)
    IndAssets = {};
    TotalValue = 0;
end

```

How Class Properties Are Used

- **Name** — Stores the name of the client as a character string. The client's name is passed to the constructor as an input argument.
- **IndAsset** — A cell array that stores asset objects (i.e., `DocStock`, `DocBond`, and `DocSavings` objects). These asset objects are passed to the `DocPortfolio` constructor as input arguments and assigned to the property from within the constructor function.
- **IndAsset** — The structure of this property is known only to `DocPortfolio` class member functions so the property's `SetAccess` attribute is set to `private`.
- **TotalValue** — Stores the total value of the client's assets. The class constructor determines the value of each asset by querying the asset's `CurrentValue` property and summing the result. Access to the `TotalValue` property is restricted to `DocPortfolio` class member functions by setting the property's `SetAccess` attribute to `private`.

Using the DocPortfolio Class

The `DocPortfolio` class is designed to provide information about the financial assets owned by a client. There are three possible types of assets that a client can own: stocks, bonds, and savings accounts.

The first step is to create an asset object to represent each type of asset owned by the client:

```

XYZStock = DocStock('XYZ Stocks',200,12.34);
USTBonds = DocBond('U.S. Treasury Bonds',1600,3.2,2.8);
SaveAccount = DocSavings('MyBank Acc # 123',2000,6);
VictoriaSelna = DocPortfolio('Victoria Selna',...
    XYZStock,...
    SaveAccount,...
    USTBonds)

```

The DocPortfolio object displays the following information:

```
VictoriaSelna =  
  
Assets for Client: Victoria Selna  
Description: XYZ Stocks  
Date: 11-Mar-2008  
Type: stock  
Current Value: $2468.00  
Number of shares: 200  
Share price: $12.34  
Description: MyBank Acc # 123  
Date: 11-Mar-2008  
Type: savings  
Current Value: $2000.00  
Interest Rate: 6.00%  
Description: U.S. Treasury Bonds  
Date: 11-Mar-2008  
Type: bond  
Current Value: $1828.57  
Face value of bonds: $1600  
Yield: 3.20%  
  
Total Value: $6296.57
```

“The DocPortfolio pie3 Method” on page 17-23 provides a graphical display of the portfolio.

The DocPortfolio Constructor Method

The DocPortfolio constructor method takes as input arguments a client’s name and a variable length list of asset objects (DocStock, DocBond, and DocSavings objects in this example).

The IndAssets property is a cell array used to store all asset objects. From these objects, the constructor determines the total value of the client’s assets. This value is stored in the TotalValue property:

```
function p = DocPortfolio(name,varargin)
```

```

if nargin > 0
    p.Name = name;
    for k = 1:length(varargin)
        p.IndAssets{k} = varargin(k);
        asset_value = p.IndAssets{k}{1}.CurrentValue;
        p.TotalValue = p.TotalValue + asset_value;
    end
end
end % DocPortfolio

```

The DocPortfolio disp Method

The portfolio disp method lists the contents of each contained object by calling the object's disp method. It then lists the client name and total asset value:

```

function disp(p)
    fprintf('\nAssets for Client: %s\n',p.Name);
    for k = 1:length(p.IndAssets)
        disp(p.IndAssets{k}{1}) % Dispatch to corresponding disp
    end
    fprintf('\nTotal Value: $%0.2f\n',p.TotalValue);
end % disp

```

The DocPortfolio pie3 Method

The DocPortfolio class overloads the MATLAB pie3 function to accept a portfolio object and display a 3-D pie chart illustrating the relative asset mix of the client's portfolio. MATLAB calls the @DocPortfolio/pie3.m version of pie3 whenever the input argument is a single portfolio object:

```

function pie3(p)
% Step 1: Get the current value of each asset
    stock_amt = 0; bond_amt = 0; savings_amt = 0;
    for k = 1:length(p.IndAssets)
        if isa(p.IndAssets{k},'DocStock')
            stock_amt = stock_amt + p.IndAssets{k}.CurrentValue;
        elseif isa(p.IndAssets{k},'DocBond')
            bond_amt = bond_amt + p.IndAssets{k}.CurrentValue;
        elseif isa(p.IndAssets{k},'DocSavings')
            savings_amt = savings_amt + p.IndAssets{k}.CurrentValue;
        end % if
    end

```

```

        end % for

% Step 2: Create labels and data for the pie graph
k = 1;
if stock_amt ~= 0
    label(k) = {'Stocks'};
    pie_vector(k) = stock_amt;
    k = k + 1;
end % if
if bond_amt ~= 0
    label(k) = {'Bonds'};
    pie_vector(k) = bond_amt;
    k = k + 1;
end % if
if savings_amt ~= 0
    label(k) = {'Savings'};
    pie_vector(k) = savings_amt;
end % if

% Step 3: Call pie3, adjust fonts and colors
pie3(pie_vector,label);set(gcf,'Renderer','zbuffer')
set(findobj(gca,'Type','Text'),...
'FontSize',14,'FontWeight','bold')
colormap prism
stg(1) = [{'Portfolio Composition for ',p.Name}];
stg(2) = [{'Total Value of Assets: $',num2str(p.TotalValue,'%0.2f')}];
title(stg,'FontSize',10)
end % pie3

```

There are three parts in the overloaded `pie3` method.

- Step 1 — Get the `CurrentValue` property of each contained asset object and determine the total value in each category.
- Step 2 — Create the pie chart labels and build a vector of graph data, depending on which objects are present in the portfolio.
- Step 3 — Call the MATLAB `pie3` function, make some font and colormap adjustments, and add a title.

Visualizing a Portfolio

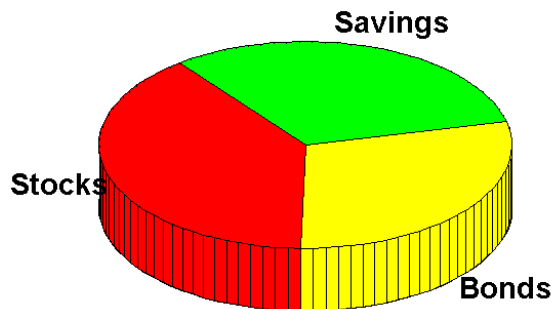
You can use a `DocPortfolio` object to present an individual's financial portfolio. For example, given the following assets:

```
XYZStock = DocStock('XYZ Stocks',200,12.34);  
USTBonds = DocBond('U.S. Treasury Bonds',1600,3.2,2.8);  
SaveAccount = DocSavings('MyBank Acc # 123',2000,6);  
VictoriaSelna = DocPortfolio('Victoria Selna',...  
    XYZStock,...  
    SaveAccount,...  
    USTBonds);
```

you can use the class's `pie3` method to display the relative mix of assets as a pie chart.

```
pie3(VictoriaSelna)
```

Portfolio Composition for Victoria Selna
Total Value of Assets: \$6296.57



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