

**Stateflow<sup>®</sup>**

User's Guide



**MATLAB<sup>®</sup>&SIMULINK<sup>®</sup>**

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# Stateflow Chart Concepts

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- “Finite State Machine Concepts” on page 1-2
- “The Stateflow Chart” on page 1-4

# Finite State Machine Concepts

Stateflow charts can contain sequential decision logic based on state machines. A finite state machine is a representation of an event-driven (reactive) system. In an event-driven system, the system makes a transition from one state (mode) to another, if the condition defining the change is true.

For example, you can use a state machine to represent the automatic transmission of a car. The transmission has these operating states: park, reverse, neutral, drive, and low. As the driver shifts from one position to another, the system makes a transition from one state to another, for example, from park to reverse.

## Finite State Machine Representations

Traditionally, designers used truth tables to represent relationships among the inputs, outputs, and states of a finite state machine. The resulting table describes the logic necessary to control the behavior of the system under study. Another approach to designing event-driven systems is to model the behavior of the system by describing it in terms of transitions among states. The occurrence of events under certain conditions determine the state that is active. State-transition charts and bubble charts are graphical representations based on this approach.

## Stateflow Chart Representations

A Stateflow chart can contain sequential and combinatorial logic in the form of state transition diagrams, flow charts, state transition tables, and truth tables. A state transition diagram is a graphical representation of a finite state machine. States and transitions form the basic building blocks of a sequential logic system. Another way to represent sequential logic is a state transition table, which allows you to enter the state logic in tabular form. You can also represent combinatorial logic in a chart with flow charts and truth tables.

You can include Stateflow charts as blocks in a Simulink® model. The collection of these blocks in a Simulink model is the Stateflow machine.

A Stateflow chart enables the representation of hierarchy, parallelism, and history. You can organize complex systems by defining a parent and offspring object structure. For example, you can organize states within other higher-level states. A system with parallelism can have two or more orthogonal states active at the same time. You can also specify the destination state of a transition based on historical information.

## Notation

Notation defines a set of objects and the rules that govern the relationships between those objects. Stateflow chart notation provides a way to communicate the design information in a Stateflow chart.

Stateflow chart notation consists of these elements:

- A set of graphical objects
- A set of nongraphical text-based objects
- Defined relationships between those objects



## Semantics

Semantics describe how to interpret chart notation. A typical Stateflow chart contains actions associated with transitions and states. The semantics describe the sequence of these actions during chart execution.

## Bibliography

[1] Harel, D "Statecharts: A Visual Formalism for Complex Systems." *Science of Computer Programming* Vol. 8, 1987, pp. 231-274.

[2] Hatley, D. J. and I. A. Pirbhai. *Strategies for Real-Time System Specification*. New York, NY: Dorset House Publishing, 1988.

## See Also

Chart | State Transition Table | Truth Table

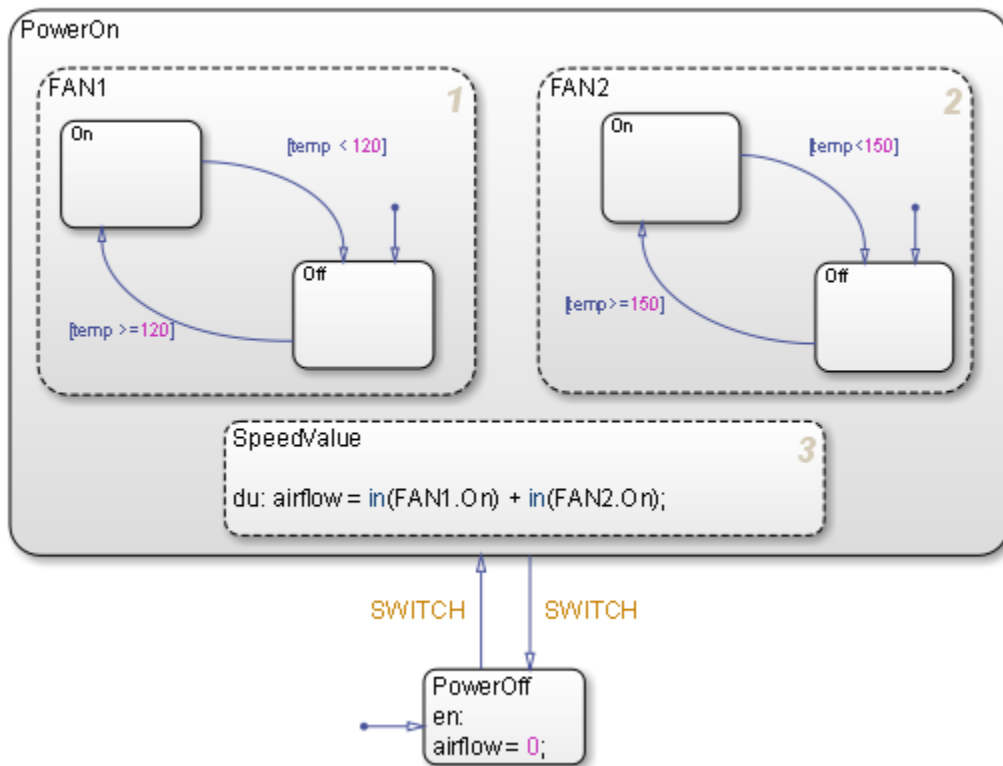
## More About

- "Overview of Stateflow Objects" on page 2-2
- "Model Reactive Systems in Stateflow" on page 4-2
- "How Stateflow Objects Interact During Execution" on page 3-5
- "Specify Properties for Stateflow Charts" on page 28-2

## The Stateflow Chart

To get hands-on experience using Stateflow software, you will build a Stateflow chart in incremental steps that follow the basic workflow described in “Model Reactive Systems in Stateflow” on page 4-2.

You will build a Stateflow chart that maintains air temperature at 120 degrees in a physical plant. The Stateflow controller operates two fans. The first fan turns on if the air temperature rises above 120 degrees and the second fan provides additional cooling if the air temperature rises above 150 degrees. When completed, your Stateflow chart should look something like this:



As you can see from the title bar, the chart is called Air Controller and is part of a Simulink model called sf\_aircontrol. When you build this chart, you will learn how to work with the following elements of state-transition charts:

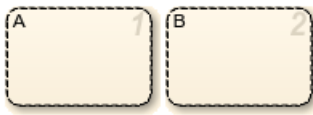
**Exclusive (OR) states.** States that represent mutually exclusive modes of operation. No two exclusive (OR) states can ever be active or execute at the same time. Exclusive (OR) states are represented graphically by a solid rectangle:



The Air Controller chart contains six exclusive (OR) states:

- PowerOn
- PowerOff
- FAN1.On
- FAN1.Off
- FAN2.On
- FAN2.Off

**Parallel (AND) states.** States that represent independent modes of operation. Two or more parallel (AND) states at the same hierarchical level can be active concurrently, although they execute in a serial fashion. Parallel (AND) states are represented graphically by a dashed rectangle with a number indicating execution order:



The Air Controller chart contains three parallel (AND) states:

- FAN1
- FAN2
- SpeedValue

**Transitions.** Graphical objects that link one state to another and specify a direction of flow. Transitions are represented by unidirectional arrows:



The Air Controller chart contains six transitions, from

- PowerOn to PowerOff
- PowerOff to PowerOn
- FAN1.On to FAN1.Off
- FAN1.Off to FAN1.On
- FAN2.On to FAN2.Off
- FAN2.Off to FAN2.On

**Default transitions.** Graphical objects that specify which exclusive (OR) state is to be active when there is ambiguity between two or more exclusive (OR) states at the same level in the hierarchy. Default transitions are represented by arrows with a closed tail:



The Air Controller chart contains default transitions:

- At the chart level, the default transition indicates that the state PowerOff is activated (wakes up) first when the chart is activated.

- In the FAN1 and FAN2 states, the default transitions specify that the fans be powered off when the states are activated.

**State actions.** Actions executed based on the status of a state.

The Air Controller chart contains two types of state actions:

- **entry (en)** action in the PowerOff state. Entry actions are executed when the state is entered (becomes active).
- **during (du)** action in the SpeedValue state. During actions are executed for a state while it is active and no valid transition to another state is available.

### Other types of state actions

There are other types of state actions besides **entry** and **during**, but they involve concepts that go beyond the scope of this guide. For more information, see “Syntax for States and Transitions”.

**Conditions.** Boolean expressions that allow a transition to occur when the expression is true. Conditions appear as labels for the transition, enclosed in square brackets ([ ]).

The Air Controller chart provides conditions on the transitions between FAN1.On and FAN1.Off, and between FAN2.On and FAN2.Off, based on the air temperature of the physical plant at each time step.

**Events.** Objects that can trigger a variety of activities, including:

- Waking up a Stateflow chart
- Causing transitions to occur from one state to another (optionally in conjunction with a condition)
- Executing actions

The Air Controller chart contains two edge-triggered events:

- **CLOCK** wakes up the Stateflow chart at each rising or falling edge of a square wave signal.
- **SWITCH** allows transitions to occur between PowerOff and PowerOn at each rising or falling edge of a pulse signal.

# Stateflow Chart Notation

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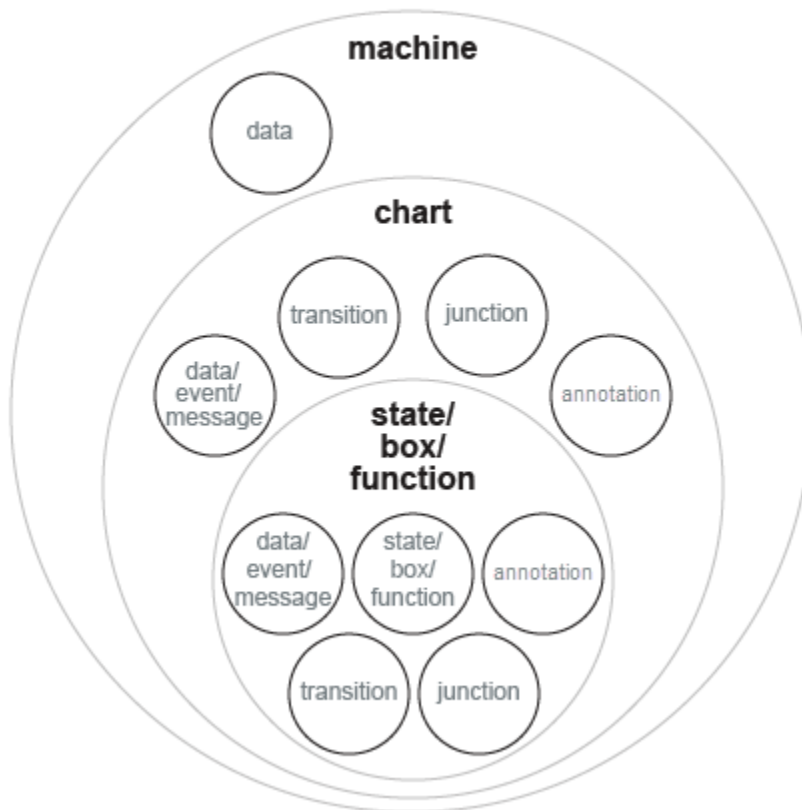
- “Overview of Stateflow Objects” on page 2-2
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “States” on page 2-8
- “State Hierarchy” on page 2-17
- “State Decomposition” on page 2-19
- “Transitions” on page 2-21
- “Control Chart Behavior by Using Specialized Transitions” on page 2-28
- “Self-Loop Transitions” on page 2-29
- “Inner Transitions” on page 2-30
- “Default Transitions” on page 2-33
- “Combine Transitions and Junctions to Create Branching Paths” on page 2-36
- “History Junctions” on page 2-41
- “Reusable Functions in Charts” on page 2-42

## Overview of Stateflow Objects

### Hierarchy of Stateflow Objects

Stateflow objects are arranged in a hierarchy based on containment. That is, one Stateflow object can contain other Stateflow objects.

#### Stateflow Hierarchy














The highest object in Stateflow hierarchy is the Stateflow machine. The Stateflow machine contains all of the Stateflow charts in a Simulink model. In addition, the Stateflow machine for a model can contain its own data.

Stateflow charts can contain states, boxes, functions, data, events, messages, transitions, junctions, and annotations. States, boxes, and functions can contain other states, boxes, functions, transitions, junctions, annotations, data, events, and messages. Levels of nesting can continue indefinitely.

### Graphical Objects

To manage graphical objects, use the Stateflow Editor. This table lists each type of graphical object and the palette icon to use for drawing the object.

Type of Graphical Object	Palette Icon	Reference
State		“Represent Operating Modes by Using States” on page 4-5
Transition	Not applicable. Point and drag from the source state to the destination state.	“Transition Between Operating Modes” on page 4-14
Connective junction		“Combine Transitions and Junctions to Create Branching Paths” on page 2-36
Default transition		“Default Transitions” on page 2-33
Box		“Group Chart Objects by Using Boxes” on page 8-4
Simulink based state		“Simulink Subsystems as States” on page 6-2
Simulink function		“Reuse Simulink Components in Stateflow Charts” on page 11-2
Graphical function		“Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
MATLAB® function		“Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
Truth table function		“Use Truth Tables to Model Combinatorial Logic” on page 10-2
History junction		“Record State Activity by Using History Junctions” on page 8-2
Annotation		“Add Descriptive Comments in a Chart” on page 8-32

## Nongraphical Objects

You can define data, event, and message objects that do not appear graphically in the Stateflow Editor. To manage nongraphical objects, use the Symbols pane or Model Explorer. For more information, see:

- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2
- “Use the Model Explorer with Stateflow Objects” on page 34-10

## Data Objects

A Stateflow chart stores and retrieves data that it uses to control its execution. Stateflow data resides in its own workspace, but you can also access data that resides externally in the Simulink model or application that embeds the Stateflow machine. You must define any internal or external data that you use in a Stateflow chart.

### **Event Objects**

An event is a Stateflow object that can trigger a whole Stateflow chart or individual actions in a chart. Because Stateflow charts execute by reacting to events, you specify and program events into your charts to control their execution. You can broadcast events to every object in the scope of the object sending the event, or you can send an event to a specific object. You can define explicit events that you specify directly, or you can define implicit events to take place when certain actions are performed, such as entering a state. For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

### **Message Objects**

Stateflow message objects are queued objects that can carry data. You can send a message from one Stateflow chart to another to communicate between charts. You can also send local messages within a chart. You define the type of message data. You can view the lifeline of a message in the Sequence Viewer block. For more information, see “Communicate with Stateflow Charts by Sending Messages” on page 15-2.



## Guidelines for Naming Stateflow Objects

You can name Stateflow objects with a combination of alphanumeric and underscore characters.

- Names cannot begin with a numeric character or contain embedded spaces.
- Name length should comply with the maximum identifier length enforced by Simulink Coder™ software. You can set the **Maximum identifier length** parameter. The default is 31 characters and the maximum length you can specify is 256 characters.
- Avoid using reserved keywords to name Stateflow objects. These keywords are part of the action language syntax.

---

**Note** Do not use the file names `sf.slx` for Simulink models or `sf.sfx` for standalone Stateflow charts in MATLAB. Using these file names can shadow Stateflow program files and result in unpredictable behavior.

---

### Reserved Keywords

Usage in Action Language Syntax	Keywords	Syntax References
Boolean symbols	<ul style="list-style-type: none"> <li>• true</li> <li>• false</li> </ul>	“Boolean Symbols, true and false” on page 16-12
Change detection	<ul style="list-style-type: none"> <li>• hasChanged</li> <li>• hasChangedFrom</li> <li>• hasChangedTo</li> </ul>	“Detect Changes in Data Values” on page 16-64
Complex data	<ul style="list-style-type: none"> <li>• complex</li> <li>• imag</li> <li>• real</li> </ul>	“Supported Operations for Complex Data” on page 27-4
Data types	<ul style="list-style-type: none"> <li>• boolean</li> <li>• double</li> <li>• int64</li> <li>• int32</li> <li>• int16</li> <li>• int8</li> <li>• single</li> <li>• uint64</li> <li>• uint32</li> <li>• uint16</li> <li>• uint8</li> </ul>	“Specify Type of Stateflow Data” on page 12-27

Usage in Action Language Syntax	Keywords	Syntax References
Data type operations	<ul style="list-style-type: none"> <li>• cast</li> <li>• type</li> </ul>	<p>“Type Cast Operations” on page 16-8</p> <p>“Specify Type of Stateflow Data” on page 12-27</p>
Explicit events	<ul style="list-style-type: none"> <li>• send</li> </ul>	<p>“Broadcast Local Events to Synchronize Parallel States” on page 14-23</p>
Implicit events	<ul style="list-style-type: none"> <li>• change</li> <li>• chg</li> <li>• enter</li> <li>• en</li> <li>• exit</li> <li>• ex</li> <li>• tick</li> </ul>	<p>“Control Chart Behavior by Using Implicit Events” on page 14-26</p>
Literal symbols	<ul style="list-style-type: none"> <li>• inf</li> <li>• t</li> </ul>	<p>“Supported Symbols in Actions” on page 16-12</p>
MATLAB functions and data	<ul style="list-style-type: none"> <li>• matlab</li> <li>• ml</li> </ul>	<p>“Access MATLAB Functions and Workspace Data in C Charts” on page 16-20</p>
	<ul style="list-style-type: none"> <li>• this</li> </ul>	<p>“App Design”</p>
Messages	<ul style="list-style-type: none"> <li>• discard</li> <li>• forward</li> <li>• isvalid</li> <li>• length</li> <li>• receive</li> <li>• send</li> </ul>	<p>“Control Message Activity in Stateflow Charts” on page 15-9</p>
State actions	<ul style="list-style-type: none"> <li>• bind</li> <li>• du</li> <li>• during</li> <li>• en</li> <li>• entry</li> <li>• ex</li> <li>• exit</li> <li>• on</li> </ul>	<p>“States” on page 2-8</p>
State activity	<ul style="list-style-type: none"> <li>• in</li> </ul>	<p>“Check State Activity by Using the in Operator” on page 13-17</p>

Usage in Action Language Syntax	Keywords	Syntax References
String manipulation	<ul style="list-style-type: none"> <li>• <code>ascii2str</code></li> <li>• <code>str2ascii</code></li> <li>• <code>str2double</code></li> <li>• <code>strcat</code></li> <li>• <code>strcmp</code></li> <li>• <code>strcpy</code></li> <li>• <code>strlen</code></li> <li>• <code>substr</code></li> <li>• <code>tostring</code></li> </ul>	<p>“Manage Textual Information by Using Strings” on page 24-2</p>
Temporal logic	<ul style="list-style-type: none"> <li>• <code>after</code></li> <li>• <code>at</code></li> <li>• <code>before</code></li> <li>• <code>count</code></li> <li>• <code>duration</code></li> <li>• <code>elapsed</code></li> <li>• <code>et</code></li> <li>• <code>every</code></li> <li>• <code>msec</code></li> <li>• <code>sec</code></li> <li>• <code>temporalCount</code></li> <li>• <code>usec</code></li> </ul>	<p>“Control Chart Execution by Using Temporal Logic” on page 16-36</p>

## See Also

### More About

- “Supported Symbols in Actions” on page 16-12
- “Supported Operations for Chart Data” on page 16-5
- “Supported Operations for Vectors and Matrices” on page 21-4
- “Supported Operations for Fixed-Point Data” on page 26-12
- “Supported Operations for Complex Data” on page 27-4

## States

A state describes an operating mode of a reactive system. In a Stateflow chart, states are used for sequential design to create state transition diagrams.

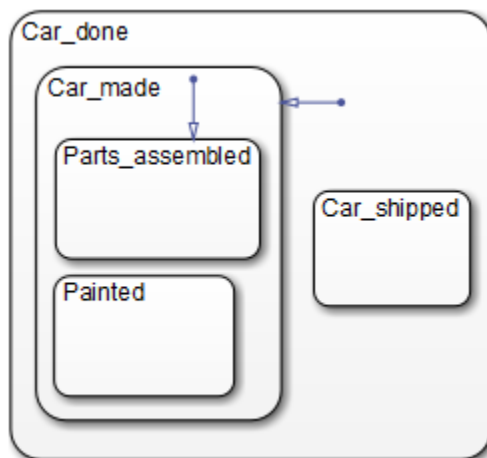
States can be active or inactive. The activity or inactivity of a state can change depending on events and conditions. The occurrence of an event drives the execution of the state transition diagram by making states become active or inactive. At any point during execution, active and inactive states exist.

### State Hierarchy

To manage multilevel state complexity, use hierarchy in your Stateflow chart. With hierarchy, you can represent multiple levels of subcomponents in a system.

#### State Hierarchy Example

In the following example, three levels of hierarchy appear in the chart. Drawing one state within the boundaries of another state indicates that the inner state is a substate (or child) of the outer state (or superstate). The outer state is the parent of the inner state.



In this example, the chart is the parent of the state `Car_done`. The state `Car_done` is the parent state of the `Car_made` and `Car_shipped` states. The state `Car_made` is also the parent of the `Parts_assembled` and `Painted` states. You can also say that the states `Parts_assembled` and `Painted` are children of the `Car_made` state.

To represent the Stateflow hierarchy textually, use a slash character (`/`) to represent the chart and use a period (`.`) to separate each level in the hierarchy of states. The following list is a textual representation of the hierarchy of objects in the preceding example:

- `/Car_done`
- `/Car_done.Car_made`
- `/Car_done.Car_shipped`
- `/Car_done.Car_made.Parts_assembled`
- `/Car_done.Car_made.Painted`

## Objects That a State Can Contain

States can contain all other Stateflow objects. Stateflow chart notation supports the representation of graphical object hierarchy in Stateflow charts with containment. A state is a superstate if it contains other states. A state is a substate if it is contained by another state. A state that is neither a superstate nor a substate of another state is a state whose parent is the Stateflow chart itself.

States can also contain nongraphical data, event, and message objects. The hierarchy of this containment appears in the Model Explorer. You define data, event, and message containment by specifying the parent object.

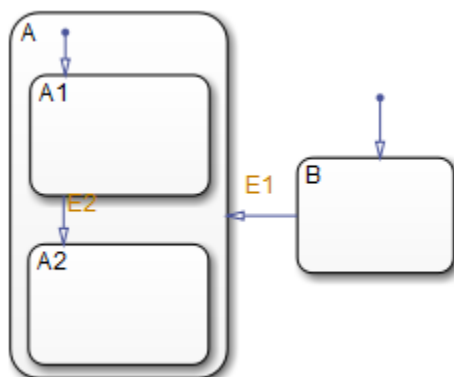
## State Decomposition

Every state (or chart) has a decomposition that dictates what type of substates the state (or chart) can contain. All substates of a superstate must be of the same type as the superstate decomposition. State decomposition can be exclusive (OR) or parallel (AND).

### Exclusive (OR) State Decomposition

Substates with solid borders indicate exclusive (OR) state decomposition. Use this decomposition to describe operating modes that are mutually exclusive. When a state has exclusive (OR) decomposition, only one substate can be active at a time.

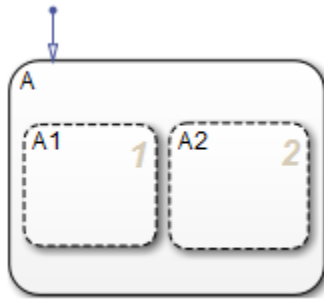
In the following example, either state A or state B can be active. If state A is active, either state A1 or state A2 can be active at a given time.



### Parallel (AND) State Decomposition

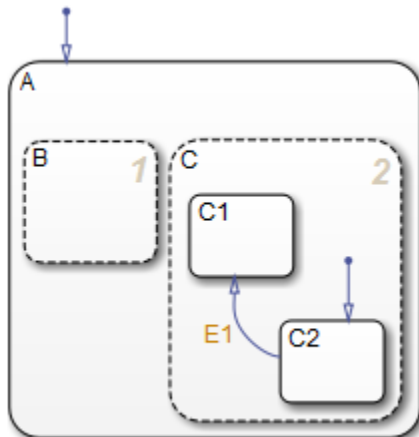
Substates with dashed borders indicate parallel (AND) decomposition. Use this decomposition to describe concurrent operating modes. When a state has parallel (AND) decomposition, all substates are active at the same time.

In the following example, when state A is active, A1 and A2 are both active at the same time.



The activity within parallel states is essentially independent, as demonstrated in the following example.

In the following example, when state A becomes active, both states B and C become active at the same time. When state C becomes active, either state C1 or state C2 can be active.

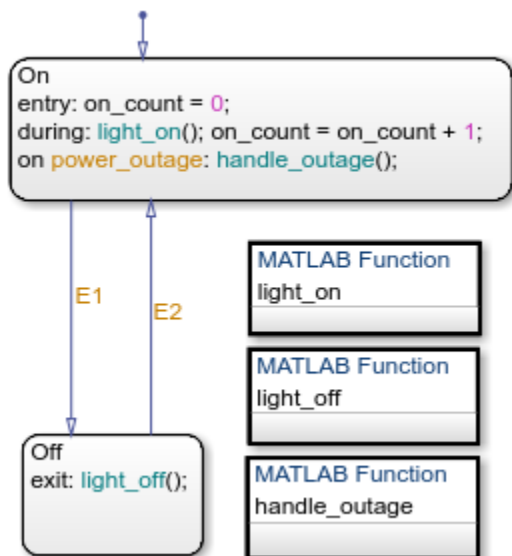


### State Labels

The label for a state appears on the top left corner of the state rectangle with the following general format:

```
name/  
entry:entry actions  
during:during actions  
exit:exit actions  
on event_name:on event_name actions  
on message_name:on message_name actions  
bind:events
```

The following example demonstrates the components of a state label.



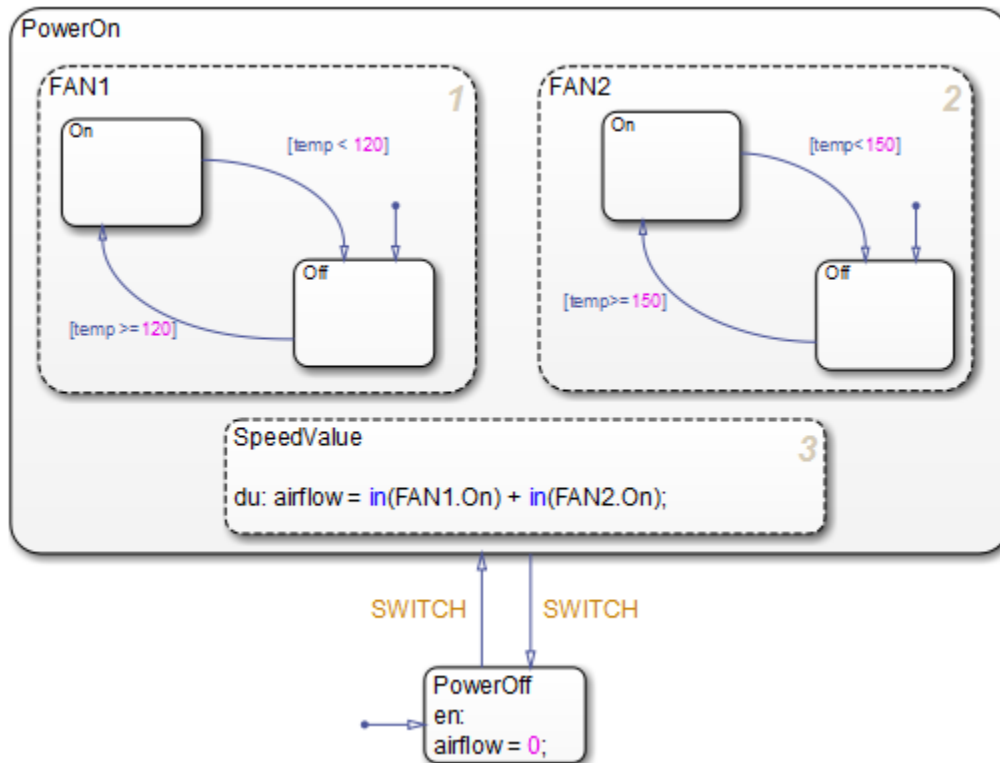
Each action in the state label appears in the subtopics that follow. For more information on state actions, see “Execution of a Stateflow Chart” on page 3-23.

## State Name

A state label starts with the name of the state followed by an optional / character. In the preceding example, the state names are `On` and `Off`. Valid state names consist of alphanumeric characters and can include the underscore (`_`) character. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

Hierarchy provides some flexibility in naming states. The name that you enter on the state label must be unique when preceded by ancestor states. The name in the Stateflow hierarchy is the text you enter as the label on the state, preceded by the names of parent states separated by periods. Each state can have the same name appear in the label, as long as their full names within the hierarchy are unique.

The following example shows how unique naming of states works.



Each of these states has a unique name because of its location in the chart. The full names for the states in FAN1 and FAN2 are:

- PowerOn.FAN1.On
- PowerOn.FAN1.Off
- PowerOn.FAN2.On
- PowerOn.FAN2.Off

### State Actions

After the name, you enter optional action statements for the state with a keyword label that identifies the type of action. You can specify none, some, or all of them. The colon after each keyword is required. The slash following the state name is optional as long as it is followed by a carriage return.

For each type of action, you can enter more than one action by separating each action with a carriage return, semicolon, or a comma. You can specify actions for more than one event or message by adding additional `on event_name` or `on message_name` lines.

If you enter the name and slash followed directly by actions, the actions are interpreted as entry action(s). This shorthand is useful if you are specifying only entry actions.

This table summarizes the different state action types.

State Action	Abbreviation	Description
entry	en	Executes when the state becomes active.



State Action	Abbreviation	Description
exit	ex	Executes when the state is active and a transition out of the state occurs.
during	du	Executes when the state is active and a specific event occurs.
bind	none	Binds an event or data object so that only that state and its children can broadcast the event or change the data value.
on <i>event_name</i>	none	Executes when the state is active and it receives a broadcast of <i>event_name</i> .
on <i>message_name</i>	none	Executes when a message <i>message_name</i> is available.
on after( <i>n,event_name</i> ) on after( <i>n,sec</i> ) on after( <i>n,msec</i> ) on after( <i>n,usec</i> )	none	Executes when: <ul style="list-style-type: none"> <li>the event <i>event_name</i> has occurred at least <i>n</i> times since the associated state became active.</li> <li>at least <i>n</i> units of time have elapsed since the associated state became active.</li> </ul> For more information, see <i>after</i> .
on at( <i>n,event_name</i> ) on at( <i>n,sec</i> )	none	Executes when: <ul style="list-style-type: none"> <li>the event <i>event_name</i> has occurred exactly <i>n</i> times since the associated state became active.</li> <li>exactly <i>n</i> seconds have elapsed since the associated state became active.</li> </ul> For more information, see <i>at</i> .
on before( <i>n,event_name</i> ) on before( <i>n,sec</i> ) on before( <i>n,msec</i> ) on before( <i>n,usec</i> )	none	Executes when: <ul style="list-style-type: none"> <li>the event <i>event_name</i> has occurred fewer than <i>n</i> times since the associated state became active.</li> <li>fewer than <i>n</i> units of time have elapsed since the associated state became active.</li> </ul> For more information, see <i>before</i> .

State Action	Abbreviation	Description
<code>on every(n,event_name)</code> <code>on every(n,sec)</code>	none	Executes: <ul style="list-style-type: none"> <li>every n<sup>th</sup> occurrence of the event <i>event_name</i> since the associated state became active.</li> <li>every n seconds since the associated state became active.</li> </ul> For more information, see <i>every</i> .

**entry Actions**

Entry actions are executed when a state becomes active. Entry actions consist of the prefix `entry` (or the abbreviation `en`) followed by a colon (`:`) and one or more actions. To separate multiple entry actions, use semicolons or commas. You can also enter the actions on separate lines.

In the preceding example, the entry action `id = x+y` executes when the chart takes the default transition and state A becomes active. See “Enter a Chart or State” on page 3-28.

**exit Actions**

Exit actions are executed when a state is active and a transition out of the state occurs. Exit actions consist of the prefix `exit` (or the abbreviation `ex`) followed by a colon (`:`) and one or more actions. To separate multiple exit actions, use semicolons or commas. You can also enter the actions on separate lines.

In the preceding example, the exit action `time_out` executes when the chart takes one of the transitions from state A to state B or C. See “Exit a State” on page 3-34.

**during Actions**

During actions are executed when a state is active, an event occurs, and no valid transition to another state or the current state is available. During actions consist of the prefix `during` (or the abbreviation `du`) followed by a colon (`:`) and one or more actions. To separate multiple during actions, use semicolons or commas. You can also enter the actions on separate lines.

In the preceding example, the during action `switch_on()` executes whenever the state C is active because there are no valid transitions to another state. See “Execution of a Stateflow Chart” on page 3-23.

**bind Actions**

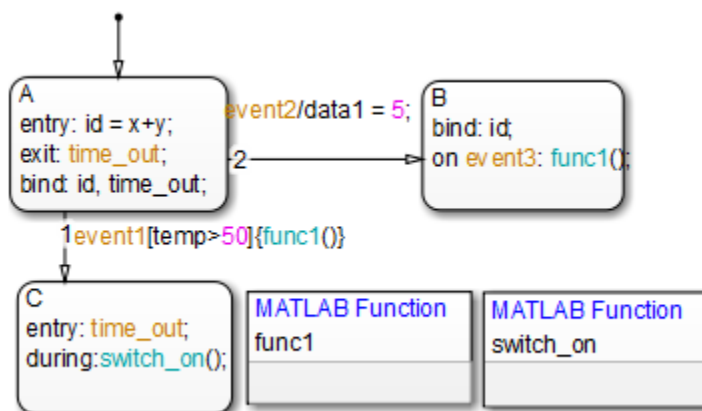
You can bind the data and events to a state by using a `bind` action. A `bind` action consists of the prefix `bind` followed by a colon (`:`) and one or more events or data. To separate multiple events and data, use semicolons or commas. You can also enter the events and data on separate lines.

Only a state and its children can change data or broadcast events bound to that state. Other states can read the bound data or listen for the bound event, but they cannot change the bound data or send the bound events.

Bind actions apply to a chart whether the binding state is active or not. In the preceding example, the bind action `bind: id, time_out` for state A binds the data `id` and the event `time_out` to state A.

This binding prevents any other state (or its children) in the chart from changing `id` or broadcasting event `time_out`.

If a state includes actions that change data or broadcast events that bind to another state, a compile-time error occurs. For example, this chart contains two state actions that produce errors.



State Action	Reason for Error
<code>bind: id</code> in state B	Only one state can change the data <code>id</code> , which is bound to state A
<code>entry: time_out</code> in state C	Only one state can broadcast the event <code>time_out</code> , which is bound to state A

Binding a function-call event to a state also binds the function-call subsystem that it calls. The function-call subsystem is enabled when the binding state is entered and disabled when the binding state is exited. For more information about this behavior, see “Control Function-Call Subsystems by Using bind Actions” on page 16-29.

Bind actions are supported only in Stateflow charts in Simulink models.

### on Actions

On actions are executed when the state is active and it receives an event or message. On actions consist of the prefix `on` followed by a unique event `event_name` or message `message_name`, a colon (`:`), and one or more actions. To separate multiple on actions, use semicolons or commas. You can also enter the actions on separate lines.

You can specify actions for more than one event or message. For example, if you want different events to trigger different actions, enter multiple on action statements in the state action label:

```

on ev1: action1();
on ev2: action2();
  
```

If multiple events occur at the same time, the corresponding on actions execute in the order that they appear in the state action label. For instance, in the previous example, if events `ev1` and `ev2` occur at the same time, then `action1()` executes first and `action2()` executes second. See “Execution of a Stateflow Chart” on page 3-23.

## **See Also**

### **Related Examples**

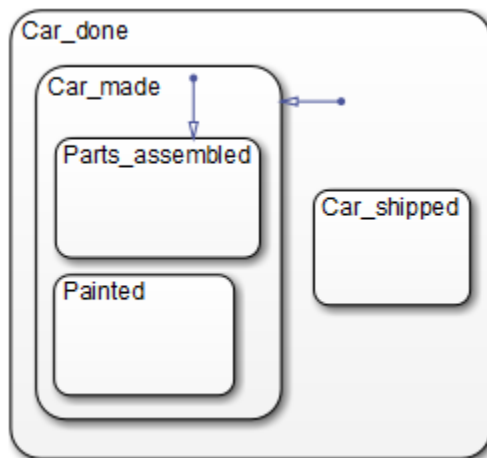
- “Execution of a Stateflow Chart” on page 3-23
- “Enter a Chart or State” on page 3-28
- “Exit a State” on page 3-34
- “Eliminate Redundant Code by Combining State Actions” on page 16-2
- “Control Function-Call Subsystems by Using bind Actions” on page 16-29
- “Control Chart Execution by Using Temporal Logic” on page 16-36

## State Hierarchy

To manage multilevel state complexity, use hierarchy in your Stateflow chart. With hierarchy, you can represent multiple levels of subcomponents in a system.

### State Hierarchy Example

In the following example, three levels of hierarchy appear in the chart. Drawing one state within the boundaries of another state indicates that the inner state is a substate (or child) of the outer state (or superstate). The outer state is the parent of the inner state.



In this example, the chart is the parent of the state `Car_done`. The state `Car_done` is the parent state of the `Car_made` and `Car_shipped` states. The state `Car_made` is also the parent of the `Parts_assembled` and `Painted` states. You can also say that the states `Parts_assembled` and `Painted` are children of the `Car_made` state.

To represent the Stateflow hierarchy textually, use a slash character (`/`) to represent the chart and use a period (`.`) to separate each level in the hierarchy of states. The following list is a textual representation of the hierarchy of objects in the preceding example:

- `/Car_done`
- `/Car_done.Car_made`
- `/Car_done.Car_shipped`
- `/Car_done.Car_made.Parts_assembled`
- `/Car_done.Car_made.Painted`

### Objects That a State Can Contain

States can contain all other Stateflow objects. Stateflow chart notation supports the representation of graphical object hierarchy in Stateflow charts with containment. A state is a superstate if it contains other states. A state is a substate if it is contained by another state. A state that is neither a superstate nor a substate of another state is a state whose parent is the Stateflow chart itself.

States can also contain nongraphical data, event, and message objects. The hierarchy of this containment appears in the Model Explorer. You define data, event, and message containment by specifying the parent object.

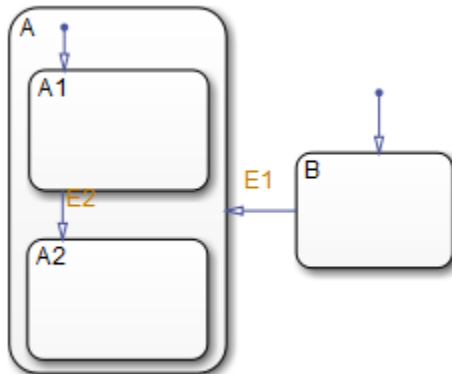
## State Decomposition

Every state (or chart) has a decomposition that dictates what type of substates the state (or chart) can contain. All substates of a superstate must be of the same type as the superstate decomposition. State decomposition can be exclusive (OR) or parallel (AND).

### Exclusive (OR) State Decomposition

Substates with solid borders indicate exclusive (OR) state decomposition. Use this decomposition to describe operating modes that are mutually exclusive. When a state has exclusive (OR) decomposition, only one substate can be active at a time.

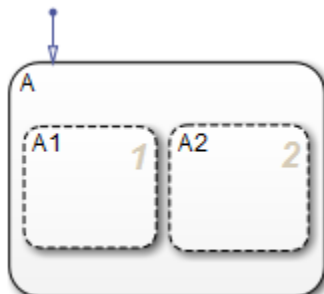
In the following example, either state A or state B can be active. If state A is active, either state A1 or state A2 can be active at a given time.



### Parallel (AND) State Decomposition

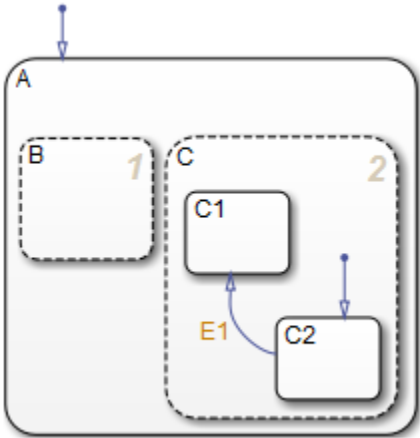
Substates with dashed borders indicate parallel (AND) decomposition. Use this decomposition to describe concurrent operating modes. When a state has parallel (AND) decomposition, all substates are active at the same time.

In the following example, when state A is active, A1 and A2 are both active at the same time.



The activity within parallel states is essentially independent, as demonstrated in the following example.

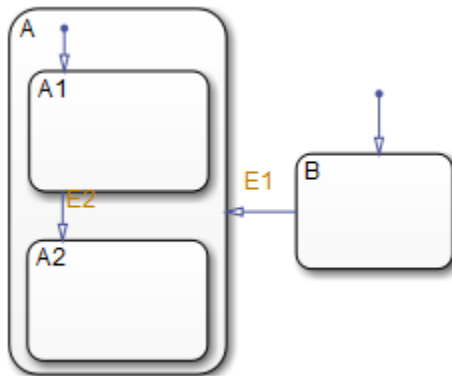
In the following example, when state A becomes active, both states B and C become active at the same time. When state C becomes active, either state C1 or state C2 can be active.





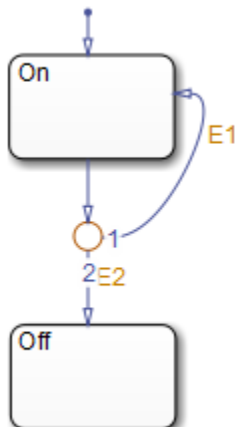
## Transitions

A transition is a line with an arrowhead that links one graphical object to another. In most cases, a transition represents the passage of the system from one mode (state) to another. A transition typically connects a source and a destination object. The source object is where the transition begins and the destination object is where the transition ends. The following chart shows a transition from a source state, B, to a destination state, A.



Junctions divide a transition into transition segments. In this case, a full transition consists of the segments taken from the origin to the destination state. Each segment is evaluated in the process of determining the validity of a full transition.

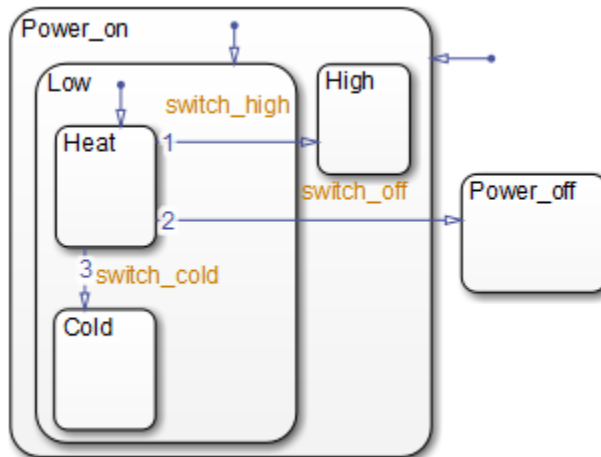
The following example has two segmented transitions: one from state On to state Off, and the other from state On to itself:



A default transition is a special type of transition that has no source object. See “Default Transitions” on page 2-33 for details.

## Transition Hierarchy

Transitions cannot contain other objects the way that states can. However, transitions are contained by states. The hierarchy for a transition is described in terms of its parent, source, and destination states. The parent is the lowest level that contains the source and destination of the transition. Consider the parents for the transitions in the following example:



The following table resolves the parentage of each transition in the preceding example. The / character represents the chart. Each level in the hierarchy of states is separated by the period (.) character.

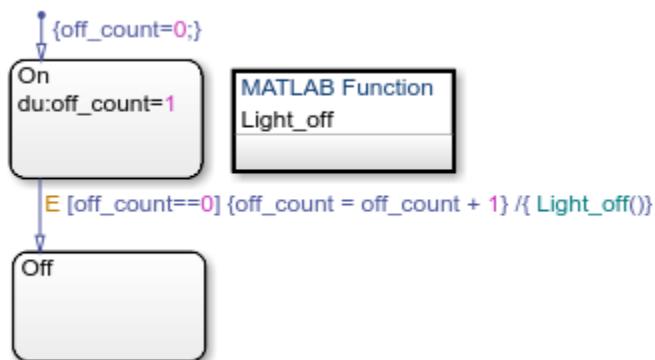
Transition Label	Transition Parent	Transition Source	Transition Destination
switch_off	/	/Power_on.Low.Heat	/Power_off
switch_high	/Power_on	/Power_on.Low.Heat	/Power_on.High
switch_cold	/Power_on.Low	/Power_on.Low.Heat	/Power_on.Low.Cold

### Transition Labels

A transition label can consist of an event or message, a condition, a condition action, and a transition action. Each part of the label is optional. The ? character is the default transition label. Transition labels have this overall format:

*event\_or\_message[condition]{condition\_action}/transition\_action*

This example illustrates the parts of a transition label.



Transition	Event Trigger	Condition	Condition Action	Transition Action
State A to state C	event1	temp > 50	func1()	None

Transition	Event Trigger	Condition	Condition Action	Transition Action
State A to state B	event2	None	None	data1 = 5

### Event or Message Triggers

In transition label syntax, event or message triggers appear first as the name of an event or message. They have no distinguishing special character to separate them from other actions in a transition label. In the example in “Transitions” on page 2-21, both transitions from state A have event triggers. The transition from state A to state B has the event trigger `event2` and the transition from state A to state C has the event trigger `event1`.

Event triggers specify an event that causes the transition to be taken, provided the condition, if specified, is true. Specifying an event is optional. Message triggers specify the transition to be taken if the message is present in the message queue. The absence of an event or message indicates that the transition is taken upon the occurrence of any event. Multiple events or messages are specified using the OR logical operator (`|`).

### Conditions

In transition label syntax, conditions are Boolean expressions enclosed in square brackets (`[ ]`). In the example in “Transitions” on page 2-21, the transition from state A to state C has the condition `temp > 50`.

A condition is a Boolean expression to specify that a transition occurs given that the specified expression is true. Follow these guidelines for defining and using conditions:

- The condition expression must be a Boolean expression that evaluates to true (1) or false (0).
- The condition expression can consist of any of the following:
  - Boolean operators that make comparisons between data and numeric values
  - A function that returns a Boolean value
  - An `in(state_name)` condition that evaluates to true when the state specified as the argument is active. For more information, see “Check State Activity by Using the `in` Operator” on page 13-17.
  - Temporal logic conditions (see “Control Chart Execution by Using Temporal Logic” on page 16-36)
- The condition expression can call a graphical function, truth table function, or MATLAB function that returns a numeric value.

For example, `[test_function(x, y) < 0]` is a valid condition expression.

- The condition expression should not call a function that causes the chart to change state or modify any variables.
- Boolean expressions can be grouped using `&` for expressions with AND relationships and `|` for expressions with OR relationships.
- Assignment statements are not valid condition expressions.
- Unary increment and decrement actions are not valid condition expressions.

### Condition Actions

In transition label syntax, condition actions follow the transition condition and are enclosed in curly braces ({}). In the example in “Transitions” on page 2-21, the transition from state A to state C has the condition action `func1()`, a function call.

Condition actions are executed as soon as the condition is evaluated as true, but before the transition destination has been determined to be valid. If no condition is specified, an implied condition evaluates to true and the condition action is executed.

### Transition Actions

In transition label syntax, transition actions are preceded with a forward slash (/) and are enclosed in curly braces ({}). In the example in “Transitions” on page 2-21, the transition from state A to state B has the transition action `data1 = 5`. In C charts, transition actions are not required to be enclosed in curly braces. In charts that use MATLAB as the action language, the syntax is auto corrected if the curly braces are missing from the transition action. See “Auto Correction When Using MATLAB as the Action Language” on page 17-2.

Transition actions execute only after the complete transition path is taken. They execute after the transition destination has been determined to be valid, and the condition, if specified, is true. If the transition consists of multiple segments, the transition action executes only after the entire transition path to the final destination is determined to be valid.

Transition actions are supported only in Stateflow charts in Simulink models.

### Valid Transitions

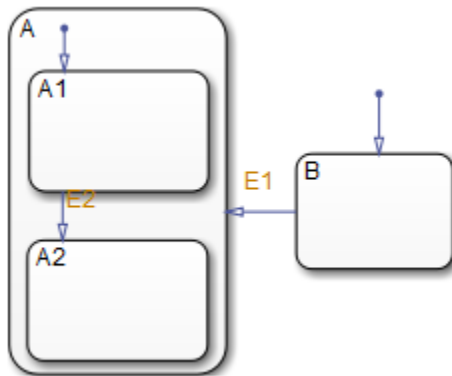
Usually, a transition is valid when the source state of the transition is active and the transition label is valid. Default transitions are different because there is no source state. Validity of a default transition to a substate is evaluated when there is a transition to its superstate, assuming the superstate is active. This labeling criterion applies to both default transitions and general case transitions. The following table lists possible combinations of valid transition labels.

Transition Label	Is Valid If...
Event only	That event occurs
Event and condition	That event occurs and the condition is true
Message only	That message occurs
Message and condition	That message occurs and the condition is true
Condition only	Any event occurs and the condition is true
Action only	Any event occurs
Not specified	Any event occurs

### Transition Connections

#### Transitions to and from Exclusive (OR) States

This example shows simple transitions to and from exclusive (OR) states.

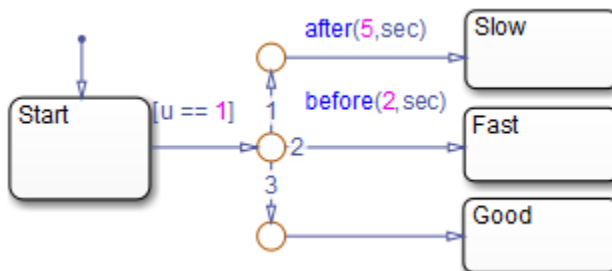


The following transition...	Is valid when...
B to A	State B is active and the event E1 occurs.
A1 to A2	State A1 is active and event E2 occurs.

See “Transition Between Exclusive States” on page B-4 for more information on the semantics of this notation.

### Transitions to and from Junctions

The following chart shows transitions to and from connective junctions.



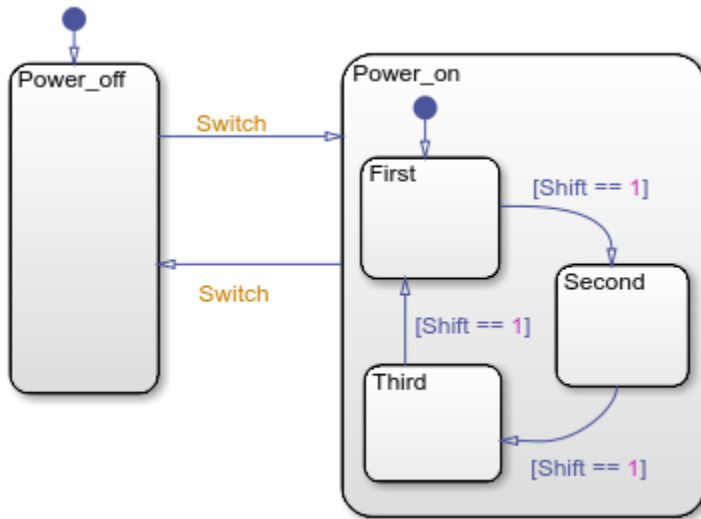
The chart uses temporal logic to determine when the input u equals 1.

If the input equals 1...	A transition occurs from...
Before t = 2	Start to Fast
Between t = 2 and t = 5	Start to Good
After t = 5	Start to Slow

For more information about temporal logic, see “Control Chart Execution by Using Temporal Logic” on page 16-36. For more information on the semantics of this notation, see “Transition from a Common Source to Multiple Destinations” on page B-28.

### Transitions to and from Exclusive (OR) Superstates

This example shows transitions to and from an exclusive (OR) superstate and the use of a default transition.

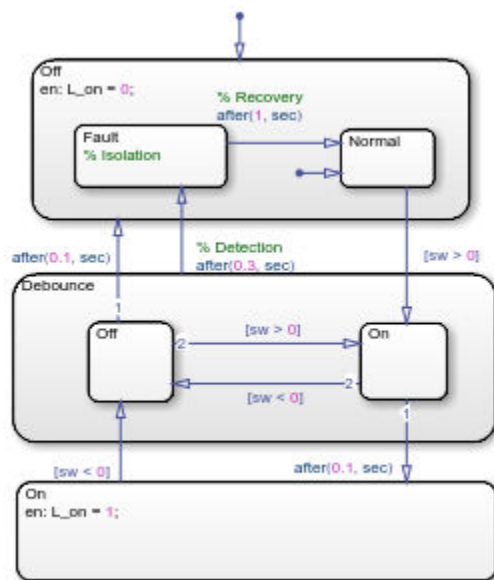


The chart has two states at the highest level in the hierarchy, **Power\_off** and **Power\_on**. By default, **Power\_off** is active. The event **Switch** toggles the system between the **Power\_off** and **Power\_on** states. **Power\_on** has three substates: **First**, **Second**, and **Third**. By default, when **Power\_on** becomes active, **First** also becomes active. When **Shift** equals 1, the system transitions from **First** to **Second**, **Second** to **Third**, **Third** to **First**, for each occurrence of the event **Switch**, and then the pattern repeats.

For more information on the semantics of this notation, see “Control Chart Execution by Using Default Transitions” on page B-14.

### Transitions to and from Substates

The following example shows transitions to and from exclusive (OR) substates.



For details on how this chart works, see “Debounce Signals with Fault Detection” on page 30-14. For information on the semantics of this notation, see “Transition from a Substate to a Substate with Events” on page B-7.

## **See Also**

### **More About**

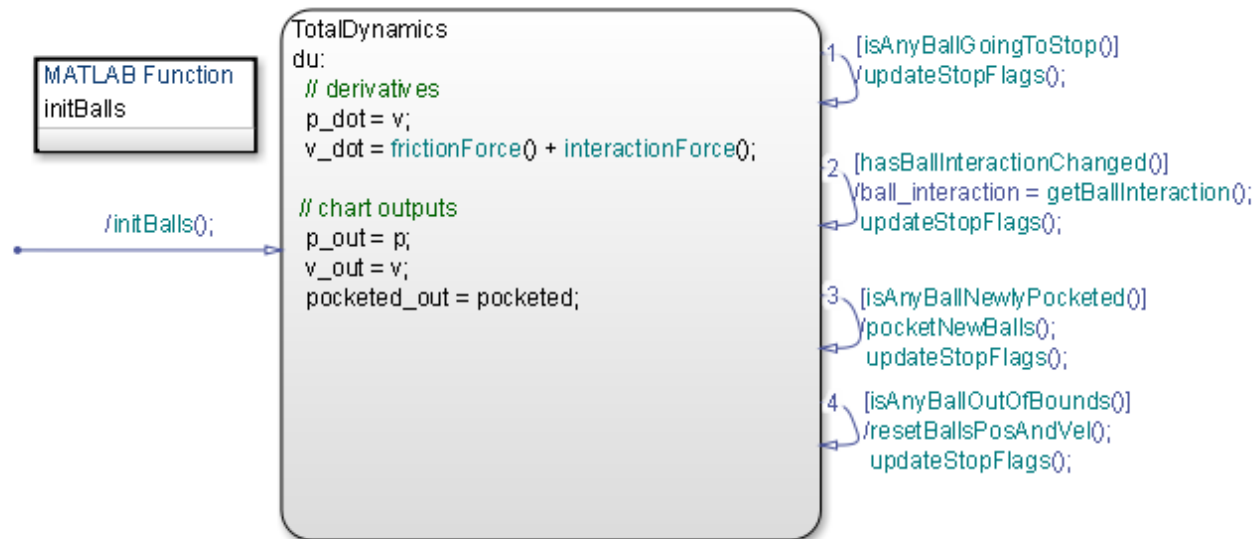
- “Default Transitions” on page 2-33
- “Control Chart Execution by Using Condition Actions” on page B-9
- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Communicate with Stateflow Charts by Sending Messages” on page 15-2

## **Control Chart Behavior by Using Specialized Transitions**



## Self-Loop Transitions

A self-loop transition is a transition that originates from and terminates on the same state. The following chart contains four self-loop transitions:



MATLAB Function  
yn = isAnyBallOutOfBounds

MATLAB Function f = interactionForce

MATLAB Function  
balli = getBallInteraction

MATLAB Function resetBallsPosAndVel

MATLAB Function  
yn = hasBallInteractionChanged

MATLAB Function  
yn = isAnyBallNewlyPocketed

MATLAB Function pocketNewBalls

MATLAB Function  
yn = nearHole(pp)

MATLAB Function  
yn = isAnyBallGoingToStop

MATLAB Function updateStopFlags

MATLAB Function  
f = frictionForce

See these sections for more information about the semantics of this notation:

- “Self-Loop Transition” on page B-24
- “For-Loop Construct” on page B-25

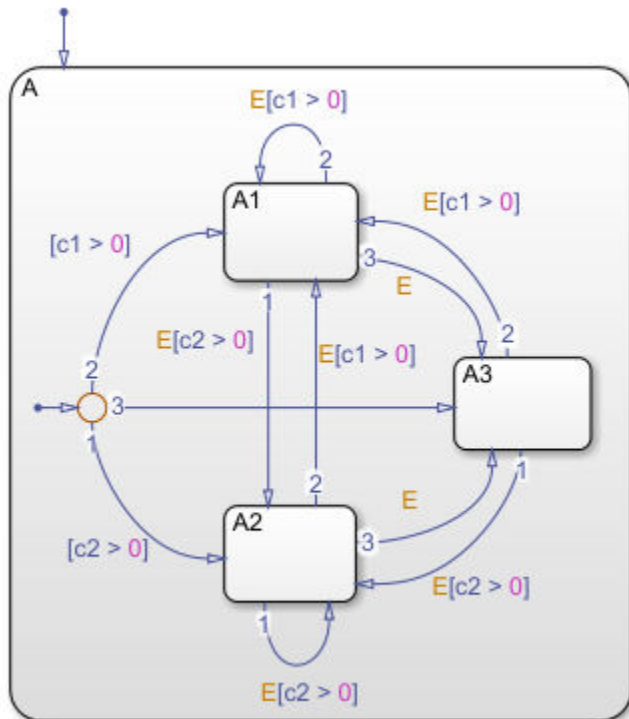
## Inner Transitions

An inner transition is a transition that does not exit the source state. Inner transitions are powerful when defined for superstates with exclusive (OR) decomposition. Use of inner transitions can greatly simplify a Stateflow chart, as shown by the following examples:

- “Before Using an Inner Transition” on page 2-30
- “After Using an Inner Transition to a Connective Junction” on page 2-30
- “Using an Inner Transition to a History Junction” on page 2-31

### Before Using an Inner Transition

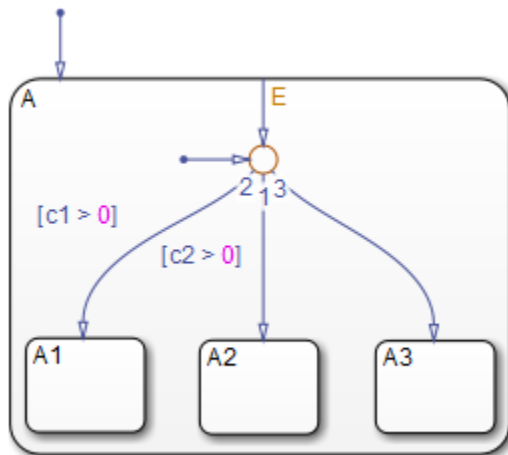
This chart is an example of how you can simplify logic using an inner transition.



Any event occurs and awakens the Stateflow chart. The default transition to the connective junction is valid. The destination of the transition is determined by  $[c1 > 0]$  and  $[c2 > 0]$ . If  $[c1 > 0]$  is true, the transition to A1 is true. If  $[c2 > 0]$  is true, the transition to A2 is valid. If neither  $[c1 > 0]$  nor  $[c2 > 0]$  is true, the transition to A3 is valid. The transitions among A1, A2, and A3 are determined by E,  $[c1 > 0]$ , and  $[c2 > 0]$ .

### After Using an Inner Transition to a Connective Junction

This example simplifies the preceding example using an inner transition to a connective junction.



An event occurs and awakens the chart. The default transition to the connective junction is valid. The destination of the transitions is determined by  $[c1 > 0]$  and  $[c2 > 0]$ .

You can simplify the chart by using an inner transition in place of the transitions among all the states in the original example. If state A is already active, the inner transition is used to reevaluate which of the substates of state A is to be active. When event E occurs, the inner transition is potentially valid. If  $[c1 > 0]$  is true, the transition to A1 is valid. If  $[c2 > 0]$  is true, the transition to A2 is valid. If neither  $[c1 > 0]$  nor  $[c2 > 0]$  is true, the transition to A3 is valid. This chart design is simpler than the previous one.

---

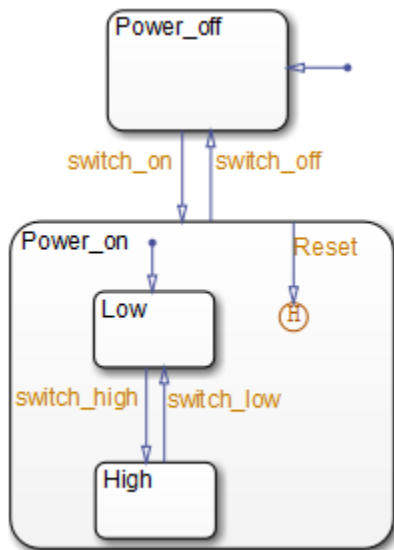
**Note** When you use an inner transition to a connective junction, an active substate can exit and reenter when the transition condition for that substate is valid. For example, if substate A1 is active and  $[c1 > 0]$  is true, the transition to A1 is valid. In this case:

- 1 Exit actions for A1 execute and complete.
  - 2 A1 becomes inactive.
  - 3 A1 becomes active.
  - 4 Entry actions for A1 execute and complete.
- 

See “Process the First Event with an Inner Transition to a Connective Junction” on page B-20 for more information on the semantics of this notation.

## Using an Inner Transition to a History Junction

This example shows an inner transition to a history junction.



State `Power_on.High` is initially active. When event `Reset` occurs, the inner transition to the history junction is valid. Because the inner transition is valid, the currently active state, `Power_on.High`, is exited. When the inner transition to the history junction is processed, the last active state, `Power_on.High`, becomes active (is reentered). If `Power_on.Low` was active under the same circumstances, `Power_on.Low` would be exited and reentered as a result. The inner transition in this example is equivalent to drawing an outer self-loop transition on both `Power_on.Low` and `Power_on.High`.

See “Example of History Junctions” on page 2-41 for another example using a history junction.

See “Inner Transition to a History Junction” on page B-21 for more information on the semantics of this notation.

## Default Transitions

A default transition specifies which exclusive (OR) state to enter when there is ambiguity among two or more neighboring exclusive (OR) states. A default transition has a destination but no source object. For example, a default transition specifies which substate of a superstate with exclusive (OR) decomposition the system enters by default, in the absence of any other information, such as a history junction. A default transition can also specify that a junction should be entered by default.

### Drawing Default Transitions

Click the **Default transition** button in the toolbar, and click a location in the drawing area close to the state or junction you want to be the destination for the default transition. Drag the mouse to the destination object to attach the default transition. In some cases, it is useful to label default transitions.

A common programming mistake is to create multiple exclusive (OR) states without a default transition. In the absence of the default transition, there is no indication of which state becomes active by default. Note that this error is flagged when you simulate the model with the **State Inconsistencies** option enabled.

### Label Default Transitions

You can label default transitions as you would other transitions. For example, you might want to specify that one state or another should become active depending upon the event that has occurred. In another situation, you might want to have specific actions take place that are dependent upon the destination of the transition.

---

**Tip** When labeling default transitions, ensure that there is at least one valid default transition. Otherwise, a chart can transition into an inconsistent state.

---

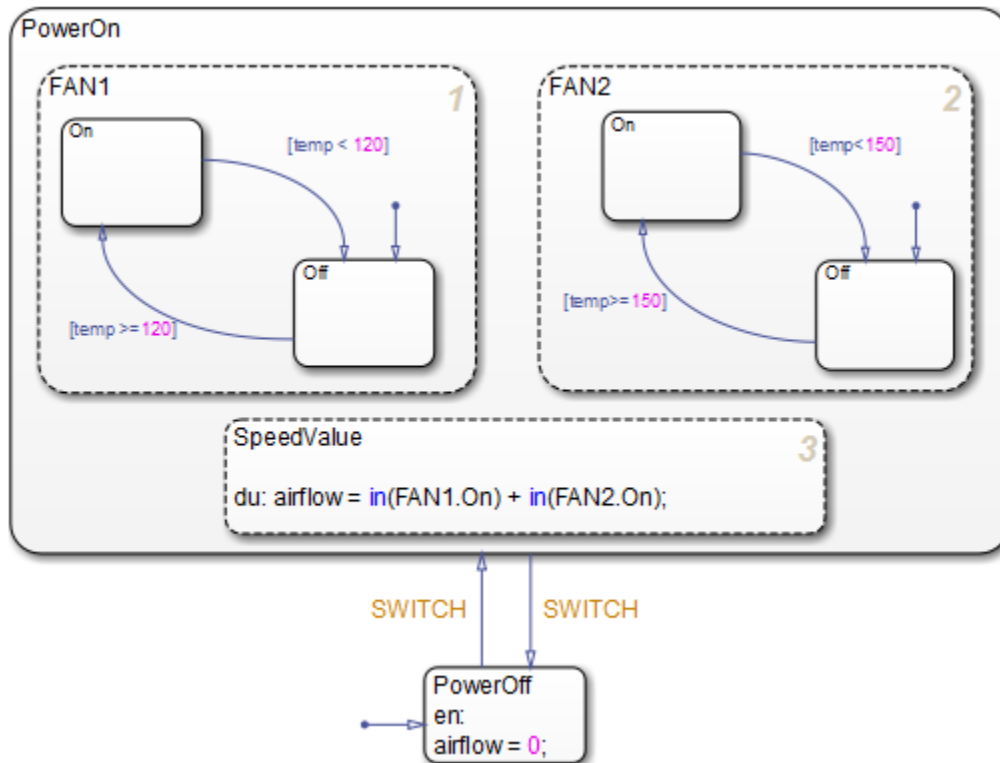
### Default Transition Examples

The following examples show the use of default transitions in Stateflow charts:

- “Default Transition to a State Example” on page 2-33
- “Default Transition to a Junction Example” on page 2-34
- “Default Transition with a Label Example” on page 2-35

#### Default Transition to a State Example

This example shows a default transition to a state.

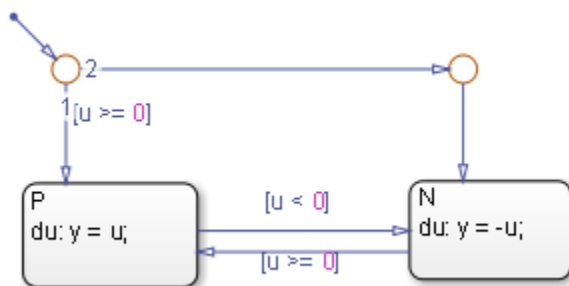


Without the default transition to state **PowerOff**, when the Stateflow chart wakes up, none of the states becomes active. A state inconsistency error is reported at run time.

See “Control Chart Execution by Using Default Transitions” on page B-14 for information on the semantics of this notation.

### Default Transition to a Junction Example

This example shows a default transition to a connective junction.

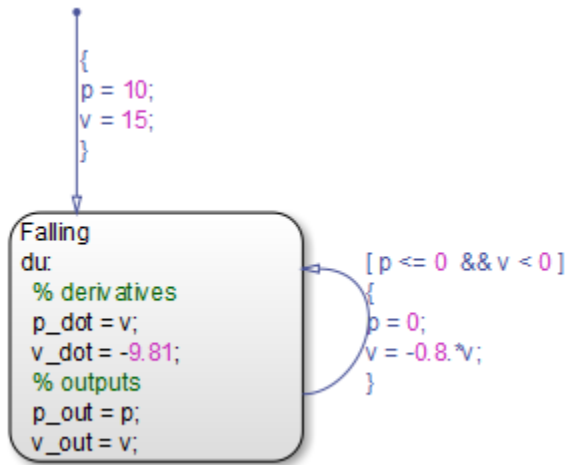


The default transition to the connective junction defines that upon entering the chart, the destination depends on the condition of each transition segment.

See “Default Transition to a Junction” on page B-14 for information on the semantics of this notation.

### Default Transition with a Label Example

This example shows a default transition with a label.



When the chart wakes up, the data `p` and `v` initialize to 10 and 15, respectively.

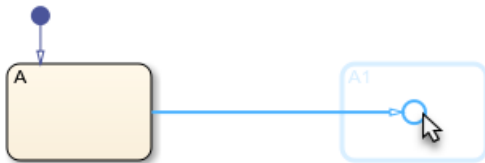
See "Labeled Default Transitions" on page B-16 for more information on the semantics of this notation.

## Combine Transitions and Junctions to Create Branching Paths


A connective junction represents a decision point in a transition path. You can combine transitions and connective junctions to create paths from a common source to multiple destinations or from multiple sources to a common destination. For more information on the semantics of branching paths, see “Represent Multiple Paths by Using Connective Junctions” on page B-23.

### Add a Connective Junction

When you add a transition to a chart, the Stateflow Editor provides graphical cues that allow you to add a junction or a state. To place a junction at the end of the transition, click the circular junction cue.



Alternatively, to add an isolated junction to a chart:

- 1 Open the Stateflow Editor.
- 2 From the object palette, click the **Junction** icon  and move the pointer to the chart canvas. A connective junction appears.
- 3 To place the connective junction, click a location on the canvas.

### Modify Connective Junction Properties

To change the size of one or more connective junctions:

- 1 Select the connective junctions.
- 2 Right-click one of the selected junctions and select **Junction Size**.
- 3 From the drop-down list, select a junction size.

To change other properties of a connective junction, right-click a connective junction and select **Properties**. The Connective Junction dialog box displays these properties:

- **Parent** — Parent state of the connective junction. To bring the parent to the foreground, click the hypertext link. This property is read-only.
- **Description** — Textual description of the junction. You can enter a brief description and comments.
- **Document link** — Link to online documentation for the junction. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow evaluates the link and displays the documentation.



## Examples of Transition Paths with Connective Junctions

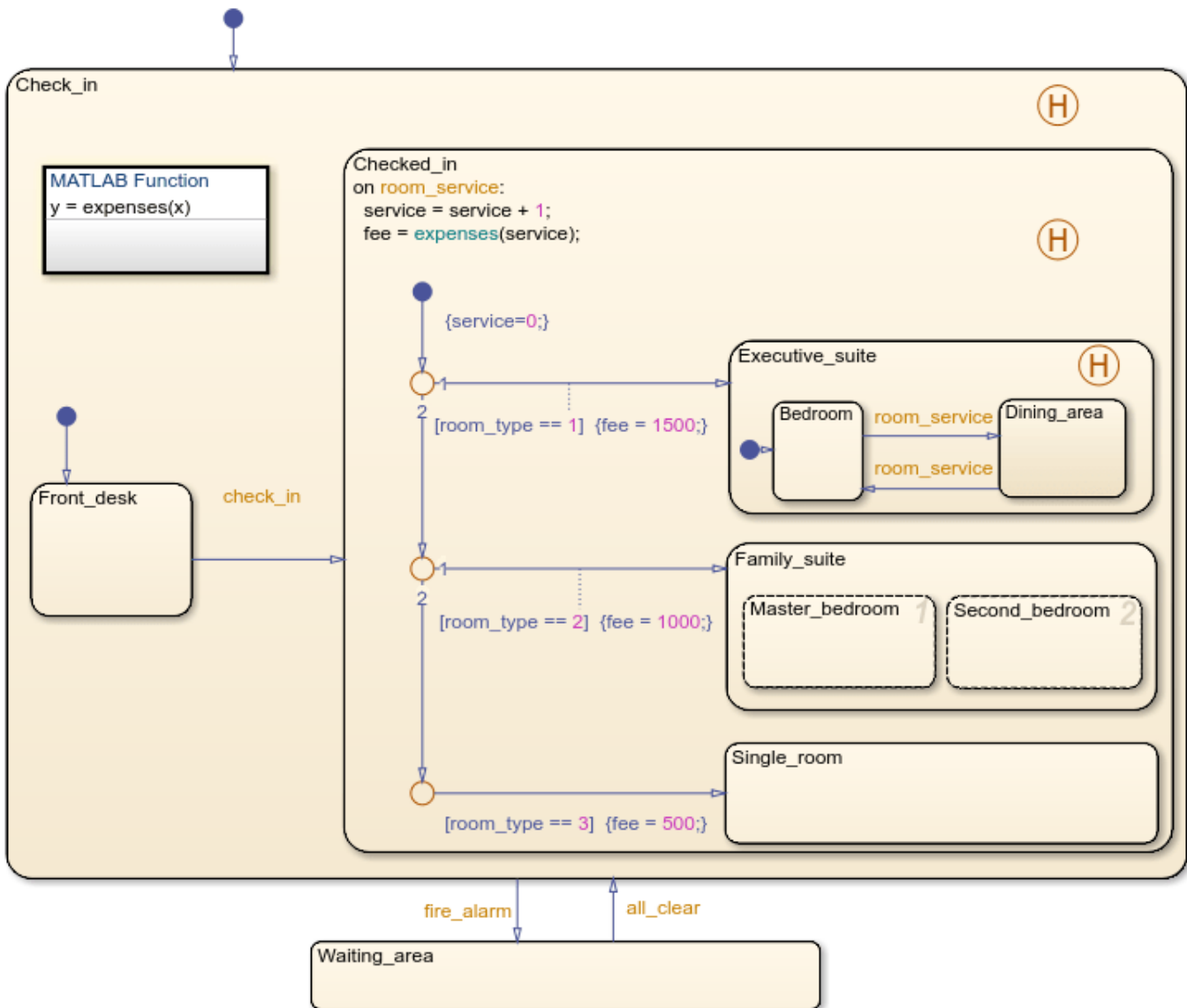
By combining transitions and connective junctions, you can construct common transition patterns such as:

- `if-then-else` decision patterns
- `for` loop patterns
- `while` loop patterns

To reduce the creation time of these patterns, use the Pattern Wizard. For more information, see “Create Flow Charts by Using Pattern Wizard” on page 5-5.

### **If-then-else Pattern with All Conditions Specified**

In this example, the state `Checked_in` has a default transition path with three connective junctions. Each branch of the path is guarded by a condition.



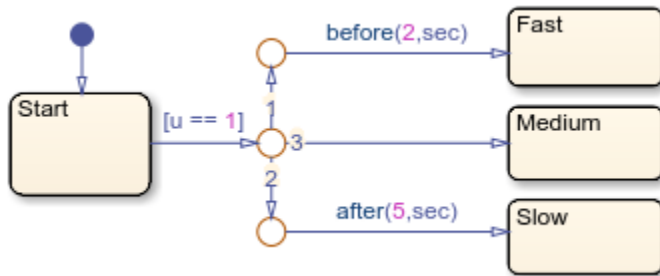
If the state `Front_desk` is active, the event `check_in` triggers the execution of the default transition in `Checked_in`. The outcome of the default transition depends on the value of `room_type`:

- If `room_type` is 1, the substate `Executive_suite` becomes active.
- If `room_type` is 2, the substate `Family_suite` becomes active.
- If `room_type` is 3, the substate `Single_room` becomes active.
- If none of these conditions is true, the default transition path is not valid and `Front_desk` remains active.

For more information about this chart, see “How Stateflow Objects Interact During Execution” on page 3-5.

### If-then-else Pattern with an Unconditional Transition

In this example, the transition from state `Start` has three connective junctions. The first two branches of the path are guarded by a condition. The last branch of the path is unconditional.



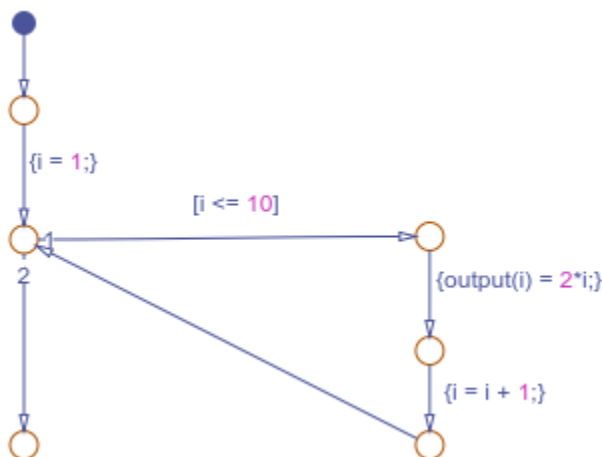
The chart uses temporal logic to determine when the input `u` equals 1:

- If `u` equals 1 before time  $t = 2$ , the state `Fast` becomes active.
- If `u` equals 1 between  $t = 2$  and  $t = 5$ , the state `Good` becomes active.
- If `u` equals 1 after  $t = 5$ , the state `Slow` becomes active.

For more information about this chart, see “Detect Elapsed Time” on page 16-42.

### For Loop Pattern

In this example, a flow chart uses a combination of transitions and connective junctions to construct a for loop.

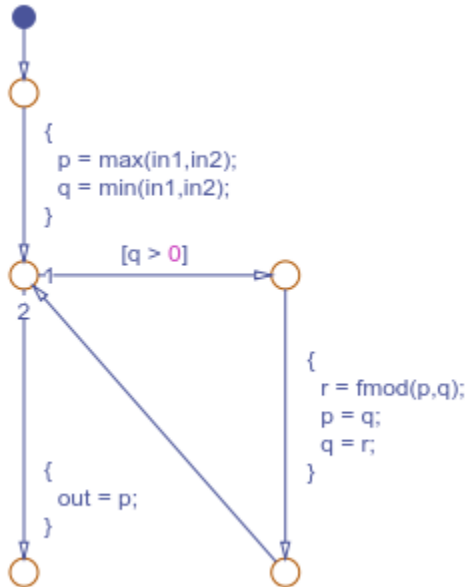


As the value of the counter `i` increases from 1 to 10, the flow chart defines the elements of an array `output`. The loop in this flow chart is equivalent to this snippet of MATLAB code:

```
for i = 1:10
    output(i) = 2*i;
end
```

### While Loop Pattern

In this example, a flow chart combines transitions and connective junctions to construct a while loop that computes the greatest common divisor of the inputs.



The loop in this flow chart is equivalent to this snippet of C code:

```
while(q > 0) {
    r = fmod(p,q);
    p = q;
    q = r;
}
```

### See Also

#### More About

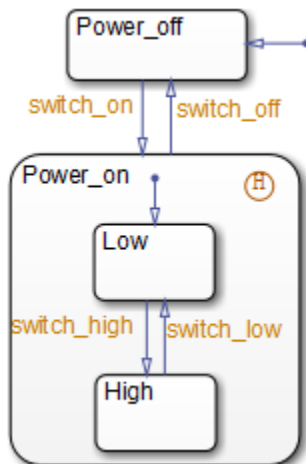
- “Create Flow Charts by Using Pattern Wizard” on page 5-5
- “Represent Multiple Paths by Using Connective Junctions” on page B-23
- “How Stateflow Objects Interact During Execution” on page 3-5
- “Control Chart Execution by Using Temporal Logic” on page 16-36

## History Junctions

A history junction represents historical decision points in the Stateflow chart. The decision points are based on historical data relative to state activity. Placing a history junction in a superstate indicates that historical state activity information is used to determine the next state to become active. The history junction applies only to the level of the hierarchy in which it appears.

### Example of History Junctions

The following example uses a history junction:



Superstate **Power\_on** has a history junction and contains two substates. If state **Power\_off** is active and event **switch\_on** occurs, the system can enter **Power\_on.Low** or **Power\_on.High**. The first time superstate **Power\_on** is entered, substate **Power\_on.Low** is entered because it has a default transition. At some point afterward, if state **Power\_on.High** is active and event **switch\_off** occurs, superstate **Power\_on** is exited and state **Power\_off** becomes active. Then event **switch\_on** occurs. Because **Power\_on.High** was the last active substate, it becomes active again. After the first time **Power\_on** becomes active, the history junction determines whether to enter **Power\_on.Low** or **Power\_on.High**.

See “Default Transition and a History Junction” on page B-15 for more information on the semantics of this notation.

### History Junctions and Inner Transitions

By specifying an inner transition to a history junction, you can specify that, based on a specified event or condition, the active state is to be exited and then immediately reentered.

See “Using an Inner Transition to a History Junction” on page 2-31 for an example of this notation.

See “Inner Transition to a History Junction” on page B-21 for more information on the semantics of this notation.

## Reusable Functions in Charts

State actions and transition conditions can be complicated enough that defining them inline on the state or transition is not feasible. In this case, express the conditions or actions using one of the following types of Stateflow functions:

- Flow chart — Encapsulate flow charts containing if-then-else, switch-case, for, while, or do-while patterns. For more information, see “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18.
- MATLAB — Write matrix-oriented algorithms; call MATLAB functions for data analysis and visualization. For more information, see “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2.
- Simulink — Call Simulink function-call subsystems directly to streamline design and improve readability. For more information, see “Reuse Simulink Components in Stateflow Charts” on page 11-2.
- Truth table — Represent combinational logic for decision-making applications such as fault detection and mode switching. For more information, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

Use the function format that is most natural for the type of calculation required in the state action or transition condition.

If the four standard types of Stateflow functions do not work, you can write your own C or C++ code for integration with your chart. For more information about custom code integration, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### See Also

#### More About

- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Reuse Custom Code in Stateflow Charts” on page 31-23

# Stateflow Semantics

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- “Stateflow Semantics” on page 3-2
- “How Stateflow Objects Interact During Execution” on page 3-5
- “Modeling Guidelines for Stateflow Charts” on page 3-19
- “Types of Chart Execution” on page 3-21
- “Execution of a Stateflow Chart” on page 3-23
- “Enter a Chart or State” on page 3-28
- “Exit a State” on page 3-34
- “Evaluate Transitions” on page 3-37
- “Super Step Semantics” on page 3-45
- “Super Step” on page 3-51
- “Use Events to Execute Charts” on page 3-53
- “Group and Execute Transitions” on page 3-58
- “Execution Order for Parallel States” on page 3-60

## Stateflow Semantics

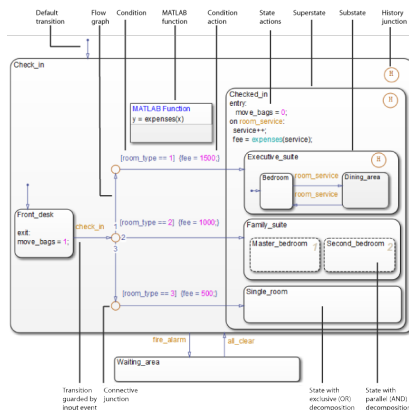
In Stateflow, semantics describe the execution behavior of your Stateflow chart. Various factors can affect how your chart executes, including:

- Explicit or implicit ordering of states
- Transition ordering between states
- Events sent by parallel or superstates

As you build your chart, you expect it to behave in a certain way. By knowing how these factors affect your chart, you can create a chart that behaves with intentional interaction of the graphical and nongraphical objects. Graphical and nongraphical objects are the building blocks for all Stateflow charts.

## Stateflow Objects

Stateflow objects are the building blocks of Stateflow charts. These objects can be categorized as either graphical or nongraphical. Graphical objects consist of objects that appear graphically in a chart. Nongraphical objects appear textually in a chart and often refer to data, events, and messages. This chart shows a variety of both graphical and nongraphical objects.



## Graphical Objects

To build graphical objects, use the object palette in the Stateflow Editor (see “Stateflow Editor Operations” on page 4-20).

Graphical Objects	Types	References
Flow charts	Decision logic patterns	“Flow Charts in Stateflow” on page 5-2
	Loop logic patterns	
Functions	Graphical functions	“Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
	MATLAB functions	“Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2



Graphical Objects	Types	References
	Truth table functions	“Use Truth Tables to Model Combinatorial Logic” on page 10-2
	Simulink functions	“Reuse Simulink Components in Stateflow Charts” on page 11-2
Junctions	Connective junctions	“Combine Transitions and Junctions to Create Branching Paths” on page 2-36
	History junctions	“History Junctions” on page 2-41
States	States with exclusive (OR) decomposition	“Exclusive (OR) State Decomposition” on page 2-9
	States with parallel (AND) decomposition	“Parallel (AND) State Decomposition” on page 2-9
	Substates and superstates	“Create Substates and Superstates” on page 4-5
Transitions	Default transitions	“Default Transitions” on page 2-33
	Object-to-object transitions	“Transition Connections” on page 2-24
	Inner transitions	
	Self-loop transitions	

## Nongraphical Objects

You create nongraphical objects textually in your chart. See “Add Stateflow Data” on page 12-2, “Define Events in a Chart” on page 14-2, and “Define Messages in a Chart” on page 15-2 for details. Examples of nongraphical objects include:

Nongraphical Object	Description	Reference
Condition	Boolean expression that specifies that a transition path is valid if the expression is true; part of a transition label	“Transition Labels” on page 2-22 and “Conditions” on page 2-23
Condition action	Action that executes as soon as the condition evaluates to true; part of a transition label	“Transition Labels” on page 2-22 and “Condition Actions” on page 2-24
State actions	Expressions that specify actions to take when a state is active, such as initializing or updating data; part of a state label	“State Labels” on page 2-10 and “States” on page 2-8
Function calls	Expression used to activate a specific function within a chart.	“Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2 and “Reuse Simulink Components in Stateflow Charts” on page 11-2
Temporal logic statements	Operators that are used to control chart actions.	“Control Chart Execution by Using Temporal Logic” on page 16-36

## **See Also**

### **More About**

- “Graphical Objects” on page 2-2
- “Nongraphical Objects” on page 2-3
- “Types of Chart Execution” on page 3-21

## How Stateflow Objects Interact During Execution

During execution, Stateflow objects interact with each other to simulate real-world behavior. In the following model, different Stateflow objects are shown and their interactions are explained.

### Overview of the Example Model

The example model shows how common graphical and nongraphical objects in a chart interact during execution. These objects include:

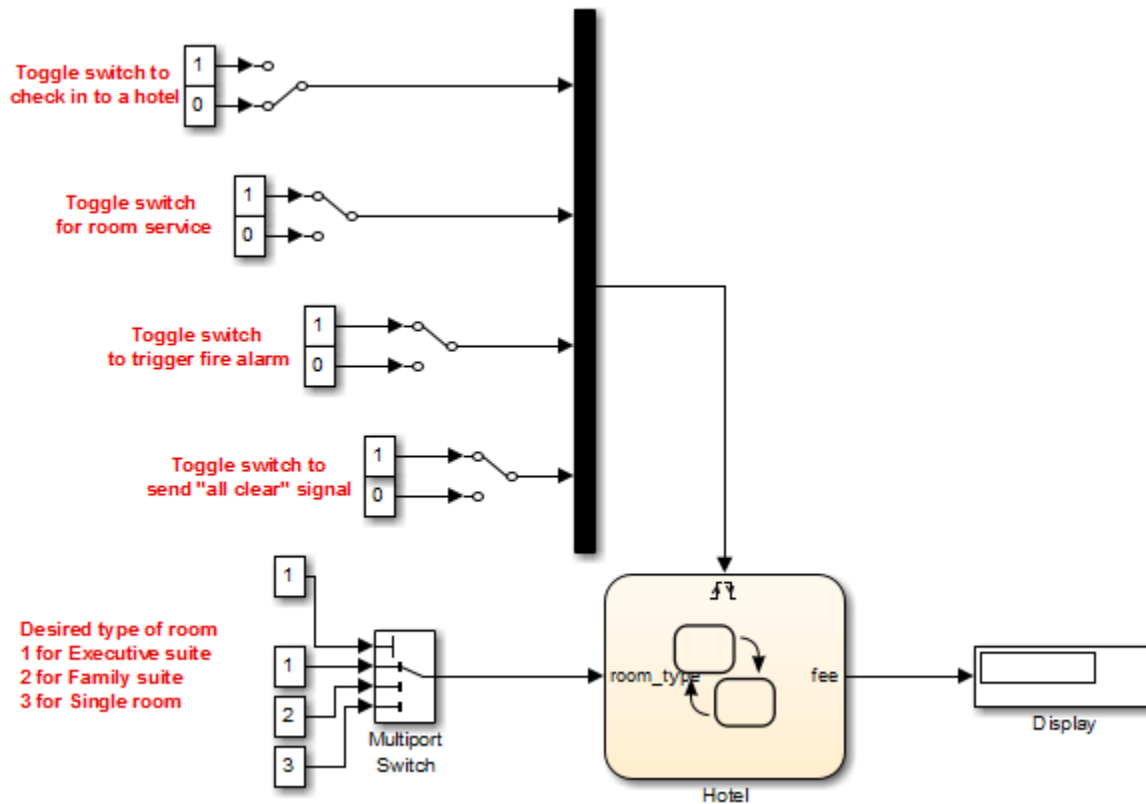
- Conditions and condition actions
- Exclusive (OR) states
- Flow charts
- Function calls
- History junctions
- Parallel (AND) states
- State actions
- Transitions guarded by input events

For details of the chart semantics, see “Phases of Chart Execution” on page 3-8.

### Model of the Check-In Process for a Hotel

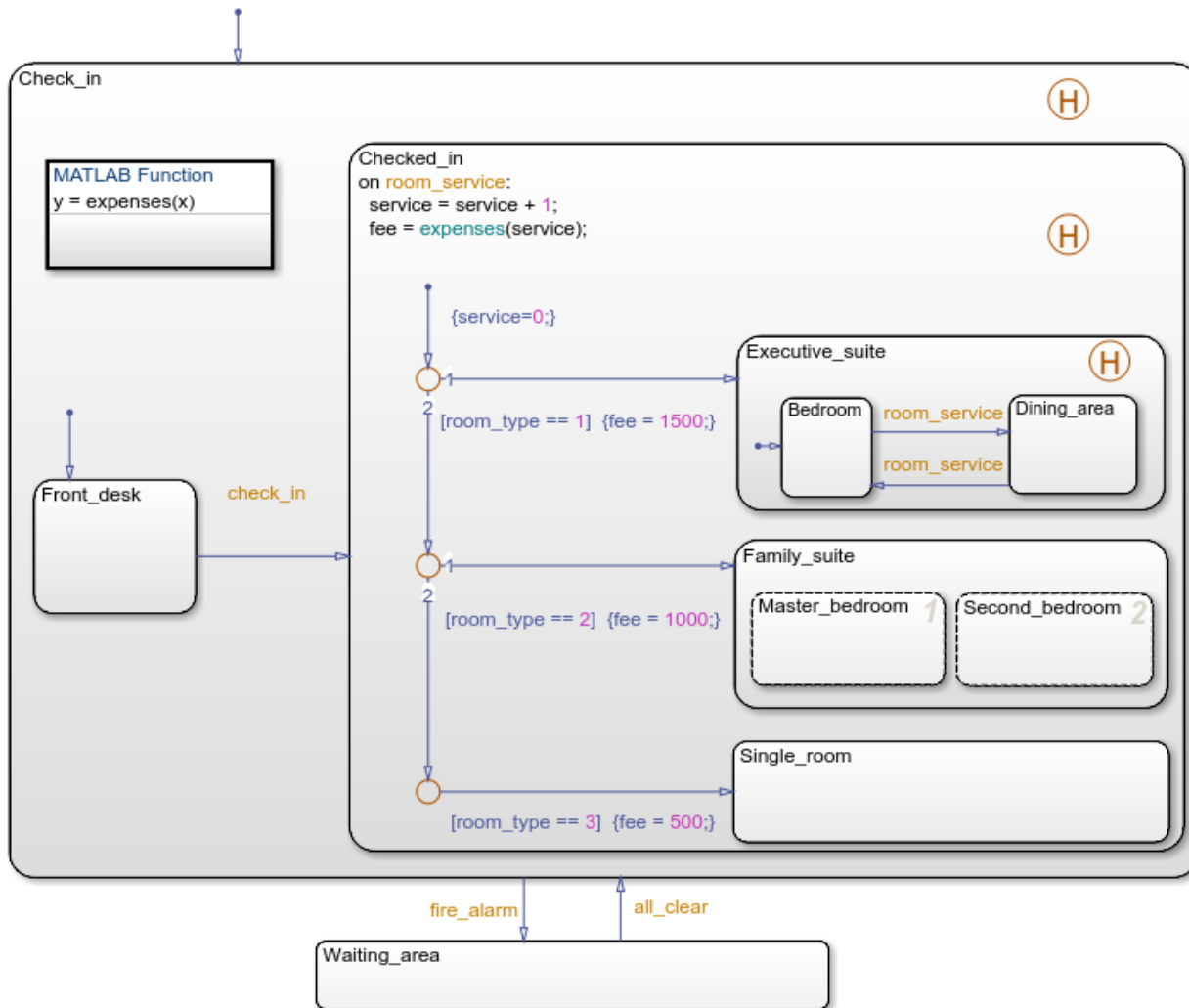
This example uses the hotel check-in process to explain Stateflow chart semantics.

The `sf_semantics_hotel_checkin` model consists of four Manual Switch blocks, one Mux block, one Multiport Switch block, a Hotel chart, and a Display block.



Block	Purpose	Rationale
Manual Switch	Enable toggling between two settings during simulation without having to pause or restart.	During simulation, you can interactively trigger the chart by sending one of these input events: <ul style="list-style-type: none"> <li>• Checking in to a hotel</li> <li>• Calling room service</li> <li>• Triggering a fire alarm</li> <li>• Sending an all-clear signal after a fire alarm</li> </ul>
Mux	Combine multiple input signals into a vector.	A chart can support multiple input events only if they connect to the trigger port of a chart as a vector of inputs.
Multiport Switch	Enable selection among more than two inputs.	This block provides a value for the chart input data <code>room_type</code> , where each room type corresponds to a number (1, 2, or 3).  A Manual Switch block cannot support more than two inputs, but a Multiport Switch block can.
Display	Show up-to-date numerical value for input signal.	During simulation, any change to the chart output data <code>fee</code> appears in the display.

The Hotel chart contains graphical objects, such as states and history junctions, and nongraphical objects, such as conditions and condition actions.



For a mapping of objects to their locations in the chart, see “Stateflow Objects” on page 3-2.

## How the Chart Interacts with Simulink Blocks

### Chart Initialization

When simulation starts, the chart wakes up and executes its default transitions because the **Execute (enter) Chart At Initialization** option is on (see “Execution of a Chart at Initialization” on page 3-21). Then the chart goes to sleep.

**Note** If this option is off, the chart does not wake up until you toggle one of the Manual Switch blocks. You can verify the setting for this option in the Chart properties dialog box. Right-click inside the top level of the chart and select **Properties** from the context menu.

### Chart Interaction with Other Blocks

The chart wakes up again only when an *edge-triggered* input event occurs: `check_in`, `room_service`, `fire_alarm`, or `all_clear`. When you toggle a Manual Switch block for an input event during simulation, the chart detects a rising or falling edge and wakes up. While the chart is awake:

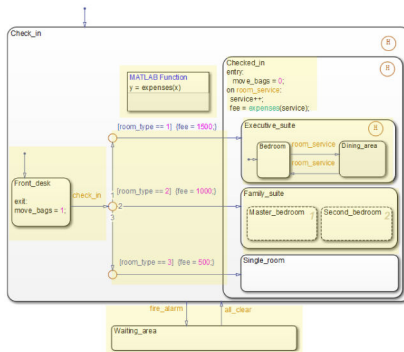
- The Multiport Switch block provides a value for the chart input data `room_type`.
- The Display block shows any change in value for the chart output data `fee`.

### Chart Inactivity

After completing all possible phases of execution, the chart goes back to sleep.

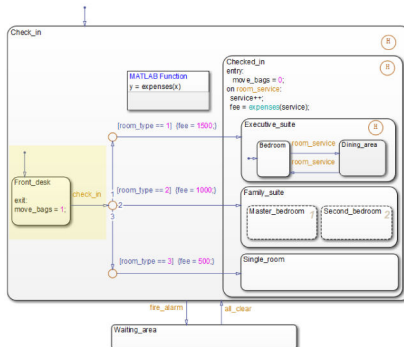
### Phases of Chart Execution

The following sections explain chart execution for each shaded region of the Hotel chart.



### Phase: Chart Initialization

This section describes what happens in the `Front_desk` state just after the chart wakes up.



Stage	Hotel Scenario	Chart Behavior
1	Your first stop is at the front desk of the hotel.	At the chart level, the default transition to <code>Check_in</code> occurs, making that state active. Then, the default transition to <code>Front_desk</code> occurs, making that state active.  For reference, see “Enter a Chart or State” on page 3-28.
2	You leave the front desk after checking in to the hotel.	The <code>check_in</code> event guards the outgoing transition from <code>Front_desk</code> . When the chart receives an event broadcast for <code>check_in</code> , the transition becomes valid.  For reference, see “How Stateflow Charts Respond to Events” on page 3-53.
3	Just before you leave the front desk, you pick up your bags to move to your room.	Just before the transition occurs, the <code>exit</code> action of <code>Front_desk</code> sets the <code>move_bags</code> local data to 1. Then, <code>Front_desk</code> becomes inactive.  For reference, see “Exit a State” on page 3-34.

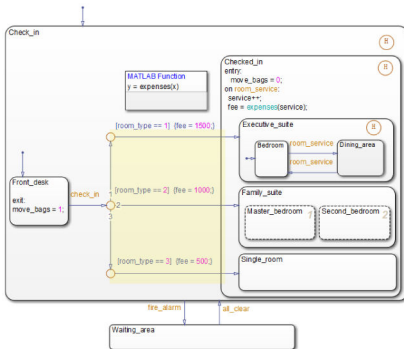
**Modeling Guidelines for Chart Initialization.** The following guidelines apply to chart initialization.

Modeling Guideline	Why This Guideline Applies	Reference
Use exclusive (OR) decomposition when no two states at a level of the hierarchy can be active at the same time.	This guideline ensures proper chart execution. For example, <code>Check_in</code> and <code>Waiting_area</code> are exclusive (OR) states, because you cannot be inside and outside the hotel at the same time.	<ul style="list-style-type: none"> <li>• “State Decomposition” on page 2-9</li> <li>• “Specify Substate Decomposition” on page 4-7</li> </ul>
Use a default transition to mark the first state to become active among exclusive (OR) states.	This guideline prevents state inconsistency errors during chart execution.	<ul style="list-style-type: none"> <li>• “Default Transitions” on page 2-33</li> <li>• “State Inconsistencies” on page 33-33</li> </ul>
Use events, instead of conditions, to guard transitions that depend on occurrences without inherent numerical value.	Since you cannot easily quantify the numerical value of checking into a hotel, model such an occurrence as an event.	<ul style="list-style-type: none"> <li>• “Activate a Stateflow Chart by Sending Input Events” on page 14-7</li> </ul>

Modeling Guideline	Why This Guideline Applies	Reference
<p>Use an <code>exit</code> action to execute a statement once, just before a state becomes inactive.</p>	<p>Other types of state actions execute differently and do not apply:</p> <ul style="list-style-type: none"> <li>• Entry actions execute once, just after a state becomes active.</li> <li>• During actions execute at every time step (except the first time step after a state becomes active). Execution continues as long as the chart remains in that state and no valid outgoing transitions exist.</li> <li>• On <code>event_name</code> actions execute only after receiving an event broadcast.</li> </ul>	<ul style="list-style-type: none"> <li>• “States” on page 2-8</li> </ul>

**Phase: Evaluation of Outgoing Transitions from a Single Junction**

This section describes what happens after exiting the `Front_desk` state: the evaluation of a group of outgoing transitions from a single junction.



Stage	Hotel Scenario	Chart Behavior
1	<p>You can move to one of three types of rooms.</p>	<p>After the <code>check_in</code> event triggers a transition out of <code>Front_desk</code>, three transition paths are available based on the type of room you select with the Multiport Switch block. Transition testing occurs based on the priority you assign to each path.</p> <p>For reference, see “Order of Execution for a Set of Flow Charts” on page 3-58.</p>



Stage	Hotel Scenario	Chart Behavior
2	If you choose an executive suite, the base fee is 1500.	<p>If the <code>room_type</code> input data equals 1, the top transition is valid. If this condition is true, the condition action executes by setting the <code>fee</code> output data to 1500.</p> <hr/> <p><b>Note</b> If the top transition is not valid, control flow backtracks to the central junction so that testing of the next transition can occur. This type of backtracking is intentional.</p> <p>To learn about <i>unintentional</i> backtracking and how to avoid it, see “Backtrack in Flow Charts” on page B-30 and “Best Practices for Creating Flow Charts” on page 5-2.</p>
3	If you choose a family suite, the base fee is 1000.	If <code>room_type</code> equals 2, the middle transition is valid. If this condition is true, the condition action executes by setting <code>fee</code> to 1000.
4	If you choose a single room, the base fee is 500.	If <code>room_type</code> equals 3, the bottom transition is valid. If this condition is true, the condition action executes by setting <code>fee</code> to 500.

### What happens if `room_type` has a value other than 1, 2, or 3?

Because the Multiport Switch block outputs only 1, 2, or 3, `room_type` cannot have any other values. However, if `room_type` has a value other than 1, 2, or 3, the chart stays in the `Front_desk` state. This behavior applies because no transition path out of that state is valid.

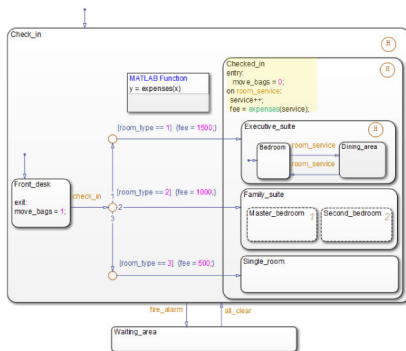
**Modeling Guidelines for Evaluation of Outgoing Transitions.** The following guidelines apply to transition syntax.

Modeling Guideline	Why This Guideline Applies	Reference
Use conditions, instead of events, to guard transitions that depend on occurrences with numerical value.	Because you can quantify a type of hotel room numerically, express the choice of room type as a condition.	“Flow Charts in Stateflow” on page 5-2
Use condition actions instead of transition actions whenever possible.	<p>Condition actions execute as soon as the condition evaluates to true. Transition actions do not execute until after the transition path is complete, to a terminating junction or a state.</p> <p>Unless an execution delay is necessary, use condition actions instead of transition actions.</p>	“Transitions” on page 2-21

Modeling Guideline	Why This Guideline Applies	Reference
Use explicit ordering to control the testing order of a group of outgoing transitions.	You can specify <i>explicit</i> or <i>implicit</i> ordering of transitions. By default, a chart uses explicit ordering. If you switch to implicit ordering, the transition testing order can change when graphical objects move.	“Transition Evaluation Order” on page 3-38

**Phase: Execution of State Actions for a Superstate**

This section describes what happens after you enter the Checked\_in state, regardless of which substate becomes active.



Stage	Hotel Scenario	Chart Behavior
1	After reaching your desired room, you finish moving your bags.	The entry action executes by setting the move_bags local data to 0.
2	If you order room service, your hotel bill increases by a constant amount.	<p>If the chart receives an event broadcast for room_service, these actions occur:</p> <ol style="list-style-type: none"> <li>1 The counter for the service local data increments by 1.</li> <li>2 A function call to expenses occurs, which returns the value of the hotel bill stored by the fee output data.</li> </ol> <p>For reference, see “How Stateflow Charts Respond to Events” on page 3-53.</p>

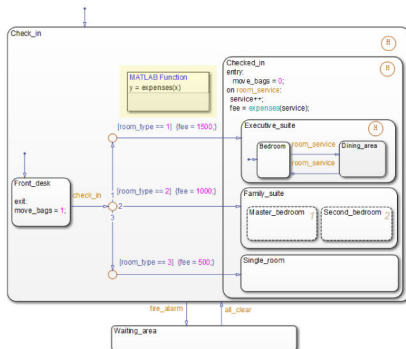
**Modeling Guidelines for Execution of State Actions.** The following guidelines apply to state actions.

Modeling Guideline	Why This Guideline Applies	Reference
Use an entry action to execute a statement once, right after a state becomes active.	Other types of state actions execute differently and do not apply: <ul style="list-style-type: none"> <li>• During actions execute at every time step until there is a valid transition out of the state.</li> </ul>	“States” on page 2-8

Modeling Guideline	Why This Guideline Applies	Reference
Use an <i>On event_name</i> or <i>On message_name</i> action to execute a statement only after receiving an event broadcast or a message.	<ul style="list-style-type: none"> <li>Exit actions execute once, just before a state becomes inactive.</li> </ul>	
Use a superstate to enclose multiple substates that share the same state actions.	This guideline enables reuse of state actions that apply to multiple substates. You write the state actions only <i>once</i> , instead of writing them separately in each substate.	“Create Substates and Superstates” on page 4-5

**Phase: Function Call from a State Action**

This part of the chart describes how you can perform function calls while a state is active.



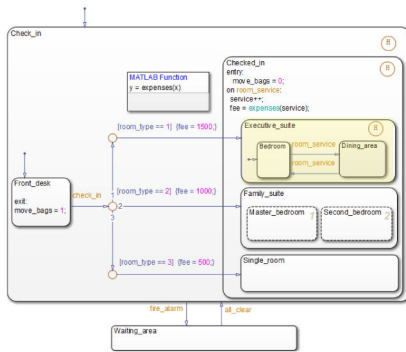
Stage	Hotel Scenario	Chart Behavior
1	Based on your room type and the total number of room service requests, you can track your hotel bill.	<p>expenses is a MATLAB function that takes the total number of room service requests as an input and returns the current hotel bill as an output.</p> <p>If you double-click the function box, you see this script in the function editor:</p> <pre>function y = expenses(x)  if (room_type == 1)     y = 1500 + (x*50); else     if (room_type == 2)         y = 1000 + (x*25);     else         y = 500 + (x*5);     end end end</pre>

**Modeling Guidelines for Function Calls.** The following guidelines apply to function calls.

Modeling Guideline	Why This Guideline Applies	Reference
Use MATLAB functions for performing numerical computations in a chart.	MATLAB functions are better at handling numerical computations than graphical functions, truth tables, or Simulink functions.	"Reuse MATLAB Code by Defining MATLAB Functions" on page 9-2
Use descriptive names in function signatures.	Descriptive function names enhance readability of chart objects.	

**Phase: Execution of State with Exclusive Substates**

This part of the chart shows how a state with exclusive (OR) decomposition executes.



Stage	Hotel Scenario	Chart Behavior
1	When you reach the executive suite, you enter the bedroom first.  <b>Note</b> The executive suite has separate bedroom and dining areas. Therefore, you can be in only one area of the suite at any time.	When the condition <code>room_type == 1</code> is true, the condition action <code>fee = 1500</code> executes. Completion of that transition path triggers these state initialization actions:  <ol style="list-style-type: none"> <li>1 Checked_in becomes active and executes its entry action.</li> <li>2 Executive_suite becomes active.</li> <li>3 The default transition to Bedroom occurs, making that state active.</li> </ol> For reference, see "Enter a Chart or State" on page 3-28.
2	When you order room service, you enter the dining area to eat.	When the <code>room_service</code> event occurs, the transition from Bedroom to Dining_area occurs.
3	When you want the food removed from the dining area, you order room service again and then return to the bedroom.	When the <code>room_service</code> event occurs, the transition from Dining_area to Bedroom occurs.

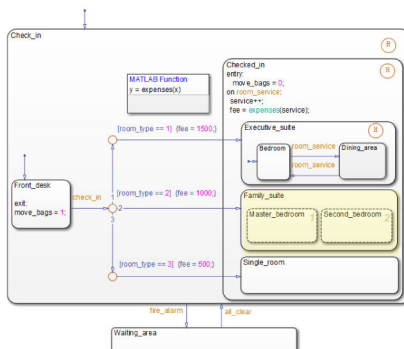
Stage	Hotel Scenario	Chart Behavior
4	If you leave the executive suite because of a fire alarm, you return to your previous room after the all-clear signal.	If a transition out of <code>Executive_suite</code> occurs, the history junction records the last active substate, <code>Bedroom</code> or <code>Dining_area</code> . For details on how this transition can occur, see “Phase: Events Guard Transitions Between States” on page 3-17.

**Modeling Guidelines for Execution of Exclusive (OR) States.** The following guidelines apply to exclusive (OR) states.

Modeling Guideline	Why This Guideline Applies	Reference
Use exclusive (OR) decomposition when no two states at that level of the hierarchy can be active at the same time.	This guideline ensures proper chart execution. For example, <code>Bedroom</code> and <code>Dining_area</code> are exclusive (OR) states, because you cannot be in both places at the same time.	<ul style="list-style-type: none"> <li>• “State Decomposition” on page 2-9</li> <li>• “Specify Substate Decomposition” on page 4-7</li> </ul>
If reentry to a state with exclusive (OR) decomposition depends on the previously active substate, use a history junction. This type of junction records the active substate when the chart exits the state.	<p>If you do not record the previously active substate, the default transition occurs and the wrong substate can become active upon state reentry.</p> <p>For example, if you were eating when a fire alarm sounded, you would return to the bedroom instead of the dining room.</p>	<ul style="list-style-type: none"> <li>• “History Junctions” on page 2-41</li> </ul>

**Phase: Execution of State with Parallel Substates**

This part of the chart shows how a state with parallel (AND) decomposition executes.



Stage	Hotel Scenario	Chart Behavior
1	When your family reaches the suite, family members can be in both bedrooms (for example, parents in the master bedroom and children in the second bedroom). A default room choice does not apply.	<p>When the condition <code>room_type == 2</code> is true, the condition action <code>fee = 1000</code> executes. Completion of that transition path triggers these state initialization actions:</p> <ol style="list-style-type: none"> <li>1 Checked_in becomes active and executes its entry action.</li> <li>2 Family_suite becomes active.</li> <li>3 The parallel states wake up in the order given by the number in the upper right corner of each state: <code>Master_bedroom</code>, then <code>Second_bedroom</code>.</li> </ol> <p><b>How do I specify the order?</b></p> <p>To specify the order:</p> <ol style="list-style-type: none"> <li>a Verify that the chart uses explicit ordering. <ul style="list-style-type: none"> <li>In the Chart properties dialog box, select the <b>User-specified state/transition execution order</b> check box.</li> </ul> </li> <li>b Right-click in a parallel state and select a number from the <b>Execution Order</b> menu.</li> </ol> <p>For reference, see “Enter a Chart or State” on page 3-28.</p>
2	You can occupy both rooms at the same time.	<code>Master_bedroom</code> and <code>Second_bedroom</code> remain active at the same time.

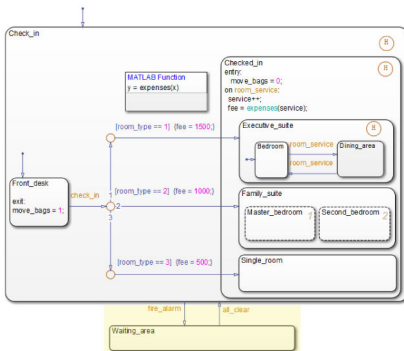
**Modeling Guidelines for Execution of Parallel (AND) States.** The following guidelines apply to parallel (AND) states.

Modeling Guideline	Why This Guideline Applies	Reference
Use parallel (AND) decomposition when all states at that level of the hierarchy can be active at the same time.	This guideline ensures proper chart execution. For example, <code>Master_bedroom</code> and <code>Second_bedroom</code> are parallel states, because you can occupy both rooms at the same time.	<ul style="list-style-type: none"> <li>• “State Decomposition” on page 2-9</li> <li>• “Specify Substate Decomposition” on page 4-7</li> </ul>
Use <i>no</i> history junctions in states with parallel (AND) decomposition.	This guideline prevents compile-time errors. Since all parallel states at a level of hierarchy are active at the same time, history junctions have no meaning.	<ul style="list-style-type: none"> <li>• “History Junctions” on page 2-41</li> </ul>

Modeling Guideline	Why This Guideline Applies	Reference
Use explicit ordering to control the execution order of parallel (AND) states.	You can specify <i>explicit</i> or <i>implicit</i> ordering of parallel states. By default, a chart uses explicit ordering. If you switch to implicit ordering, the execution order can change when parallel states move.	<ul style="list-style-type: none"> <li>“Execution Order for Parallel States” on page 3-60</li> </ul>

**Phase: Events Guard Transitions Between States**

This part of the chart describes how events can guard transitions between exclusive (OR) states.



Stage	Hotel Scenario	Chart Behavior
1	If a fire alarm sounds, you leave the hotel and move to a waiting area outside.	<p>When the chart receives an event broadcast for <code>fire_alarm</code>, a transition occurs from a substate of <code>Check_in</code> to <code>Waiting_area</code>.</p> <p><b>How does this transition occur?</b></p> <p>Suppose that <code>Check_in</code>, <code>Checked_in</code>, <code>Executive_suite</code>, and <code>Dining_area</code> are active when the chart receives <code>fire_alarm</code>.</p> <ol style="list-style-type: none"> <li>States become inactive in <i>ascending</i> order of hierarchy: <ol style="list-style-type: none"> <li><code>Dining_area</code></li> <li><code>Executive_suite</code></li> <li><code>Checked_in</code></li> <li><code>Check_in</code></li> </ol> </li> <li><code>Waiting_area</code> becomes active.</li> </ol>

Stage	Hotel Scenario	Chart Behavior
2	If an all-clear signal occurs, you can leave the waiting area and return to your previous location inside the hotel.	<p>When the chart receives an event broadcast for <code>all_clear</code>, a transition from <code>Waiting_area</code> to the previously active substate of <code>Check_in</code> occurs.</p> <p>The history junction at each level of hierarchy in <code>Check_in</code> enables the chart to remember which substate was previously active before the transition to <code>Waiting_area</code> occurred.</p> <p><b>How does this transition occur?</b></p> <p>Suppose that <code>Check_in</code>, <code>Checked_in</code>, <code>Executive_suite</code>, and <code>Dining_area</code> were active when the chart received <code>fire_alarm</code>.</p> <ol style="list-style-type: none"> <li>1 <code>Waiting_area</code> becomes inactive.</li> <li>2 States become active in <i>descending</i> order of hierarchy:             <ol style="list-style-type: none"> <li>a <code>Check_in</code></li> <li>b <code>Checked_in</code> (The default transition does not apply.)</li> <li>c <code>Executive_suite</code></li> <li>d <code>Dining_area</code> (The default transition does not apply.)</li> </ol> </li> </ol>

**Modeling Guidelines for Guarding Transitions.** The following guideline discusses the use of events versus conditions.

Modeling Guideline	Why This Guideline Applies	Reference
Use events, instead of conditions, to guard transitions that depend on occurrences without numerical value.	Because you cannot easily quantify the numerical value of a fire alarm or an all-clear signal, model such an occurrence as an event.	"Activate a Stateflow Chart by Sending Input Events" on page 14-7



## Modeling Guidelines for Stateflow Charts

Use these guidelines to efficiently model charts with events, states, and transitions.

### Use signals of the same data type for input events

When you use multiple input events to trigger a chart, verify that all input signals use the same data type. Otherwise, simulation stops and an error message appears. For more information, see “Data Types Allowed for Input Events” on page 14-9.

### Use a default transition to mark the first state to become active among exclusive (OR) states

This guideline prevents state inconsistency errors during chart execution.

### Use condition actions instead of transition actions whenever possible

Condition actions execute as soon as the condition evaluates to true. Transition actions do not execute until after the transition path is complete, to a terminating junction or a state.

Unless an execution delay is necessary, use condition actions instead of transition actions.

### Use explicit ordering to control the testing order of a group of outgoing transitions

You can specify *explicit* or *implicit* ordering of transitions. By default, a chart uses explicit ordering. If you switch to implicit ordering, the transition testing order can change when graphical objects move.

### Verify intended backtracking behavior in flow charts

If your chart contains unintended backtracking behavior, a warning message appears with instructions on how to avoid that problem. For more information, see “Best Practices for Creating Flow Charts” on page 5-2.

### Use a superstate to enclose substates that share the same state actions

When you have multiple exclusive (OR) states that perform the same state actions, group these states in a superstate and define state actions at that level.

This guideline enables reuse of state actions that apply to multiple substates. You write the state actions only once, instead of writing them separately in each substate.

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**Note** You cannot use boxes for this purpose because boxes do not support state actions.

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## **Use MATLAB functions for performing numerical computations in a chart**

MATLAB functions are better at handling numerical computations than graphical functions, truth tables, or Simulink functions.

## **Use descriptive names in function signatures**

Descriptive function names enhance readability of chart objects.

## **Use history junctions to record state history**

If reentry to a state with exclusive (OR) decomposition depends on the previously active substate, use a history junction. This type of junction records the active substate when the chart exits the state. If you do not record the previously active substate, the default transition occurs and the wrong substate can become active upon state reentry.

## **Do not use history junctions in states with parallel (AND) decomposition**

This guideline prevents compile-time errors. Since all parallel states at a level of hierarchy are active at the same time, history junctions have no meaning.

## **Use explicit ordering to control the execution order of parallel (AND) states**

You can specify *explicit* or *implicit* ordering of parallel states. By default, a chart uses explicit ordering. If you switch to implicit ordering, the execution order can change when parallel states move.

## Types of Chart Execution

### Life Cycle of a Stateflow Chart

Stateflow charts go through several stages of execution:

Stage	Description
Inactive	Chart has no active states
Active	Chart has active states
Sleeping	Chart has active states, but no events to process

When a Simulink model first triggers a Stateflow chart, the chart is inactive and has no active states. After the chart executes and completely processes its initial trigger event from the Simulink model, it transfers control back to the model and goes to sleep. At the next Simulink trigger event, the chart changes from the sleeping to active stage.

See “Use Events to Execute Charts” on page 3-53.

### Execution of an Inactive Chart

When a chart is inactive and first triggered by an event from a Simulink model, it first executes its set of default flow charts (see “Order of Execution for a Set of Flow Charts” on page 3-58). If this action does not cause an entry into a state and the chart has parallel decomposition, then each parallel state becomes active (see “Enter a Chart or State” on page 3-28).

If executing the default flow paths does not cause state entry, a state inconsistency error occurs.

### Execution of an Active Chart

After a chart has been triggered the first time by the Simulink model, it is an active chart. When the chart receives another event from the model, it executes again as an active chart. If the chart has no states, each execution is equivalent to initializing a chart. Otherwise, the active substates execute. Parallel states execute in the same order that they become active.

### Execution of a Chart at Initialization

By default, the first time a chart wakes up, it executes the default transition paths. At this time, the chart can access inputs, write to outputs, and broadcast events.

If you want your chart to begin executing from a known configuration, you can enable the **Execute (enter) Chart At Initialization** chart property. When you turn on this option, the state configuration of a chart initializes at time 0 instead of the first occurrence of an input event. The default transition paths of the chart execute during the model initialization phase at time 0, corresponding to the `mdlInitializeConditions()` (Simulink) phase for S-functions. For more information, see “Execute (enter) chart at initialization” on page 28-5.

**Note** If an output of this chart connects to a SimEvents® block, do not select this check box. To learn more about using Stateflow charts and SimEvents blocks together in a model, see the SimEvents documentation.

---

Due to the transient nature of the initialization phase, do not perform certain actions in the default transition paths of the chart — and associated state entry actions — which execute at initialization. Follow these guidelines:

- Do not access chart input data, because blocks connected to chart input ports might not have initialized their outputs yet.
- Do not call exported graphical functions from other charts, because those charts might not have initialized yet.
- Do not broadcast function-call output events, because the triggered subsystems might not have initialized yet.

You can control the level of diagnostic action for invalid access to chart input data in the **Diagnostics** > **Stateflow** pane of the Configuration Parameters dialog box. For more information, see the documentation for the “Invalid input data access in chart initialization” (Simulink) diagnostic.

Execute at initialization is ignored in Stateflow charts that do not contain states.

### See Also

#### More About

- “Execution of a Stateflow Chart” on page 3-23
- “Exit a State” on page 3-34
- “Evaluate Transitions” on page 3-37

## Execution of a Stateflow Chart

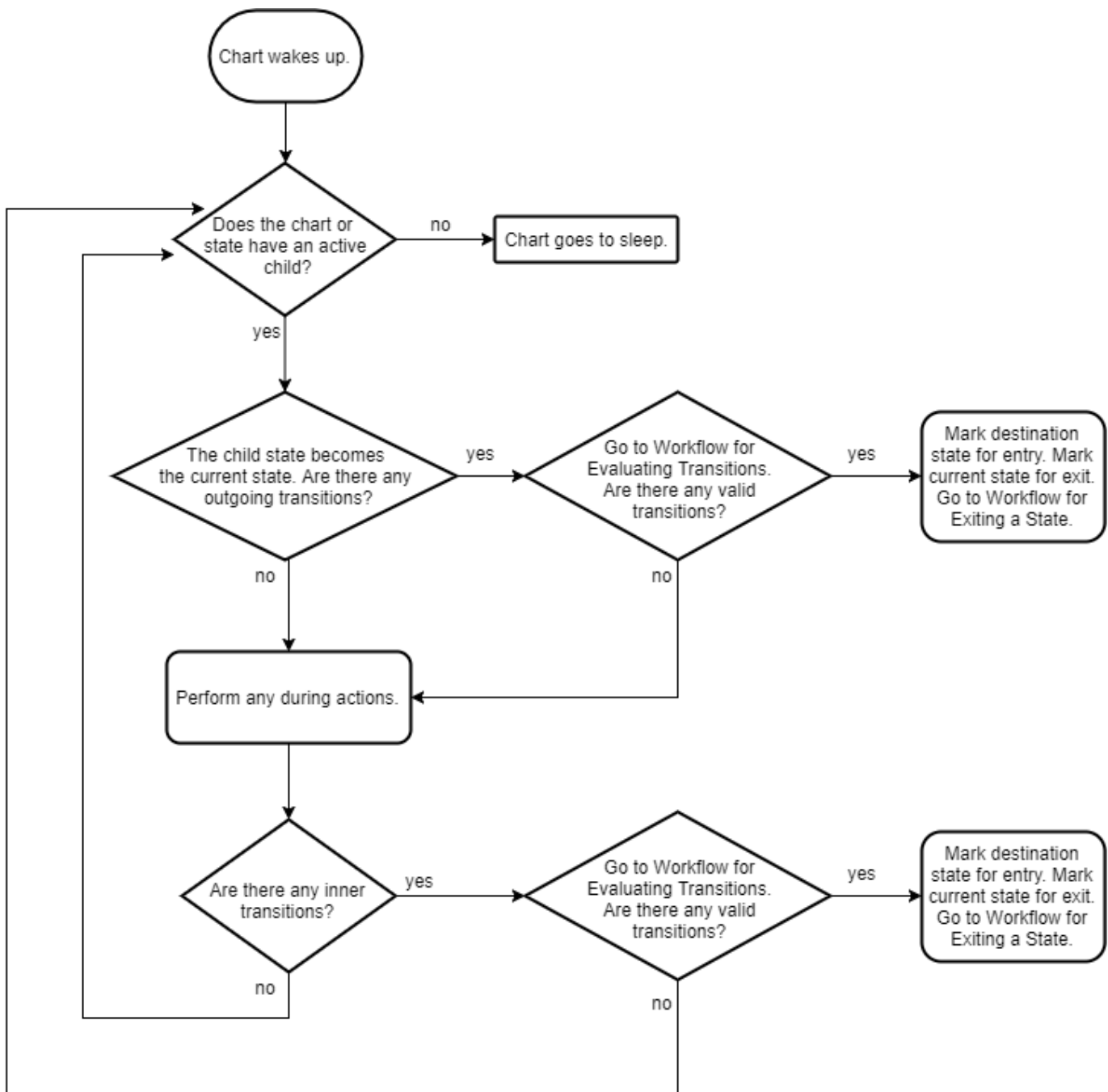
When a Stateflow chart wakes up, the chart follows a workflow and executes actions. A Stateflow chart wakes up:

- At each time step according to the Simulink solver.
- When the Stateflow chart receives an event.

When a chart wakes up for the first time, the chart is initialized and becomes active. See “Chart Entry” on page 3-30. Once the chart is active but with no more actions to take, the chart goes to sleep until it is triggered by a new time step or an event.

### Workflow for Stateflow Chart Execution

This flow chart shows the progression of events that Stateflow takes for executing a chart or state. In this flow chart, the current state refers to the state in which a decision or a process is taking place.



## During Actions

During actions for a state execute when:

- The state is active, a new time step occurs, and no valid transition to another state is available.
- The state is active, an event occurs, and no valid transition to another state is available.

During actions are preceded by the prefix `during` or `du`, and then followed by a required colon (`:`), followed by one or more actions. Separate multiple actions with a carriage return, semicolon (`;`), or a comma (`,`). If you do not specify the state action type explicitly for a statement, the chart treats that statement as an entry,during action.

A state performs its `during` actions (if specified) when the chart wakes up. The preceding flow chart depicts the process of state execution and shows when `during` actions occur.

If your Stateflow chart does not contain states, each time the chart is executed, Stateflow always evaluates the default transition path.

## Outgoing Transition

Stateflow marks outgoing transitions for evaluation as a part of the execution of a Stateflow chart. Once an outgoing transition is marked for evaluation, follow the “Workflow for Evaluating Transitions” on page 3-38. For more information about how Stateflow evaluates outgoing transitions, see “Evaluate Transitions” on page 3-37.

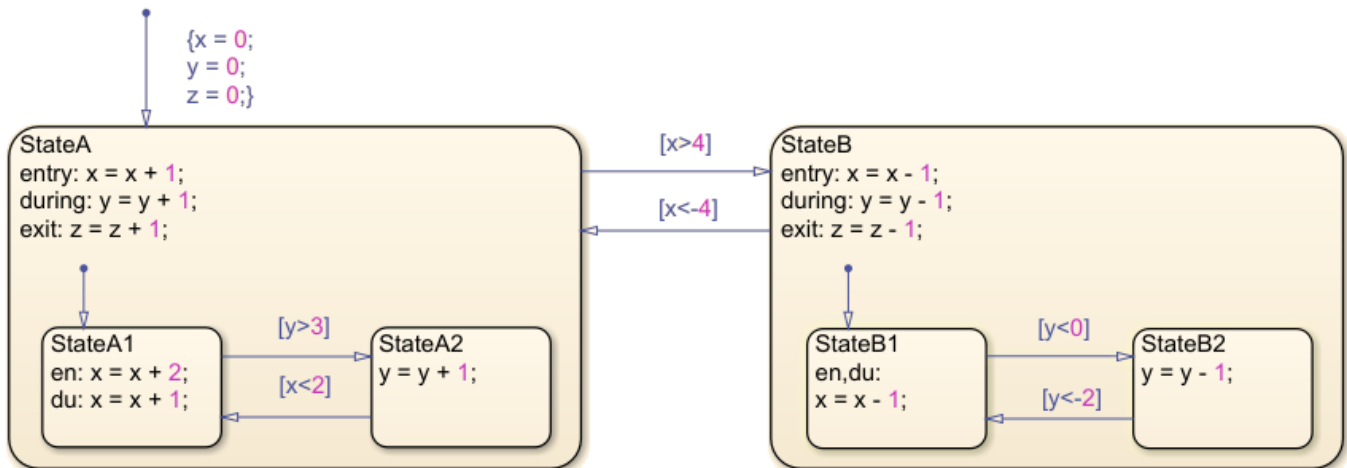
## Inner Transitions

Stateflow marks inner transitions for evaluation as a part of the execution of a Stateflow chart. Once an inner transition is marked for evaluation, follow the “Workflow for Evaluating Transitions” on page 3-38. For more information about how Stateflow evaluates inner transitions, see “Evaluate Transitions” on page 3-37.

## Chart Execution with a Valid Transition

In this example, the Stateflow chart is initialized and the entry actions are performed for StateA and StateA1. A new time step occurs and the chart wakes up.

At this time step,  $x = 5$ ,  $y = 2$ , and  $z = 0$ .



By following the “Workflow for Stateflow Chart Execution” on page 3-23, the execution steps for chart execution are in this order:

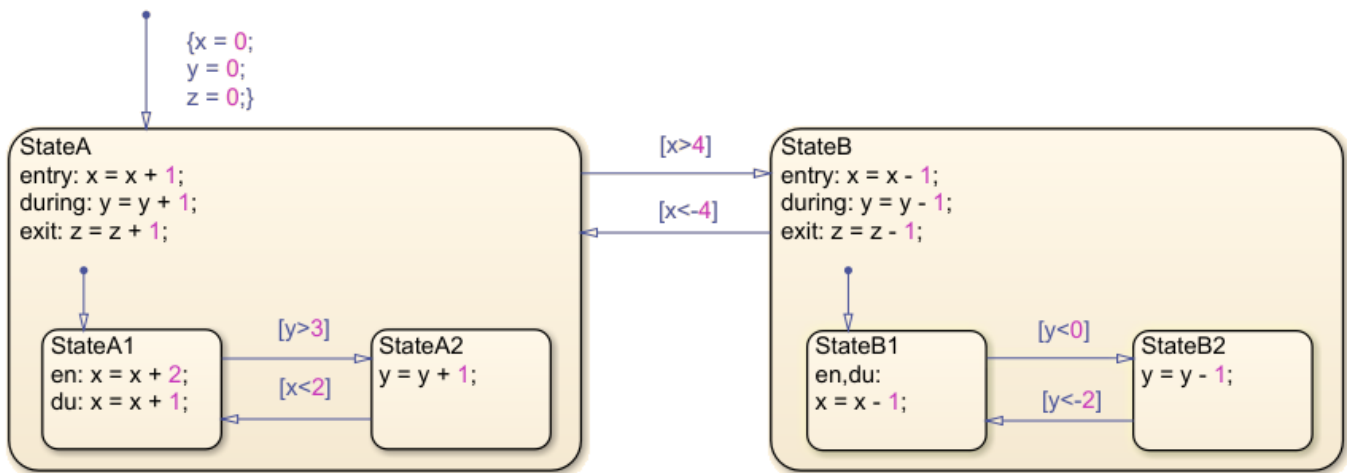
- 1 The chart has an active substate, StateA.
- 2 StateA has an outgoing transition to StateB. By following the “Workflow for Evaluating Transitions” on page 3-38, the transition is determined to be valid.
- 3 StateB is marked for entry and StateA is marked for exit.

To complete the time step, follow the “Workflow for Exiting a State” on page 3-34 for StateA and the “Workflow for Entering a Chart or State” on page 3-28 for StateB.

### Chart Execution Without a Valid Transition

In this example, the Stateflow chart is initialized and the entry actions are performed for StateA and StateA1. A new time step occurs and the chart wakes up.

At this time step,  $x = 3$ ,  $y = 0$ , and  $z = 0$ .



By following the “Workflow for Stateflow Chart Execution” on page 3-23 until the chart goes to sleep, the execution steps for chart execution are in this order:

- 1 The chart has an active substate, StateA.
- 2 StateA has an outgoing transition to StateB. By following the “Workflow for Evaluating Transitions” on page 3-38, the transition is determined to be invalid.
- 3 Perform the during actions for StateA. Now  $y = 1$ .
- 4 StateA does not have any inner transitions.
- 5 The active substate of StateA is StateA1.
- 6 StateA1 has an outgoing transition to StateA2. By following the “Workflow for Evaluating Transitions” on page 3-38, the transition is determined to be invalid.
- 7 Perform the during actions for StateA1. Now  $x = 4$ .
- 8 StateA1 does not have any active substates.
- 9 The chart goes to sleep.

Steps 1 through 9 take place in the second time step.



## **See Also**

### **More About**

- “Enter a Chart or State” on page 3-28
- “Exit a State” on page 3-34
- “Evaluate Transitions” on page 3-37

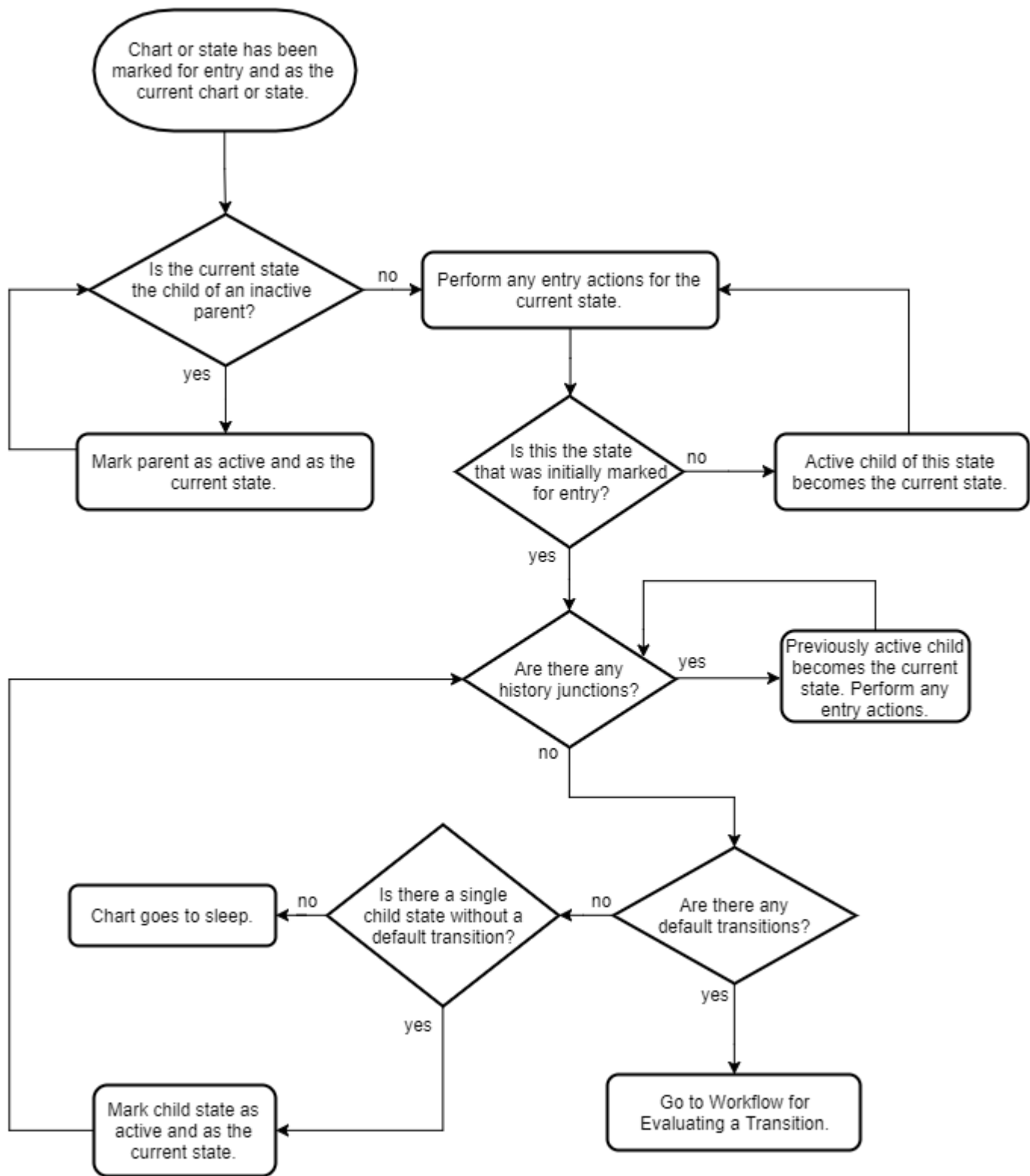
### Enter a Chart or State

Chart and state entry occurs when:

- A chart is activated for the first time. This is called chart initialization.
- A valid transition into a state exists. See “Evaluate Transitions” on page 3-37.

#### Workflow for Entering a Chart or State

This flow chart shows the progression of events that Stateflow takes for entry into a chart or a state. In this flow chart, the current state refers to the state in which a decision or a process is taking place.



## Chart Entry

The first time that your Stateflow chart becomes active is called initialization. When initialization of your chart occurs, the chart is entered and Stateflow executes any default transitions for exclusive (OR) states. If the states at the top level of your chart are parallel (AND), they become active based on their order number.

If you want your chart to take any default transitions before time  $t = 0$ , in the Chart Properties dialog box, select the **Execute (enter) chart at initialization** check box. This option causes the Stateflow chart to initialize at the same time as Simulink initialization. The default transition paths of the chart then execute during the model initialization phase.

## State Entry

When a state is marked for entry, entry actions for a state execute. Once your chart is active and has gone through initialization, the top-level state becomes active. A state is marked for entry in one of these ways:

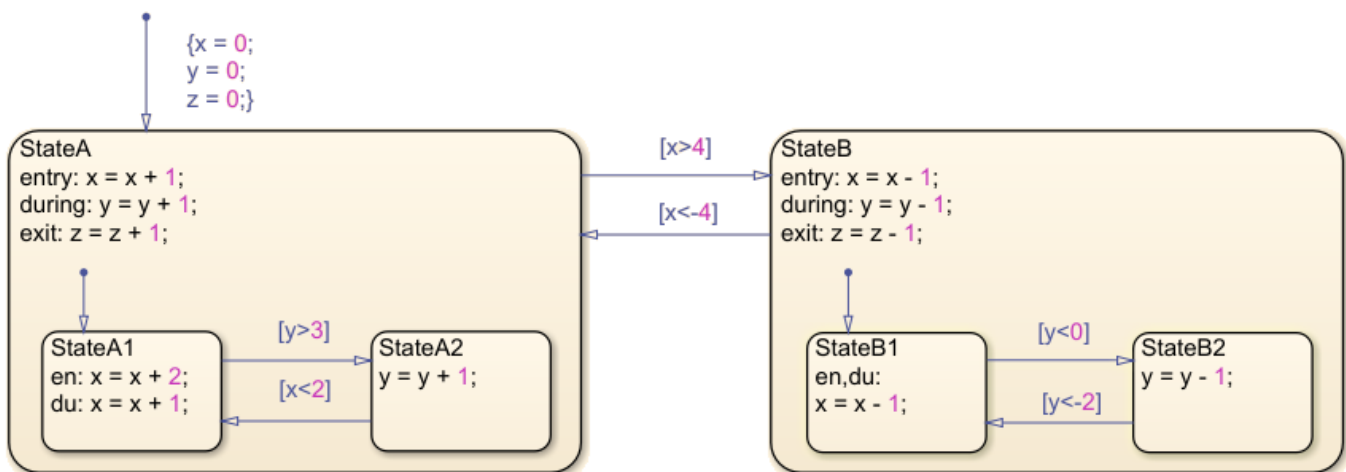
- An incoming transition crosses state boundaries.
- An incoming transition ends at the state boundary.
- The state is a parallel state child of an active state.

## Entry Actions

Entry actions are preceded by the prefix `entry` or `en` for short, followed by a required colon (`:`), and then followed by one or more actions. You separate multiple actions by using a carriage return, a semicolon (`;`), or a comma (`,`). If you do not specify the state action type explicitly for a statement, the chart treats that statement as an `entry,during` action.

## Enter a Stateflow Chart

In this example, the first time the chart becomes active, chart initialization occurs.



By following the “Workflow for Entering a Chart or State” on page 3-28 until the chart goes to sleep, the steps for chart initialization are in this order:

- 1 The default transition actions are executed, and  $x = 0$ ,  $y = 0$ , and  $z = 0$ .
- 2 StateA is marked for entry.
- 3 StateA is not a substate of an inactive parent. Perform the entry actions for StateA. Now  $x = 1$ .
- 4 StateA is the state that was initially marked for entry.
- 5 StateA does not contain any history junctions.
- 6 There is a default transition to the substate, StateA1. Go to the Evaluate Transitions flow chart.
- 7 By following the Evaluate Transitions flow chart, mark StateA1 for entry. Go to the Exit Actions flow chart.
- 8 The current state, StateA, is a superstate of the destination state, StateA1. Return to the Entry Actions flow chart.
- 9 StateA1 is not a substate of an inactive parent. Perform entry actions for StateA1. Now  $x = 3$ .
- 10 StateA1 is the state that was initially marked for entry.
- 11 StateA1 does not contain any history junctions.
- 12 StateA1 does not contain any default transitions.
- 13 StateA1 does not contain any single substates.
- 14 The chart goes to sleep.

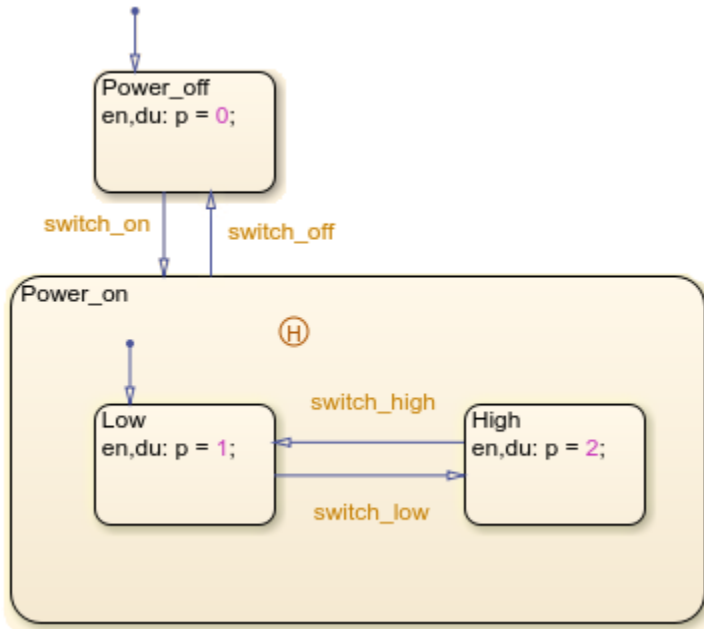
Steps 1 through 14 take place in the initial time step. This completes the chart initialization process.

## Entering a State by Using History Junctions

If you want your Stateflow chart to remember and return to a substate that was previously active, regardless of a default transition, use a history junction. Placing a history junction within a state overrides the default transition leading to exclusive (OR) substates. After placing a history junction within a state, upon entry, your Stateflow chart remembers and enters the previously active substate. The history junction applies only to the level of the hierarchy in which it appears.

In this example, a light can be on or off. These options are indicated by the states `Power_on` and `Power_off`. The options are controlled by the input events `switch_on` and `switch_off`. When the light is on, it can be dim or bright. These options are indicated by the states `Low` and `High` and are controlled by the input events `switch_low` and `switch_high`.

Initially, the chart is asleep. The state `Power_off` is active. When the state `Power_on` was last active, `High` was the previously active substate. The event `switch_on` occurs and the state `Power_on` is marked for entry. At this time  $p = 0$ .



By following the “Workflow for Entering a Chart or State” on page 3-28 until the chart goes to sleep, the execution steps for entering the state `Power_on` are in this order:

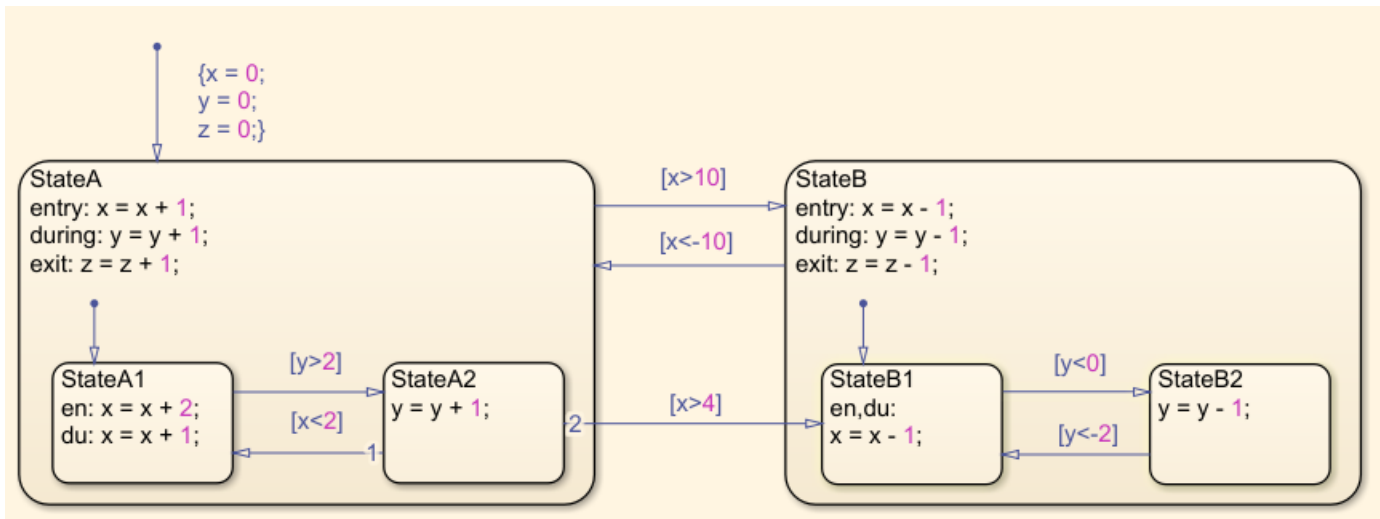
- 1 `Power_on` is not the child of an inactive parent.
- 2 There are no entry actions for `Power_on`.
- 3 `Power_on` is the state that was initially marked for entry.
- 4 There are history junctions in `Power_on`.
- 5 `High` was the previously active substate. Now  $p = 2$ .
- 6 `High` does not contain any history junctions.
- 7 `High` does not contain any default transitions.
- 8 `High` does not contain any single substates.
- 9 The chart goes to sleep.

This completes the entry actions for `Power_on` and `High`.

## Entering a State by Using Supertransitions

A supertransition is a transition between different levels in a chart. A supertransition can be between a state in a top-level chart and a state in one of its subcharts, or between states residing in different subcharts at the same or different levels in a chart. You can create supertransitions that span any number of levels in your chart.

When a state is entered through a supertransition, before the entry actions for the final destination are executed, its superstates must be marked active and their entry actions must be executed. In this example, `StateB1` has been marked for entry from `StateA2`. At this point,  $x = 5$ ,  $y = 5$ , and  $z = 1$ .



By following the “Workflow for Entering a Chart or State” on page 3-28 until the chart goes to sleep, the execution steps for entering the state **StateB1** are in this order:

- 1 **StateB1** is the substate of an inactive parent (**StateB**).
- 2 **StateB** is marked as active.
- 3 **StateB** is not the substate of an inactive parent.
- 4 Perform the entry actions for **StateB**. Now `x = 4`.
- 5 **StateB** is not the state that was initially marked for entry.
- 6 Perform the entry actions for **StateB1**. Now `x = 3`.
- 7 **StateB1** is the state that was initially marked for entry.
- 8 **StateB1** has no history junctions.
- 9 **StateB1** does not contain any default transitions.
- 10 **StateB1** does not contain any single substates.
- 11 The chart goes to sleep.

This completes the entry actions for **StateB** and **StateB1**.

## See Also

### More About

- “Execution of a Stateflow Chart” on page 3-23
- “Exit a State” on page 3-34
- “Evaluate Transitions” on page 3-37

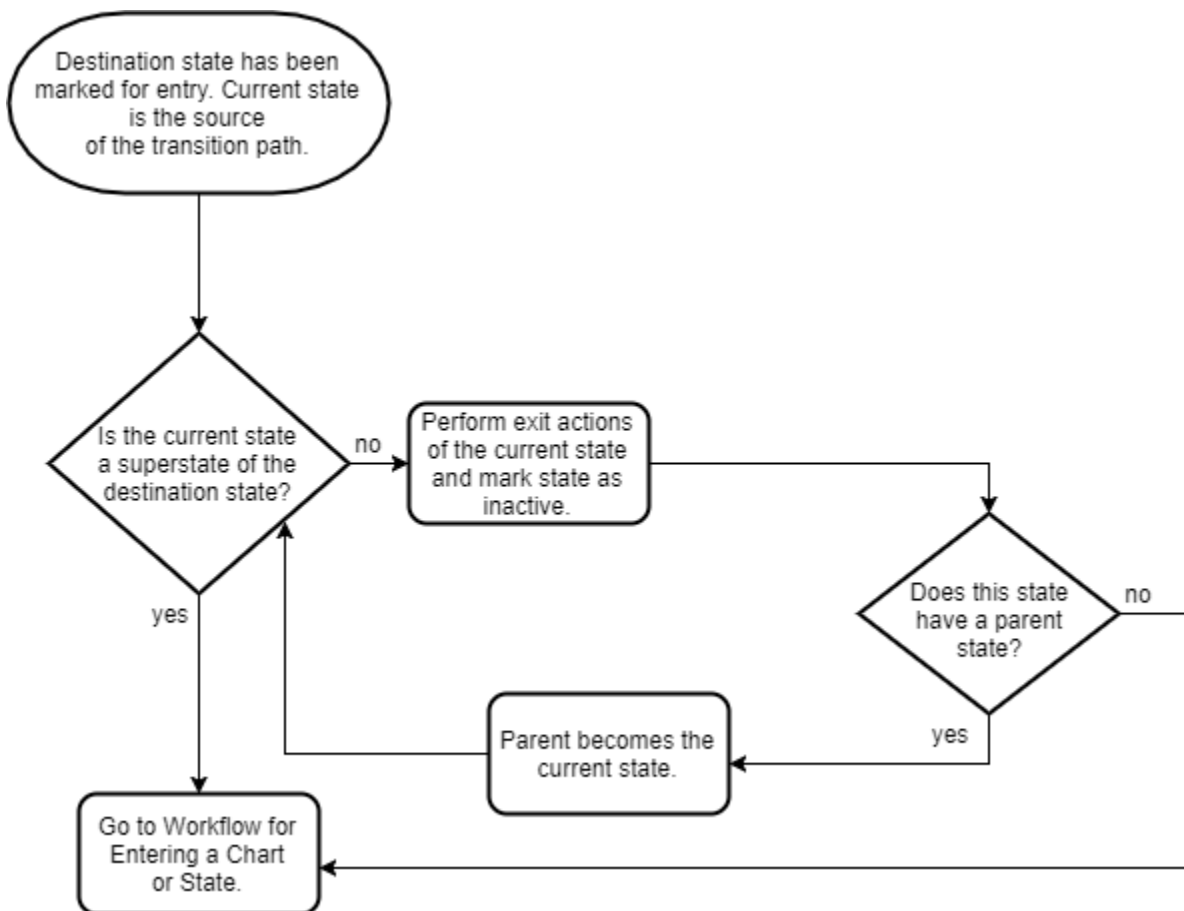
## Exit a State

When there is a valid transition out of a state, that state is marked for exit. A state is marked for exit in one of these ways:

- The outgoing transition originates at the state boundary.
- The outgoing transition crosses the state boundary.
- The destination state is a parallel state child of an activated state.

### Workflow for Exiting a State

This flow chart shows the progression of events in Stateflow for exiting a state. In this flow chart, the current state refers to the state in which a decision or a process is taking place.



### Exit Actions

Exit actions for a state execute when the state is active and a valid transition from the state exists. A state performs its exit actions before becoming inactive.

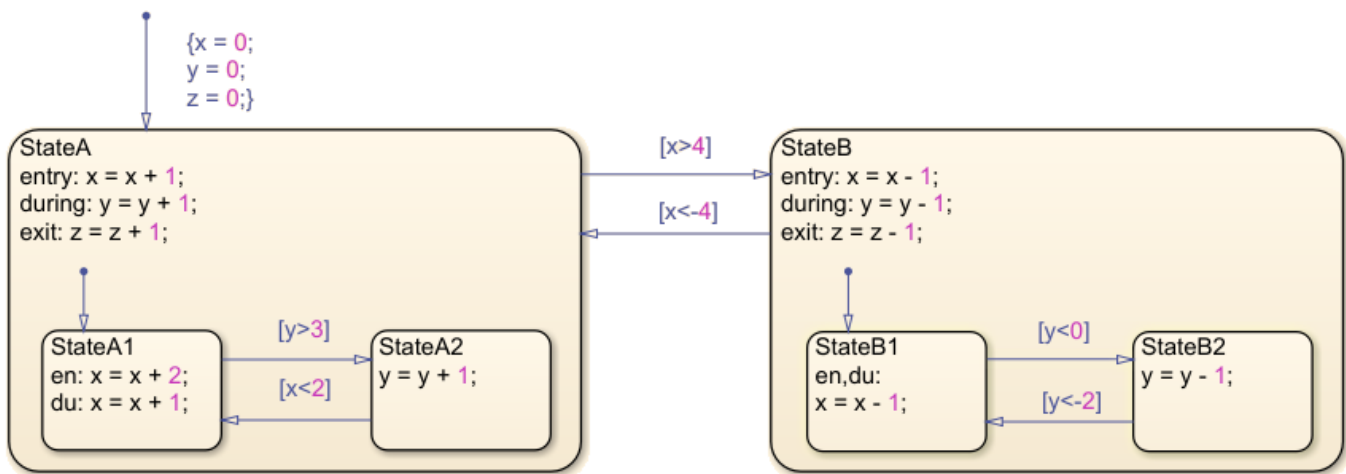
Exit actions are preceded by the prefix `exit` or `ex`, followed by a required colon (:), and then followed by one or more actions. Separate multiple actions with a carriage return, semicolon (;), or a comma (,).



## Exit a State Example

In this example, the Stateflow chart is initialized and the entry actions are performed for `StateA` and `StateA1`. For this chart, the during actions for this chart have occurred twice. A new time step occurs, and then the chart wakes up.

By following the “Workflow for Stateflow Chart Execution” on page 3-23 and the “Workflow for Evaluating Transitions” on page 3-38, `StateB` has been marked for entry. `StateA` is the source of the transition. At this time step  $x = 5$ ,  $y = 2$ , and  $z = 0$ .



By following the flow chart for state exit actions until the chart goes to sleep, the execution steps for this chart are in this order:

- 1 `StateA` is not a superstate of `StateB`.
- 2 Perform the exit actions of `StateA` and mark `StateA` as inactive. Now  $z = 1$ .
- 3 `StateA` does not have a parent state.
- 4 Go to “Entry Actions” on page 3-30.

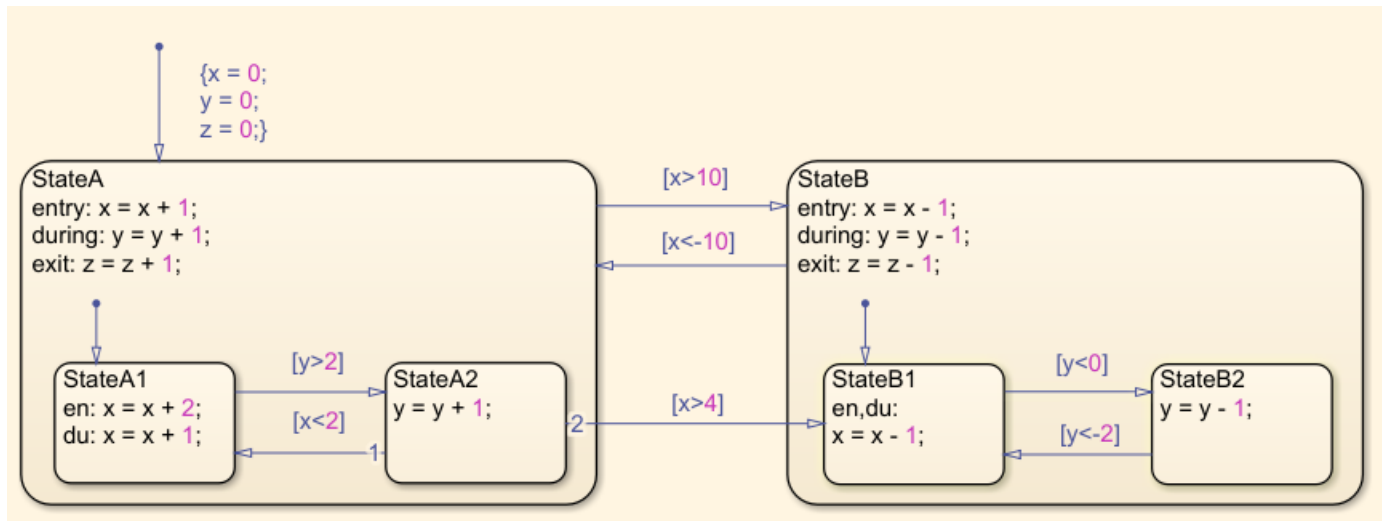
These steps complete the exit workflow for `StateA`. However, the chart is not yet asleep.

Perform the “Workflow for Entering a Chart or State” on page 3-28 for `StateB` to complete the time step.

## Exit a State by Using Supertransitions

A supertransition is a transition between different levels in a chart. A supertransition can be between a state in a top-level chart and a state in one of its substates, or between states residing in different substates. You can create supertransitions that span any number of levels in your chart.

When a state is exited through a supertransition, after the exit actions for the source of the transition are executed, its superstates are marked inactive and exit actions of the superstates are executed. In this example, `StateA2` is marked for exit and `StateB1` is marked for entry. At this point,  $x = 5$ ,  $y = 5$ , and  $z = 0$ .



By following the “Workflow for Entering a Chart or State” on page 3-28 until the chart goes to sleep, the execution steps for exiting the state StateA2 are in this order:

- 1 StateA2 is not a superstate of the destination state (StateB1).
- 2 Perform the exit actions for StateA2 and mark StateA2 as inactive.
- 3 StateA2 does have a parent state, StateA.
- 4 StateA is not a superstate of the destination state (StateB1).
- 5 Perform the exit actions for StateA, and mark StateA as inactive.
- 6 StateA does not have a parent state.

These actions complete the exit workflow for StateA2 and StateA. However, the chart is not yet asleep.

Perform the “Workflow for Entering a Chart or State” on page 3-28 for StateB and StateB1 to complete the time step.

## See Also

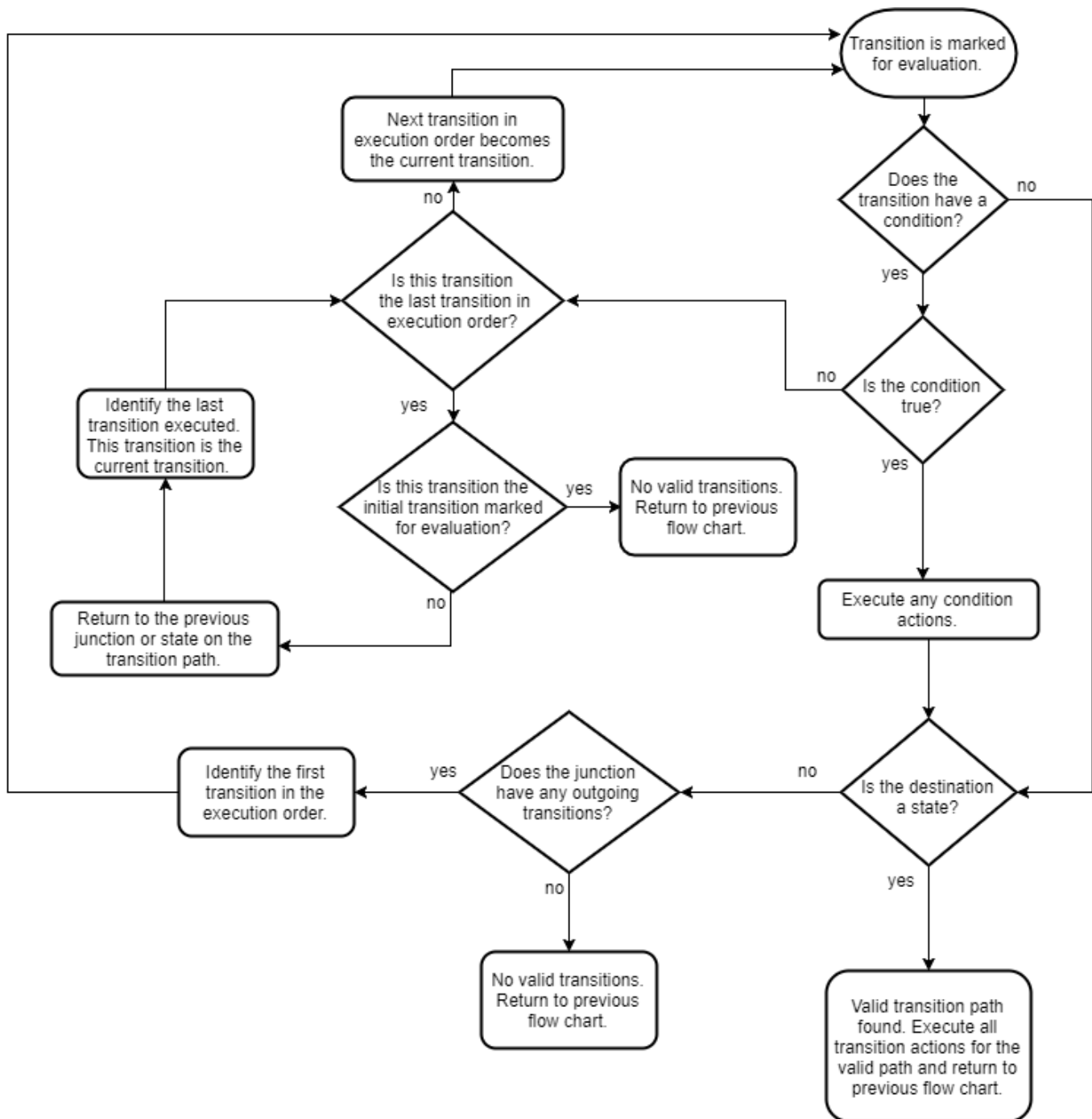
### More About

- “Execution of a Stateflow Chart” on page 3-23
- “Enter a Chart or State” on page 3-28
- “Evaluate Transitions” on page 3-37

## Evaluate Transitions

Stateflow uses transitions in charts to move from one exclusive (OR) state to another exclusive (OR) state. For the entry and execution workflows of chart execution, Stateflow evaluates transitions to determine if they are valid. A valid transition is a transition whose condition labels are true and whose path ends at a state. If a transition is valid, Stateflow exits from the source state and enters the destination state. To learn about when evaluation occurs during the execution and entry workflows, see “Execution of a Stateflow Chart” on page 3-23 and “Enter a Chart or State” on page 3-28.

## Workflow for Evaluating Transitions



## Transition Evaluation Order

When multiple transitions originate from a single source, such as a state or junction, Stateflow uses evaluation order to determine when to test each transition. Depending on which action language your chart uses, you can create the order of your transitions explicitly or implicitly. Whether explicitly or

implicitly ordered, transitions show a number near the source of the transition that designates the transition order.

---

**Note** Use explicit ordering to avoid your transitions from changing order while you are editing a chart.

---

### Explicit Ordering

When you open a new Stateflow chart, all outgoing transitions from a source are automatically numbered in the order in which you create them. The order starts with 1 and continues to the next available number for the source.

To change the execution order of a transition, right-click the transition, place your cursor over **Execution Order**, and select the order in which you want your transition to execute. When you change a transition number, the Stateflow chart automatically renumbers the other outgoing transitions for the source by preserving their relative order.

### Implicit Ordering

For C charts in implicit ordering mode, a Stateflow chart evaluates a group of outgoing transitions from a single source based on:

- Hierarchy.

A chart evaluates a group of outgoing transitions in an order based on the hierarchical level of the parent of each transition.

- Label.

A chart evaluates a group of outgoing transitions with equal hierarchical priority based on the labels, in the following order of precedence:

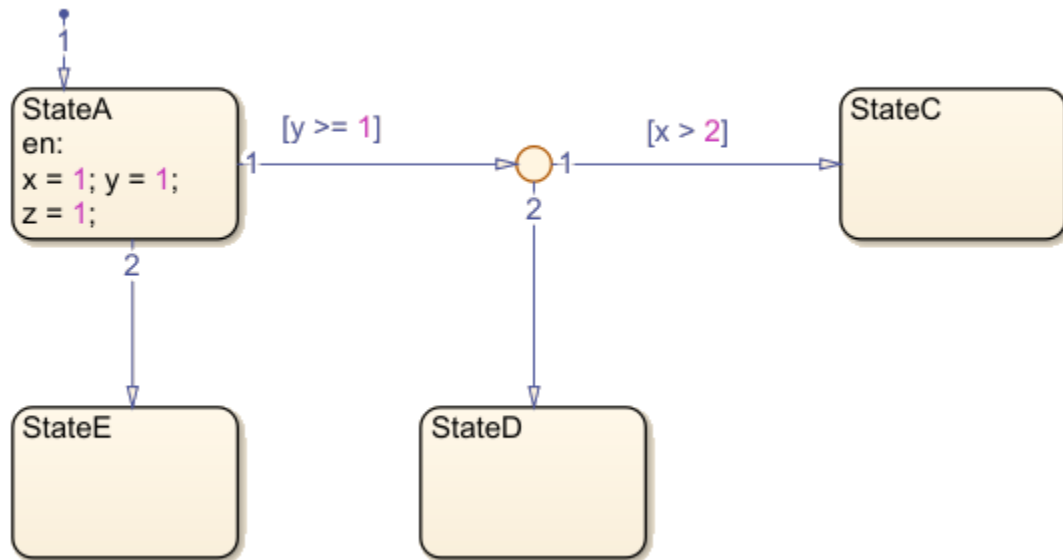
- 1 Labels with events and conditions
- 2 Labels with events
- 3 Labels with conditions
- 4 No label

- Angular surface position of transition source.

A chart evaluates a group of outgoing transitions with equal hierarchical and label priority based on angular position on the surface of the source object. The transition with the smallest clock position has the highest priority. For example, a transition with a 2 o'clock source position has a higher priority than a transition with a 4 o'clock source position. A transition with a 12 o'clock source position has the lowest priority.

### Outgoing Transition Example

In this example, the Stateflow chart is initialized and the entry actions are performed for `StateA`. A new time step occurs and the chart wakes up. By following the “Workflow for Stateflow Chart Execution” on page 3-23, Stateflow finds multiple outgoing transitions from `StateA`. At this time step  $x = 1$ ,  $y = 1$ , and  $z = 1$ .



### Evaluate Outgoing Transitions

By following the “Workflow for Evaluating Transitions” on page 3-38, the steps for evaluating the transitions of this chart are in this order:

- 1 Transition 1 from StateA is marked for evaluation.
- 2 Transition 1 from StateA has a condition.
- 3 The condition is true.
- 4 The destination of transition 1 from StateA is not a state.
- 5 The junction does have outgoing transitions.
- 6 Transition 1 from the junction is marked for evaluation.
- 7 Transition 1 from the junction has a condition.
- 8 The condition is false.
- 9 Transition 2 from the junction is marked for evaluation.
- 10 Transition 2 from the junction does not have a condition.
- 11 The destination of transition 2 from the junction is a state (StateD).
- 12 StateD is marked for entry, and StateA is marked for exit.

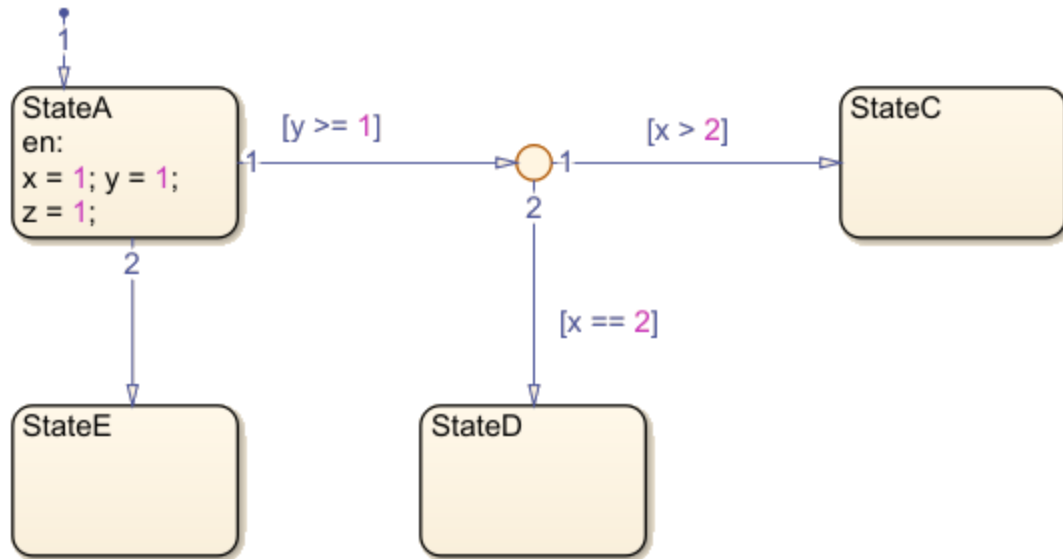
To complete the time step, follow the “Workflow for Exiting a State” on page 3-34 for StateA and the “Workflow for Entering a Chart or State” on page 3-28 for StateE.

### Outgoing Transition Example with Backtracking

When all outgoing transitions from a source are invalid or do not end with a terminating junction, but there are previously unevaluated transitions, Stateflow returns to the previous state or junction to evaluate all possible paths.

In this example, the Stateflow chart is initialized and the entry actions are performed for StateA. A new time step occurs, and the chart wakes up. By following the “Workflow for Stateflow Chart

Execution” on page 3-23, Stateflow finds multiple outgoing transitions from StateA. At this time step  $x = 1$ ,  $y = 1$ , and  $z = 1$ .



### Evaluate Outgoing Transitions with Backtracking

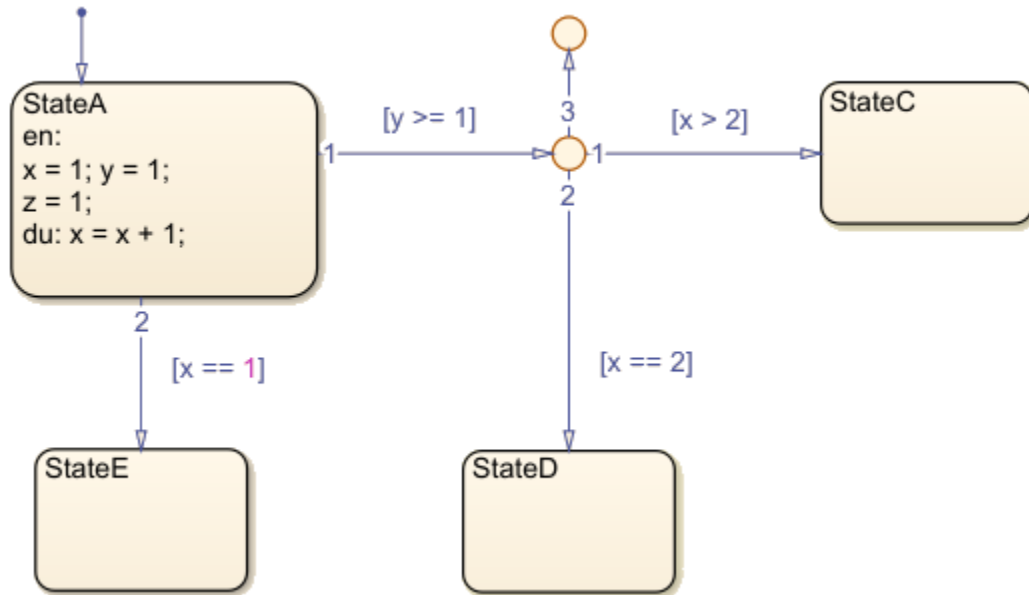
By following the “Workflow for Evaluating Transitions” on page 3-38, the steps for evaluating the transitions of this chart are in this order:

- 1 Transition 1 from StateA is marked for evaluation.
- 2 Transition 1 from StateA has a condition.
- 3 The condition is true.
- 4 The destination of transition 1 from StateA is not a state.
- 5 The junction does have outgoing transitions.
- 6 Transition 1 from the junction is marked for evaluation.
- 7 Transition 1 from the junction has a condition.
- 8 The condition is false.
- 9 Transition 2 from the junction is marked for evaluation.
- 10 Transition 2 from the junction has a condition.
- 11 The condition is false.
- 12 Transition 2 from StateA is marked for evaluation.
- 13 Transition 2 from StateA does not have a condition.
- 14 The destination of transition 2 from StateA is a state (StateE).
- 15 StateE is marked for entry, and StateA is marked for exit.

To complete the time step, follow the “Workflow for Exiting a State” on page 3-34 for StateA and the “Workflow for Entering a Chart or State” on page 3-28 for StateE.

### Prevent Backtracking

In this example, a terminating junction prevents backtracking. The Stateflow chart is initialized and the entry actions are performed for StateA. A new time step occurs and the chart wakes up. By following the “Workflow for Stateflow Chart Execution” on page 3-23, Stateflow finds multiple outgoing transitions from StateA. At this time step  $x = 1$ ,  $y = 1$ , and  $z = 1$ .



By following the “Workflow for Evaluating Transitions” on page 3-38, the steps for evaluating the transitions of this chart are in this order:

- 1 Transition 1 from StateA is marked for evaluation.
- 2 Transition 1 from StateA has a condition.
- 3 The condition is true.
- 4 The destination of transition 1 from StateA is not a state.
- 5 The junction does have outgoing transitions.
- 6 Transition 1 from the junction is marked for evaluation.
- 7 Transition 1 from the junction has a condition.
- 8 The condition is false.
- 9 Transition 2 from the junction is marked for evaluation.
- 10 Transition 2 from the junction has a condition.
- 11 The condition is false.
- 12 Transition 3 from the junction is marked for evaluation.
- 13 Transition 3 from the junction does not have a condition.
- 14 The destination is not a state and does not have any outgoing transitions.
- 15 Return to “Workflow for Stateflow Chart Execution” on page 3-23.

To complete the time step, follow the “Workflow for Stateflow Chart Execution” on page 3-23 for StateA, starting where you left off.



## Condition and Transition Actions

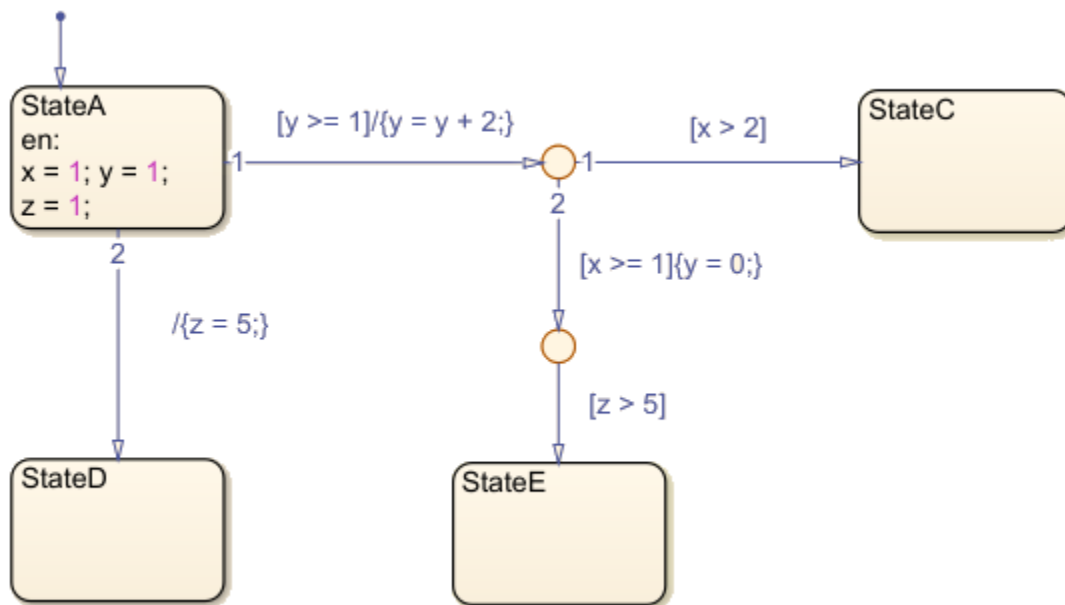
### Condition Actions

In transition label syntax, condition actions follow the transition condition and are enclosed in curly braces (`{}`). Condition actions are executed when the condition is evaluated as true but before the transition path has been determined to be valid.

### Transition Actions

In transition label syntax, transition actions are preceded with a forward slash (`/`) and are enclosed in curly braces (`{}`). Transition actions execute only after the transition path is determined to be valid.

In this example, both condition actions and transition actions exist. The Stateflow chart is initialized and the entry actions are performed for StateA. A new time step occurs and the chart wakes up. There are multiple outgoing transitions from StateA. At this time step  $x = 1$ ,  $y = 1$ , and  $z = 1$ .



### Evaluate Outgoing Transitions with Condition and Transition Actions

By following the “Workflow for Evaluating Transitions” on page 3-38, the steps for evaluating the transitions of this chart are in this order:

- 1 Transition 1 from StateA is marked for evaluation.
- 2 Transition 1 from StateA has a condition (`[y >= 1]`).
- 3 The condition is true.
- 4 There are no condition actions.
- 5 The destination of transition 1 from StateA is not a state.
- 6 The junction does have outgoing transitions.
- 7 Transition 1 from the junction is marked for evaluation.
- 8 Transition 1 from the junction has a condition (`[x > 2]`).

- 9 The condition is false.
- 10 Transition 2 from the junction is marked for evaluation.
- 11 Transition 2 from the junction has a condition ( $[x \geq 1]$ ).
- 12 The condition is true.
- 13 There is a condition action ( $\{y = 0;\}$ ). Now  $y = 0$ .
- 14 The junction does have outgoing transitions.
- 15 The transition from the junction is marked for evaluation.
- 16 Transition 1 from the junction has a condition ( $[z \geq 5]$ ).
- 17 The condition is false.
- 18 Transition 2 from StateA is marked for evaluation.
- 19 Transition 2 from StateA does not have a condition.
- 20 The destination of transition 2 from StateA is a state (StateD).
- 21 StateD is marked for entry, and StateA is marked for exit. Execute the transition action for this valid path ( $/\{z = 5\}$ ). Now  $z = 5$ .

To complete the time step, follow the “Workflow for Exiting a State” on page 3-34 for StateA and the “Workflow for Entering a Chart or State” on page 3-28 for StateE.

## See Also

### More About

- “Execution of a Stateflow Chart” on page 3-23
- “Enter a Chart or State” on page 3-28
- “Exit a State” on page 3-34

## Super Step Semantics

By default, Stateflow charts execute once for each input event or time step. If you are modeling a system that must react quickly to inputs, you can enable super step semantics. Super step semantics are supported only in Stateflow charts in a Simulink model.

When you enable super step semantics, a Stateflow chart executes multiple times for every active input event or for every time step when the chart has no input events. The chart takes valid transitions until *either* of these conditions occurs:

- No more valid transitions exist, that is, the chart is in a stable active state configuration.
- The number of transitions taken exceeds a user-specified maximum number of iterations.

In a super step, your chart responds faster to inputs but performs more computations in each time step. Therefore, when generating code for an embedded target, make sure that the chart can finish the computation in a single time step. To achieve this behavior, fine-tune super step parameters by setting an upper limit on the number of transitions that the chart takes per time step (see “Maximum Number of Iterations” on page 3-45).

For simulation targets, specify whether the chart goes to the next time step or generates an error if it reaches the maximum number of transitions prematurely. However, in generated code for embedded targets, the chart always goes to the next time step after taking the maximum number of transitions.

### Maximum Number of Iterations

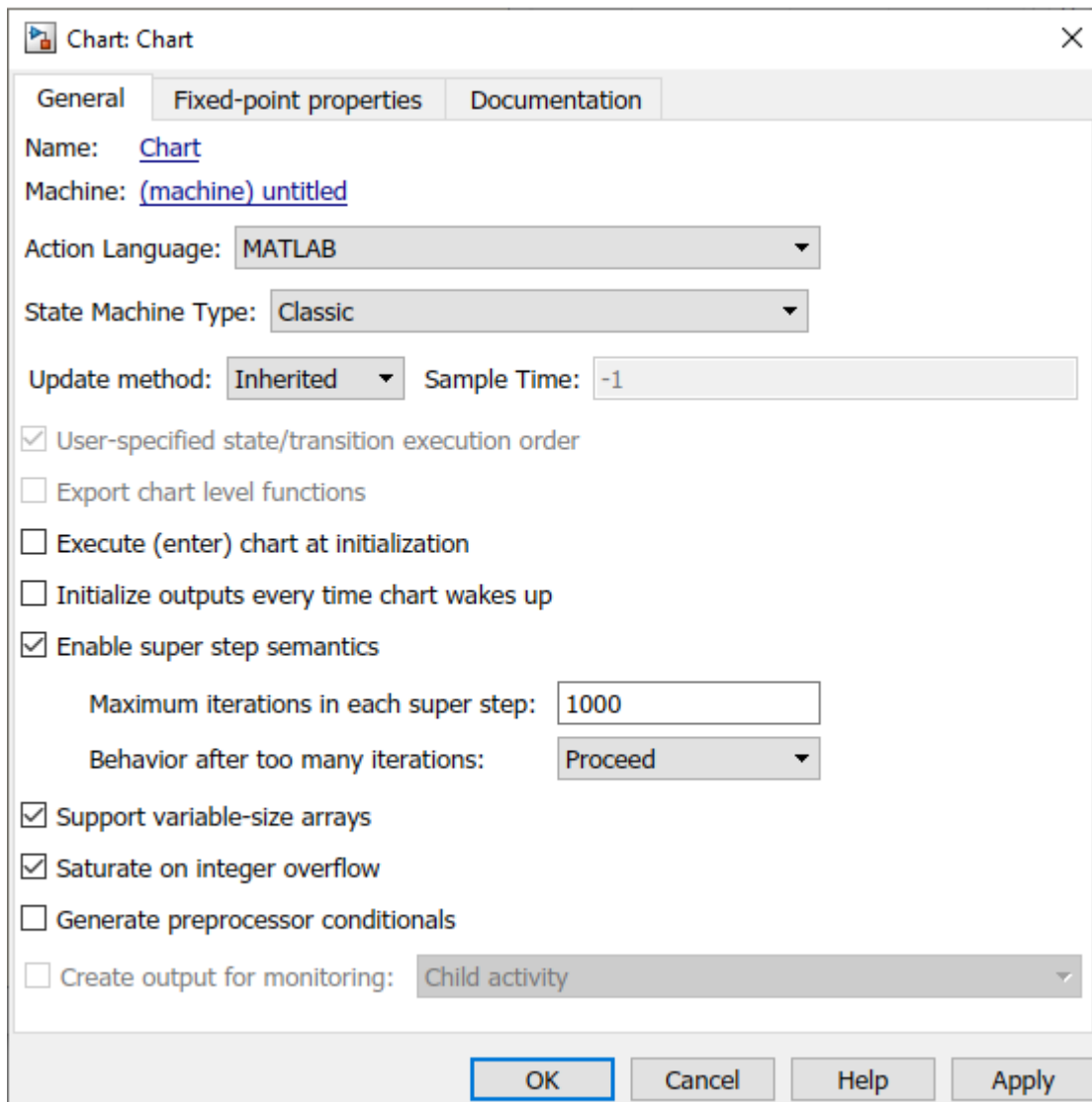
In a super step, your chart always takes at least one transition. Therefore, when you set a maximum number of iterations in each super step, the chart takes that number of transitions plus 1. For example, if you specify 10 as the maximum number of iterations, your chart takes 11 transitions in each super step. To set maximum number of iterations in each super step, see “Enable Super Step Semantics” on page 3-45.

### Enable Super Step Semantics

To enable super step semantics:

- 1 Right-click inside the top level of a chart and select **Properties** from the context menu.
- 2 In the Chart properties dialog box, select the **Enable super step semantics** check box.

Two additional fields appear below that check box.



- 3 Enter a value in the field **Maximum iterations in each super step**.

The chart always takes one transition during a super step, so the value  $N$  that you specify represents the maximum number of *additional* transitions (for a total of  $N+1$ ). Try to choose a number that allows the chart to reach a stable state within the time step, based on the mode logic of your chart. For more information, see “Maximum Number of Iterations” on page 3-45

- 4 Select an action from the drop-down menu in the field **Behavior after too many iterations**.

Your selection determines how the chart behaves during simulation if it exceeds the maximum number of iterations in the super step before reaching a stable state.

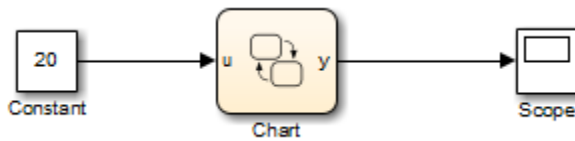
Behavior	Description
<b>Proceed</b>	The chart goes back to sleep with the last active state configuration, that is, after updating local data at the last valid transition in the super step.

Behavior	Description
<b>Throw Error</b>	Simulation stops and the chart generates an error, indicating that too many iterations occurred while trying to reach a stable state.  <b>Note</b> Selecting <b>Throw Error</b> can help detect infinite loops in transition cycles (see “Detection of Infinite Loops in Transition Cycles” on page 3-50).

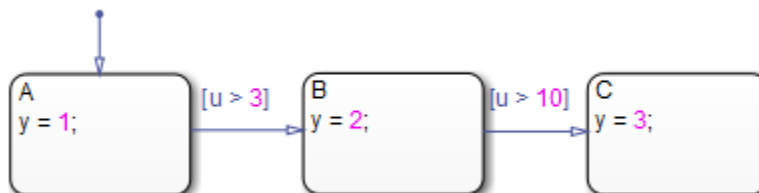
**Note** This option is relevant only for simulation targets. For embedded targets, code generation goes to the next time step rather than generating an error.

## Super Step Example

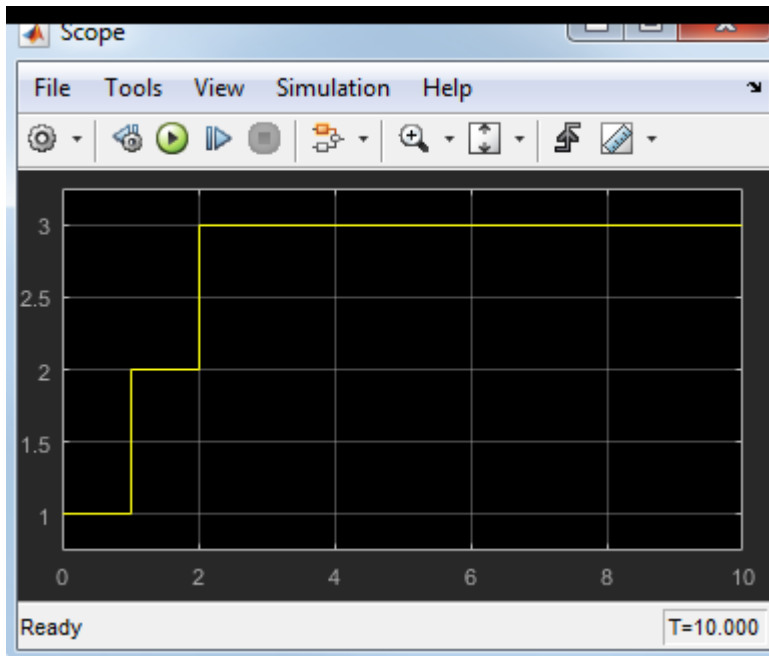
The following model shows how super step semantics differs from default semantics:



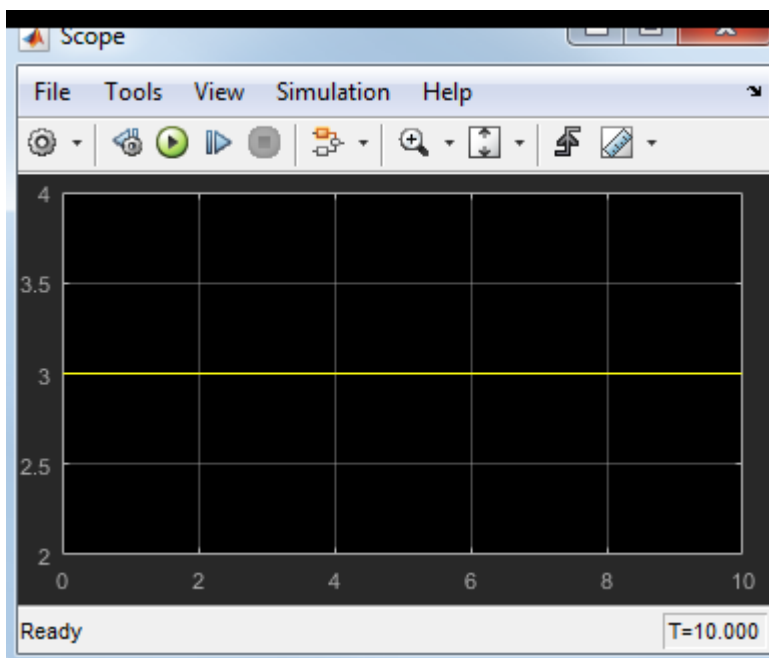
In this model, a Constant block outputs a constant value of 20 to input  $u$  in a Stateflow chart. Because the value of  $u$  is always 20, each transition in the chart is valid:



By default, the chart takes only one transition in each simulation step, incrementing  $y$  each time.

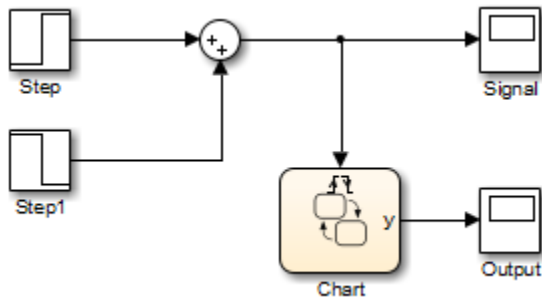


When you enable super step semantics, the chart takes all valid transitions in each time step, stopping at state C with  $y = 3$ .

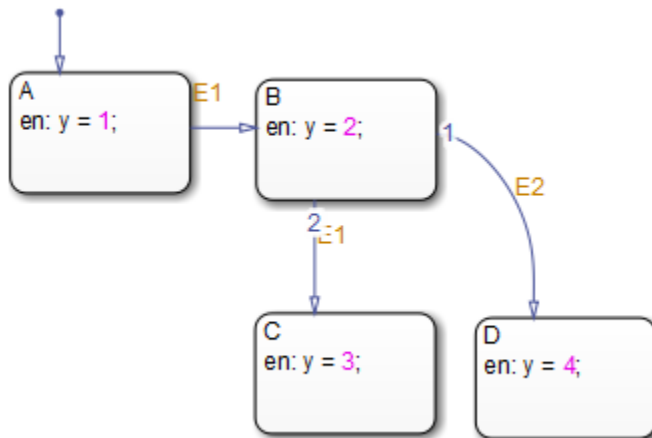


### How Super Step Semantics Works with Multiple Input Events

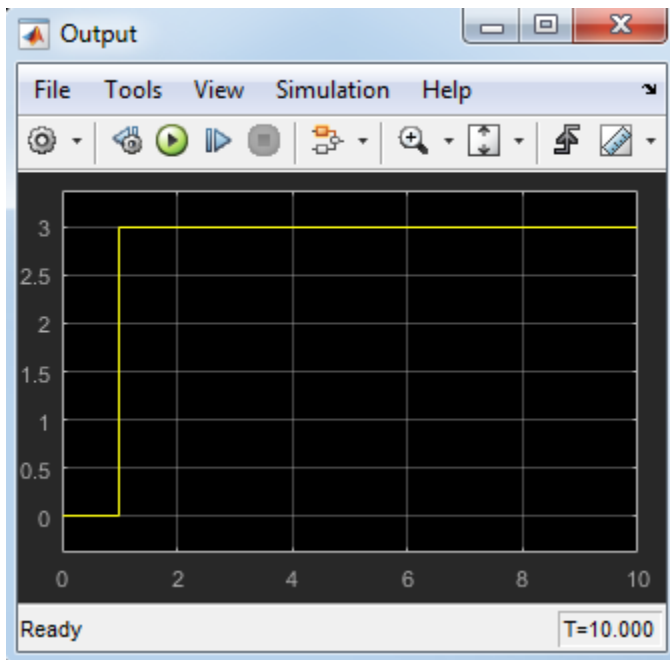
When you enable super step semantics for a chart with multiple active input events, the chart takes all valid transitions for the first active event before it begins processing the next active event. For example, consider the following model:



In this model, the Sum block produces a 2-by-1 vector signal that goes from [0,0] to [1,1] at time  $t = 1$ . As a result, when the model wakes up the chart, events E1 and E2 are both active:



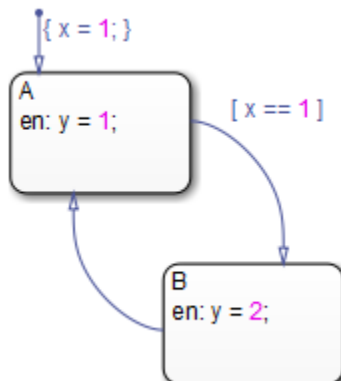
If you enable super step semantics, the chart takes all valid transitions for event E1. The chart takes transitions from state A to B and then from state B to C in a single super step. The scope shows that  $y = 3$  at the end of the super step:



In a super step, this chart never transitions to state D because there is no path from state C to state D.

### Detection of Infinite Loops in Transition Cycles

If your chart contains transition cycles, taking multiple transitions in a single time step can cause infinite loops. Consider the following example:



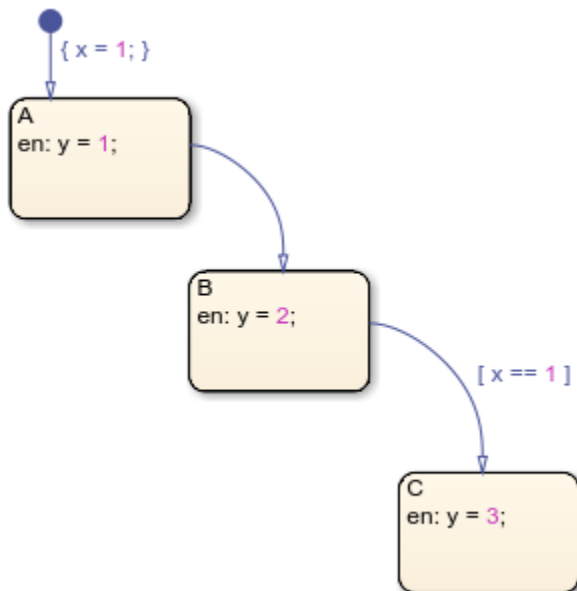
In this example, the transitions between states A and B cycle and produce an infinite loop because the value of  $x$  remains constant at 1. One way to detect infinite loops is to configure your chart to generate an error if it reaches a maximum number of iterations in a super step. See “Enable Super Step Semantics” on page 3-45.

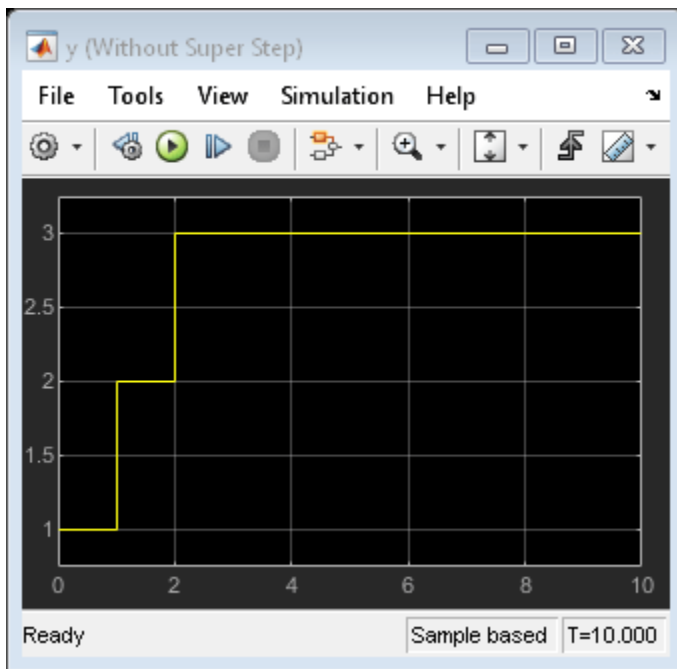
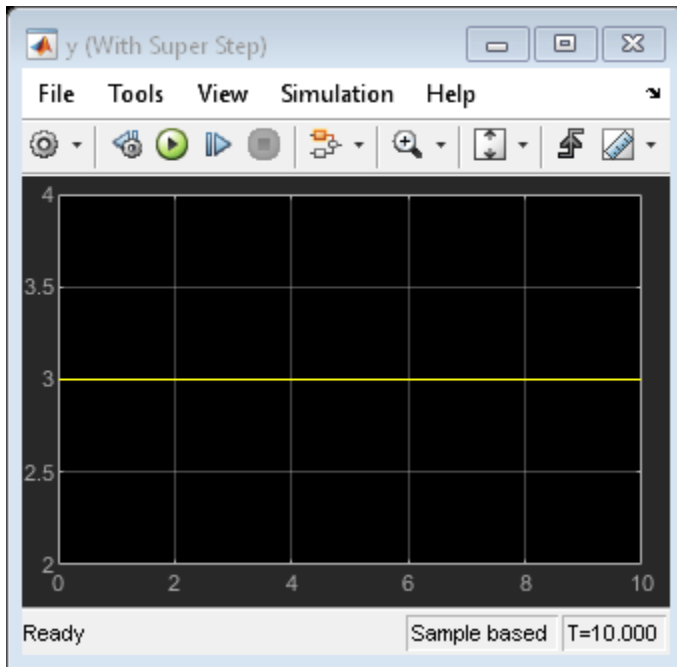


## Super Step

This model shows the use of super step semantics on a Stateflow® chart which allows the chart to repeatedly take all possible transitions from the current state to get to a stable state configuration before going to the next simulation step. This example shows two exactly identical Stateflow charts except that one has the super step mode disabled and the other has the super step mode enabled.

Run the simulation and compare the output from the two charts on the scopes. In the output from the chart 'Without Super Step' the value changes in steps till it reaches its final steady state whereas in the chart 'With Super Step' the value immediately reaches its steady state because of the super step semantics.





## See Also

## More About

- "Super Step Semantics" on page 3-45

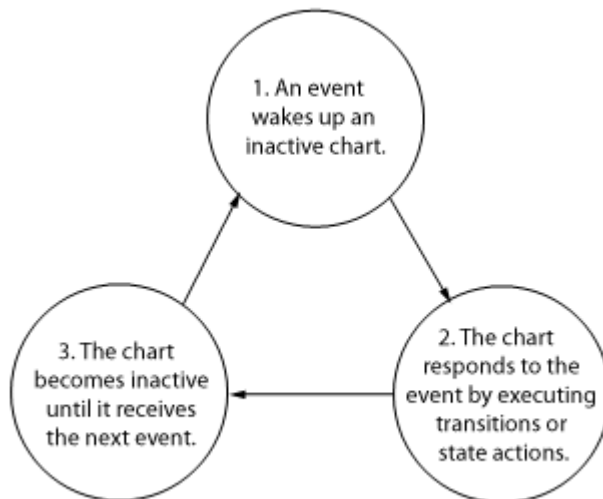
## Use Events to Execute Charts

An event is a nongraphical object that can wake up and trigger actions in Stateflow chart. For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

### How Stateflow Charts Respond to Events

Stateflow charts respond to events in a cyclical manner.

- 1 An event wakes up an inactive chart.
- 2 The chart responds to the event by executing transitions and state actions from the top down through the chart hierarchy. Starting at the chart level:
  - a The chart checks for valid transitions between states.
  - b The chart executes **during** and **on** actions for the active state.
  - c The chart proceeds to the next level down the hierarchy.
- 3 The chart becomes inactive until it receives the next event.



For more information, see “Execution of a Stateflow Chart” on page 3-23.

### Events in Simulink Models

In Simulink models, Stateflow charts receive input events from other blocks in the model.

While processing an event, a state or transition action can generate explicit or implicit events that trigger additional steps. For example:

- The operator `send` can broadcast local or output events.
- The operators `enter` and `exit` can generate implicit local events when the chart execution enters or exits a state.
- The operator `change` can generate an implicit local event when the chart sets the value of a variable.

In each case, the chart interrupts its current activity to process the new event. When the activity caused by the new event finishes executing, the chart returns to the activity that was taking place before the interruption.

---

**Note** In a Simulink model, the execution of output edge-trigger events is equivalent to toggling the value of an output data value between 0 and 1. This type of event does not interrupt the current activity of a chart. Instead, the receiving block processes the event the next time that the model executes the block. For more information, see “Activate a Simulink Block by Sending Output Events” on page 14-14.

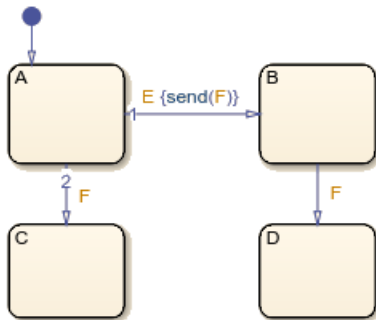
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### Early Return Logic

The results of processing a local event can conflict with the action that was taking place before the event was generated. Depending on the type of action, charts resolve these conflicts by using early return logic.

Action Type	Early Return Logic
State entry action	If the state is no longer active after the local event is processed, the chart stops the process of entering the state. The chart does not perform the remaining statements in the entry action.
State during action	If the state is no longer active after the local event is processed, the chart stops executing the state. The chart does not perform the remaining statements in the during action.
State exit action	If the state is no longer active after the local event is processed, the chart stops the process of exiting the state. The chart does not perform the remaining statements in the exit action nor any transition actions and state entry actions that result from exiting the state.
Condition action	If the source state of the inner or outer transition path, or the parent state of the default transition path, is no longer active after the local event is processed, the chart stops the transition process. The chart does not perform the remaining actions on the transition path or any state exit and entry actions that result from taking the transition.
Transition action	If the parent of the transition path is not active, or if the parent has an active substate, the chart stops the transition process. The chart does not perform the remaining actions on the transition path or any state entry actions that result from taking the transition.

For example, in this chart, the input event E and the local event F trigger the transitions between states.



Suppose that state A is active when the chart receives event E. The chart responds to the event with these steps:

- 1 The chart determines that the transition from the active state A to state B is valid as a result of event E.
- 2 The chart executes the condition action of the valid transition and broadcasts event F.
- 3 The chart interrupts the transition from state A to state B and begins to process event F.
- 4 The chart determines that the transition from the active state A to state C is valid as a result of event F.
- 5 State A executes its `exit` action.
- 6 State A becomes inactive.
- 7 State C becomes active.
- 8 State C executes its `entry` action.

After the chart processes event F, state C is the active state of the chart. Because state A is no longer active, the chart uses early return logic and stops the transition from state A to state B.

---

**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to `none`, `warning`, or `error`. The default setting is `warning`.

---

## Events in Standalone Charts

Standalone Stateflow charts receive an input event when you call the `step` function or an input event function in MATLAB.

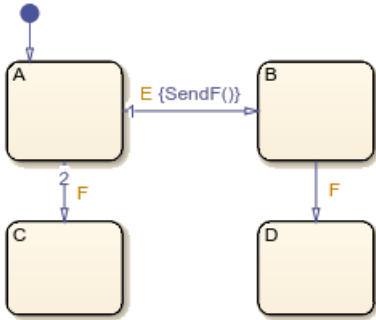
Standalone charts also receive implicit events from MATLAB timer objects associated with the absolute-time temporal logic operators `after`, `at`, and `every`. These operators define temporal logic in terms of wall-clock time. If the state associated with the temporal logic operator becomes inactive before the chart processes the implicit event, the event does not wake up the chart.

### Queuing of Events

If a chart is processing another operation when it receives an event, the chart queues the event for execution when the current step is completed. You can specify the size of the event queue by setting

the configuration option `-eventQueueSize` when you create the chart object. For more information, see “Chart Object Configuration Options” on page 35-4.

For example, in this chart, the input events E and F trigger the transitions between states. Assume that `SendF` is a function in the MATLAB path that calls the input event function F.



Suppose that state A is active when the chart receives event E. The chart responds to the event with these steps:

- 1 The chart determines that the transition from the active state A to state B is valid as a result of event E.
- 2 The chart executes the condition action of the valid transition and calls the function `SendF`.
- 3 `SendF` calls the input event function F. Because the chart is busy processing a condition action, it queues event F.
- 4 The chart completes executing the condition action.
- 5 State A executes its `exit` action.
- 6 State A becomes inactive.
- 7 State B becomes active.
- 8 State B executes its `entry` action.
- 9 The chart begins to process the queued event F.
- 10 The chart determines that the transition from the active state B to state D is valid as a result of event F.
- 11 State B executes its `exit` action.
- 12 State B becomes inactive.
- 13 State D becomes active.
- 14 State D executes its `entry` action.

After the chart processes event F, state D is the active state of the chart.

## See Also

after | at | change | enter | every | exit | send | timer

## More About

- “Execution of a Stateflow Chart” on page 3-23

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Control Chart Behavior by Using Implicit Events” on page 14-26
- “Control Chart Execution by Using Temporal Logic” on page 16-36

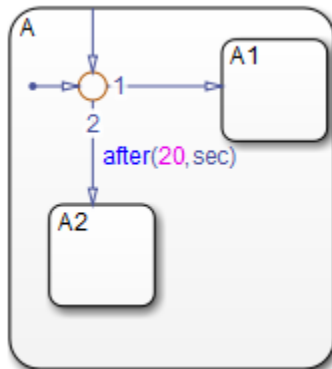
## Group and Execute Transitions

### Transition Flow Chart Types

Before executing transitions for an active state or chart, Stateflow software groups transitions by the following types:

- Default flow charts are all default transition segments that start with the same parent.
- Inner flow charts are all transition segments that originate on a state and reside entirely within that state.
- Outer flow charts are all transition segments that originate on the respective state but reside at least partially outside that state.

Each set of flow charts includes other transition segments connected to a qualifying transition segment through junctions and transitions. Consider the following example:



In this example, state A has both an inner and a default transition that connect to a junction with outgoing transitions to states A.A1 and A.A2. If state A is active, its set of inner flow charts includes:

- The inner transition
- The outgoing transitions from the junction to state A.A1 and A.A2

In addition, the set of default flow charts for state A includes:

- The default transition to the junction
- The two outgoing transitions from the junction to state A.A1 and A.A2

In this case, the two outgoing transition segments from the junction are members of more than one flow chart type.

### Order of Execution for a Set of Flow Charts

Each flow chart group executes in the order of group priority until a valid transition appears. The default transition group executes first, followed by the outer transitions group and then the inner transitions group. Each flow chart group executes as follows:

- 1 Order the group's transition segments for the active state.



An active state can have several possible outgoing transitions. The chart orders these transitions before checking them for validity. See “Transition Evaluation Order” on page 3-38.

- 2** Select the next transition segment in the set of ordered transitions.
- 3** Test the transition segment for validity.
- 4** If the segment is invalid, go to step 2.
- 5** If the destination of the transition segment is a state, do the following:
  - a** Testing of transition segments stops and a transition path forms by backing up and including the transition segment from each preceding junction back to the starting transition.
  - b** The states that are the immediate substates of the parent of the transition path exit (see “Exit a State” on page 3-34).
  - c** The transition action from the final transition segment of the full transition path executes.
  - d** The destination state becomes active (see “Enter a Chart or State” on page 3-28).
- 6** If the destination is a junction with no outgoing transition segments, do the following:
  - a** Testing stops without any state exits or entries.
- 7** If the destination is a junction with outgoing transition segments, repeat step 1 for the set of outgoing segments.
- 8** After testing all outgoing transition segments at a junction, take the following actions:
  - a** Backtrack the incoming transition segment that brought you to the junction.
  - b** Continue at step 2, starting with the next transition segment after the backup segment.

The set of flow charts completes execution when all starting transitions have been tested.

## Execution Order for Parallel States

### Ordering for Parallel States

Although multiple parallel (AND) states in the same chart execute concurrently, the Stateflow chart must determine when to activate each one during simulation. This ordering determines when each parallel state performs the actions that take it through all stages of execution.

Unlike exclusive (OR) states, parallel states do not typically use transitions. Instead, order of execution depends on:

- Explicit ordering

Specify explicitly the execution order of parallel states on a state-by-state basis (see “Explicit Ordering of Parallel States” on page 3-60).

- Implicit ordering

Override explicit ordering by letting a Stateflow chart use internal rules to order parallel states (see “Implicit Ordering of Parallel States” on page 3-61).

Parallel states are assigned priority numbers based on order of execution. The lower the number, the higher the priority. The priority number of each state appears in the upper right corner.

Because execution order is a chart property, all parallel states in the chart inherit the property setting. You cannot mix explicit and implicit ordering in the same Stateflow chart. However, you can mix charts with different ordering modes in the same Simulink model.

In code that is generated from Stateflow charts that contain parallel states, each state executes based on its order.

### Explicit Ordering of Parallel States

By default, a Stateflow chart orders parallel states explicitly based on execution priorities you set.

#### How Explicit Ordering Works

When you open a new Stateflow chart — or one that does not yet contain any parallel states — the chart automatically assigns priority numbers to parallel states in the order you create them. Numbering starts with the next available number within the parent container.

When you enable explicit ordering in a chart that contains implicitly ordered parallel states, the implicit priorities are preserved for the existing parallel states. When you add new parallel states, execution order is assigned in the same way as for new Stateflow charts — in order of creation.

You can reset execution order assignments at any time on a state-by-state basis, as described in “Set Execution Order for Parallel States Individually” on page 3-61. When you change execution order for a parallel state, the Stateflow chart automatically renumbers the other parallel states to preserve their relative execution order. For details, see “Order Maintenance for Parallel States” on page 3-62.

#### Order Parallel States Explicitly

To use explicit ordering for parallel states, perform these tasks:

- 1 “Enable Explicit Ordering at the Chart Level” on page 3-61
- 2 “Set Execution Order for Parallel States Individually” on page 3-61

### Enable Explicit Ordering at the Chart Level

To enable explicit ordering for parallel states, follow these steps:

- 1 Right-click inside the top level of the chart and select **Properties** from the context menu.

The Chart properties dialog box appears.

- 2 Select the **User-specified state/transition execution order** check box.
- 3 Click **OK**.

If your chart already contains parallel states that have been ordered implicitly, the existing priorities are preserved until you explicitly change them. When you add new parallel states in explicit mode, your chart automatically assigns priorities based on order of creation (see “How Explicit Ordering Works” on page 3-60). However you can now explicitly change execution order on a state-by-state basis, as described in “Set Execution Order for Parallel States Individually” on page 3-61.

### Set Execution Order for Parallel States Individually

In explicit ordering mode, you can change the execution order of individual parallel states. Right-click the parallel state of interest and select a new priority from the **Execution Order** menu.

## Implicit Ordering of Parallel States

### Rules of Implicit Ordering for Parallel States

In implicit ordering mode, a Stateflow chart orders parallel states implicitly based on location. Priority goes from top to bottom and then left to right, based on these rules:

- The higher the vertical position of a parallel state in the chart, the higher the execution priority for that state.
- Among parallel states with the same vertical position, the leftmost state receives highest priority.

The following example shows how these rules apply to top-level parallel states and parallel substates.



**Note** Implicit ordering creates a dependency between design layout and execution priority. When you rearrange parallel states in your chart, you can accidentally change order of execution and affect simulation results. For more control over your designs, use the default explicit ordering mode to set execution priorities.

---

#### Order Parallel States Implicitly

To use implicit ordering for parallel states, follow these steps:

- 1 Right-click inside the top level of the chart and select **Properties** from the context menu.
- 2 In the Chart properties dialog box, clear the **User-specified state/transition execution order** check box.
- 3 Click **OK**.

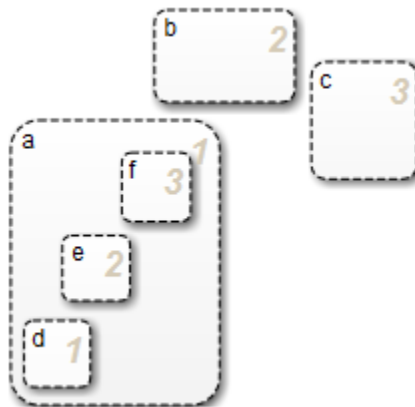
#### Order Maintenance for Parallel States

Whether you use explicit or implicit ordering, a chart tries to reconcile execution priorities when you remove, renumber, or add parallel states. In these cases, a chart reprioritizes the parallel states to:

- Fill in gaps in the sequence so that ordering is contiguous
- Ensure that no two states have the same priority
- Preserve the intended relative priority of execution

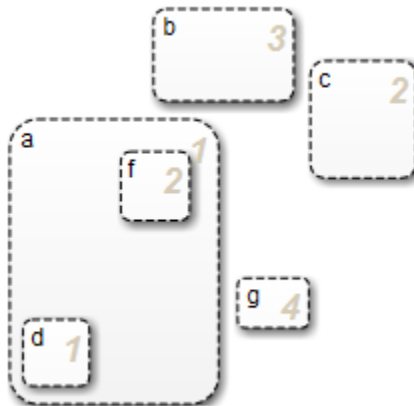
#### How a Chart Preserves Relative Priorities in Explicit Mode

For explicit ordering, a chart preserves the user-specified priorities. Consider this example of explicit ordering:



Because of explicit ordering, the priority of each state and substate matches the order of creation in the chart. The chart reprioritizes the parallel states and substates when you perform these actions:

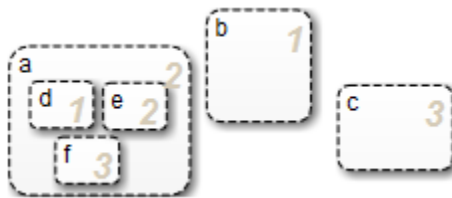
- 1 Change the priority of top-level state **b** to 3.
- 2 Add a top-level state **g**.
- 3 Remove substate **e**.



The chart preserves the priority set explicitly for top-level state *b*, but renumbers all other parallel states to preserve their prior relative order.

### How a Chart Preserves Relative Priorities in Implicit Mode

For implicit ordering, a chart preserves the intended relative priority based on geometry. Consider this example of implicit ordering:



If you remove top-level state *b* and substate *e*, the chart automatically reprioritizes the remaining parallel states and substates to preserve implicit geometric order:



### Execution Priorities in Restored States

There are situations in which you need to restore a parallel state after you remove it from a Stateflow chart. In implicit ordering mode, a chart reassigns the execution priority based on where you restore the state. If you return the state to its original location in the chart, you restore its original priority.

However, in explicit ordering mode, a chart cannot always reinstate the original execution priority to a restored state. It depends on *how* you restore the state.

If you remove a state by...	And restore the state by...	What is the priority?
Deleting, cutting, dragging outside the boundaries of the parent state, or dragging so its boundaries overlap the parent state	Using the undo command	The original priority is restored.
Dragging outside the boundaries of the parent state or so its boundaries overlap the parent state <i>and</i> releasing the mouse button	Dragging it back into the parent state	The original priority is lost. The Stateflow chart treats the restored state as the last created and assigns it the lowest execution priority.
Dragging outside the boundaries of the parent state or so its boundaries overlap the parent state <i>without</i> releasing the mouse button	Dragging it back into the parent state	The original priority is restored.
Dragging so its boundaries overlap one or more sibling states	Dragging it to a location with no overlapping boundaries inside the same parent state	The original priority is restored.
Cutting	Pasting	The original priority is lost. The Stateflow chart treats the restored state as the last created and assigns it the lowest execution priority.

## Switching Between Explicit and Implicit Ordering

If you switch to implicit mode after explicitly ordering parallel states, the Stateflow chart resets execution order to follow implicit rules of geometry. However, if you switch from implicit to explicit mode, the chart does not restore the original explicit execution order.

## Execution Order of Parallel States in Boxes and Subcharts

When you group parallel states inside a box, the states retain their relative execution order. In addition, the Stateflow chart assigns the box its own priority based on the explicit or implicit ordering rules that apply. This priority determines when the chart activates the parallel states inside the box.

When you convert a state with parallel decomposition into a subchart, its substates retain their relative execution order based on the prevailing explicit or implicit rules.

# Create Stateflow Charts

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- “Model Reactive Systems in Stateflow” on page 4-2
- “Represent Operating Modes by Using States” on page 4-5
- “Transition Between Operating Modes” on page 4-14
- “Stateflow Editor Operations” on page 4-20

## Model Reactive Systems in Stateflow

### Identify System Attributes

Before you build a Stateflow chart in a Simulink model, identify your system attributes by answering these questions:

- 1 What are your interfaces?
  - a What are the event triggers to which your system reacts?
  - b What are the inputs to your system?
  - c What are the outputs from your system?
- 2 Does your system have any operating modes?
  - a If the answer is yes, what are the operating modes?
  - b Between which modes can you transition? Are there any operating modes that run in parallel?

If your system has no operating modes, the system is stateless. If your system has operating modes, the system is modal.

### Select a State Machine Type

After identifying your system attributes, the first step is to create a new chart. For more information, see `sfnw`. Select one of the following state machine types:

- Classic — The default machine type. Provides the full set of semantics for MATLAB charts and C charts.
- Mealy — Machine type in which output is a function of inputs *and* state.
- Moore — Machine type in which output is a function of state.

For more information, see “How Stateflow Objects Interact During Execution” on page 3-5, “Differences Between MATLAB and C as Action Language Syntax” on page 17-5, and “Overview of Mealy and Moore Machines” on page 7-2.

### Specify State Actions and Transition Conditions

After you create an empty chart, answer the following questions:

- 1 For each state, what are the actions you want to perform?
- 2 What are the rules for transitioning between your states? If your chart has no states, what are the rules for transitioning between branches of your flow logic?

Using your answers to those questions, specify state actions and transition conditions:

- 1 Draw states to represent your operating modes, if any. See “Represent Operating Modes by Using States” on page 4-5.
- 2 Implement the state actions by adding state labels that use the appropriate syntax. See “States” on page 2-8.



- 3 Draw transitions to represent the direction of flow logic, between states or between branches of your flow chart. See “Transition Between Operating Modes” on page 4-14.
- 4 Implement the transition conditions by adding transition labels that use the appropriate syntax. See “Transitions” on page 2-21.

## Define Persistent Data to Store State Variables

After adding state actions and transition conditions to your chart, determine if the chart requires any local or persistent data to store state variables. If so, follow these steps:

- 1 Add local data to the appropriate level of the chart hierarchy. See “Add Stateflow Data” on page 12-2.

You can also use the Symbol Wizard to add data to your chart. See “Resolve Symbols Through the Symbol Wizard” on page 31-37.

- 2 Specify the type, size, complexity, and other data properties. See “Set Data Properties” on page 12-5.

## Simplify State Actions and Transition Conditions with Function Calls

State actions and transition conditions can be complex enough that defining them inline on the state or transition is not feasible. In this case, express the actions or conditions using one of the following types of Stateflow functions:

- Flow chart — Encapsulate flow charts containing if-then-else, switch-case, for, while, or do-while patterns.
- MATLAB — Write matrix-oriented algorithms; call MATLAB functions for data analysis and visualization.
- Simulink — Call Simulink function-call subsystems directly to streamline design and improve readability.
- Truth table — Represent combinational logic for decision-making applications such as fault detection and mode switching.

Use the function format that is most natural for the type of calculation in the state action or transition condition. For more information on the four types of functions, see:

- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Use Truth Tables to Model Combinatorial Logic” on page 10-2

If the four types of Stateflow functions do not work, you can write your own C or C++ code for integration with your chart. For more information about custom code integration, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

## Check That Your System Representation Is Complete

Does your Stateflow chart fully express the logical or event-driven components of your system?

- If the answer is yes, you are done.
- If the answer is no, you can create a separate chart or add hierarchy to your current chart.
  - To create a new chart, repeat all the steps in this basic workflow.
  - To add hierarchy, repeat the previous three steps on lower levels of the current chart.

## Represent Operating Modes by Using States

A state describes an operating mode of a reactive system. In a Stateflow chart, states are used for sequential design to create state transition diagrams.

States can be active or inactive. The activity or inactivity of a state can change depending on events and conditions. The occurrence of an event drives the execution of the state transition diagram by making states become active or inactive. For more information, see “States” on page 2-8.

### Create a State

You create states by drawing them in the editor for a particular chart (block). Follow these steps:

- 1 Select the State tool:



- 2 Move your pointer into the drawing area.

In the drawing area, the pointer becomes state-shaped (rectangular with oval corners).

- 3 Click in a particular location to create a state.

The created state appears with a question mark (?) label in its upper left-hand corner.

- 4 Click the question mark.

A text cursor appears in place of the question mark.

- 5 Enter a name for the state and click outside of the state when finished.

The label for a state specifies its required name and optional actions. See “Label States” on page 4-11 for more detail.

### Move and Resize States

To move a state, do the following:

- 1 Click and drag the state.
- 2 Release it in a new position.

To resize a state, do the following:

- 1 Place your pointer over a corner of the state.

When your pointer is over a corner, it appears as a double-ended arrow (PC only; pointer appearance varies with other platforms).

- 2 Click and drag the state's corner to resize the state and release the left mouse button.

### Create Substates and Superstates

A substate is a state that can be active only when another state, called its parent, is active. States that have substates are known as superstates. To create a substate, click the State tool and drag a new state into the state you want to be the superstate. A Stateflow chart creates the substate in the

specified parent state. You can nest states in this way to any depth. To change the parentage of a substate, drag it from its current parent in the chart and drop it in its new parent.

---

**Note** A parent state must be graphically large enough to accommodate all its substates. You might need to resize a parent state before dragging a new substate into it. You can bypass the need for a state of large graphical size by declaring a superstate to be a subchart. See “Encapsulate Modal Logic by Using Subcharts” on page 8-10 for details.

---

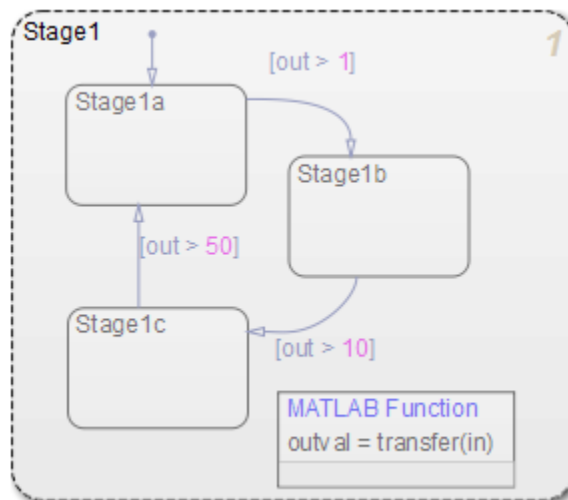
## Group States

### When to Group a State

Group a state to move all graphical objects inside a state together. When you group a state, the chart treats the state and its contents as a single graphical unit. This behavior simplifies editing of a chart. For example, moving a grouped state moves all substates and functions inside that state.

### How to Group a State

You can group a state by right-clicking it and then selecting **Group & Subchart > Group** in the context menu. The state appears shaded in gray to indicate that it is now grouped.



### When to Ungroup a State

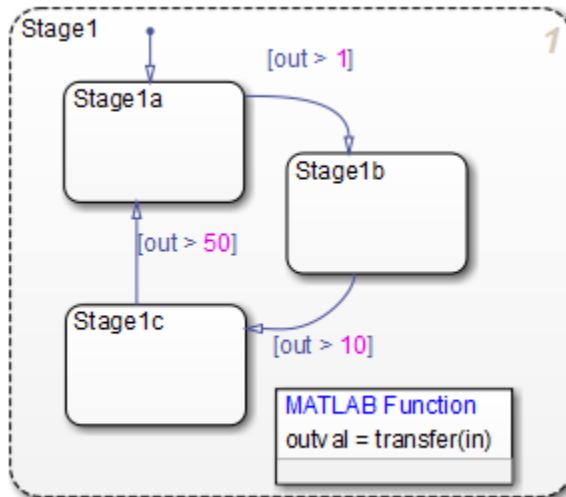
You must ungroup a state before performing these actions:

- Selecting objects inside the state
- Moving other graphical objects into the state

If you try to move objects such as states and graphical functions into a grouped state, you see an invalid intersection error message. Also, the objects with an invalid intersection have a red border.

### How to Ungroup a State

You can ungroup a state by right-clicking it and then clearing **Group & Subchart > Group** in the context menu. The background of the state no longer appears gray.



## Specify Substate Decomposition

You specify whether a superstate contains parallel (AND) states or exclusive (OR) states by setting its decomposition. A state whose substates are all active when it is active has parallel (AND) decomposition. A state in which only one substate is active when it is active has exclusive (OR) decomposition. An empty state's decomposition is exclusive.

To alter a state's decomposition, select the state, right-click to display the state's **Decomposition** context menu, and select **OR (Exclusive)** or **AND (Parallel)** from the menu.

You can also specify the state decomposition of a chart. In this case, the Stateflow chart treats its top-level states as substates. The chart creates states with exclusive decomposition. To specify a chart's decomposition, deselect any selected objects, right-click to display the chart's **Decomposition** context menu, and select **OR (Exclusive)** or **AND (Parallel)** from the menu.

The appearance of the substates indicates the decomposition of their superstate. Exclusive substates have solid borders, parallel substates, dashed borders. A parallel substate also contains a number in its upper right corner. The number indicates the activation order of the substate relative to its sibling substates.

## Specify Activation Order for Parallel States

You can specify activation order by using one of two methods: explicit or implicit ordering.

- By default, when you create a new Stateflow chart, explicit ordering applies. In this case, you specify the activation order on a state-by-state basis.
- You can also override explicit ordering by letting the chart order parallel states based on location. This mode is known as implicit ordering.

For more information, see “Explicit Ordering of Parallel States” on page 3-60 and “Implicit Ordering of Parallel States” on page 3-61.

---

**Note** The activation order of a parallel state appears in its upper right corner.

## Change State Properties

Use the State dialog box to view and change the properties for a state. To access the State dialog box:

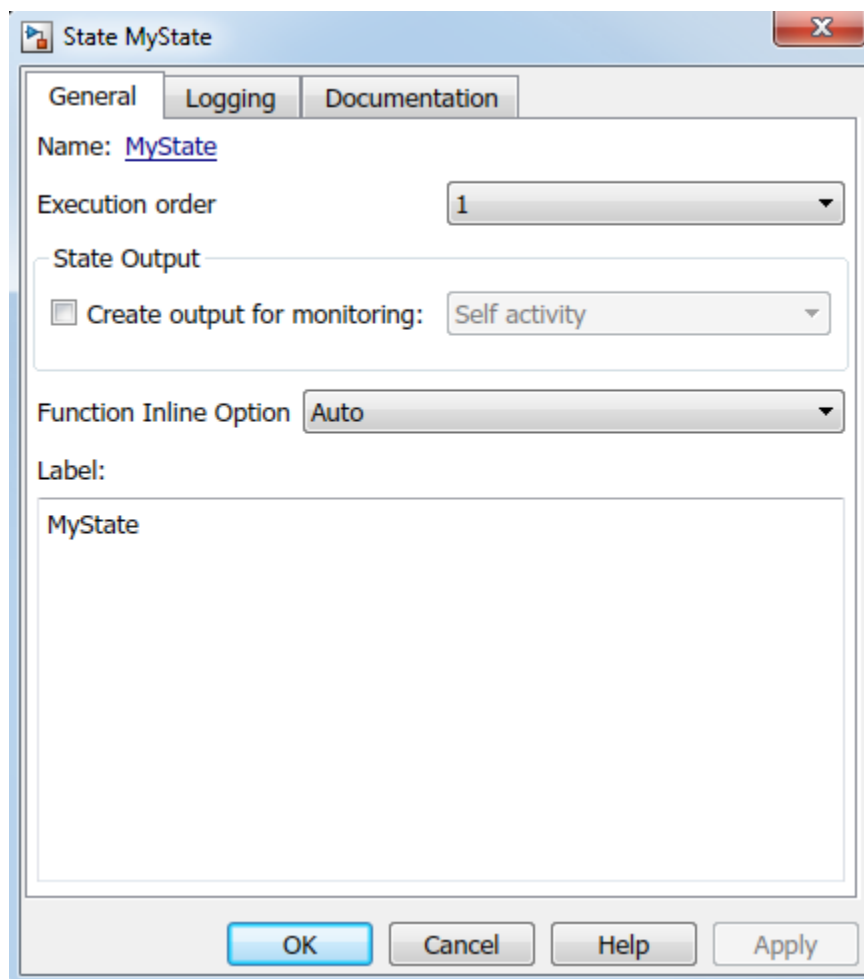
- 1 Right-click the state and select **Properties**.

The State properties dialog box appears. For descriptions of properties, see “Properties You Can Set in the General Pane” on page 4-8 and “Properties You Can Set in the Logging Pane” on page 4-9.

- 2 Modify property settings and then click one of these buttons:
  - **Apply** to save the changes and keep the State dialog box open
  - **Cancel** to return to the previous settings
  - **OK** to save the changes and close the dialog box
  - **Help** to display the documentation in an HTML browser window

### Properties You Can Set in the General Pane

The **General** pane of the State properties dialog box appears as shown.

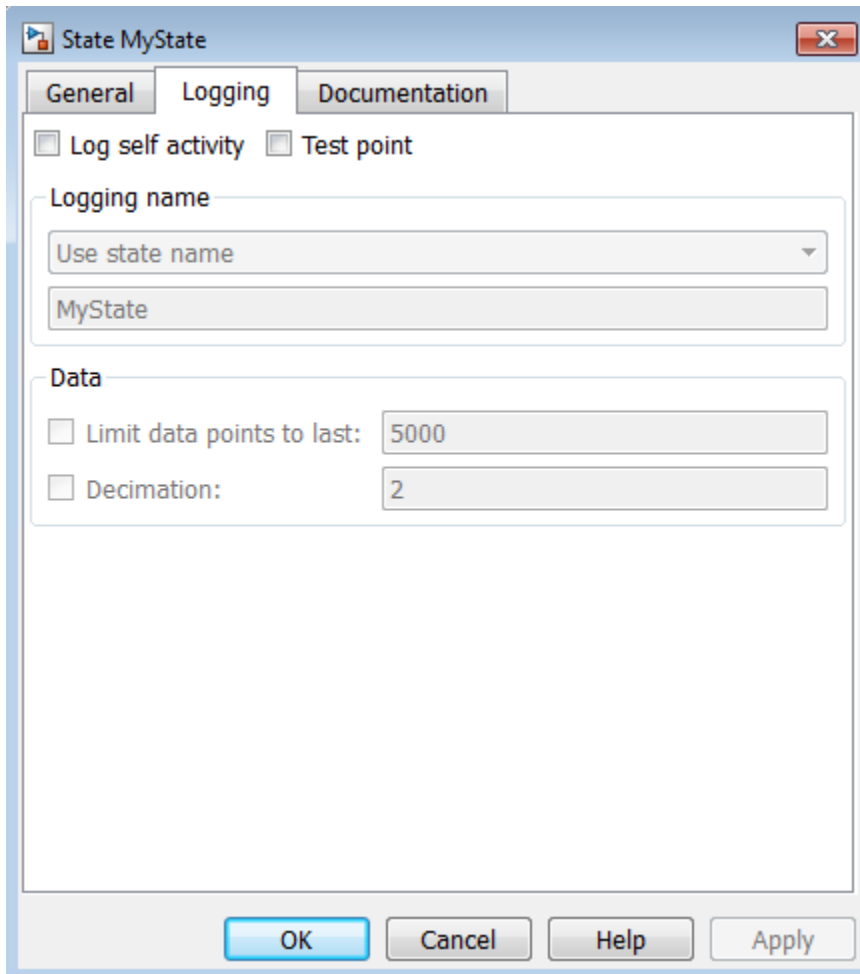


You can set these properties in the **General** pane.

Property	Description
<b>Name</b>	Stateflow chart name; read-only; click this hypertext link to bring the state to the foreground.
<b>Execution order</b>	Set the execution order of a parallel (AND) state. This property does not appear for exclusive (OR) states. See “Execution Order for Parallel States” on page 3-60.
<b>Create data for monitoring</b>	Select this option to create state activity data. See “Monitor State Activity Through Active State Data” on page 13-2.
<b>Function Inline Option</b>	<p>Select one of these options to control the inlining of state functions in generated code:</p> <ul style="list-style-type: none"> <li>• <b>Auto</b> Inlines state functions based on an internal heuristic.</li> <li>• <b>Inline</b> Always inlines state functions in the parent function, as long as the function is not part of a recursion. See “Inline State Functions in Generated Code” (Simulink Coder)</li> <li>• <b>Function</b> Creates separate static functions for each state.</li> </ul>
<b>Label</b>	The label for the state, which includes the name of the state and its associated actions. See “Label States” on page 4-11.

### Properties You Can Set in the Logging Pane

The **Logging** pane of the State properties dialog box appears as shown.



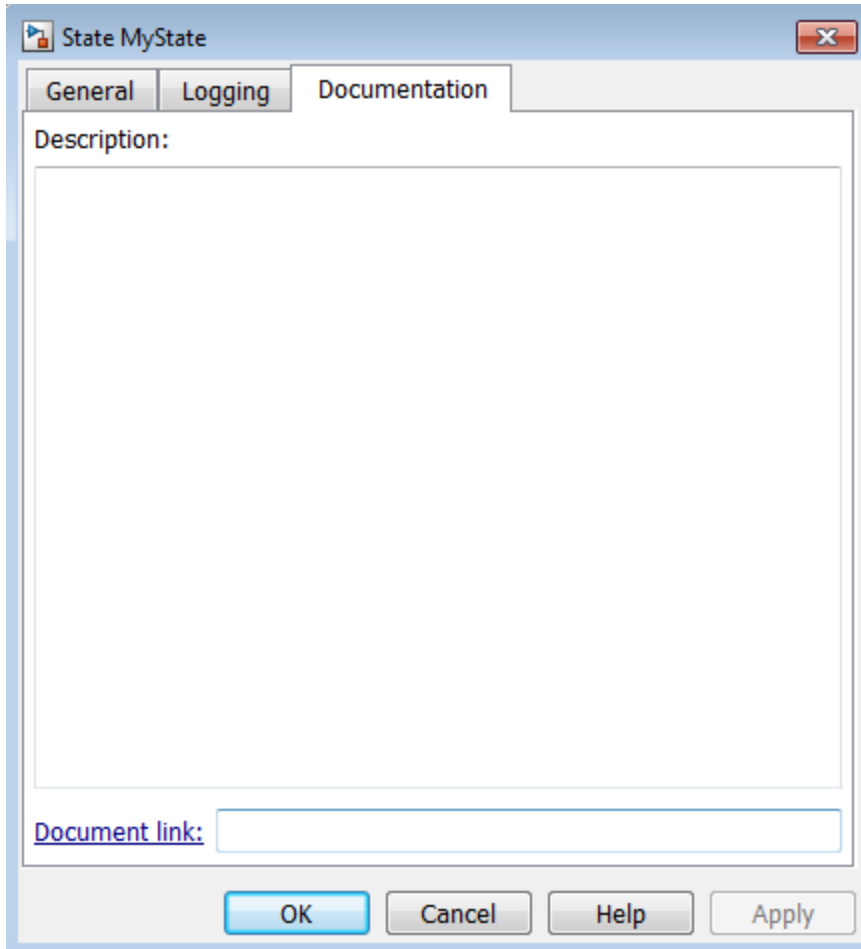
You can set these properties in the **Logging** pane.

Property	Description
<b>Log self activity</b>	Saves the self activity value to the MATLAB workspace during simulation.
<b>Test point</b>	Designates the state as a test point that can be monitored with a floating scope during model simulation. You can also log test point values into MATLAB workspace objects. See “Monitor Test Points in Stateflow Charts” on page 33-39.
<b>Logging name</b>	Specifies the name associated with the logged self activity. Simulink software uses the signal name as its logging name by default. To specify a custom logging name, select <b>Custom</b> from the list box and enter the new name in the adjacent edit field.
<b>Limit data points to last</b>	Limits the self activity logged to the most recent samples.
<b>Decimation</b>	Limits self activity logged by skipping samples. For example, a decimation factor of 2 saves every other sample.



## Properties You Can Set in the Documentation Pane

The **Documentation** pane of the State properties dialog box appears as shown.



You can set these properties in the **Documentation** pane.

Property	Description
<b>Description</b>	Textual description or comment.
<b>Document link</b>	Enter a URL address or a general MATLAB command. Examples are <code>www.mathworks.com</code> , <code>mailto:email_address</code> , and <code>edit /spec/data/speed.txt</code> .

## Label States

The label for a state specifies its required name for the state and the optional actions executed when the state is entered, exited, or receives an event while it is active.

State labels have the following general format.

```
name/
entry:entry actions
```

during:*during actions*  
 exit:*exit actions*  
 bind:*data and events*  
 on *event\_or\_message\_name: on event\_or\_message\_name actions*

The italicized entries in this format have the following meanings:

Keyword	Entry	Description
Not applicable	<i>name</i>	A unique reference to the state with optional slash
entry or en	<i>entry actions</i>	Actions executed when a particular state is entered as the result of a transition taken to that state
during or du	<i>during actions</i>	Actions that are executed when a state receives an event while it is active with no valid transition away from the state
exit or ex	<i>exit actions</i>	Actions executed when a state is exited as the result of a transition taken away from the state
bind	<i>data or events</i>	Binds the specified data or events to this state. Bound data can be changed only by this state or its children, but can be read by other states. Bound events can be broadcast only by this state or its children.
on	<i>event_or_message_name</i>  and  <i>on event_name actions</i>	A specified event or message  and  Actions executed when a state is active and the specified event occurs or message is present.  For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2 and “Communicate with Stateflow Charts by Sending Messages” on page 15-2.

**Enter the Name**

Initially, a state's label is empty. The Stateflow chart indicates this by displaying a ? in the state's label position (upper left corner). Begin labeling the state by entering a name for the state with the following steps:

- 1 Click the state.

The state turns to its highlight color and a question mark character appears in the upper left-hand corner of the state.

- 2 Click the ? to edit the label.

An editing cursor appears. You are now free to type a label.

Enter the state's name in the first line of the state's label. Names are case sensitive. To avoid naming conflicts, do not assign the same name to sibling states. However, you can assign the same name to states that do not share the same parent.

After labeling the state, click outside it. Otherwise, continue entering actions. To reedit the label, click the label text near the character position you want to edit.

## Enter Actions

After entering the name of the state in the label, you can enter actions for any of the following action types:

- **Entry Actions** — begin on a new line with the keyword `entry` or `en`, followed by a colon, followed by one or more action statements on one or more lines. To separate multiple actions on the same line, use a comma or a semicolon.

You can begin entry actions on the same line as the state's name. In this case, begin the entry action with a forward slash (/) instead of the entry keyword.

- **Exit Actions** — begin on a new line with the keyword `exit` or `ex`, followed by a colon, followed by one or more action statements on one or more lines. To separate multiple actions on the same line, use a comma or a semicolon.
- **During Actions** — begin on a new line with the keyword `during` or `du`, followed by a colon, followed by one or more action statements on one or more lines. To separate multiple actions on the same line, use a comma or a semicolon.
- **Bind Actions** — begin on a new line with the keyword `bind` followed by a colon, followed by one or more data or events on one or more lines. To separate multiple actions on the same line, use a comma or a semicolon.
- **On Actions** — begin with the keyword `on`, followed by a space and the name of an event or message, followed by a colon, followed by one or more action statements on one or more lines, for example

```
on ev1: exit();
```

To separate multiple actions on the same line, use a comma or a semicolon. If you want different events to trigger different actions, enter multiple `on` blocks in the state label. Each block specifies the action for a specific event or message, for example:

```
on ev1: action1(); on ev2: action2();
```

The execution of the actions you enter for a state is dependent only on their action type, and not the order in which you enter actions in the label. If you do *not* specify the action type explicitly for a statement, the chart treats that statement as an entry action.

---

**Tip** You can also edit the label in the properties dialog box for the state. See “Change State Properties” on page 4-8.

---

## See Also

States

## More About

- “States” on page 2-8
- “Eliminate Redundant Code by Combining State Actions” on page 16-2
- “Record State Activity by Using History Junctions” on page 8-2
- “Monitor State Activity Through Active State Data” on page 13-2

## Transition Between Operating Modes

A transition is a line with an arrowhead that links one graphical object to another. In most cases, a transition represents the passage of the system from one mode (state) to another. A transition typically connects a source and a destination object. The source object is where the transition begins and the destination object is where the transition ends. For more information, see “Transitions” on page 2-21.

### Create a Transition

Follow these steps to create transitions between states and junctions:

- 1 Place your pointer on or close to the border of a source state or junction.  
The pointer changes to crosshairs.
- 2 Click and drag a transition to a destination state or junction.
- 3 Release on the border of the destination state or junction.

Attached transitions obey the following rules:

- Transitions do not attach to the corners of states. Corners are used exclusively for resizing.
- Transitions exit a source and enter a destination at angles perpendicular to the source or destination surface.
- All transitions have smart behavior.

To delete a transition, click it and press the **Delete** key.

See the following sections for help with creating self-loop and default transitions:

- “Create Self-Loop Transitions” on page 4-16
- “Create Default Transitions” on page 4-17

### Label Transitions

Transition labels contain syntax that accompanies the execution of a transition. The following topics discuss creating and editing transition labels:

- “Edit Transition Labels” on page 4-14
- “Transition Label Format” on page 4-15

#### Edit Transition Labels

Label unlabeled transitions as follows:

- 1 Select (left-click) the transition.

The transition changes to its highlight color and a question mark (?) appears on the transition. The ? character is the default empty label for transitions.

- 2 Left-click the ? to edit the label.

You can now type a label.

To apply and exit the edit, deselect the object. To reedit the label, simply left-click the label text near the character position you want to edit.

### Transition Label Format

Transition labels have the following general format:

```
event_or_message [condition]{condition_action}/transition_action
```

Specify, as appropriate, relevant names for `event_or_message`, `condition`, `condition_action`, and `transition_action`.

Label Field	Description
<code>event_or_message</code>	The event or message that causes the transition to be evaluated.
<code>condition</code>	Defines what, if anything, has to be true for the condition action and transition to take place.
<code>condition_action</code>	If the condition is true, the action specified executes and completes.
<code>transition_action</code>	This action executes after the source state for the transition is exited but before the destination state is entered. Transition actions are supported only in Stateflow charts in Simulink models.

Transitions do not need labels. You can specify some, all, or none of the parts of the label. Rules for writing valid transition labels include:

- Can have any alphanumeric and special character combination, with the exception of embedded spaces
- Cannot begin with a numeric character
- Can have any length
- Can have carriage returns in most cases
- Must have an ellipsis (...) to continue on the next line

### Move Transitions

You can move transition lines with a combination of several individual movements. These movements are described in the following topics:

- “Bow the Transition Line” on page 4-15
- “Move Transition Attach Points” on page 4-16
- “Move Transition Labels” on page 4-16

In addition, transitions move along with the movements of states and junctions.

#### Bow the Transition Line

You can move or “bow” transition lines with the following procedure:

- 1 Place your pointer on the transition at any point along the transition except the arrow or attach points.
- 2 Click and drag your pointer to move the transition point to another location.

Only the transition line moves. The arrow and attachment points do not move.

- 3 Release the mouse button to specify the transition point location.

The result is a bowed transition line. Repeat the preceding steps to move the transition back into its original shape or into another shape.

### Move Transition Attach Points

You can move the source or end points of a transition to place them in exact locations as follows:

- 1 Place your pointer over an attach point until it changes to a small circle.
- 2 Click and drag your pointer to move the attach point to another location.
- 3 Release the mouse button to specify the new attach point.

The appearance of the transition changes from a solid to a dashed line when you detach and release a destination attach point. Once you attach the transition to a destination, the dashed line changes to a solid line.

The appearance of the transition changes to a default transition when you detach and release a source attach point. Once you attach the transition to a source, the appearance returns to normal.

### Move Transition Labels

You can move transition labels to make the Stateflow chart more readable. To move a transition label, do the following:

- 1 Click and drag the label to a new location.
- 2 Release the left mouse button.

If you mistakenly click and then immediately release the left mouse button on the label, you will be in edit mode for the label. Press the **Esc** key to deselect the label and try again. You can also click an empty location in the chart to deselect the label.

### Change Transition Arrowhead Size

The arrowhead size is a property of the destination object. Changing one of the incoming arrowheads of an object causes all incoming arrowheads to that object to be adjusted to the same size. The arrowhead size of any selected transitions, and any other transitions ending at the same object, is adjusted.

To adjust arrowhead size:

- 1 Select the transitions whose arrowhead size you want to change.
- 2 Place your pointer over a selected transition and right-click to select **Arrowhead Size**.
- 3 Select an arrowhead size from the menu.

### Create Self-Loop Transitions

A self-loop transition is a transition whose source and destination are the same state or junction. To create a self-loop transition:


- 1 Create the transition by clicking and dragging from the source state or junction.

- 2 Press the **S** key or right-click your mouse to enable a curved transition.
- 3 Continue dragging the transition tip back to a location on the source state or junction.

For the semantics of self-loops, see “Self-Loop Transitions” on page 2-29.

## Create Default Transitions

A default transition is a transition with a destination (a state or a junction), but no apparent source object.

Click the **Default Transition** button  in the toolbar and click a location in the drawing area close to the state or junction you want to be the destination for the default transition. Drag your pointer to the destination object to attach the default transition.

The size of the endpoint of the default transition is proportional to the arrowhead size. See “Change Transition Arrowhead Size” on page 4-16.

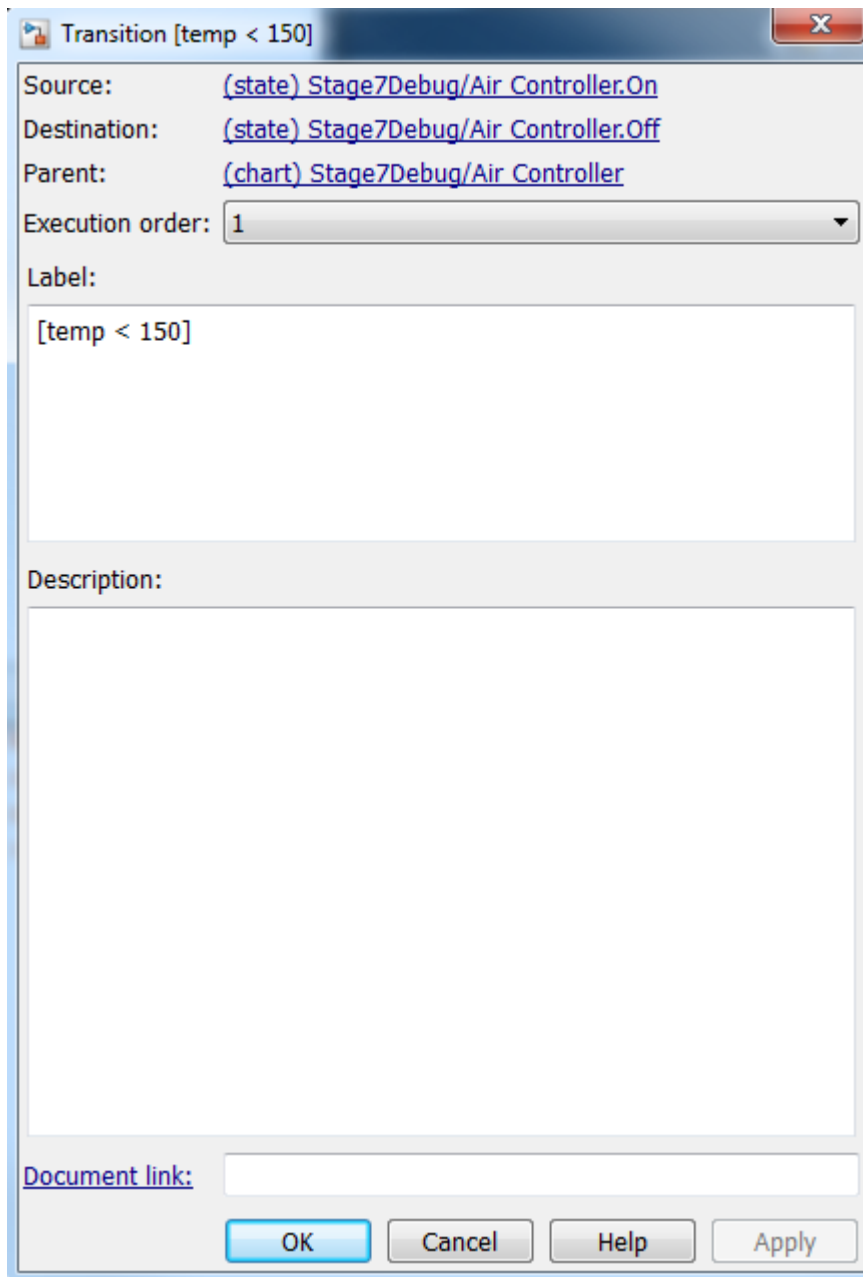
Default transitions can be labeled just like other transitions. See “Label Default Transitions” on page 2-33 for an example.

## Change Transition Properties

Use the Transition properties dialog box to view and change the properties for a transition. To access the dialog box for a particular transition:

- 1 Right-click the transition and select **Properties**.

The Transition properties dialog box appears.



The following transition properties appear in the dialog box:

Field	Description
<b>Source</b>	Source of the transition; read-only; click the hypertext link to bring the transition source to the foreground.
<b>Destination</b>	Destination of the transition; read-only; click the hypertext link to bring the transition destination to the foreground.
<b>Parent</b>	Parent of this state; read-only; click the hypertext link to bring the parent to the foreground.



Field	Description
<b>Execution order</b>	The order in which the chart executes the transition.
<b>Label</b>	The transition's label. See "Transition Labels" on page 2-22 for more information on valid label formats.
<b>Description</b>	Textual description or comment.
<b>Document link</b>	Enter a Web URL address or a general MATLAB command. Examples are <code>www.mathworks.com</code> , <code>mailto:email_address</code> , and <code>edit/spec/data/speed.txt</code> .

- 2 After making changes, click one of these buttons:
- **Apply** to save the changes and keep the Transition dialog box open.
  - **Cancel** to return to the previous settings for the dialog box.
  - **OK** to save the changes and close the dialog box.
  - **Help** to display Stateflow online help in an HTML browser window.

## See Also

Transitions

## More About

- "Transitions" on page 2-21
- "Default Transitions" on page 2-33
- "Inner Transitions" on page 2-30
- "Self-Loop Transitions" on page 2-29

## Stateflow Editor Operations

### Stateflow Editor

Use the Stateflow Editor to draw, zoom, modify, print, and save a chart shown in the window.

Opening a Stateflow chart displays the chart in the Stateflow Editor.

To open a new Stateflow chart in the Stateflow Editor:

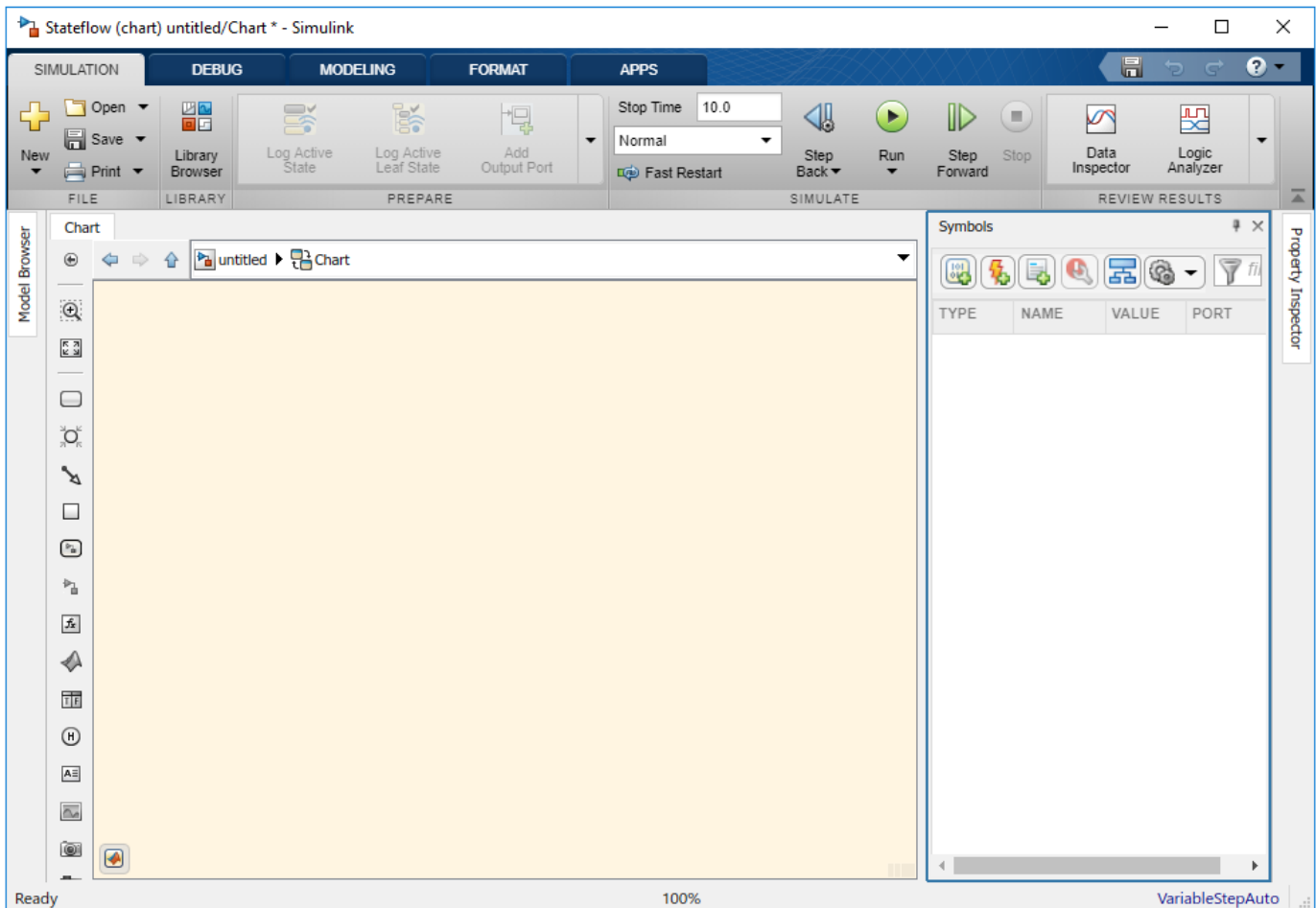
- 1 At the MATLAB command prompt, enter:

Command	Result
<code>sfnew</code>	Creates a chart with the default action language. For more information, see <code>sfnew</code> .
<code>sfnew -MATLAB</code>	Creates an empty chart with MATLAB as the action language.
<code>sfnew -C</code>	Creates an empty C chart.
<code>stateflow</code>	Creates an empty chart with the default action language and displays the Stateflow block library.

The Simulink Editor opens, with an empty chart.

- 2 Double-click the chart object.

The Stateflow Editor opens.



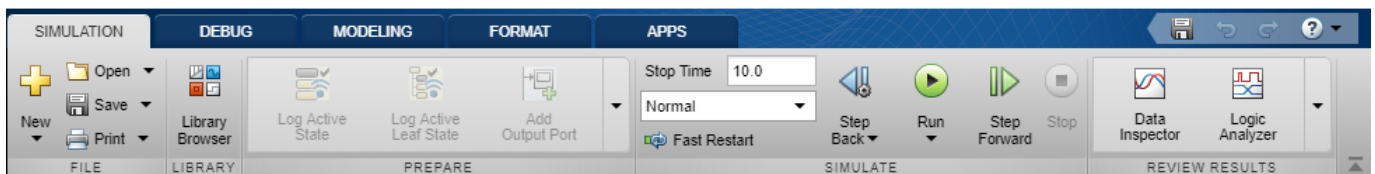
The Stateflow Editor window includes the following sections:

- **Title bar**

Stateflow (chart) untitled/Chart \* - Simulink

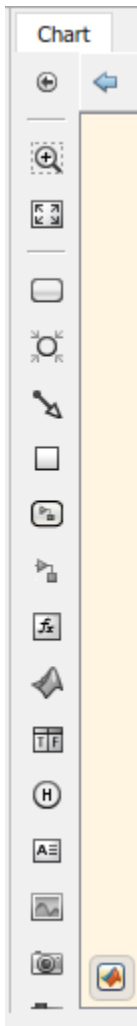
The full chart name appears here in *model name/chart name\** format. The \* character appears on the end of the chart name for a newly created chart or for an existing chart that has been edited but not saved yet.

- **Toolstrip**



Most editor commands are available from the toolstrip. You can identify each tool of the toolbar by placing your pointer over it until an identifying tool tip appears.

- **Object palette**



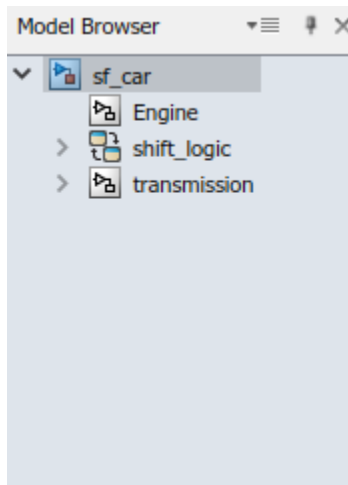
Displays a set of tools for drawing states, transitions, and other chart objects. To add an object, you can use the palette to:


- Click the icon for the object and move the cursor to the spot in the drawing area where you want to place the object.
- Drag the icon for the object into the drawing area.
- Double-click the icon and then click multiple times in the drawing area to make copies of the object.
- **Explorer bar**

untitled ▶ Chart

The breadcrumb shows the systems that you have open in the editor. Click a system in the breadcrumb to display that system. The e also contains buttons for navigating the chart hierarchy (see “Navigate Subcharts” on page 8-12).

- **Model Browser**



Click the double arrows  in the bottom left corner to open or close a tree-structured view of the model in the editor.

- **Drawing area** — This area displays an editable copy of a chart.
- **Context menus** (shortcut menus) — These menus pop up from the drawing area when you right-click an object. They display commands that apply only to that object. If you right-click an empty area of the chart, the context menu applies to the chart object.
- **Status information** — Near the top of the editor, you can see (and reset) the simulation time and the simulation mode. The bottom status bar displays the status of the Stateflow processing, tool tips, the zoom factor, and the solver.

## Undo and Redo Editor Operations

You can undo and redo operations that you perform in a chart. When you undo an operation, you reverse the last edit operation that you performed. After you undo operations in the chart, you can also redo them one at a time.

- To undo an operation in the chart, press **Ctrl + Z**.
- To redo an operation in the chart, press **Ctrl + Y**.

You can undo and redo many operations you complete on Stateflow objects in the Symbols pane or the Property Inspector.

### Exceptions for Undo

You can undo or redo all editor operations, with the following exceptions:

- You cannot undo the operation of turning subcharting off for a state previously subcharted.

To understand subcharting, see “Encapsulate Modal Logic by Using Subcharts” on page 8-10.

- You cannot undo the drawing of a supertransition or the splitting of an existing transition.

Splitting of an existing transition refers to the redirection of the source or destination of a transition segment that is part of a supertransition. For a description of supertransitions, see “Draw a Supertransition Into a Subchart” on page 8-14 and “Draw a Supertransition Out of a Subchart” on page 8-15.

- You cannot undo any changes made to the chart using the Stateflow API.

For a description of the Stateflow API, see “Stateflow Programmatic Interface”.

---

**Note** When you perform one of the preceding operations, the undo and redo buttons are disabled from undoing and redoing any prior operations.

---

## Specify Colors and Fonts in a Chart

You can change the way Stateflow displays an individual element of a chart or specify the global display options used throughout the entire chart.

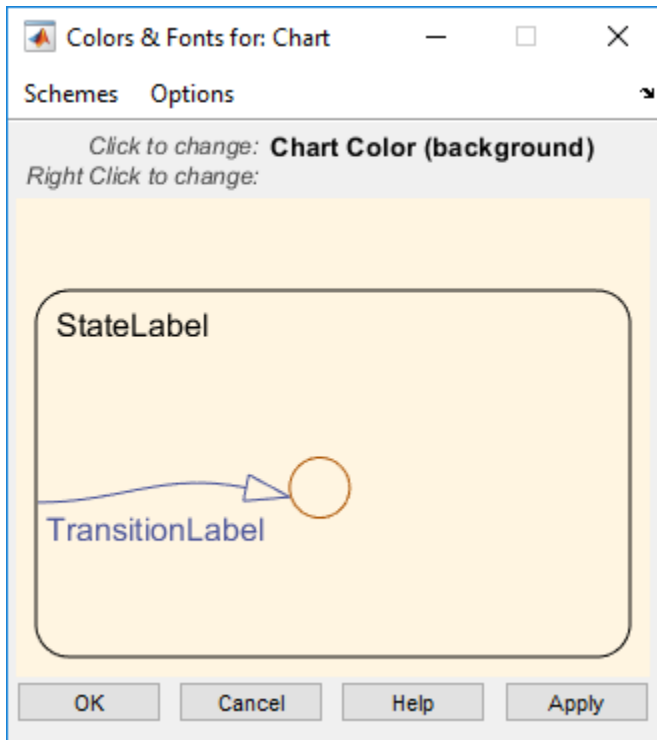
### Change Size of a Single Element

To change the display size for a single element in the chart, right-click the element, and then select a new **Format** option from the context menu. The options available depend on the element that you select.

Option	States	Transitions	Junctions	Annotations	Other Elements
Font Size	Available	Available	Not Available	Available	Available
Arrowhead Size	Available	Available	Available	Not Available	Not Available
Junction Size	Not Available	Not Available	Available	Not Available	Not Available
Font Style	Not Available	Not Available	Not Available	Available	Not Available
Shadow	Not Available	Not Available	Not Available	Available	Not Available
Text Alignment	Not Available	Not Available	Not Available	Available	Not Available

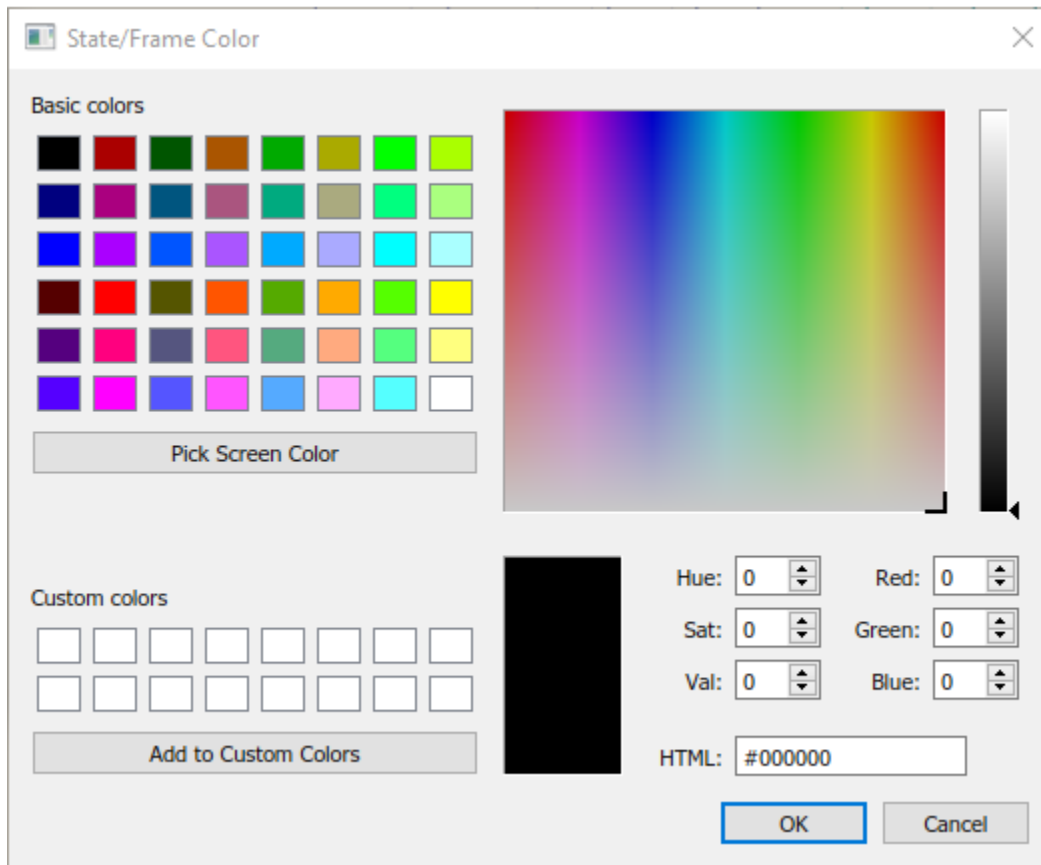
### Change Global Display Options

Through the **Colors & Fonts** dialog box, you can specify a color scheme for the chart or specify colors and label fonts for different types of objects in a chart. To open the **Colors & Fonts** dialog box, in the **Format** tab, click **Style**.



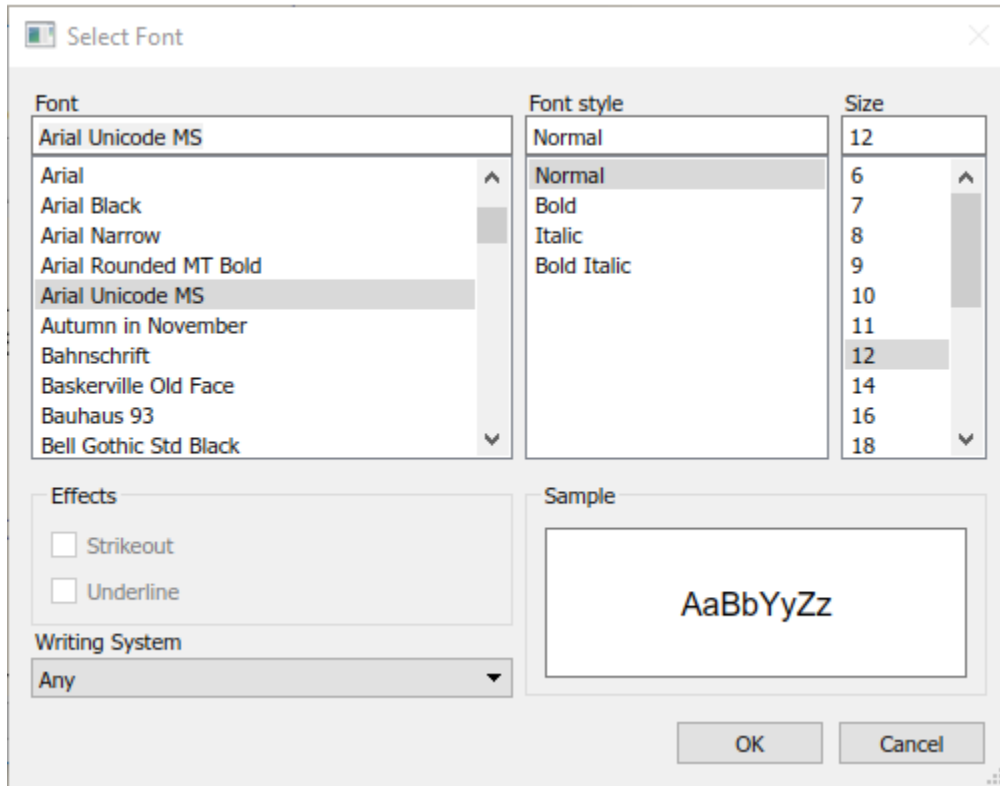
In the **Colors & Fonts** dialog box, the drawing area displays examples of the colors and label fonts specified by the current color scheme for the chart. You can choose a different color scheme from the **Schemes** menu. To modify the display options for a single type of chart element, position your pointer over the sample object.

- To change the color of the element, click the sample object and select a new color in the dialog box.



- To change the font of the element, right-click the sample object and select a new font, style, or size in the dialog box.





To apply the scheme to the chart, click **Apply**. To apply the scheme and close the dialog box, click **OK**.

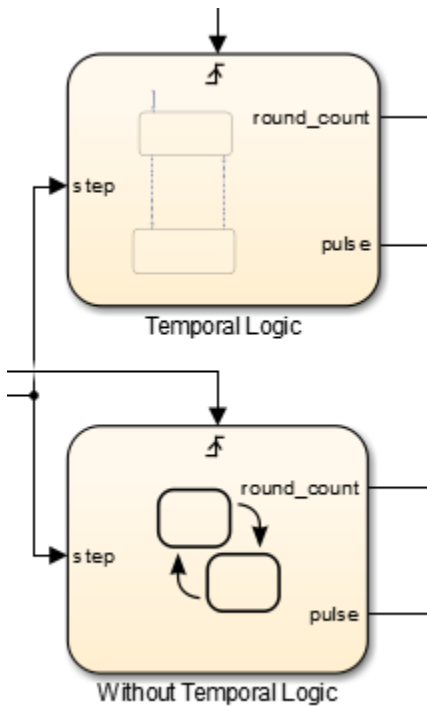
To make the scheme the default scheme for all charts, select **Options > Make this the 'Default' scheme**.

To save changes to the default color scheme, select **Options > Save defaults to disk**. If the modified scheme is not the default scheme, choosing **Save defaults to disk** has no effect.

## Content Preview for Stateflow Objects

When a chart is closed, you can preview the content of Stateflow charts in Simulink. You can see an outline of the contents of a chart. During simulation, you can see chart animation. When a chart is open, you can preview the content of subcharts and Simulink functions.

For example, the Temporal Logic chart uses content preview. The chart Without Temporal Logic does not.



To turn on content preview for Stateflow charts and subcharts, right-click the chart and select **Format > Content Preview**. For Simulink functions, right-click the function and select **Content Preview**. For details on content preview in Simulink, see “Preview Content of Model Components” (Simulink).

---

**Note** In order to see the content preview, you may need to enlarge the Stateflow chart or object.

---

## Intelligent Tab Completion for Stateflow Charts

Stateflow tab completion provides context-sensitive editing assistance. Tab completion helps you avoid typographical errors. It also helps you quickly select syntax-appropriate options for keywords, data, event, messages, and function names, without having to navigate the Model Explorer. In a Stateflow chart, to complete entries:

- 1 Type the first few characters of the word that you want.
- 2 Press **Tab** to see the list of possible matches.
- 3 Use the arrow keys to select a word.
- 4 Press **Tab** to make the selection.

Additionally, you can:

- Close the list without selecting anything by pressing the **Esc** key.
- Type additional characters onto your original term to narrow the list of possible matches.

If you press **Tab** and no words are listed, then the current word is the only possible match.

## Differentiate Elements of Action Language Syntax

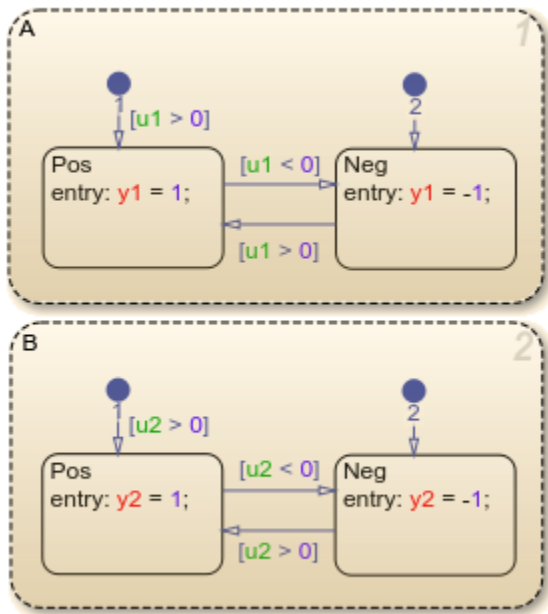
You can use color highlighting to differentiate the following syntax elements:

- Keywords
- Comments
- Events
- Messages
- Functions
- Strings
- Numbers
- Local data
- Constant data
- Input data
- Output data
- Parameter data
- Data Store Memory data

Syntax highlighting is a user preference, not a model preference.

### Default Syntax Highlighting

The following chart illustrates the default highlighting for language elements.



If the Stateflow parser cannot resolve a syntax element, the chart displays the element in the default text color.

### Edit Syntax Highlighting

- 1 In the Stateflow Editor, in the **Format** tab, click **Style > Syntax Highlighting**.

The Syntax Highlight Preferences dialog box appears.

- 2 Click the color that you want to change, choose an alternative from the color palette, and click **Apply**.
- 3 Click **OK** to close the Syntax Highlight Preferences dialog box.

### Enable and Disable Syntax Highlighting

- 1 In the Stateflow Editor, in the **Format** tab, click **Style > Syntax Highlighting**.

The Syntax Highlight Preferences dialog box appears.

- 2 Select or clear **Enable syntax highlighting** and click **OK**.

### Select and Deselect Graphical Objects

Once an object is in the drawing area, to make any changes or additions to that object, select it.

- To select an object, click anywhere inside of the object.
- To select multiple adjacent objects, click and drag a selection box so that the box encompasses or touches the objects that you want to select, and then release the mouse button.

All objects or portions of objects within the box become selected.

- To select multiple separate objects, simultaneously press the **Shift** key and click an object or box a group of objects.

This step adds objects to the list of already selected objects unless an object was already selected, in which case, the object is deselected. This type of multiple object selection is useful for selecting objects within a state without selecting the state itself.

- To deselect all selected objects, click in the drawing area, but not on an object.

When an object is selected, it appears highlighted in the color set as the selection color (blue by default; see “Specify Colors and Fonts in a Chart” on page 4-24 for more information).

### Cut and Paste Graphical Objects

You can cut objects from the drawing area or cut and then paste them as many times as you like. You can cut and paste objects from one chart to another. The chart retains a selection list of the most recently cut objects. The objects are pasted in the drawing area location closest to the current pointer location.

- To cut an object, right-click the object and select **Cut** from the context menu.
- To paste the most recently cut selection of objects, right-click in the chart and select **Paste** from the context menu.

### Copy Graphical Objects

To copy and paste an object in the drawing area, select the objects and right-click and drag them to the desired location in the drawing area. This operation also updates the chart clipboard.

---

**Note** If you copy and paste a state in the chart, these rules apply:

- If the original state uses the default ? label, then the new state retains that label.
  - If the original state does not use the default ? label, then a unique name is generated for the new state.
- 

Alternatively, to copy from one chart to another, select **Copy** and then **Paste** from the right-click context menu.

## Comment Out Objects

To Comment Out a Stateflow object, right-click the selected object and select **Comment Out**. For more information, see “Commenting Stateflow Objects in a Chart” on page 33-54.

## Format Chart Objects

To enhance readability of objects in a chart, in the Stateflow Editor you can use commands in the **Format** tab. These commands include options for:

- Alignment
- Distribution
- Resizing

You can align, distribute, or resize these chart objects:

- States
- Functions
- Boxes
- Junctions

Some of these options appear only after selecting elements within your chart.

### Align, Distribute, and Resize Chart Objects

The basic steps to align, distribute, or resize chart objects are similar.

- 1 If the chart includes parallel states or outgoing transitions from a single source, make sure that the chart uses explicit ordering.

To set explicit ordering, in the Chart properties dialog box, select **User-specified state/transition execution order**.

---

**Note** If a chart uses implicit ordering to determine execution order of parallel states or evaluation order of outgoing transitions, the order can change after you align, distribute, or resize chart objects. Using explicit ordering prevents this change from occurring. For more information, see “Execution Order for Parallel States” on page 3-60 and “Transition Evaluation Order” on page 3-38.

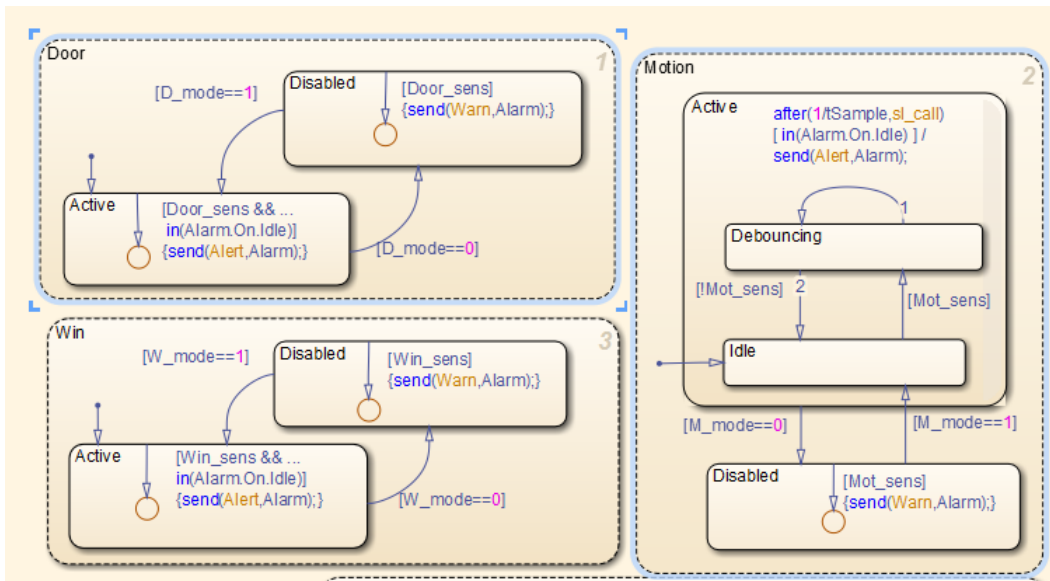
---

- 2 Select the chart objects that you want to align, distribute, or resize.

You can select objects in any order, one-by-one or by drawing a box around them.

- Decide which object to use as the anchor for aligning, distributing, or resizing other chart objects. This object is the reference object.

To set an object as the reference, right-click the object. Brackets appear around the reference object. In the following example, the Door and Motion states are selected, and the Door state is the reference.



**Note** If you select objects one-by-one, the last object that you select acts as the reference.

- Select an option from the **Format** tab to align, distribute, or resize your chosen objects.

For more information about chart object distribution options, see “Options for Distributing Chart Objects” on page 4-32

### Options for Distributing Chart Objects

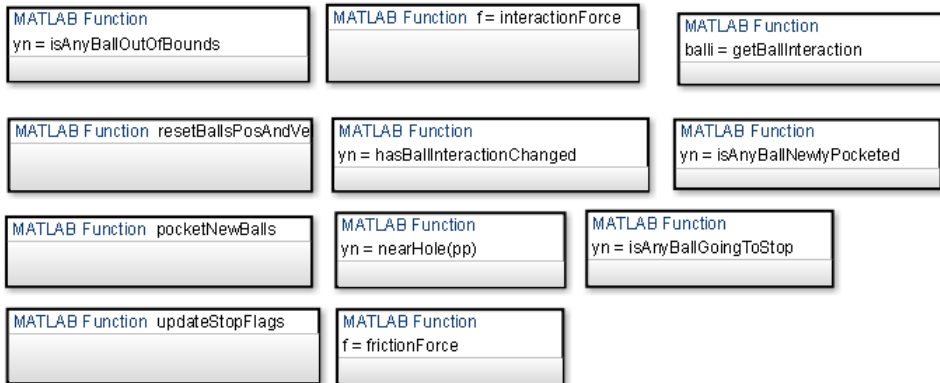
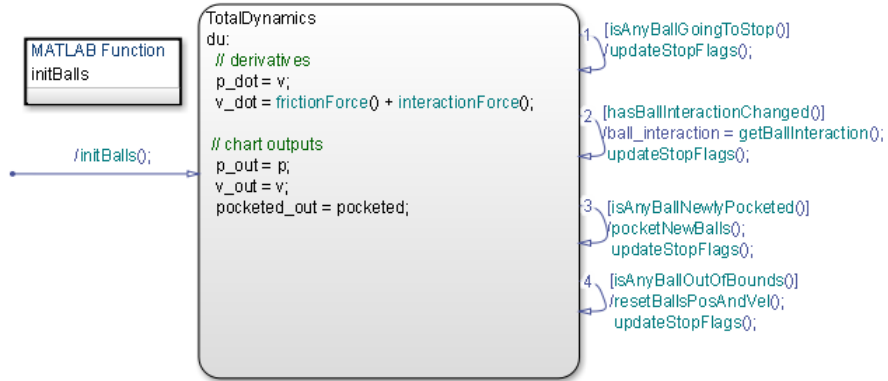
Option	Description
<b>Distribute Horizontally</b>	The center-to-center horizontal distance between any two objects is the same.  <b>Note</b> The horizontal space for distribution is the distance between the left edge of the leftmost object and the right edge of the rightmost object. If the total width of the objects you select exceeds the horizontal space available, objects can overlap after distribution.

Option	Description
<b>Distribute Vertically</b>	<p>The center-to-center vertical distance between any two objects is the same.</p> <hr/> <p><b>Note</b> The vertical space for distribution is the distance between the top edge of the highest object and the bottom edge of the lowest object. If the total height of the objects you select exceeds the vertical space available, objects can overlap after distribution.</p>
<b>Even Horizontal Gaps</b>	<p>The horizontal white space between any two objects is the same.</p> <hr/> <p><b>Note</b> The space restriction for <b>Distribute Horizontally</b> applies.</p>
<b>Even Vertical Gaps</b>	<p>The vertical white space between any two objects is the same.</p> <hr/> <p><b>Note</b> The space restriction for <b>Distribute Vertically</b> applies.</p>

### Example of Aligning Chart Objects

Suppose that you open the `sf_pool` model and see a chart with multiple MATLAB functions.

## 4 Create Stateflow Charts



To align the three MATLAB functions on the right:

- 1 Open the `sf_pool` model. Double-click the Pool block to open the chart.

---

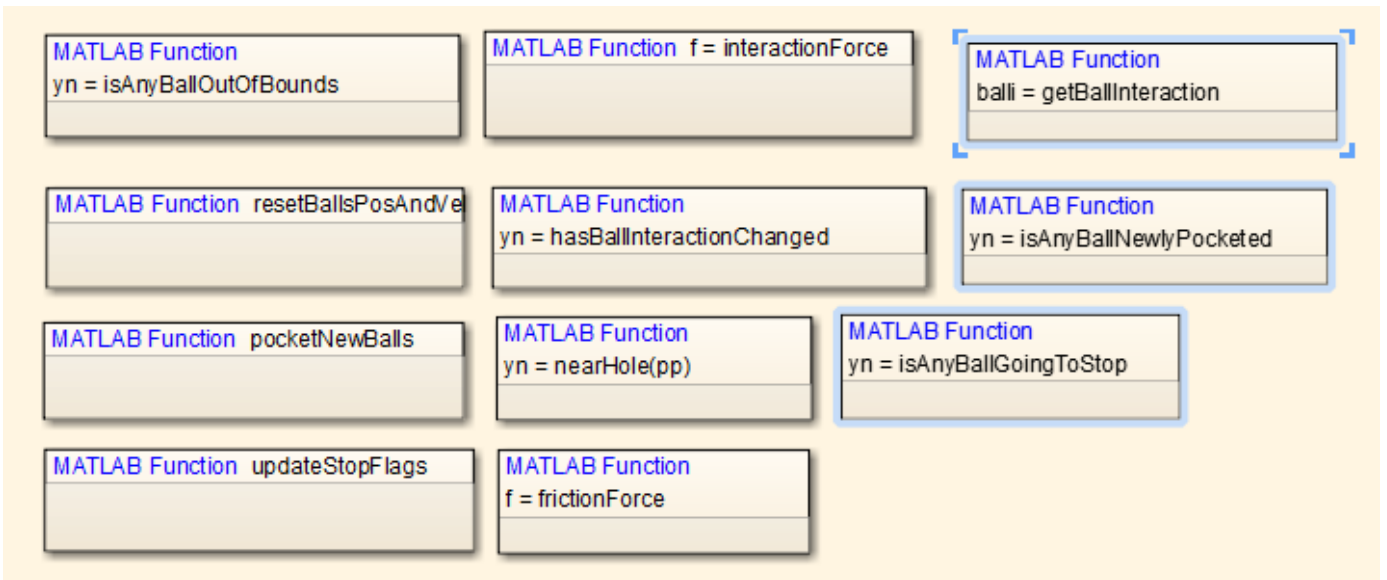
**Tip** Expand the Stateflow Editor to see the entire chart.

---

- 2 Click the function `isAnyBallGoingToStop`.
- 3 Shift-click the function `isAnyBallNewlyPocketed`.
- 4 Shift-click the function `getBallInteraction`.

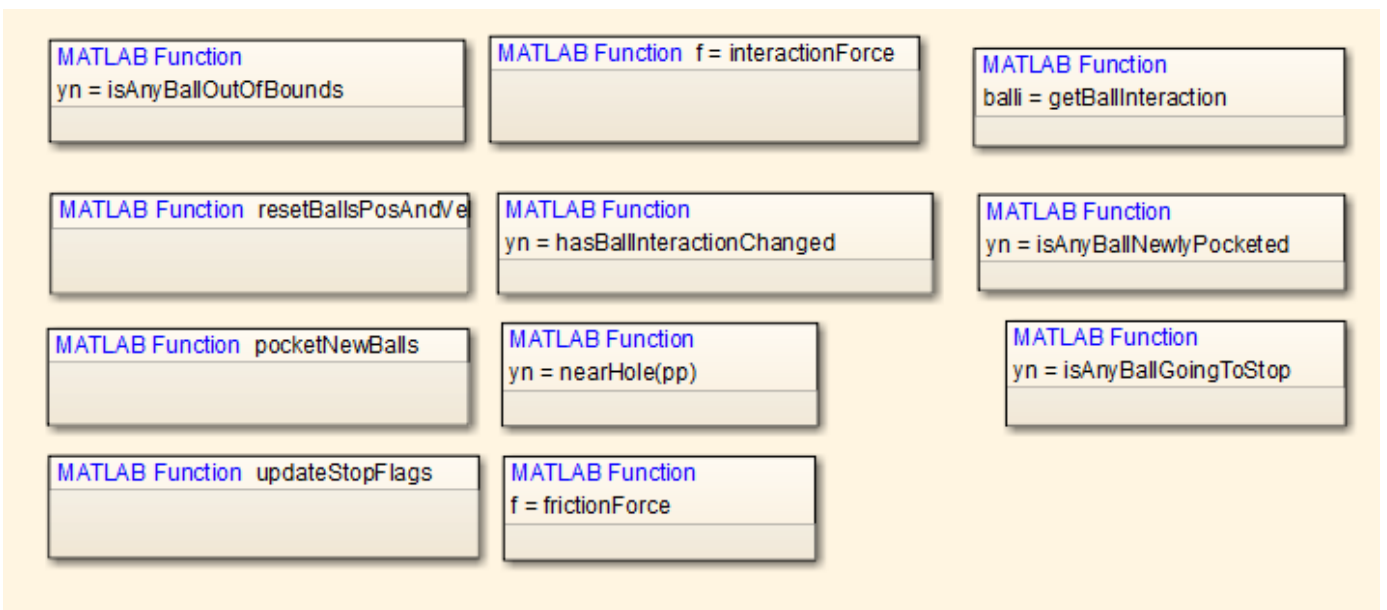
This object is the reference (or anchor) for aligning the three functions. Brackets appear around the function.





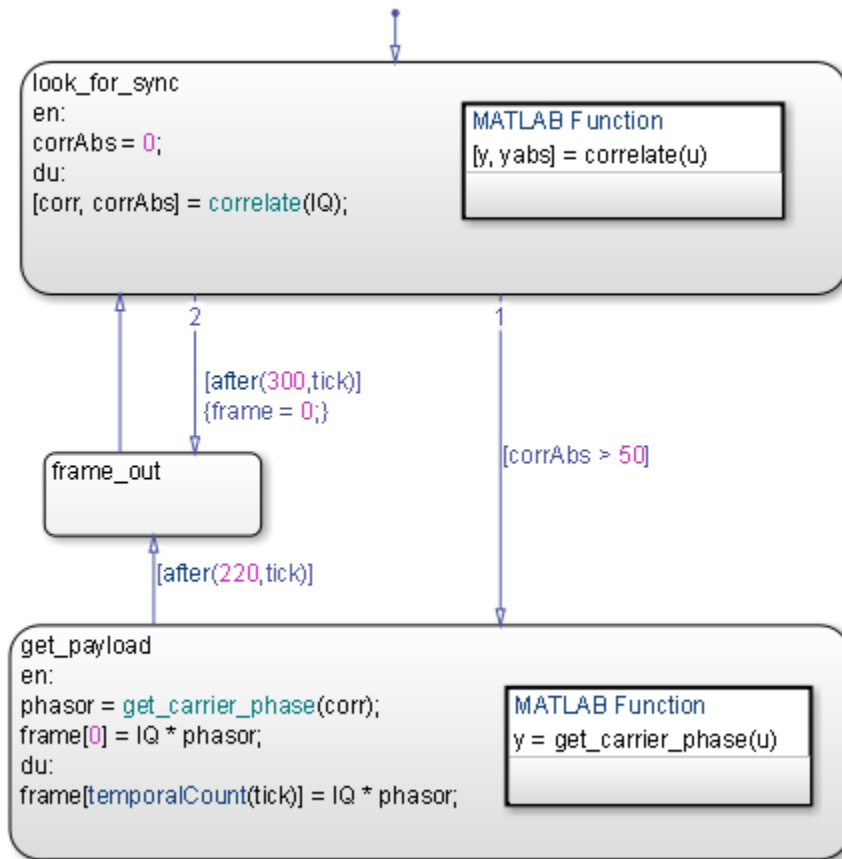
- 5 In the Format tab, click Align Right.

This step aligns the right edges of the three functions based on the right edge of `getBallInteraction`.



### Example of Distributing Chart Objects

Suppose that you open the `sf_frame_sync_controller` model and see a chart with three states.



To distribute the three states vertically:

- 1 Open the `sf_frame_sync_controller` model.

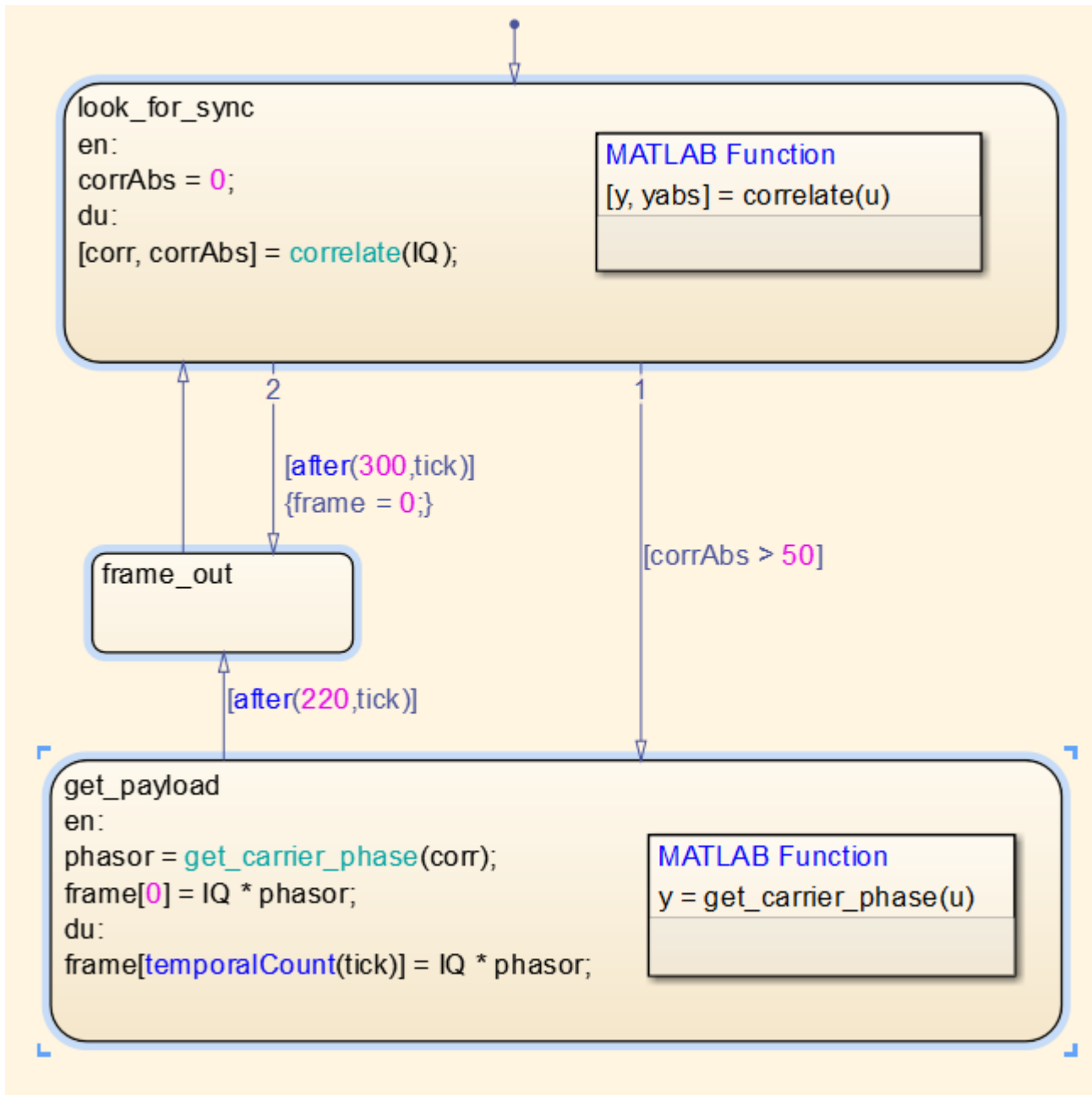
---

**Tip** Double-click the Frame Sync Controller block to open the chart.

---

- 2 Select the three states in any order.

Shift-click to select more than one state.



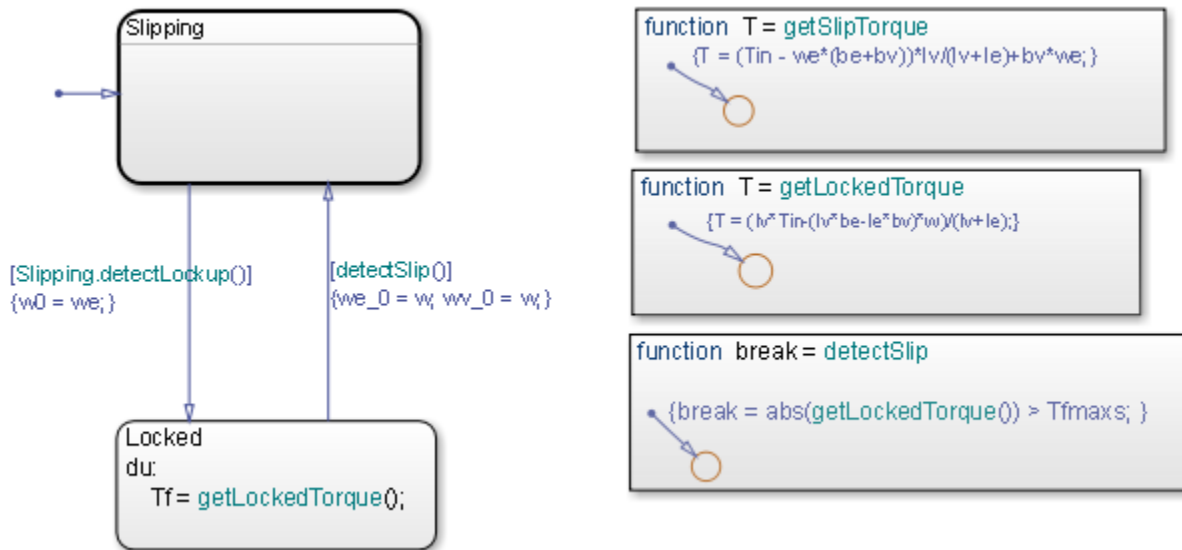
**Note** When you select the three states in any order, your reference object might differ from the one shown. This difference does not affect distribution of vertical white space.

- 3 In the **Format** tab, click **Even Vertical Gaps** .

This step ensures that the vertical white space between any two states is the same.

### Example of Resizing Chart Objects

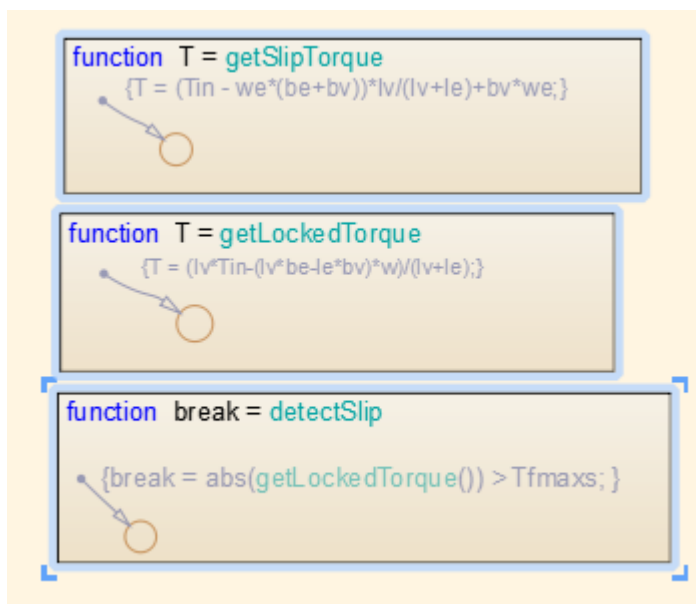
Suppose that you open the `sf_clutch_enabled_subsystems` model and see a chart with graphical functions of different sizes.




To resize the graphical functions so that they all match the size of `detectSlip`:

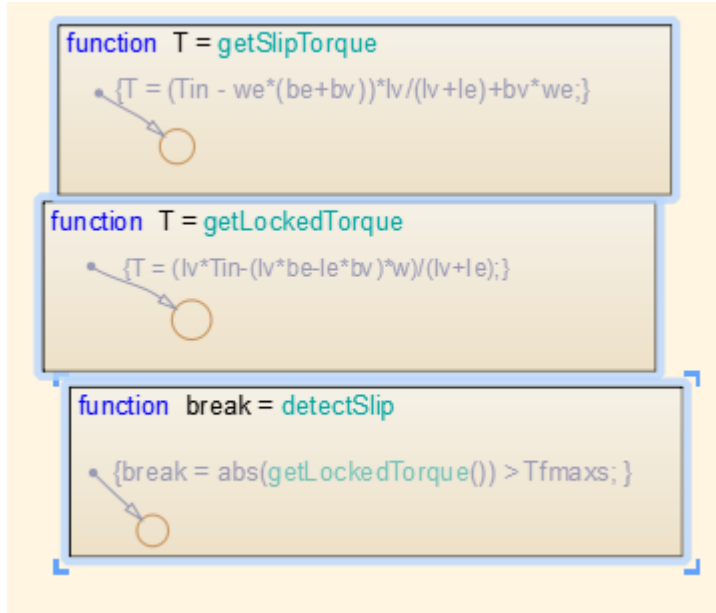
- 1 Open the `sf_clutch_enabled_subsystems` model.
- 2 In the Friction Mode chart, select the three graphical functions by drawing a box around them.
- 3 Set `detectSlip` as the reference object to use for resizing.

Right-click the function to mark it with brackets.




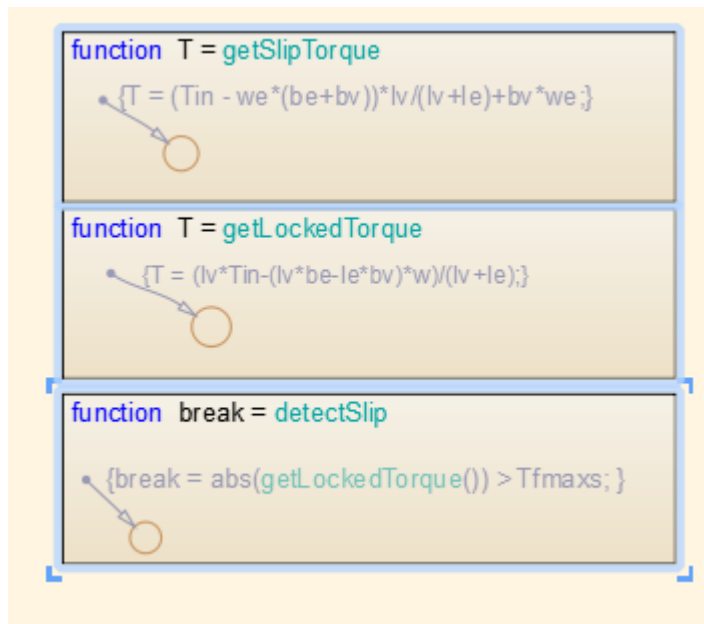
- 4 In the **Format** tab, click **Match Size** .

This step ensures that the three functions are the same size.

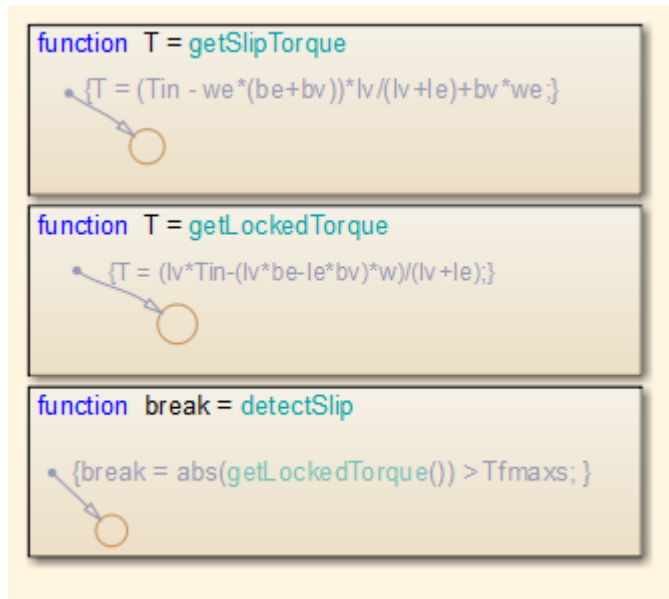


- 5 Adjust the function boxes to correct the format:

- a In the **Format** tab, click **Align Left** .



- b In the **Format** tab, click **Even Vertical Gaps** .



### Automatic Chart Formatting

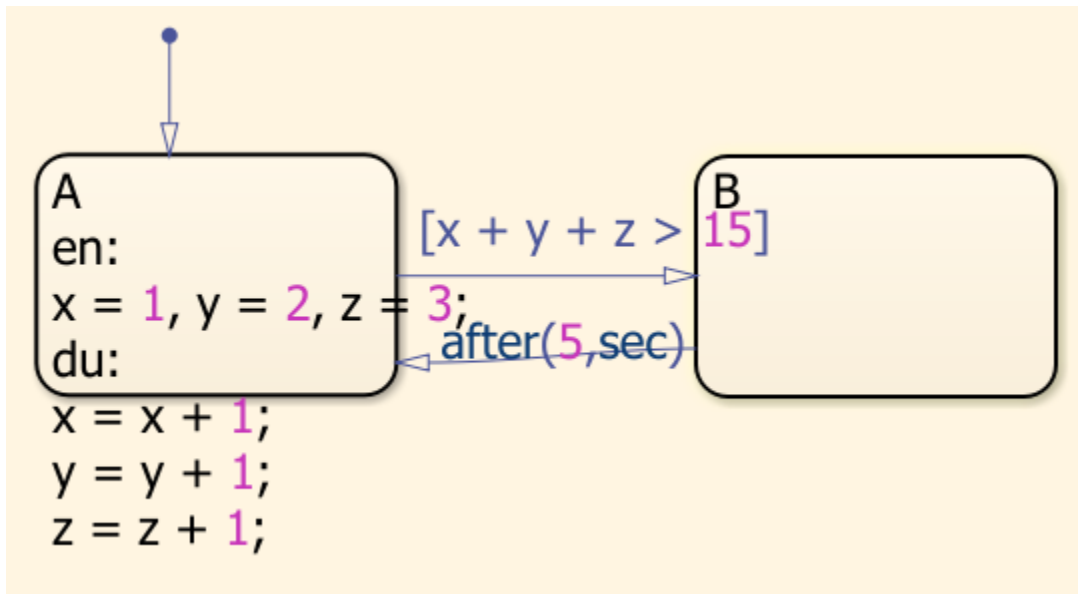
With Arrange Automatically, Stateflow arranges your charts to:

- Expand states and transitions to fit their label strings.
- Resize similar states to be the same size.
- Align states if they were slightly misaligned.
- Straightens transitions.
- Repositions horizontal transition labels to the midpoint.

In the **Format** tab, click **Auto Arrange**.

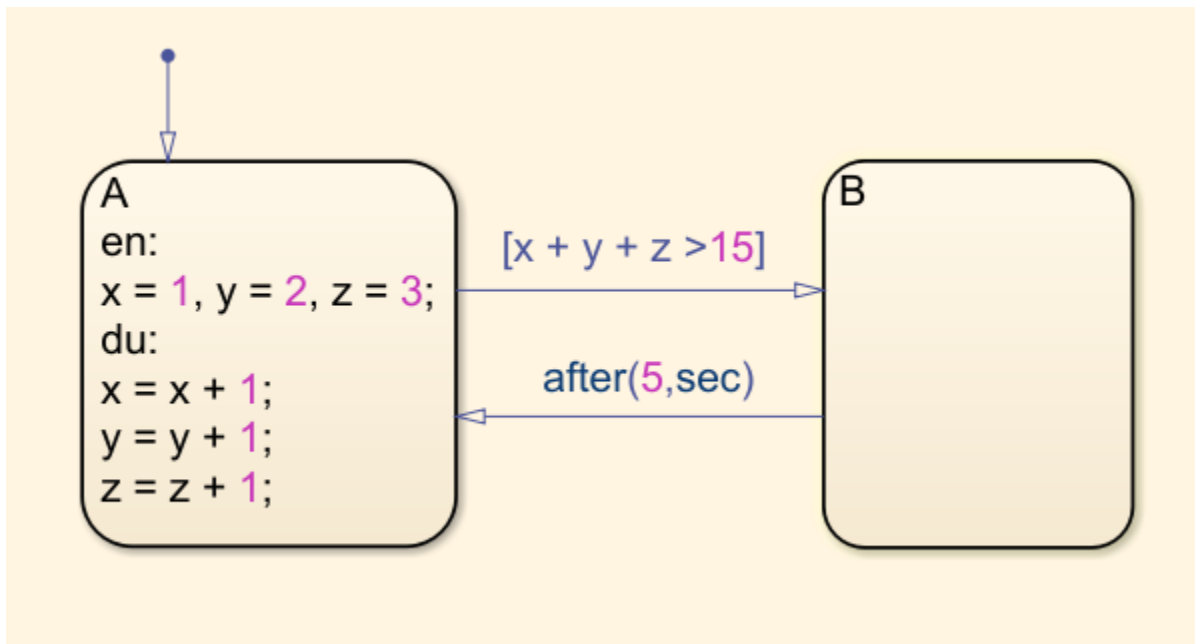
In this example, the chart has:

- 1 State actions that are outside of the boundary for state A.
- 2 A transition condition that overlaps state B.
- 3 A transition that is not horizontal.



After the layout has been automatically arranged:

- 1 The state actions are contained within state A.
- 2 The transition condition does not overlap into state B.
- 3 The lower transition is horizontal.



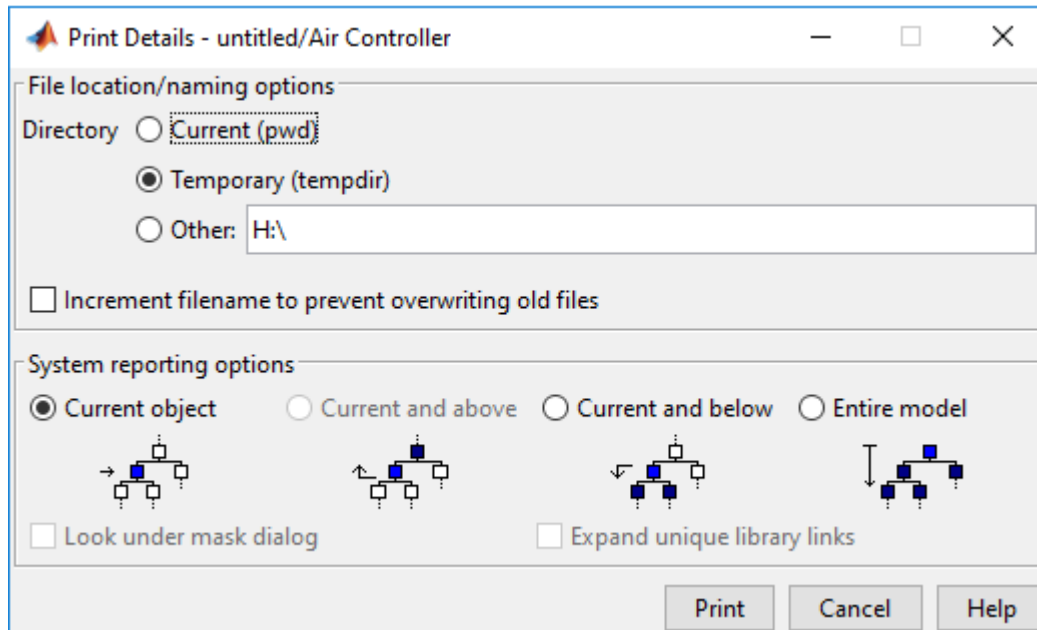
## Generate a Model Report

The **Print Details** report is an extension of the **Print Details** report in the Simulink model window. It provides a report of Stateflow and Simulink objects relative to the chart currently in view from which you select the report.

To generate a model report on chart objects:

- 1 Open the chart or subchart for which you want a report.
- 2 In the **Simulation** tab, select **Print > Print Details**.

The Print Details dialog box appears.



- 3 Enter the destination directory of the report file and select options to specify what objects appear in the report.

For details on setting the fields in the **File locations/naming options** section, see “Print Model Reports” (Simulink). For details on the report you receive, see “System Report Options” on page 4-42 and “Report Format” on page 4-43.

- 4 Click **Print**.

The Print Details dialog box appears and tracks the report generation. See “Print Model Reports” (Simulink) for more details on this window.

The HTML report appears in your default browser.

---

**Tip** If you have the Simulink Report Generator™ installed, you can generate a detailed report about a system. To do so, in the **Modeling** tab, under **Design**, select **System Design Report**. For more information, see “System Design Description” (Simulink Report Generator).

---

### System Report Options

Reports for the current Stateflow chart vary with your choice of one of the **System reporting options** fields:

- **Current** — Reports on the chart or subchart in the current editor window and its immediate parent Simulink system.



- **Current and above** — This option is grayed out and unavailable for printing chart details.
- **Current and below** — Reports on the chart or subchart in the current editor window and all contents at lower levels of the hierarchy, along with the immediate Simulink system.
- **Entire model** — Reports on the entire model including all charts and all Simulink systems.

If you select this option, you can modify the report as follows:

- **Look under mask dialog** - Includes the contents of masked subsystems in the report.
- **Expand unique library links** - Includes the contents of library blocks that are subsystems in the report.

The report includes a library subsystem only once even if it occurs in more than one place in the model.

### Report Format

The general top-down format of the **Print Details** report is as follows:

- The report shows the title of the system in the Simulink model containing the chart or subchart in current view.
- A representation of Simulink hierarchy for the containing system and its subsystems follows. Each subsystem in the hierarchy links to the report of its Stateflow charts.
- The report section for the Stateflow charts of each system or subsystem begins with a small report on the system or subsystem, followed by a report of each contained chart.
- Each chart report includes a reproduction of its chart with links for subcharted states that have reports of their own.
- An appendix tabulates the covered Stateflow and Simulink objects in the report.



# Model Logic Patterns and Iterative Loops Using Flow Charts

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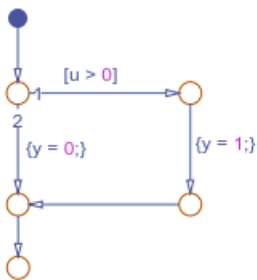
- “Flow Charts in Stateflow” on page 5-2
- “Create Flow Charts by Using Pattern Wizard” on page 5-5
- “Convert MATLAB Code into Stateflow Flow Charts” on page 5-18

## Flow Charts in Stateflow

A Stateflow flow chart is a graphical construct that models logic patterns such as decision trees and iterative loops. Flow charts represent combinatorial logic in which one result does not depend on prior results. You build flow charts by combining connective junctions and transitions without using any states. The junctions provide decision branches between different transition paths. Executing a flow chart begins at a default transition and ends at a terminating junction (a junction that has no valid outgoing transitions).

A best practice is to encapsulate flow charts in graphical functions to create modular and reusable logic that you can call anywhere in a chart. For more information about graphical functions, see “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18.

An example of a flow chart that models simple **If-Else** logic:



The flow chart models this code:

```
if u > 0
    y = 1;
else
    y = 0;
end
```

### Draw a Flow Chart

You can draw and customize flow charts manually by using connective junctions as branch points between alternate transition paths:

- 1 Open a chart.
- 2 From the editor toolbar, drag one or more connective junctions into the chart with the **Connective Junction** tool:



- 3 Add transition paths between junctions.
- 4 Label the transitions.
- 5 Add a default transition to the junction where the flow chart execution starts.

### Best Practices for Creating Flow Charts

Follow these best practices to create efficient, accurate flow charts:

**Use only one default transition**

Flows charts have a single entry point.

**Provide only one terminating junction**

Multiple terminating junctions reduce readability of a flow chart.

**Converge all transition paths to the terminating junction**

Execution of a flow chart always reaches the termination point.

**Provide an unconditional transition from every junction except the terminating junction**

If unintended backtracking occurs during simulation, a warning message appears.

You can control the level of diagnostic action for unintended backtracking in the **Diagnostics > Stateflow** pane of the Model Configuration Parameters dialog box. For more information, see the documentation for the “Unexpected backtracking” (Simulink) diagnostic.

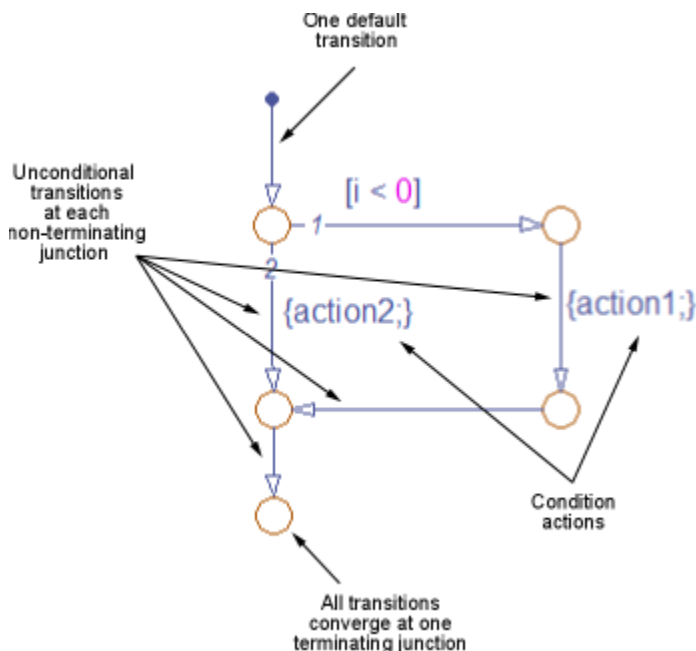
Unintended backtracking can occur at a junction under these conditions:

- The junction does not have an unconditional transition path to a state or terminating junction.
- Multiple transition paths lead to that junction.

**Use condition actions to process updates, not transition actions**

Flow charts test transitions, but do not execute them (and, therefore, never execute transition actions).

An example that illustrates these best practices:



## **See Also**

### **More About**

- “Create Flow Charts by Using Pattern Wizard” on page 5-5
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Convert MATLAB Code into Stateflow Flow Charts” on page 5-18
- “How Stateflow Objects Interact During Execution” on page 3-5

## Create Flow Charts by Using Pattern Wizard

The Pattern Wizard is a utility that generates common flow chart patterns for use in graphical functions and charts. The Pattern Wizard offers several advantages over manually creating flow charts. The Pattern Wizard:

- Generates common logic and iterative loop patterns.
- Promotes consistency in geometry and layout across patterns.
- Facilitates storing and reusing patterns from a central location.
- Allows inserting patterns in an existing flow chart.

The Pattern Wizard generates flow charts whose geometry and layout comply with the guidelines from the MathWorks Advisory Board (MAB). You can customize your flow chart by modifying the conditions and actions or by inserting additional logic patterns. You can also save your flow chart as a custom pattern in the Pattern Wizard for later reuse.

For example, suppose that you want to use the Pattern Wizard to create a graphical function for iterating over the upper triangle of a two-dimensional matrix. The function consists of two nested for loops in which the row index  $i$  is always less than or equal to the column index  $j$ . By using the Pattern Wizard, you can:

- 1 Create a flow chart for the outer loop that iterates over the row index  $i$ . See “Create Reusable Flow Charts” on page 5-5.
- 2 Extend the flow chart by inserting an inner loop that iterates over the column index  $j$ . See “Insert Logic Patterns in Existing Flow Charts” on page 5-6.
- 3 Save the flow chart as a custom pattern in the Pattern Wizard. See “Save Custom Flow Chart Patterns” on page 5-9.
- 4 Reuse the custom pattern in a graphical function. See “Reuse Custom Flow Chart Patterns” on page 5-10.

### Create Reusable Flow Charts

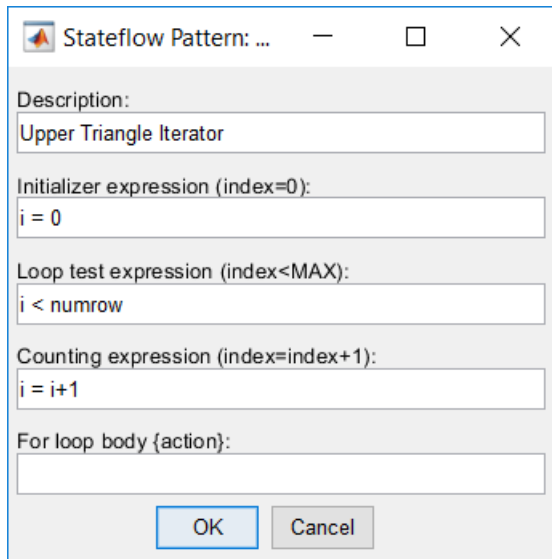
To create a flow chart, on the **Modeling** tab, select a pattern from the **Pattern** gallery. Pattern selections include:

- **If, If-Else, If-Elseif**, and other nested decision patterns.
- **For, While, and DoWhile** loop patterns.
- Switch patterns with up to four cases.
- Custom patterns that you saved for later reuse.
- Patterns that you define in a MATLAB `.m` file.

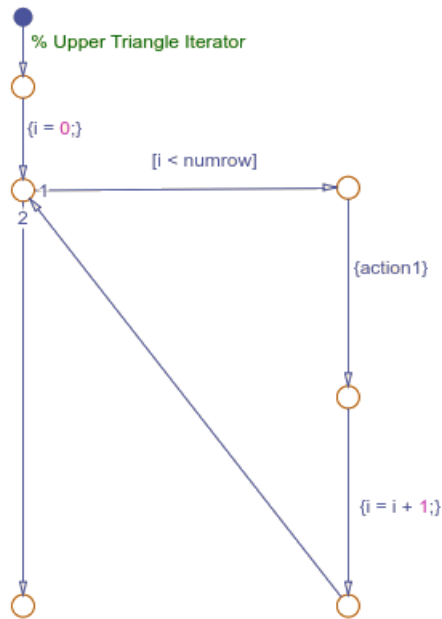
The Pattern dialog box prompts you for conditions and actions specific to the pattern that you select. For more information on flow chart patterns, see “MAB-Compliant Patterns from the Pattern Wizard” on page 5-11.

For example, to create the outer for loop in the upper triangle iterator pattern:

- 1 On the **Modeling** tab, select **Pattern > For Loop**.
- 2 In the Pattern dialog box, specify the initializer, loop test, and counting expressions for iterating through the first dimension of the matrix:



- 3 Click **OK**. The Pattern Wizard generates this flow chart.



To complete the upper triangle iterator pattern, insert a second **for** loop along the vertical transition in this flow chart.

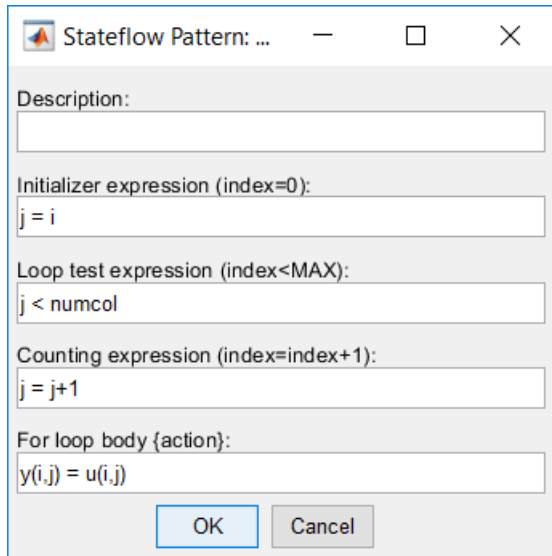
### Insert Logic Patterns in Existing Flow Charts

Use the Pattern Wizard to add loop or decision logic extensions to an existing flow chart. Select an eligible vertical transition and choose a pattern from the **Pattern** gallery. Options include decision, loop, and switch patterns. The Pattern dialog box prompts you for conditions and actions specific to the pattern that you select.



For example, to add the second loop in the upper triangle iterator pattern:

- 1 In the Stateflow Editor, from the outer `for` loop pattern, select the vertical transition labeled `{action1}`.
- 2 On the **Modeling** tab, select **Pattern > For Loop**.
- 3 In the Pattern dialog box, specify the initializer, loop test, and counting expressions for iterating through the second dimension of the matrix. The initializer expression ensures that  $i$  never exceeds  $j$ . Also enter an action that retrieves each element in the upper triangle of the matrix.



Stateflow Pattern: ...

Description:

Initializer expression (index=0):  
j = i

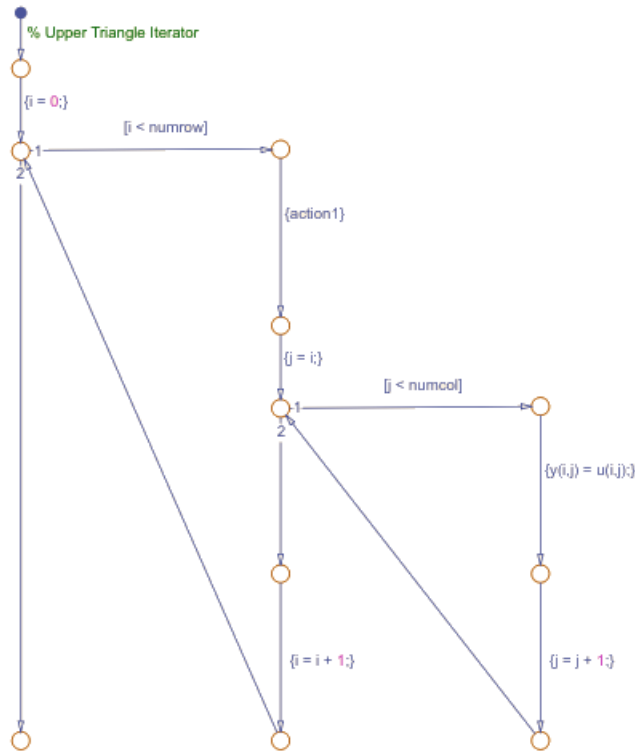
Loop test expression (index<MAX):  
j < numcol

Counting expression (index=index+1):  
j = j+1

For loop body {action}:  
y(i,j) = u(i,j)

OK Cancel

- 4 Click **OK**. The Pattern Wizard adds the second loop to the flow chart.



5 Save the model containing the pattern.

### Guidelines for Inserting Logic Patterns

When you create logic extensions:

- You can select only one transition to extend at a time. The selected transition must be exactly vertical and have a destination junction.
- You can extend only flow charts created by the Pattern Wizard.
- The Stateflow chart containing the flow chart can contain only junctions and transitions. The chart cannot contain other objects, such as states, functions, or truth tables.
- You cannot extend a pattern that has been custom-created or modified.
- You cannot choose a custom pattern as the extension.

If your selection is not eligible for insertion, when you choose a pattern from the **Pattern** gallery, you see a message instead of pattern options.

Message	Issue
Select a vertical transition	You have not selected a vertical transition.
Selected transition must be exactly vertical	You selected a transition, but it is not vertical.
Select only one vertical transition	You have selected more than one transition.

Message	Issue
Editor must contain only transitions and junctions	There are other objects, such as states, functions, or truth tables, in the chart.

## Save Custom Flow Chart Patterns

Use the Pattern Wizard to save flow chart patterns in a central location, and then easily retrieve them for reuse in graphical functions and charts. Select the flow chart with the pattern that you want to save and select **Pattern > Save As Pattern**.

For example, suppose that you want to save the upper triangle iterator pattern for later reuse:

- 1 Create a folder for storing your custom patterns. See “Guidelines for Creating a Custom Pattern Folder” on page 5-9.
- 2 In the Stateflow Editor, select the upper triangle iterator flow chart.
- 3 On the **Modeling** tab, select **Pattern > Save As Pattern**.
- 4 If you have not designated the custom pattern folder, the Pattern Wizard prompts you to select a folder. Choose the folder that you created and click **Select Folder**. You can also set the default directory that the Pattern Wizard saves to with the `sfpref` function by using 'PatternWizardCustomDir' as the first argument. For more information, see `sfpref`.
- 5 At the prompt, name your pattern `UpperTriangleIterator` and click **Save**. The Pattern Wizard saves your pattern as a model file `UpperTriangleIterator.slx` in the custom pattern folder.

---

**Note** You can use the Pattern Wizard to reuse only flow charts. To reuse states and subcharts, create an atomic subchart. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

---

### Guidelines for Creating a Custom Pattern Folder

The Pattern Wizard uses a single, flat folder for saving and retrieving flow chart patterns.

- Store all flow charts at the top level of the custom pattern folder. Do not create subfolders.
- Make sure that all flow chart files have an `.mdl` or `.slx` extension.

### Change Your Custom Pattern Folder

The Pattern Wizard remembers your choice of custom pattern folder for future sessions. To choose a different folder, rename your existing custom pattern folder and do one of the following:

- Save a new custom pattern to the Pattern Wizard.
- Reuse an existing custom pattern from the Pattern Wizard.

The Pattern Wizard prompts you to choose a new folder.

## Reuse Custom Flow Chart Patterns

The Pattern Wizard stores your flow charts as model files in the custom pattern folder. The patterns that you save in this folder appear in a drop-down list when you select **Pattern > Custom**. You can add a custom pattern directly to a chart or to a subcharted graphical function in your chart.

For example, to add the upper triangle iterator custom pattern to a graphical function:

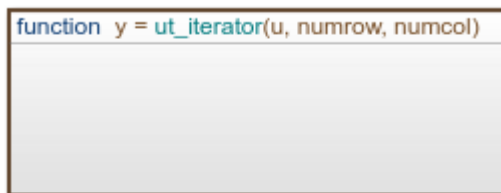
- 1 From the object palette, add a graphical function to your chart as described in “Define a Graphical Function” on page 8-18.
- 2 Enter this function signature:

```
function y = ut_iterator(u, numrow, numcol)
```

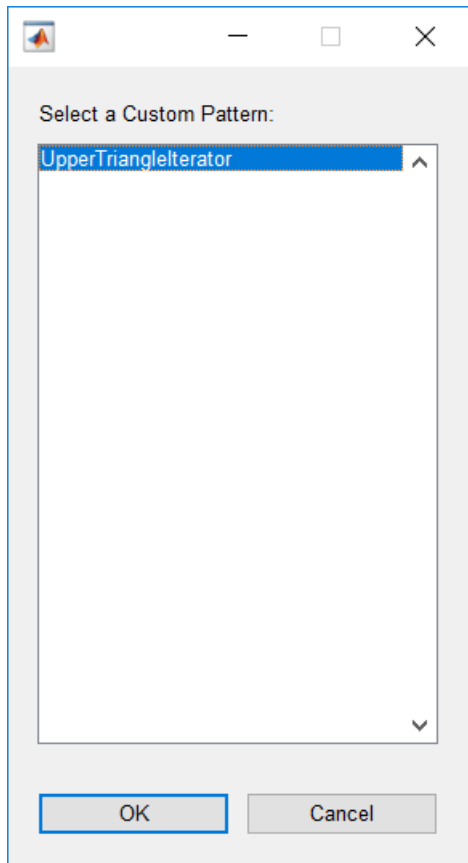
The function takes three inputs.

Input	Description
<i>u</i>	2-D matrix
<i>numrow</i>	Number of rows in the matrix
<i>numcol</i>	Number of columns in the matrix

- 3 Right-click inside the function and select **Group & Subchart > Subchart**. The function appears as an opaque box.



- 4 Double-click the subcharted function to open it.
- 5 Remove the default flow chart from the graphical function.
- 6 On the **Modeling** tab, select **Pattern > Custom**. A dialog box opens, listing all the patterns that you have saved in your custom pattern folder.



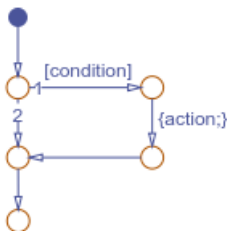
- 7 Select the upper triangle iterator pattern and click **OK**. The Pattern Wizard adds your custom pattern to the graphical function.
- 8 In the graphical function, in place of `action1`, substitute an appropriate action. This action repeats once for every row of the matrix.

## MAB-Compliant Patterns from the Pattern Wizard

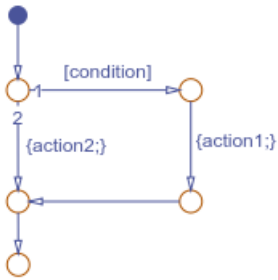
The Pattern Wizard generates flow charts whose geometry and layout comply with the guidelines from the MathWorks Advisory Board (MAB).

### Decision Patterns

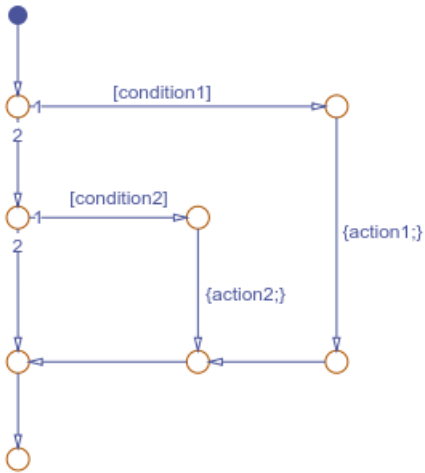
#### If



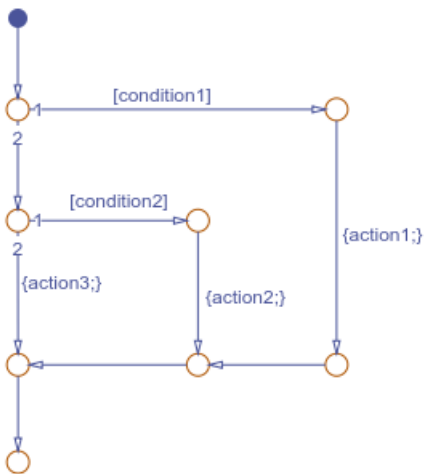
### If-Else



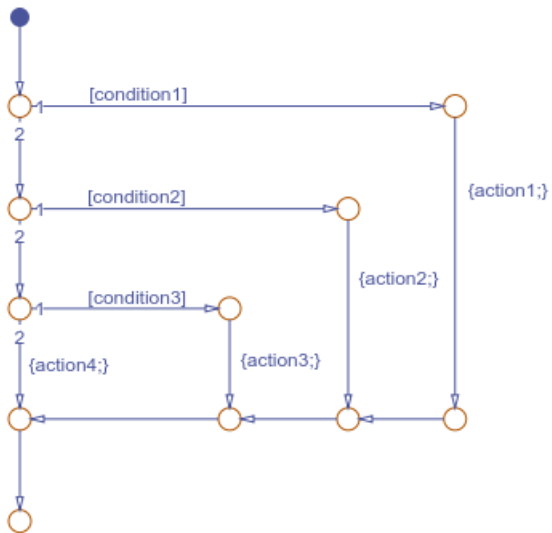
### If-Elseif



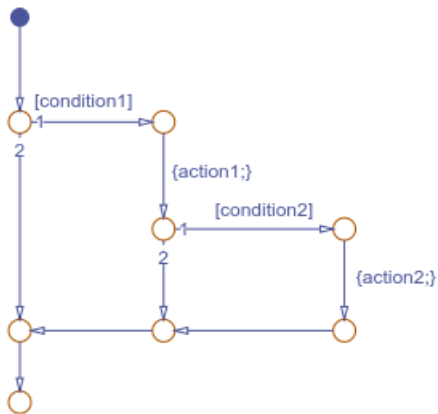
### If-Elseif-Else



### If-Elseif-Elseif-Else

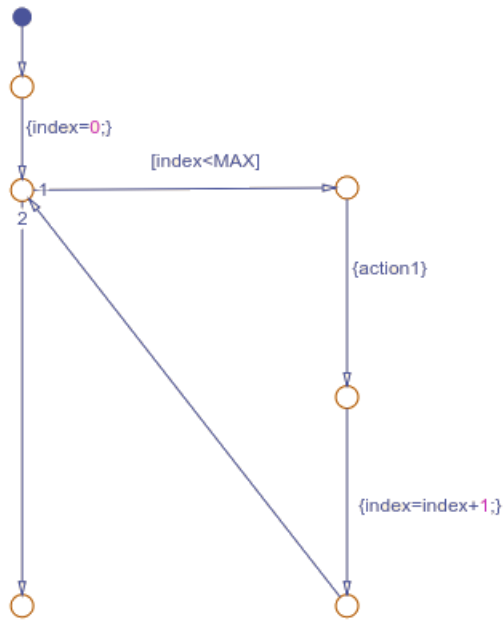


### Nested If

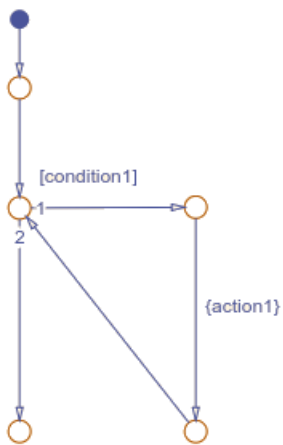


## Loop Patterns

### For Loop

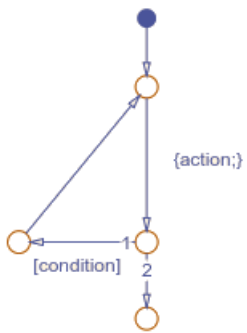


### While Loop



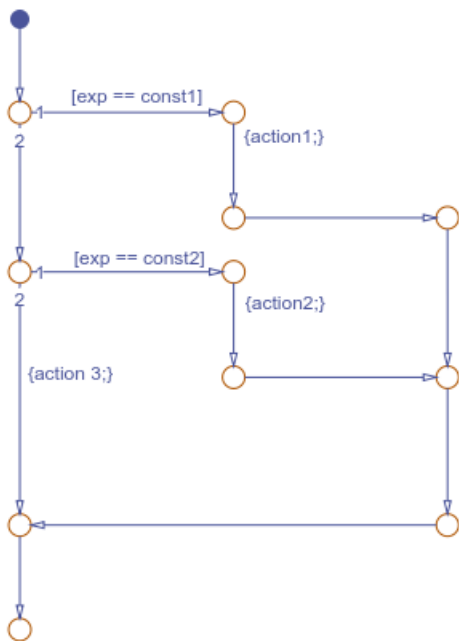


### DoWhile Loop

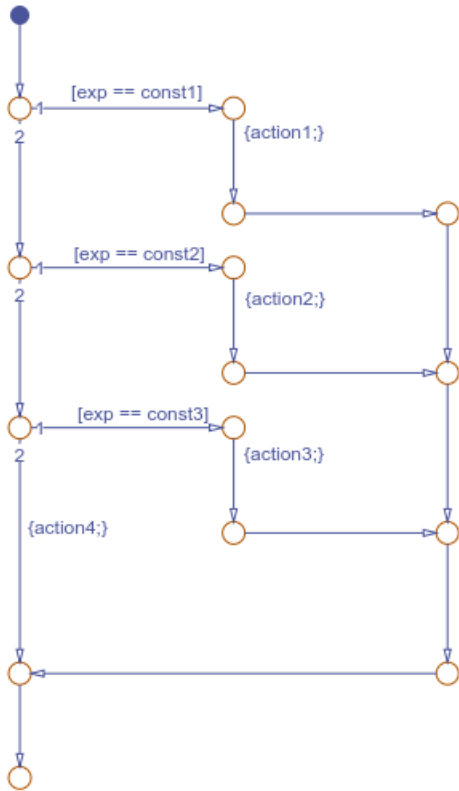


### Switch Patterns

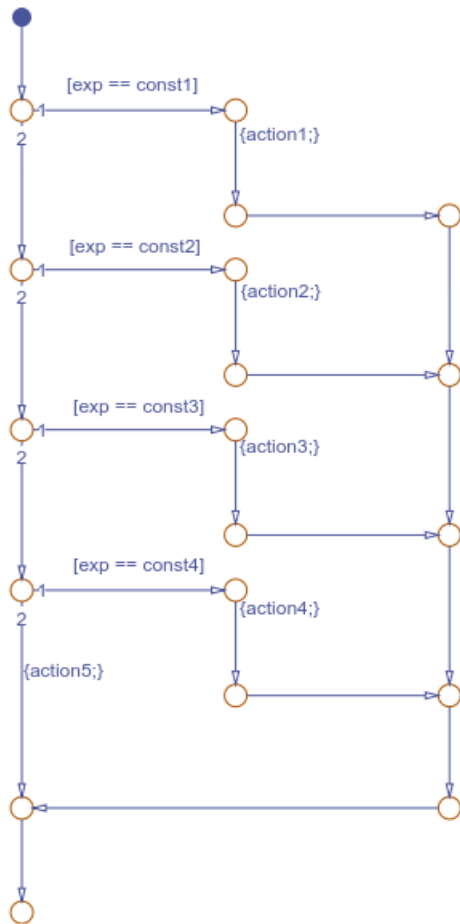
#### Two Cases



### Three Cases



## Four Cases



## See Also

### More About

- “Flow Charts in Stateflow” on page 5-2
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Convert MATLAB Code into Stateflow Flow Charts” on page 5-18

## Convert MATLAB Code into Stateflow Flow Charts

To transform your MATLAB code into Stateflow flow charts and graphical functions, use the Pattern Wizard. Supported patterns for conversion include:

- `if`, `if-else`, and other nested decision statements.
- `for` and `while` loops.
- `switch` statements.

The Pattern Wizard can convert MATLAB functions and scripts.

- MATLAB functions are converted to Stateflow graphical functions.
- MATLAB scripts are converted to Stateflow flow charts.

Converting MATLAB code is supported only in standalone Stateflow charts. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

### Create Flow Charts from MATLAB Scripts

This MATLAB script empirically verifies one instance of the Collatz conjecture. When given the numeric input  $u$ , the script computes the hailstone sequence  $n_0 = u, n_1, n_2, n_3, \dots$  by iterating this rule:

- If  $n_i$  is even, then  $n_{i+1} = n_i/2$ .
- If  $n_i$  is odd, then  $n_{i+1} = 3n_i + 1$ .

The Collatz conjecture states that every positive integer has a hailstone sequence that eventually reaches one.

```
% Hailstone sequence u, c(u), c(c(u)),...
y = [u];
while y(end) ~= 1
    y(end+1) = c(y(end));
end
disp(y);

function n = c(n)
% Compute next number in hailstone sequence.
% If n is even, then c(n) = n/2.
% If n is odd, then c(n) = 3*n+1.
    if rem(n,2) == 0
        n = n/2;
    else
        n = 3*n+1;
    end
end
```

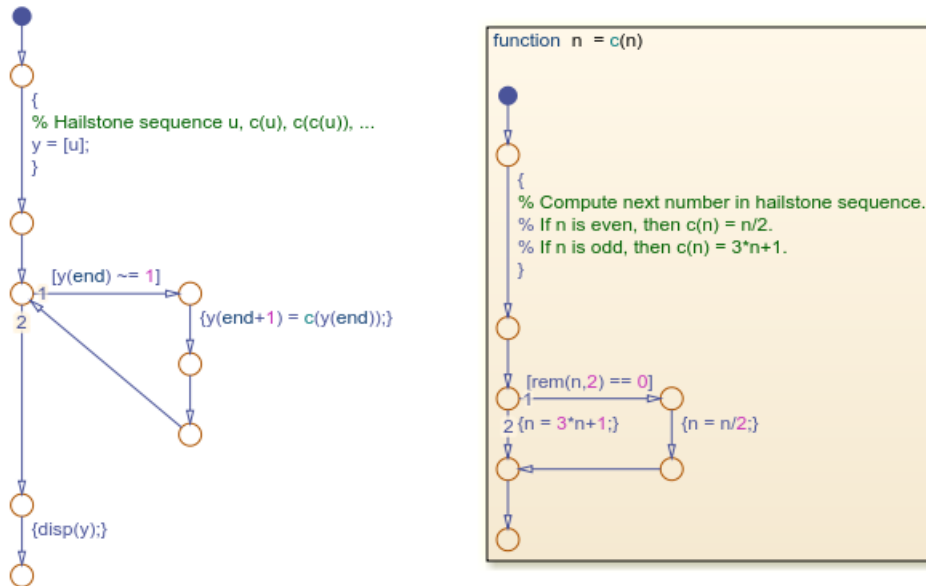
The script executes a `while` loop that repeatedly calls the auxiliary function `c` until it produces an output value of one. The function `c` consists of a conditional `if-else` statement whose output depends on the parity of the input.

To convert this script into a flow chart and a graphical function:

- 1 Open a new standalone chart.

edit `hailstone.sfx`


- On the **State Chart** tab, select **Pattern > Select File**.
- In the dialog box, choose the MATLAB script and click **Open**. The Pattern Wizard adds a flow chart and a graphical function to your Stateflow chart. Double-click the graphical function to see its contents.



- In the Symbols pane, click **Resolve Undefined Symbols** . The Stateflow Editor resolves `u` and `y` as local data.

- Save your chart.

- To execute the chart from the Stateflow Editor, in the Symbols pane, enter a value of `u = 9` and

click **Run** . While the flow chart is executing, the Stateflow Editor highlights the active transitions through chart animation. When the execution stops, the MATLAB Command Window displays the hailstone sequence, starting with a value of nine:

9 28 14 7 22 11 34 17 52 26 13 40 20 10 5

- Click **Stop** .

You can copy generated flow charts and graphical functions and paste them in other charts, including Stateflow charts in Simulink models. If your MATLAB code uses functionality that is restricted for code generation in Simulink, you must modify the flow chart actions before simulating the chart. For more information, see “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40.

**Note** Suppose that you use `nargin` in a MATLAB function that you convert to a graphical function in a chart. Because `nargin` counts the chart object as one of the input arguments of the graphical function, the value of `nargin` in the graphical function is equal to one plus the value of `nargin` in the original MATLAB function. For more information, see “Execute a Standalone Chart” on page 35-3.

## **See Also**

### **More About**

- “Flow Charts in Stateflow” on page 5-2
- “Create Flow Charts by Using Pattern Wizard” on page 5-5
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2

# Simulink Subsystems as Stateflow States

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- “Simulink Subsystems as States” on page 6-2
- “Create and Edit Simulink Based States” on page 6-11
- “Access Block State Data” on page 6-17
- “Map Variables for Simulink Based States” on page 6-23
- “Set Simulink Based State Properties” on page 6-25
- “Model a Clutch” on page 6-27

## Simulink Subsystems as States

By using a Simulink subsystem within a Stateflow state, you can model hybrid dynamic systems or systems that switch between periodic and continuous time dynamics. In your Stateflow chart, you can use Simulink based states to model a periodic or continuous dynamic system combined with switching logic that uses transitions. You can access inputs and outputs from your chart within each Simulink based state. Simulink based states are supported only in Stateflow charts in a Simulink model.

To initialize Simulink blocks when switching between Simulink based states, use Stateflow textual notation or Simulink State Reader and State Writer blocks.

To create linked Simulink based states, use libraries to save action subsystems. When you copy an action subsystem from a library model into a Stateflow chart, it appears as a linked Simulink based state. When you update the library block, the changes are reflected in all Stateflow charts containing the block.

Using Simulink based states means that you do not have to use complex textual syntax in Stateflow to model hybrid systems.

### When to Use Simulink Based States

Use Simulink based states when:

- You want to model hybrid dynamic systems that include continuous or periodic dynamics.
- The structure of the system dynamics change substantially between the various modes of operation, for example, modeling PID controllers.

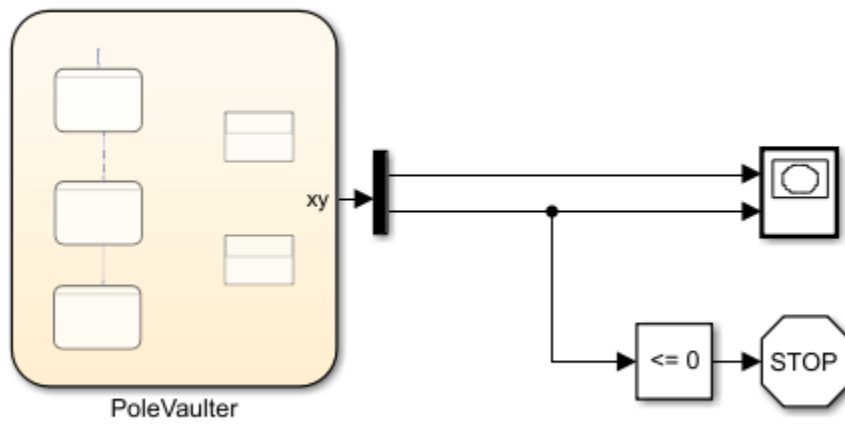
For systems where you call logic intermittently, use Simulink functions.

When the structure of the Simulink algorithm remains substantially unchanged, but certain gains or parameters switch between various models, use Simulink logic outside of Stateflow. An example of this type of algorithm is gain scheduling. See “Model Gain-Scheduled Control Systems in Simulink” (Simulink Control Design).

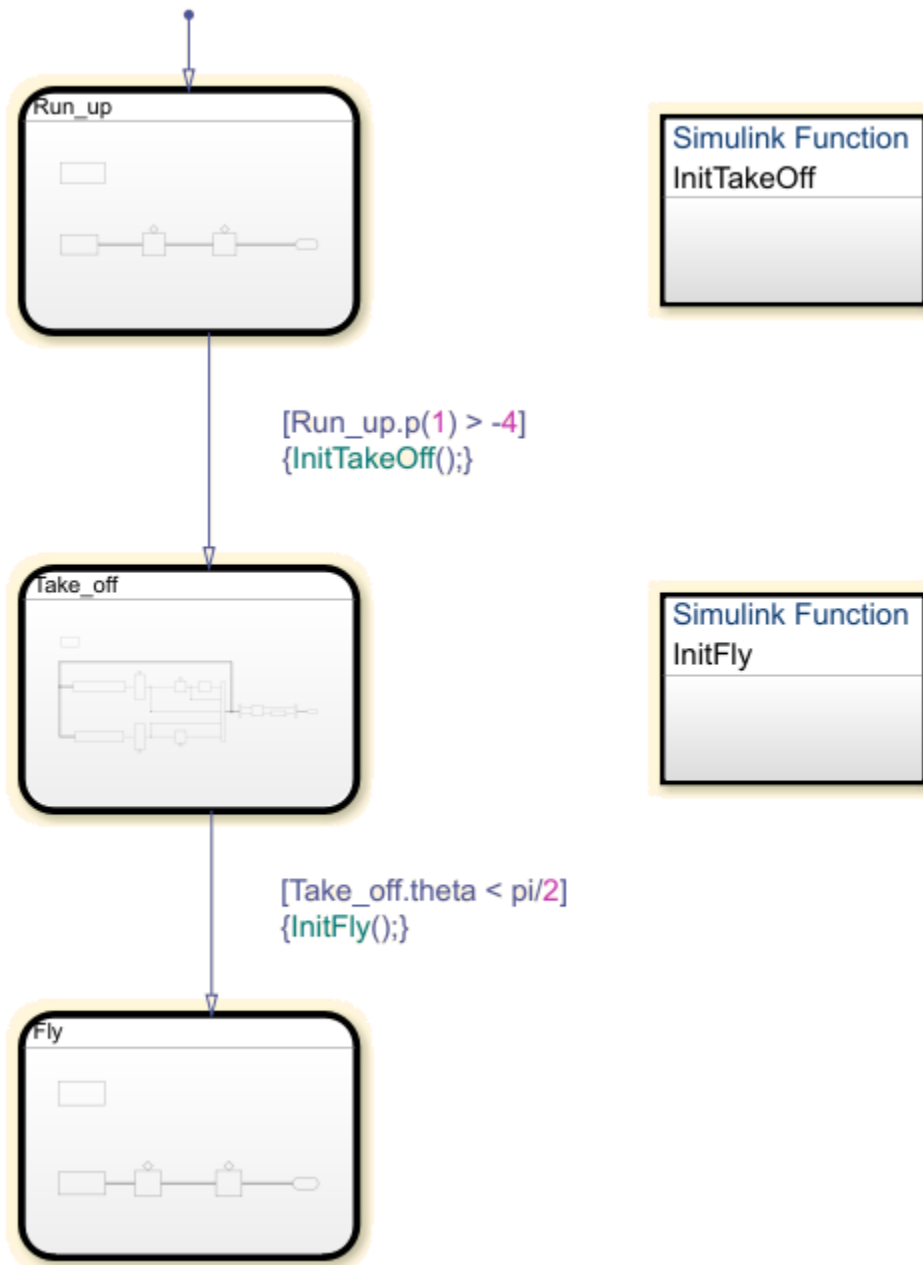
### Model a Pole Vaulter by Using Simulink Based States

This Stateflow chart models a person moving through the stages of pole vaulting by using Simulink based states. The first stage is the approach run of the vaulter, which is modeled in the Simulink based state `Run_up`. In the second stage, the vaulter plants the pole and takes off, which is modeled by the Simulink based state `Take_off`. The final stage happens when the vaulter clears the bar and releases the pole, which is modeled by the Simulink based state `Fly`.





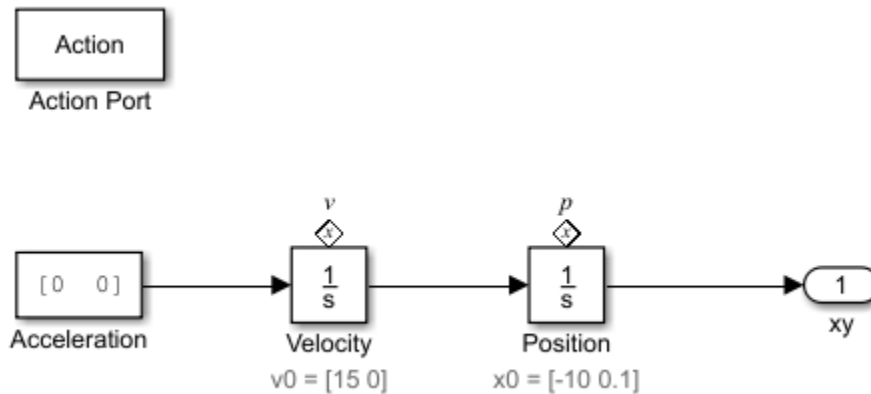
The Stateflow chart contains this logic:



The states Run\_up and Fly are easier to model by using Cartesian coordinates. The state Take\_off is easier to model by using polar coordinates. To switch from one coordinate system to another, use Simulink functions InitTakeOff and InitFly.

### Model the Approach of the Pole Vaulter

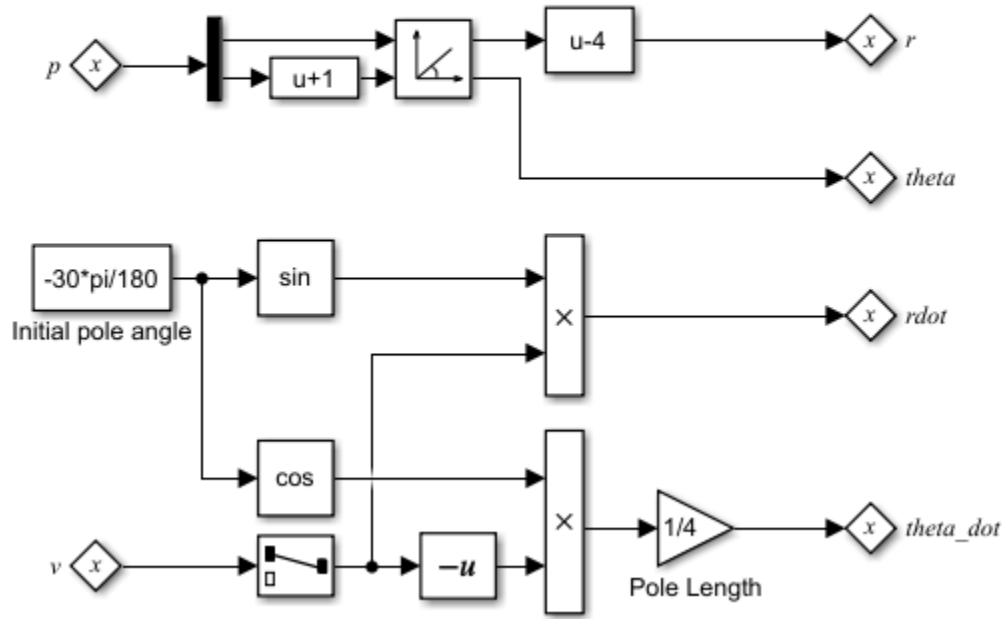
The Simulink based state Run\_up contains this logic:



The default state in the chart PoleVaultier is Run\_up. This state models the pole vaulter traveling along the ground toward the jump. The pole vaulter starts at -10 on the x-axis and runs toward zero. As the pole vaulter moves along the ground, the position of the pole vaulter in the xy-plane is continuously changing, but the state of running remains the same. In this model, the integrator blocks Position and Velocity are state owner blocks for State Reader blocks in the Simulink function InitTakeOff. This subsystem outputs the Cartesian coordinates of the pole vaulter.

### Convert Cartesian Coordinates to Polar Coordinates

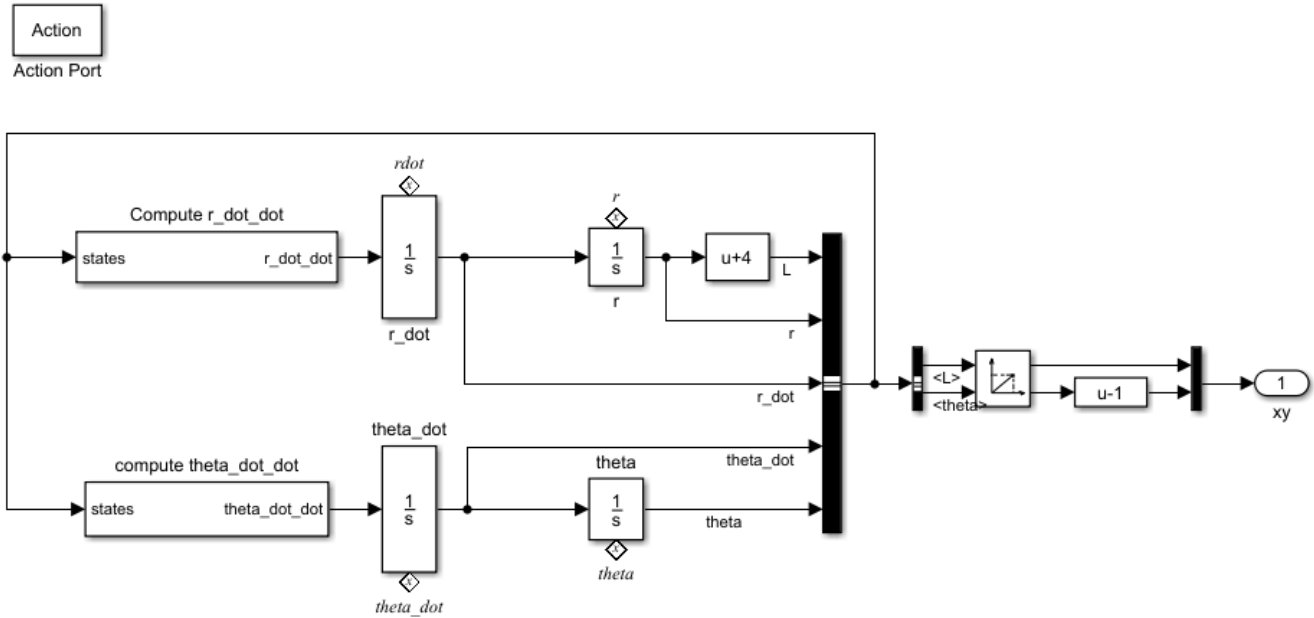
The Simulink function InitTakeOff contains this logic:



Once the position of the pole vaulter along the x-axis,  $\text{Run\_up.p}(1)$ , becomes greater than -4, the transition from  $\text{Run\_up}$  to  $\text{Take\_off}$  occurs. During the transition  $\text{InitTakeOff}$  is initialized, the State Reader block connects to its owner block, and the function is executed. This function converts the Cartesian coordinates from Position and Velocity to polar coordinates,  $r$ ,  $\theta$ ,  $\dot{r}$ , and  $\dot{\theta}$ . These coordinates are output as State Writer blocks, which are connected to owner blocks in the state  $\text{Take\_off}$ .

### Model the Take Off of the Pole Vaulter

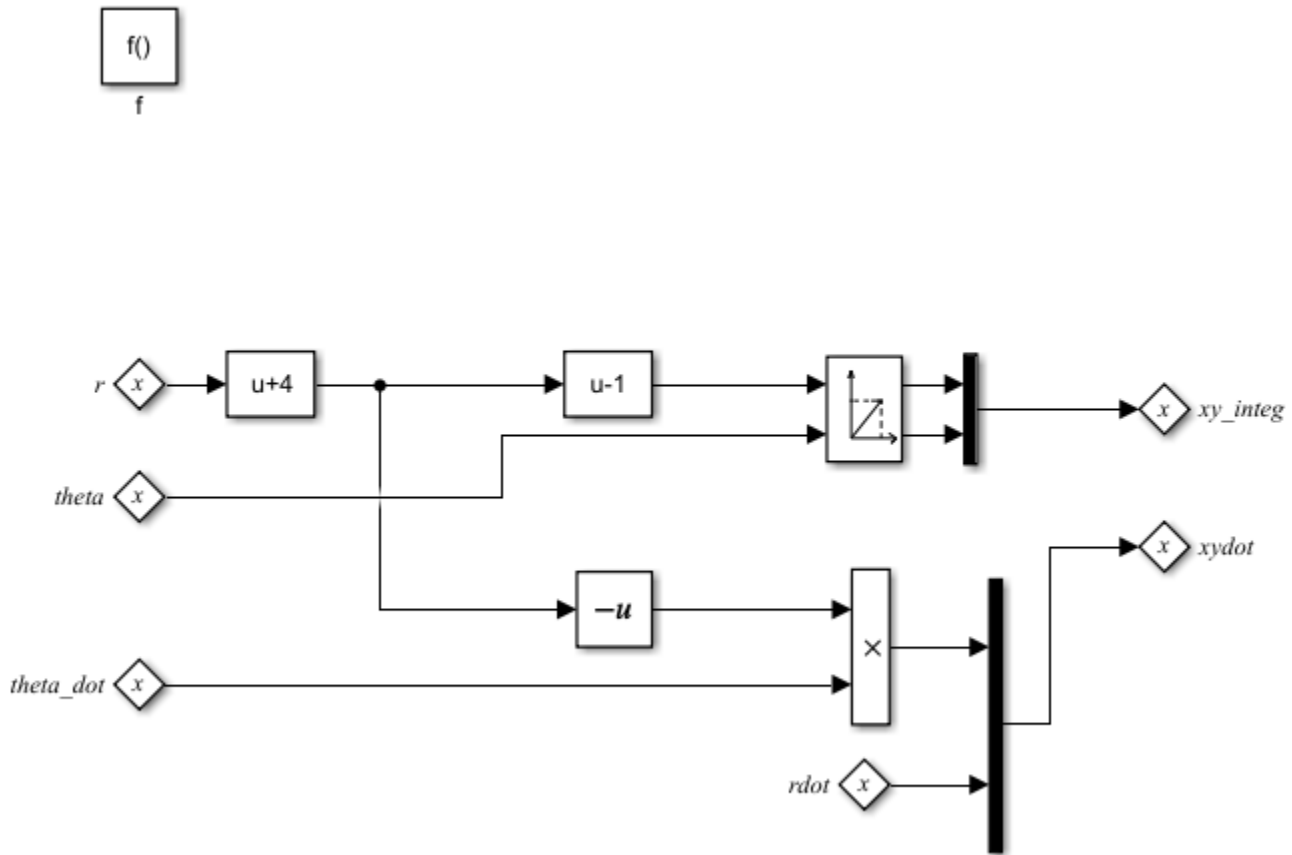
The Simulink based state  $\text{Take\_off}$  contains this logic:



Once the position of the pole vaulter along the x-axis,  $Run\_up.p(1)$ , becomes greater than -4, the active state becomes  $Take\_off$ . This Simulink subsystem models the pole vaulter during the take off phase of the jump. The subsystem outputs the Cartesian coordinates of the pole vaulter.

### Convert Polar Coordinates to Cartesian Coordinates

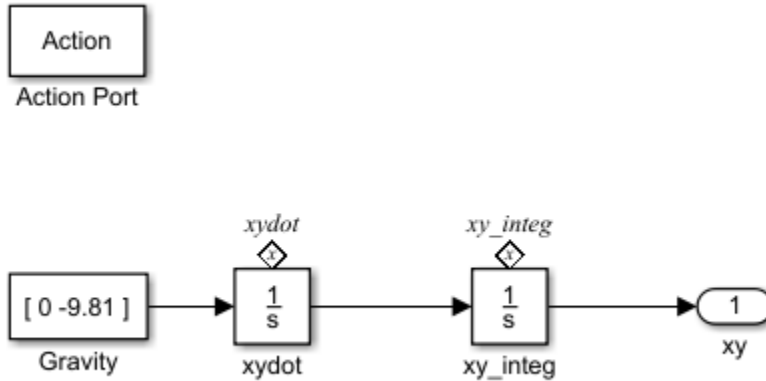
The Simulink function `InitFly` contains this logic:



Once the angle of the pole vaulter,  $\theta$ , becomes less than  $\pi/2$ , the transition from `Take_off` to `Fly` occurs. During the transition `InitFly` is initialized, the State Reader block connects to its owner block, and the function is executed. This function converts the polar coordinates from  $r$ ,  $\theta$ , and  $\theta_{dot}$  to Cartesian coordinates,  $xy\_integ$  and  $xydot$ . These coordinates are output as State Writer blocks, which are connected to owner blocks in the state `Fly`.

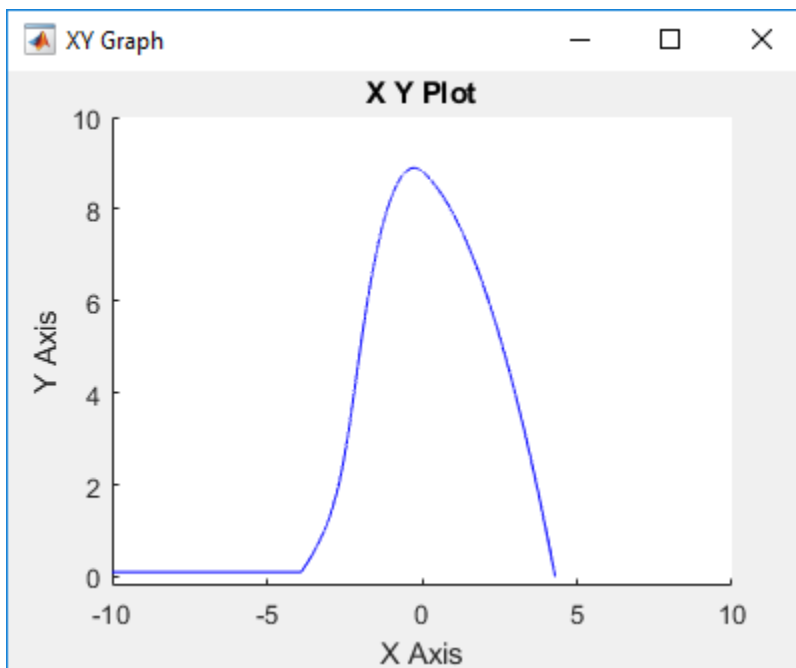
### Model the Free Fall of the Pole Vaulter

The Simulink based state `Fly` contains this logic:



Once the angle of the pole vaulter,  $\theta$ , is less than  $\pi/2$ , the active state becomes `Fly`. This state models the pole vaulter after the jump has cleared and the pole vaulter is falling to the ground. As the pole vaulter falls, the position of the pole vaulter in the x-y plane is continuously changing, but the state of falling remains the same. In this model, the integrator blocks `xydot` and `xy_integ` are state owner blocks for State Writer blocks in the Simulink function `InitFly`. This subsystem outputs the Cartesian coordinates of the pole vaulter.

The results of this simulation are seen in the XY Graph.



## Limitations

You cannot use Simulink based states with:

- Moore charts

- Discrete Event charts
- HDL Coder
- PLC Coder
- Simulink Code Inspector
- Super step transitions

Simulink based states do not support debugging.

### **See Also**

#### **More About**

- “Create and Edit Simulink Based States” on page 6-11
- “Reuse Charts in Models with Chart Libraries” on page 28-12
- “Create Custom Library” (Simulink)



## Create and Edit Simulink Based States

To model systems that switch between periodic or continuous time dynamics, use Simulink based states. Simulink based states are supported only in Stateflow charts in a Simulink model. For more information, see “Simulink Subsystems as States” on page 6-2.


You can create Simulink based state by using the drawing tool. To reuse systems from separate Simulink models, copy and paste enabled subsystems. To reuse subsystems in multiple Stateflow charts, copy and paste action subsystems that are saved in a library.

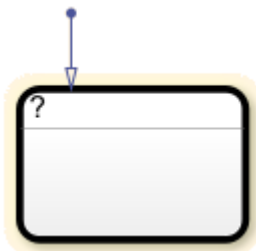
### Create a Simulink Based State

To create a Simulink based state, do one of the following:

- Create an empty Simulink based state by using the Simulink based state drawing tool.
- Create a Simulink based state from another model by copying an enabled subsystem or an action subsystem to your Stateflow chart.
- Create a linked Simulink based state by copying an action subsystem from a library to your Stateflow chart.

#### Create an Empty Simulink Based State

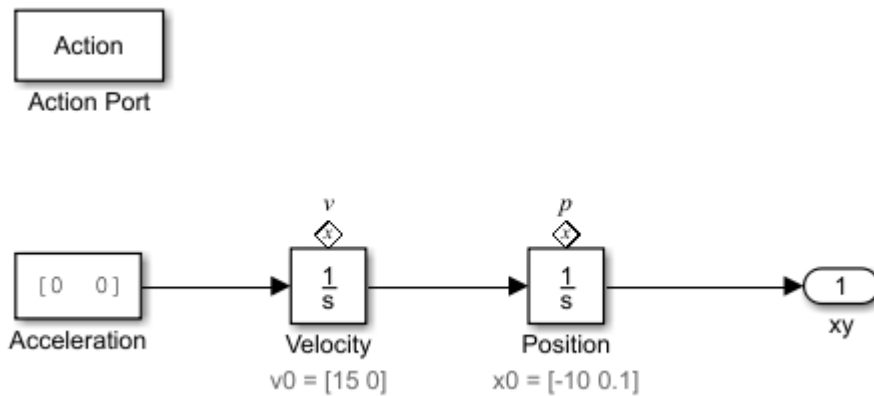
- 1 Add a Stateflow chart block to a Simulink model. To open the Stateflow Editor, double-click the block.
- 2 On the object palette, click the Simulink based state drawing tool . Move your cursor onto your chart.
- 3 To place the new Simulink based state, click the Stateflow canvas. A shaded state appears.



- 4 Enter the state label. In this example, the state models a pole vaulter running along a flat surface, so the state label is Run\_up. Simulink based states are action subsystems, so an Action Port appears with your new state.



- Build your Simulink subsystem. This subsystem outputs the Cartesian coordinates of the pole vaulter. For more information about this model, see “Access Block State Data” on page 6-17.

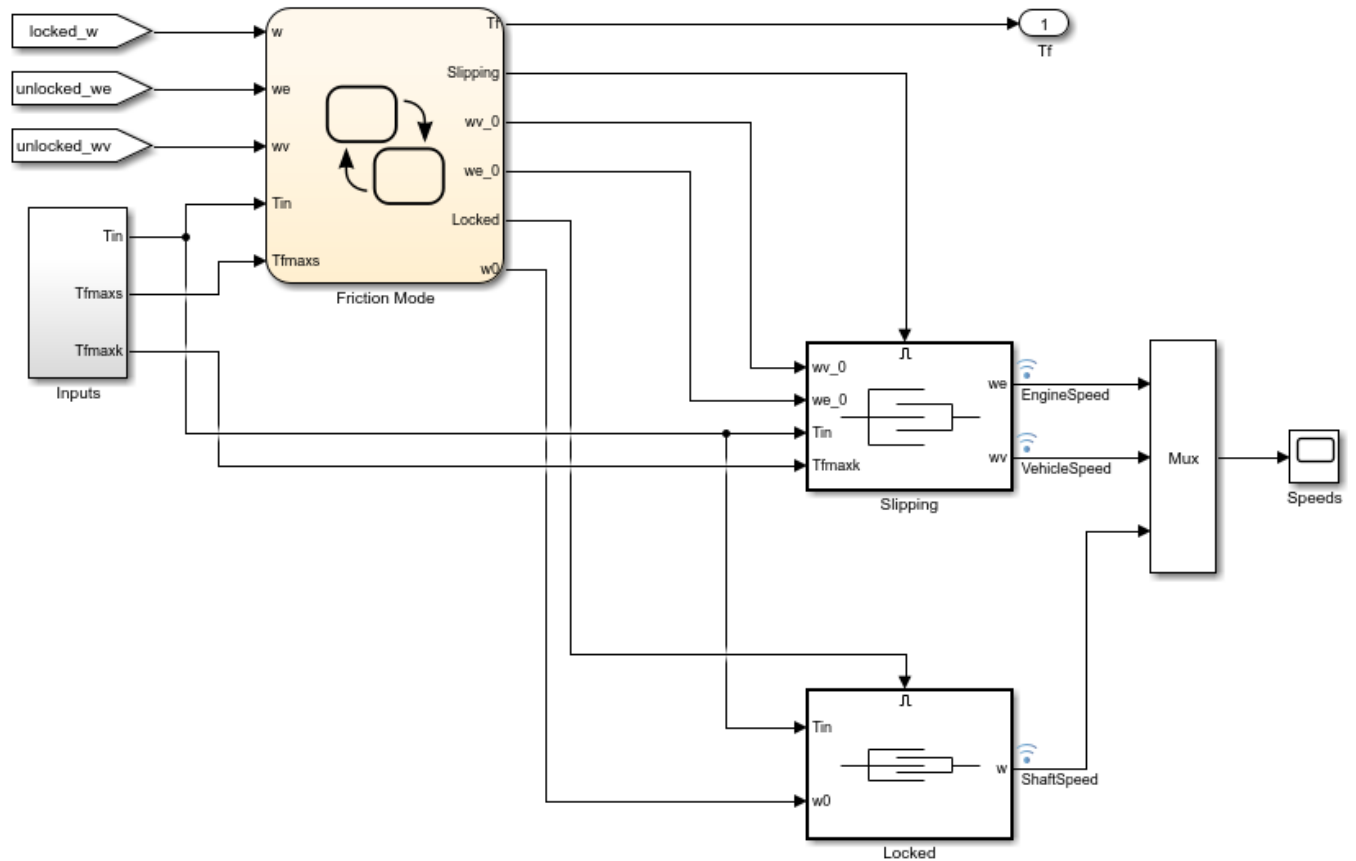


### Create a Simulink Based State from an Enabled Subsystem

To create a Simulink based state in your Stateflow chart, copy enabled subsystems from separate Simulink models. You can reuse components from Simulink models in a Stateflow chart without creating a brand new Simulink based state.

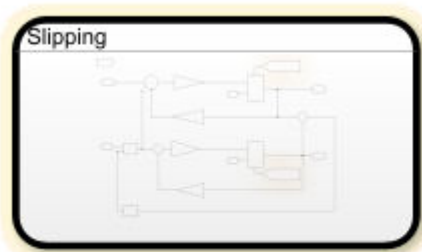
- Open the sf\_clutch\_enabled\_subsystems model.


### Building a Clutch Lock-Up Model Using Stateflow(R) and Simulink(R)



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- From the model, copy the block Slipping to your Stateflow chart.

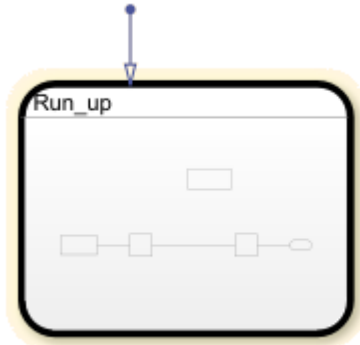


- The inports and outports of your Simulink subsystem appear as undefined symbols in your Stateflow chart. To add corresponding input and output data to your Stateflow chart, click the **Resolve undefined symbols** button .

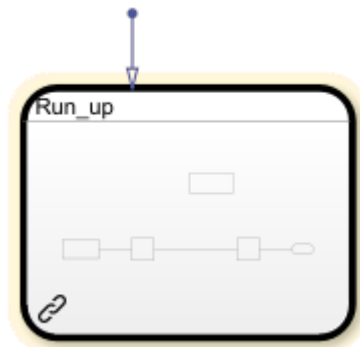
### Create a Linked Simulink Based State


To create a linked Simulink based state in your Stateflow chart, copy an action subsystem from a library to Stateflow. When the library block is updated, the changes are reflected in all Stateflow charts containing the block.

- 1 Open the library model.
- 2 Copy and paste the library block Run\_up to your Stateflow chart.



- 3 To display a link in the bottom leftmost corner on a linked subsystem, in the **Debug** tab, select **Information Overlays > Show All Links**.



- 4 The outputs of this Simulink subsystem, xy, appears as an undefined symbol in your Stateflow chart. To add a corresponding output data to your Stateflow chart, click the **Resolve undefined symbols** button .


### Create Inports and Outputs

When using Simulink based states, inports and outputs for your Simulink subsystem connect to input and output data at the Stateflow chart level. This connection allows the top-level Simulink model to read data from the subsystem contained within your Simulink based state.

When you create an empty Simulink based state, Stateflow creates inputs and outputs in your Simulink subsystem that correspond to inputs and outputs that exist in the parent Stateflow chart.

However, if you add inports and outputs to your Simulink based state after it is created, you must create corresponding input and output data for your Stateflow chart.

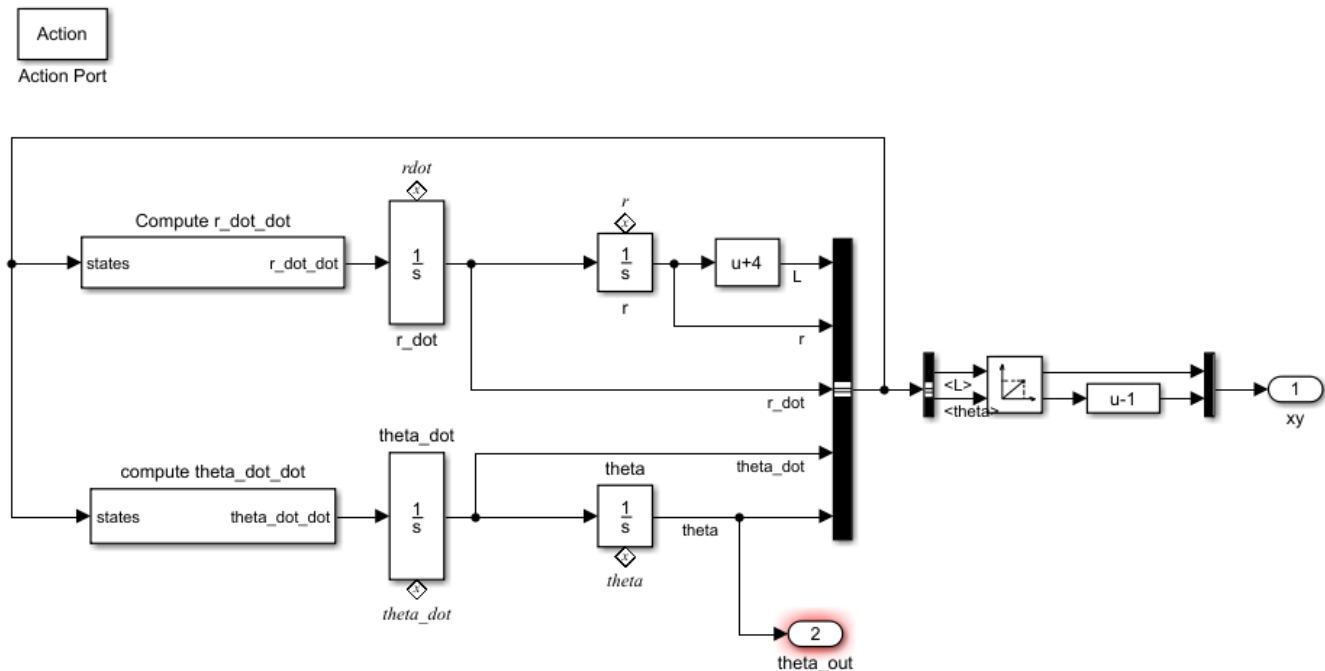
To create additional inports or outputs for a Simulink based state:


- 1 Open your Simulink based state.
- 2 Click the Simulink canvas, type `in1`, and press **Enter**. An undefined inport is created.
- 3 The undefined symbol `in1` appears in the Symbols pane of your Stateflow chart. To resolve the undefined symbol, click the **Resolve undefined symbols** button .
- 4 A chart inport named `In1` is created.

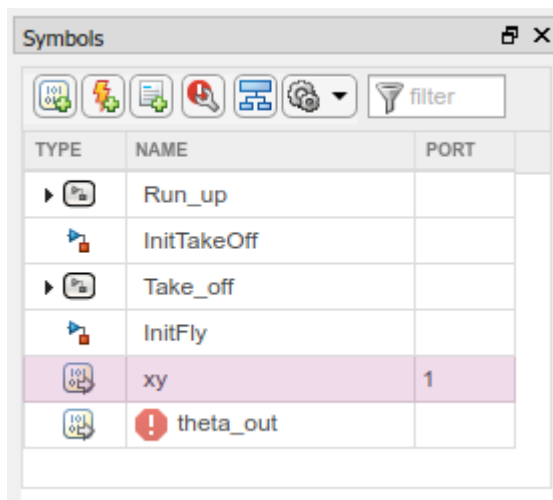
### Create an Additional Output

In this example, you create an additional output for the model `sf_pole_vault`:

- 1 To open the model.
- 2 Open the chart `PoleVault` and double-click Simulink based state `Take_off`.
- 3 Click the Simulink based state canvas and type `out1` and press **Enter**. An undefined output is created. Rename the output `theta_out` and connect it to the signal for `theta`.



- 4 In the Symbols pane of `PoleVault`, an undefined symbol for `theta_out` appears. To resolve the undefined symbol, click the **Resolve undefined symbols** button .



- 5 Stateflow creates an output in the chart called `theta_out` that corresponds to the output `theta_out`.

For more information about editing data, see “Add and Modify Data, Events, and Messages” on page 34-3.

### See Also

#### More About

- “Simulink Subsystems as States” on page 6-2
- “Access Block State Data” on page 6-17
- “Map Variables in a Simulink Based State” on page 6-23
- “Reuse Charts in Models with Chart Libraries” on page 28-12
- “Create Custom Library” (Simulink)

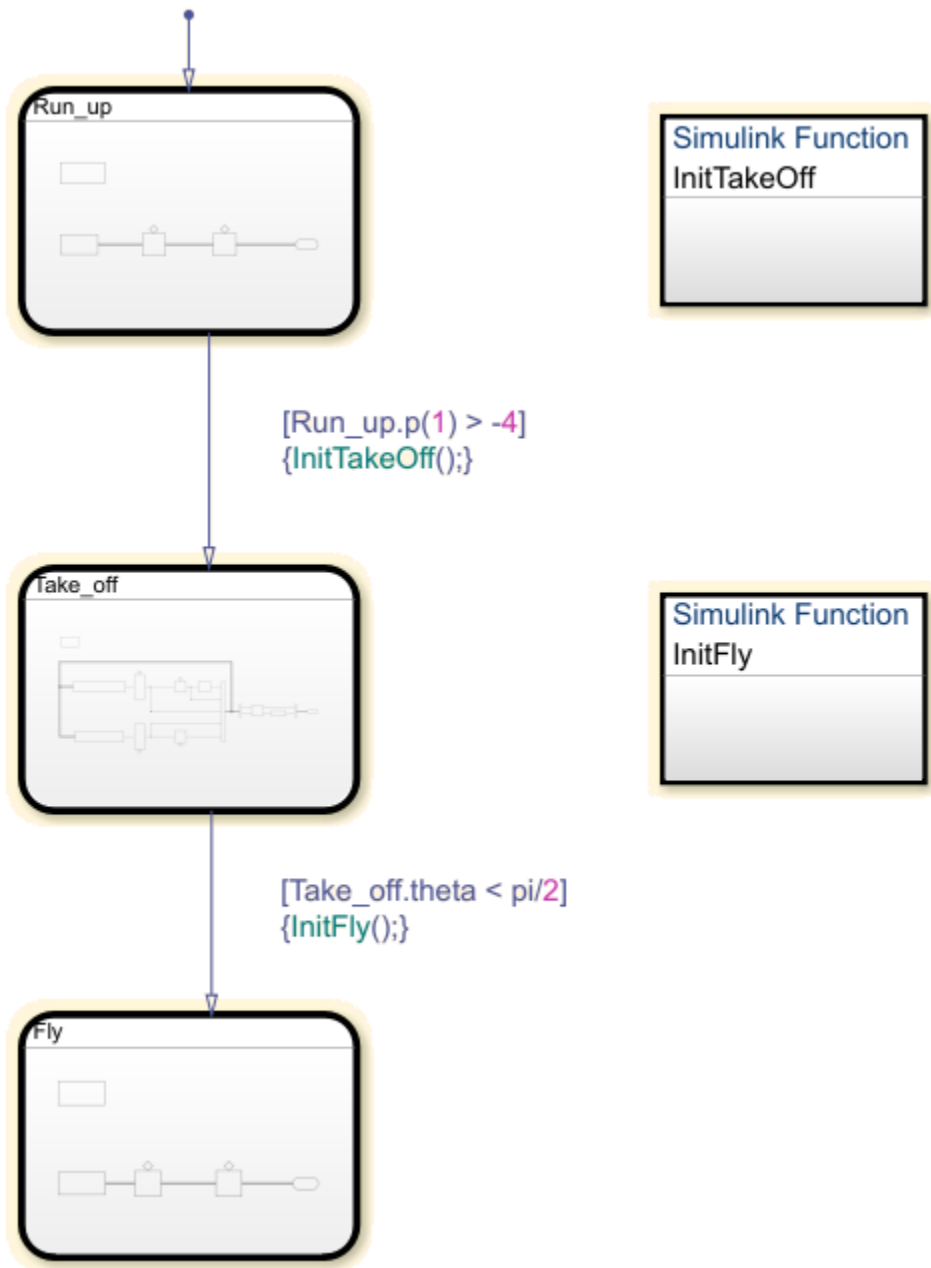
## Access Block State Data

To model systems that switch between periodic or continuous time dynamics, use Simulink based states. Simulink based states are supported only in Stateflow charts in a Simulink model. For more information, see “Simulink Subsystems as States” on page 6-2.

You can read and write the state of blocks within your Simulink based states in transition actions of your Stateflow chart. You can read and write the state of blocks textually on the chart transitions or by using Simulink State Reader and State Writer blocks.

This Stateflow chart models a person moving through the stages of pole vaulting. The first stage is the approach run of the vaulter, which is modeled by the Simulink based state `Run_up`. In the second stage, the vaulter plants the pole and takes off, which is modeled by the Simulink based state `Take_off`. The final stage happens when the vaulter clears the bar and releases the pole, which is modeled by the Simulink based state `Fly`.

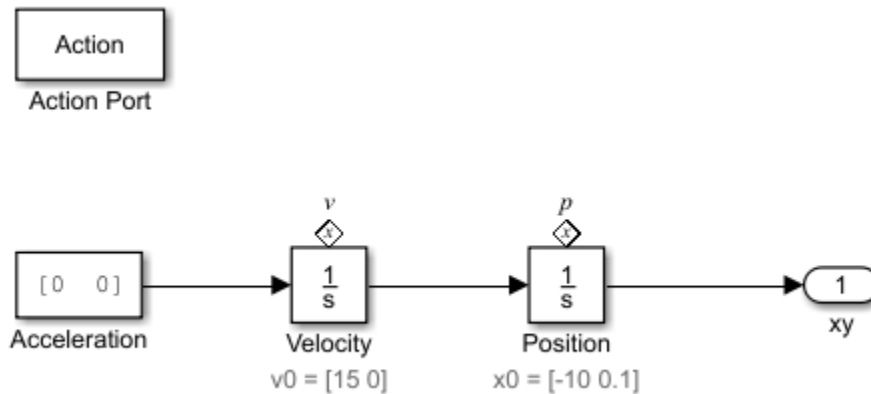
The states `Run_up` and `Fly` are easier to model by using Cartesian coordinates. The state `Take_off` is easier to model by using polar coordinates. The Simulink functions `InitTakeOff` and `InitFly` are used to switch from one coordinate system to another. For more details on this chart, see “Model a Pole Vaulter by Using Simulink Based States” on page 6-2.



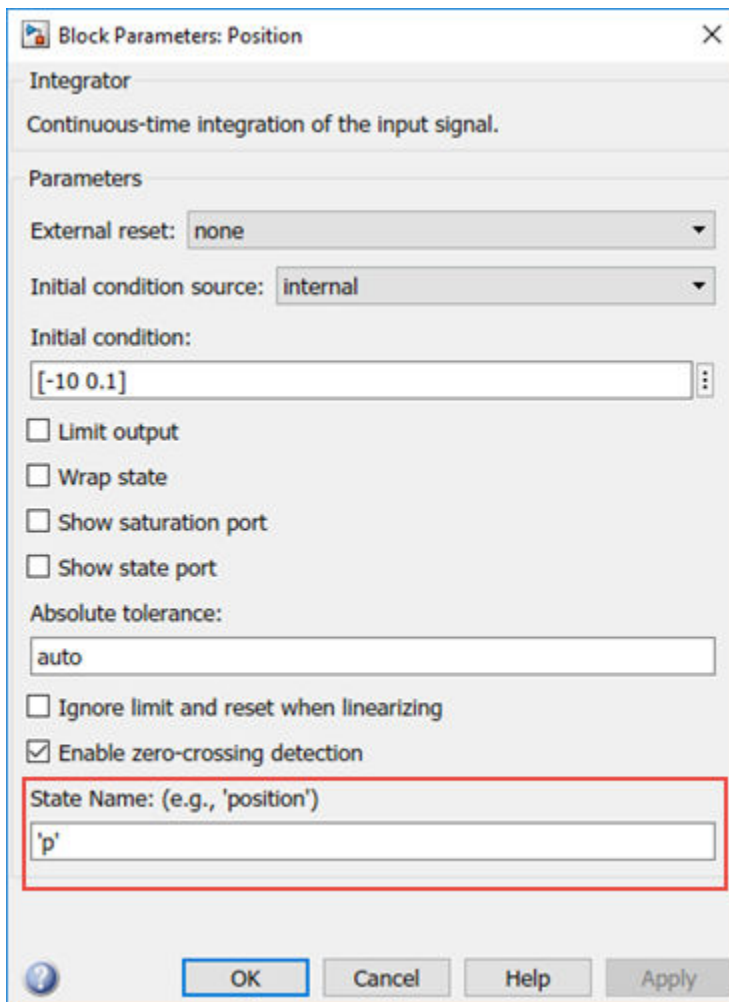
### Textual Access

This subsystem is contained within the Simulink based state Run\_up. For the transition from Run\_up to Take\_off to occur, the position of the pole vaulter along the x-axis,  $p(1)$ , must be greater than -4.

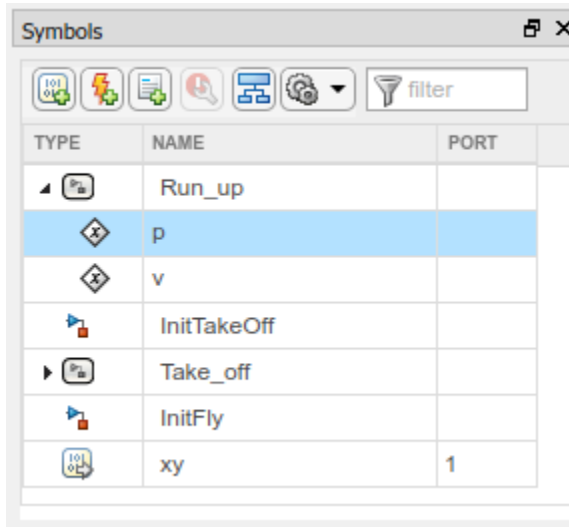





By setting the State Name of the integrator block **Position** to 'p', you can textually access the state of this block from your Stateflow chart. To access the state of the integrator block in the transition condition, type `[Run_up.p(1)> -4]`. When this condition becomes true, the transition is taken and the active state becomes **Take\_off**.



In the Symbols pane, you can see that the state 'p' appears under the state Run\_up.



## Graphical Access

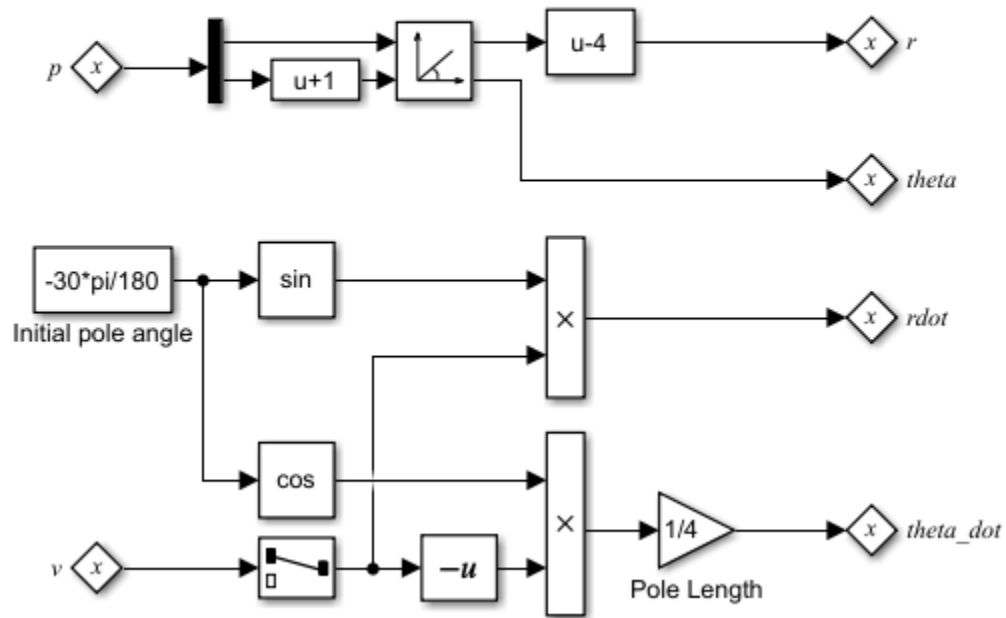
Stateflow uses State Reader and State Writer blocks to connect the subsystems within a Simulink based state to other Simulink subsystems in your model. State Reader and State Writer blocks display the name of the state owner block that they are connected to. Conversely, the state owner block displays a tag  indicating a link to a State Reader or a State Writer block. If you click the label above the tag, a list opens with a link for navigating to the State Writer block.

### Connect a State Reader Block to an Owner Block

The following subsystem is contained within the Simulink function `InitTakeOff`. The function uses State Reader blocks to connect to the state `Run_up` and reads `p` and `v`. The function then converts the Cartesian values for the position of the pole vaulter and velocity into polar coordinates, `r` and `theta` and `rdot` and `theta_dot`, respectively. These polar coordinates are then accessed by using state owner blocks in the state `Take_off`.

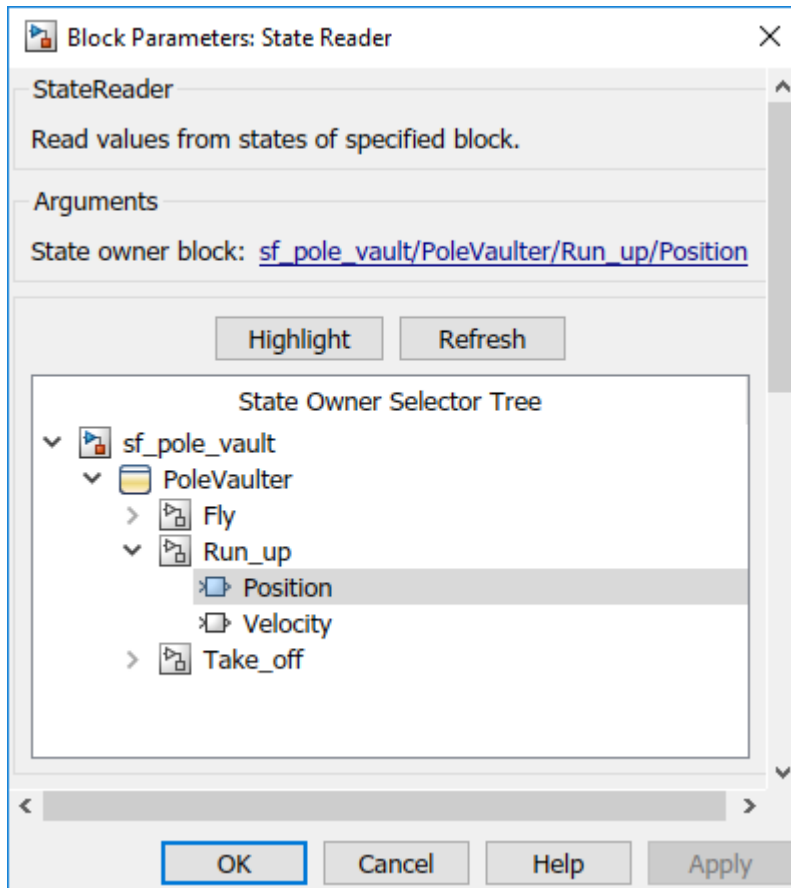
When the transition action occurs, the State Reader blocks in `InitTakeOff` read the state of their state owner blocks. Once the Simulink function finishes executing, the State Writer blocks write to the state owner blocks in the Simulink based state `Take_off`.

f()  
f



To connect a State Reader or a State Writer block to an owner block within a Simulink subsystem:

- 1 To open the properties, double-click the State Reader.
- 2 In the **State Owner Selector Tree**, navigate to the block that you want to be the state owner block. In this example, by choosing **Position**, you connect the State Reader block to the integrator **Position** in the state **Run\_up**.



- 3 By connecting the State Reader block to the Position integrator block, this Simulink function can use the state of the integrator Position to execute.

## See Also

### More About

- “Simulink Subsystems as States” on page 6-2
- State Reader (Simulink)
- State Writer (Simulink)

## Map Variables for Simulink Based States

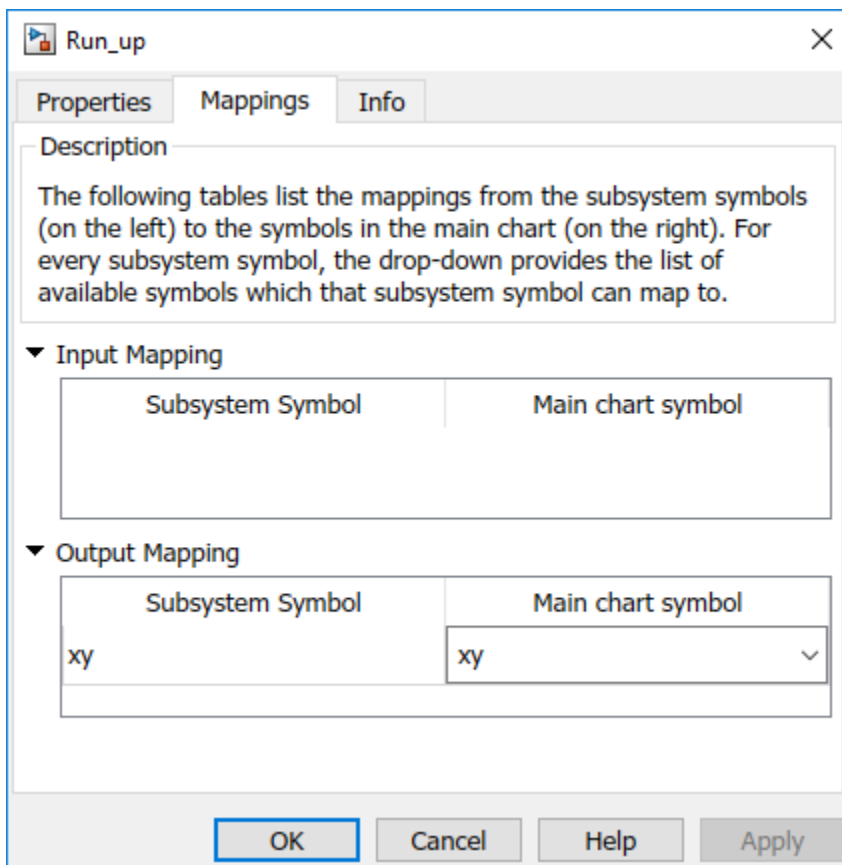
To model systems that switch between periodic or continuous time dynamics, use Simulink based states. Simulink based states are supported only in Stateflow charts in a Simulink model. For more information, see “Simulink Subsystems as States” on page 6-2.

You can access inports or outports of a subsystem within a Simulink based state by using inputs and outputs in Stateflow that have the same name as your inports and outports. For Simulink based states that are created by copying and pasting enabled subsystems and action subsystems from a library, click the **Resolve undefined symbols** button to map your Simulink inports and outports to Stateflow inputs and outputs automatically. See “Create Inports and Outports” on page 6-14.

If you are using a linked Simulink based state where the name of the inport or outport differs from the Stateflow chart input or output, you must ensure that your variables are mapped correctly. You can change your mappings from the Property Inspector or in the Mappings dialog box.

### Map Variables in a Simulink Based State

To open the mappings dialog box, select the Simulink Based State. In the **Simulink State** tab, click **Mappings**.



Under **Input Mapping**, you can specify which parent chart input maps to an inport in your Simulink subsystem.

Under **Output Mapping**, you can specify which parent chart output maps to an output in your Simulink subsystem.

### See Also

#### More About

- “Simulink Subsystems as States” on page 6-2
- “Create and Edit Simulink Based States” on page 6-11
- “Access Block State Data” on page 6-17
- “Resolve Symbols Through the Symbols Pane” on page 31-37

## Set Simulink Based State Properties

Simulink based states are Simulink subsystems within a Stateflow state that enable you to model systems that switch between periodic or continuous time dynamics. For more information, see “Simulink Subsystems as States” on page 6-2.

You can specify the properties of a Simulink based state in either the Property Inspector or the properties dialog box for the Simulink based state.

- To use the Property Inspector:
  - 1 In the **Modeling** tab, under **Design Data**, select **Property Inspector**.
  - 2 In the Stateflow Editor, select the Simulink based state.
  - 3 In the Property Inspector pane, edit the properties of the Simulink based state.
- To use the Simulink Based State properties dialog box:
  - 1 In the Stateflow Editor, right-click the Simulink based state.
  - 2 Select **Properties**.
  - 3 Edit the Simulink based state properties.

You can also specify Simulink based state properties programmatically by using `Stateflow.SimulinkBasedState` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Simulink Based State Properties

You can set the following chart properties in the **Properties** and **Info** tabs of the Property Inspector and the Simulink Based State properties dialog box.

#### Create data for monitoring self activity

Creates a data output port on the Stateflow block for this self-activity of the state.

#### Log self activity

Logs the state self-activity. View the activity of the state in the Simulation Data Inspector.

#### Logging name

Specify the signal logging name. To create a signal logging name that is different from the state name, choose **Custom**, and add the name.

#### Test point

Sets the Simulink based state as a Stateflow test point. For more information, see “Monitor Test Points in Stateflow Charts” on page 33-39.

#### Limit data points to last

Maximum number of data points to log. Default value is 5000, which means the chart logs the last 5000 data points generated by the simulation.

### Decimation

Decimation interval limits the amount of data logged by skipping samples. Default value is 2, which means the chart logs every other sample.

### Function packaging

Specify the code format generated for a Simulink based state. You can set the format to one of these options:

- **Auto** — Simulink Coder software chooses the optimal format for you based on the type and number of instances of the subsystem that exist in the model.
- **Inline** — Simulink Coder software inlines the subsystem unconditionally.
- **Nonreusable function** — Simulink Coder software explicitly generates a separate function in a separate file.
- **Reusable function** — Simulink Coder software generates a function with arguments that allows reuse of Simulink based state code when a model includes multiple instances of the Simulink based state.

For more information, see “Function packaging” (Simulink).

### Description

Simulink based state description. You can enter brief descriptions of Simulink based states in the hierarchy.

### Document Link

Link to online documentation for the Simulink based state. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow displays the documentation.

### See Also

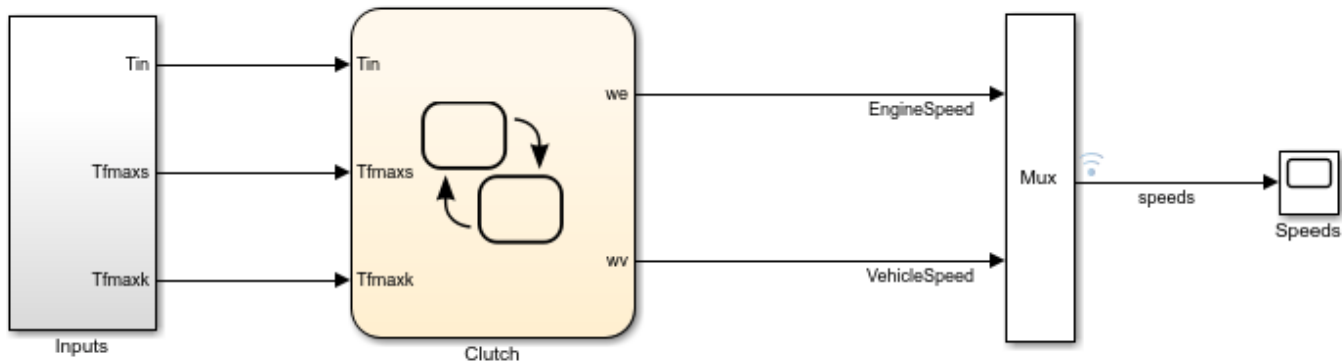
#### More About

- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Specify Size of Stateflow Data” on page 12-33
- “Specify Type of Stateflow Data” on page 12-27



## Model a Clutch

This example shows the modeling of the Simulink® clutch example using Simulink based states inside a Stateflow® chart. For a detailed explanation of the physical system, see “Building a Clutch Lock-Up Model” (Simulink).



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### Recommended Workflow

This model shows the recommended way of modeling hybrid systems by using Simulink and Stateflow. This model also covers when to use Simulink or physical modeling tools if the continuous dynamics are complex coupled with mode changes.

Modeling a hybrid system involves addressing the following concerns:

- Modeling the continuous dynamics
- Modeling the mode logic
- Initializing states when switching between modes

### Continuous Dynamics

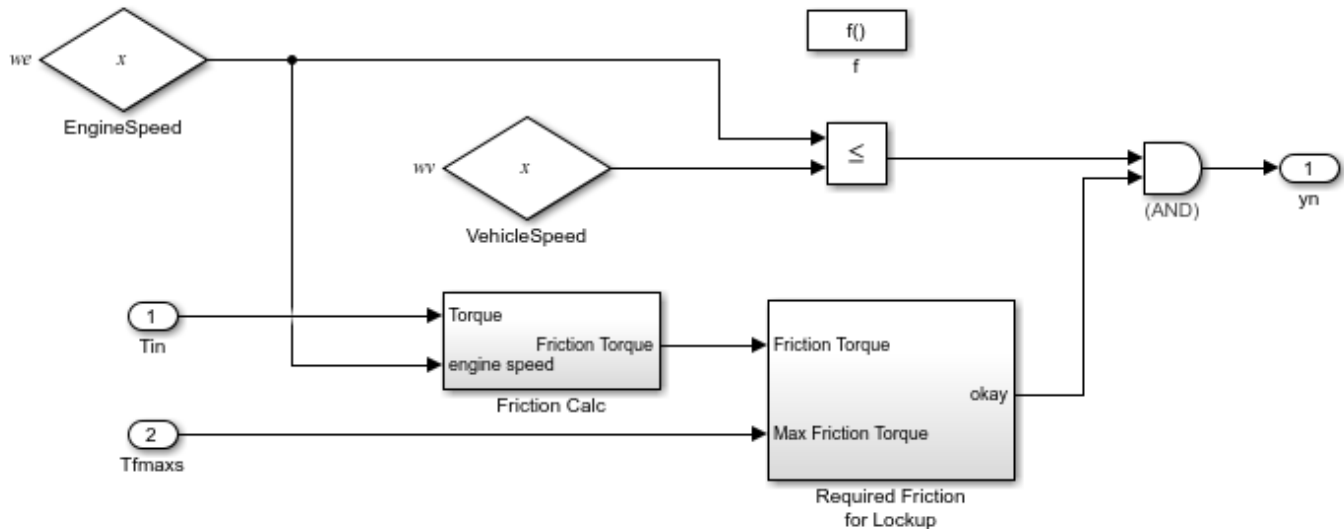
Hybrid systems have multiple modes of operation where each mode is defined by continuous dynamics. When the continuous dynamics are complex, model them by using Simulink based states. In this model, the `Locked` and `Slipping` states represent the two modes of operation of a clutch. Simulink blocks within a Simulink based state represent the logic of the state. These blocks include continuous time blocks, such as integrators. Within each Simulink based state, you can access chart inputs and outputs by creating inports and outports with the same name. Each Simulink based state reads from a subset of chart inputs and writes to all the chart outputs.

### Mode Logic

Mode logic refers to the conditions under which the model switches from one mode of operation to another. In this example, the mode logic is described by the transition logic between the two Simulink based states. The conditions needed to switch from one Simulink based state to another depend on the internal state of the integrators within in the current active mode. For example, when switching from `Slipping` to `Locked` Stateflow must read the internal state of the integrator in the `Slipping` mode.

This is possible using two different mechanisms:

**1. Using State Reader and State Writer blocks inside Simulink functions:** Stateflow can call Simulink functions on the transition logic between the two modes. Inside the Simulink function, use State Reader blocks to refer to the internal state of the integrator. For example, the Simulink function `detectLockup` uses the State Reader block `EngineSpeed` to read the state of the integrator block `sf_clutch/Clutch/Slipping/xe`.



**2. Using qualified dot notation on the transition conditions:** If the transition logic is simple and can be expressed textually, it is possible to use a syntax like `Slipping.we == ...` to refer to the state of the integrator `sf_clutch/Clutch/Slipping/xe`. For this syntax to work, the State Name parameter of the integrator has to be set to "we".

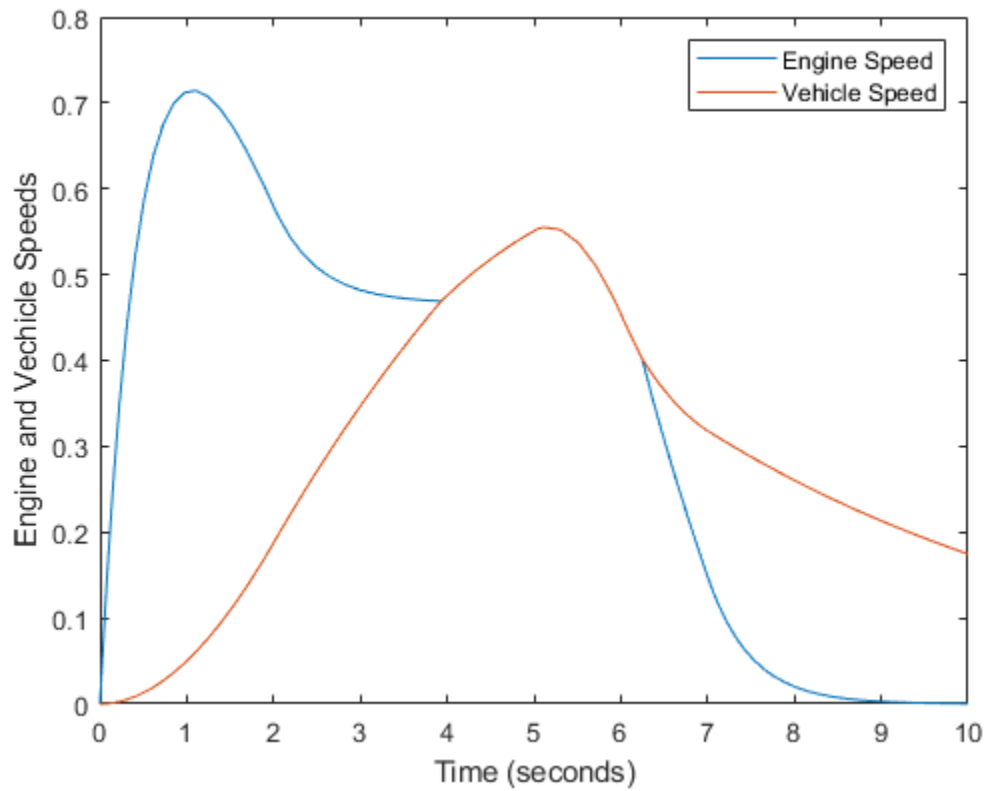
### State Handoff

When switching from one mode of operation to another, the integrators in the newly activated subsystem need to be initialized properly in order to get smooth output. This can be done using either Simulink State Reader and State Writer blocks in Simulink functions or textually using the qualified dot notation. For example, on the transition from `Slipping` to `Locked`, initialize the state of the single integrator in `Locked` by using the state of one of the integrators in `Slipping`. Initialize the state by using the syntax:

```
Locked.w = Slipping.we;
```

### Simulation Results

When the system is simulated, the engine and vehicle velocities are as shown in the following graph. The plates lock at about 4 seconds and begin slipping again at about 6.25 seconds.



## See Also

### More About

- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Building a Clutch Lock-Up Model” (Simulink)



# Build Mealy and Moore Charts

---

- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Mealy Charts” on page 7-5
- “Model a Vending Machine by Using Mealy Semantics” on page 7-7
- “Design Considerations for Moore Charts” on page 7-9
- “Model a Traffic Light by Using Moore Semantics” on page 7-12
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14
- “Sequence Recognition by Using Mealy and Moore Charts” on page 7-18
- “Karplus-Strong Algorithm by Using Moore Charts” on page 7-21
- “Initialize Persistent Variables in MATLAB Functions” on page 7-23

## Overview of Mealy and Moore Machines

In a finite state machine, *state* is a combination of local data and chart activity. "Computing state" means updating local data and making transitions from a currently active state to a new state. In state machine models, the next state is a function of the current state and its inputs:

$$X(n + 1) = f(X(n), u)$$

In this equation:

- $X(n)$  represents the state at time step  $n$ .
- $X(n+1)$  represents the state at the next time step  $n+1$ .
- $u$  represents inputs.

State persists from one time step to the next time step.

## Semantics of Mealy and Moore Machines

Mealy and Moore machines are often considered the basic, industry-standard paradigms for modeling finite-state machines. You can create charts that implement pure Mealy or Moore semantics as a subset of Stateflow chart semantics. You can use Mealy and Moore charts in simulation and code generation with Embedded Coder®, Simulink Coder, and HDL Coder™ software. Mealy and Moore semantics are supported only in Stateflow charts in Simulink models.

### Semantics of Mealy Charts

Mealy machines are finite state machines in which transitions occur on clock edges. The output of a Mealy chart is a function of inputs and state:

$$y = g(X, u)$$

At every time step, a Mealy chart wakes up, evaluates its input, and then transitions to a new configuration of active states, also called its *next state*. The chart computes its output as it transitions to the next state.

To ensure that output is a function of input and state, Mealy state machines enforce these semantics:

- Outputs do not depend on the next state.
- The chart computes outputs only in transitions, not in states.
- The chart wakes up periodically based on a system clock.

Mealy machines compute their output on transitions. Therefore, Mealy charts can compute their first output at the time that the default path for the chart executes. If you enable the chart property **Execute (enter) Chart At Initialization** for a Mealy chart, this computation occurs at  $t = 0$  (first time step). Otherwise, it occurs at  $t = 1$  (next time step). For more information, see "Execute (enter) chart at initialization" on page 28-5.

### Semantics of Moore Charts

Moore machines are finite state machines in which output is modified at clock edges. The output of a Moore chart is a function only of state:

$$y = g(X)$$

At every time step, a Moore chart wakes up, computes its output, and then evaluates its input to reconfigure itself for the next time step. For example, after evaluating its input, the chart can transition to a new configuration of active states. The chart computes its output before evaluating its input and updating its state.

To ensure that output is a function only of the current state, Moore state machines enforce these semantics:

- Outputs do not depend on inputs.
- Outputs do not depend on previous outputs.
- Outputs do not depend on temporal logic.

Moore machines compute their output in states. Therefore, Moore machines can compute outputs only *after* the default path executes. Until then, outputs take the default values.

## Create Mealy and Moore Charts

When you create a Stateflow chart, the default type is a hybrid state machine model called a *Classic* chart. Classic charts combine the semantics of Mealy and Moore charts with the extended Stateflow chart semantics.

To create a Mealy chart, at the MATLAB command prompt, enter:

```
sfnew -Mealy
```



To create a Moore chart, at the MATLAB command prompt, enter:

```
sfnew -Moore
```



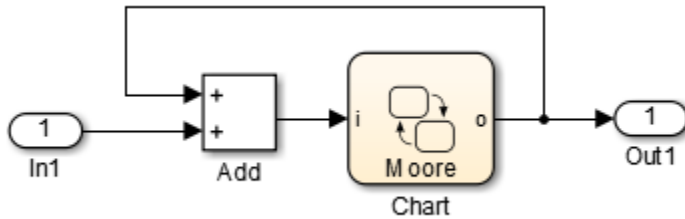
Alternatively, after adding a Stateflow chart block to a Simulink model, you can choose the type of semantics for the chart by setting the **State Machine Type** chart property. For more information, see “State Machine Type” on page 28-3.

## Advantages of Mealy and Moore Charts

Mealy and Moore charts offer these advantages over Classic Stateflow charts:

- You can verify that the Mealy and Moore charts you create conform to their formal definitions and semantic rules. Error messages appear at compile time (not at design time).
- Moore charts provide a more efficient implementation than Classic charts for C/C++ and HDL targets.
- You can use a Moore chart to model a feedback loop. In Moore charts, inputs do not have direct feedthrough. You can design a loop with feedback from the output port to the input port without

introducing an algebraic loop. Mealy and Classic charts have direct feedthrough and produce an error in the presence of an algebraic loop.



## See Also

sfnew

## More About

- “Design Considerations for Mealy Charts” on page 7-5
- “Design Considerations for Moore Charts” on page 7-9
- “Sequence Recognition by Using Mealy and Moore Charts” on page 7-18
- “Model a Vending Machine by Using Mealy Semantics” on page 7-7
- “Model a Traffic Light by Using Moore Semantics” on page 7-12
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14



## Design Considerations for Mealy Charts

Mealy machines are finite state machines in which transitions occur on clock edges. In Mealy charts, output is a function of input and state. At every time step, a Mealy chart wakes up, evaluates its input, and then transitions to a new configuration of active states, also called its *next state*. The chart computes its output as it transitions to the next state. Mealy semantics are supported only in Stateflow charts in Simulink models.

### Mealy Semantics

To ensure that output is a function of input and state, Mealy state machines enforce these semantics:

- Outputs do not depend on the next state.
- The chart computes outputs only in transitions, not in states.
- The chart wakes up periodically based on a system clock.

---

**Note** A chart provides one time base for input and clock (see “Calculate Output and State by Using One Time Base” on page 7-6).

---

### Design Rules for Mealy Charts

To conform to the Mealy definition of a state machine, ensure that every time there is a change on the input port, the chart computes outputs.

#### Compute Outputs in Condition Actions Only

You can compute outputs only in the condition actions of outer and inner transitions. A common modeling style for Mealy machines is to test inputs in conditions and compute outputs in the associated action.

#### Do Not Use State Actions or Transition Actions

You cannot use state actions or transition actions in Mealy charts. This restriction enforces Mealy semantics by:

- Preventing the chart from computing output without considering changes on the input port.
- Ensuring that output depends on the current state and not the next state.

#### Restrict Data Scope

In Mealy charts, these data restrictions apply:

- **Restrict Machine-Parented Data.** Machine-parented data is data that you define for a Stateflow machine. The Stateflow machine is the highest level of the Stateflow hierarchy. When you define data at this level, every chart in the machine can read and modify the data. To ensure that Mealy charts do not access data that can be modified unpredictably outside the chart, do not use machine-parented data.
- **Do Not Define Data Store Memory.** You cannot define data store memory (DSM) in Mealy charts because objects external to the chart can modify DSM. A Stateflow chart uses data store memory to share data with a Simulink model. Data store memory acts as global data. In the

Simulink hierarchy that contains the chart, other blocks and models can modify DSM. Mealy charts must not access data that can change unpredictably.

### **Restrict Use of Events**

Limit the use of events in Mealy charts:

- **Valid Uses:**

- Use input events to trigger the chart.
- Use event-based temporal logic to guard transitions.

The change in value of a temporal logic condition behaves like an event that the Mealy chart schedules internally. At each time step, the number of ticks before the temporal event executes depends only on the state of the chart. For more information, see “Temporal Logic Operators” on page 16-36.

---

**Note** In Mealy charts, the base event for temporal logic operators must be a predefined event such as `tick` (see “Implicit Events Based on Data and States” on page 14-26).

---

- **Invalid Uses:**

- You cannot broadcast an event of any type.
- You cannot use local events to guard transitions. Local events violate Mealy semantics because they are not deterministic and can occur while the chart computes its outputs.
- You cannot use implicit events such as `chg(data_name)`, `en(state_name)`, or `ex(state_name)`.

### **Calculate Output and State by Using One Time Base**

You can use one time base for clock and input, as determined by the Simulink solver. The Simulink solver sets the clock rate to be fast enough to capture input changes. As a result, a Mealy chart commonly computes outputs and changes states in the same time step. For more information, see “Compare Solvers” (Simulink).

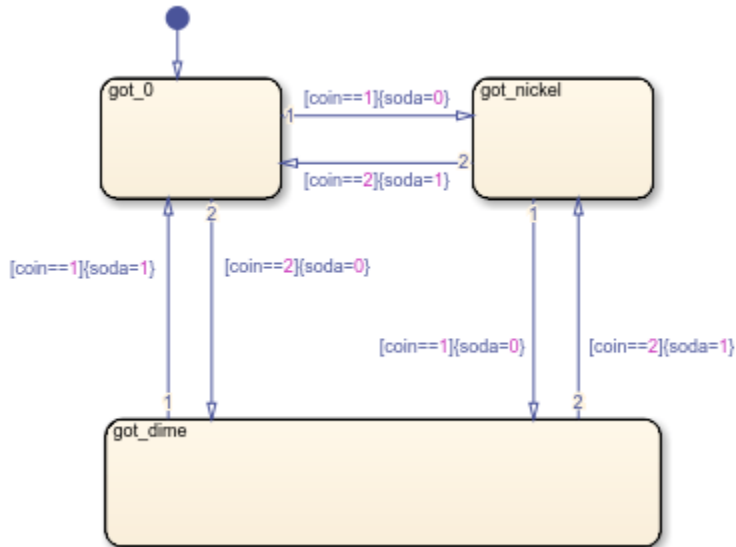
## **See Also**

### **More About**

- “Overview of Mealy and Moore Machines” on page 7-2
- “Model a Vending Machine by Using Mealy Semantics” on page 7-7
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14

## Model a Vending Machine by Using Mealy Semantics

This example shows how to use Mealy semantics to model a vending machine.



### Logic of the Mealy Vending Machine

In this example, the vending machine requires 15 cents to release a can of soda. The purchaser can insert a nickel or a dime, one at a time, to purchase the soda. The chart behaves like a Mealy machine because its output `soda` depends on both the input `coin` and current state:

**When initial state `got_0` is active.** No coin has been received or no coins are left.

- If a nickel is received (`coin == 1`), output `soda` remains 0, but state `got_nickel` becomes active.
- If a dime is received (`coin == 2`), output `soda` remains 0, but state `got_dime` becomes active.
- If input `coin` is not a dime or a nickel, state `got_0` stays active and no soda is released (output `soda = 0`).

**In active state `got_nickel`.** A nickel was received.

- If another nickel is received (`coin == 1`), state `got_dime` becomes active, but no can is released (`soda` remains at 0).
- If a dime is received (`coin == 2`), a can is released (`soda = 1`), the coins are banked, and the active state becomes `got_0` because no coins are left.
- If input `coin` is not a dime or a nickel, state `got_nickel` stays active and no can is released (output `soda = 0`).

**In active state `got_dime`.** A dime was received.

- If a nickel is received (`coin == 1`), a can is released (`soda = 1`), the coins are banked, and the active state becomes `got_0` because no coins are left.
- If a dime is received (`coin == 2`), a can is released (`soda = 1`), 15 cents are banked, and the active state becomes `got_nickel` because a nickel (change) is left.

- If input `coin` is not a dime or a nickel, state `got_dime` stays active and no can is released (output `soda = 0`).

### **Design Rules in Mealy Vending Machine**

This example of a Mealy vending machine illustrates these Mealy design rules:

- The chart computes outputs in condition actions.
- There are no state actions or transition actions.
- The chart defines chart inputs (`coin`) and outputs (`soda`).
- The value of the input `coin` determines the output: whether or not soda is released.

### **See Also**

#### **More About**

- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Mealy Charts” on page 7-5
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14

## Design Considerations for Moore Charts

Moore machines are finite state machines in which output is modified at clock edges. In Moore charts, output is a function of the current state only. At every time step, a Moore chart wakes up, computes its output, and then evaluates its input to reconfigure itself for the next time step. For example, after evaluating its input, the chart can transition to a new configuration of active states. The chart computes its output before evaluating its input and updating its state. Moore semantics are supported only in Stateflow charts in Simulink models.

### Moore Semantics

To ensure that output is a function *only* of the current state, Moore state machines enforce these semantics:

- Outputs do not depend on inputs.
- Outputs do not depend on previous outputs.
- Outputs do not depend on temporal logic.

### Design Rules for Moore Charts

To conform to the Moore definition of a state machine, ensure that every time that a Moore chart wakes up, it computes outputs from the current set of active states without regard to inputs.

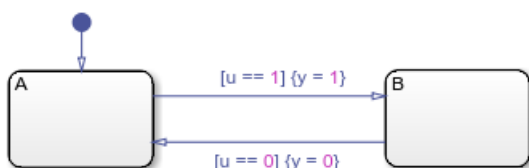
#### Restrictions on State Actions

To ensure that outputs depend solely on the current state, you can compute outputs in state actions, subject to these restrictions:

- **Combine Actions.** In Moore charts, you can include only one action per state. The action can consist of multiple command statements. Stateflow evaluates states in Moore charts from the top level down. Active states in Moore charts execute the state action before evaluating the transitions. Therefore, outputs are computed at each time step whether an outer transition is valid or not.
- **Do Not Label State Actions.** Do not label state actions in Moore charts with any keywords, such as `entry`, `during`, or `exit`. By default, Moore charts execute the actions in the active states before evaluating inputs and updating state.

#### Restrictions on Transition Actions

Transitions in Moore charts can contain condition and transition actions if these actions do not introduce a dependency between output values and input values. For example, in this chart, each transition tests the input `u` in a condition and modifies the output `y` in a condition action. Because the output value depends on the value of the input, this construct violates Moore semantics and triggers an error.



### **Do Not Use Inputs to Compute Outputs**

In Moore charts, outputs cannot depend on inputs. Using an input to contribute directly or indirectly to the computation of an output triggers an error.

### **Restrict Data Scope**

In Moore charts, these data restrictions apply:

- **Restrict Machine-Parented Data.** Machine-parented data is data that you define for a Stateflow machine. The Stateflow machine is the highest level of the Stateflow hierarchy. When you define data at this level, every chart in the machine can read and modify the data. To ensure that Moore charts do not access data that can be modified unpredictably outside the chart, do not use machine-parented data.
- **Do Not Define Data Store Memory.** You cannot define data store memory (DSM) in Moore charts because objects external to the chart can modify DSM objects. A Stateflow chart uses data store memory to share data with a Simulink model. Data store memory acts as global data. In the Simulink hierarchy that contains the chart, other blocks and models can modify DSM. Moore charts must not access data that can change unpredictably.

### **Do Not Use `coder.extrinsic` to Call Extrinsic Functions**

When calling extrinsic functions with `coder.extrinsic`, it is not possible to enforce that the outputs depend only on the current state. Calling an extrinsic function with `coder.extrinsic` in a Moore chart triggers an error.

### **Do Not Use Simulink Functions**

You cannot use Simulink functions in Moore charts. This restriction prevents violations of Moore semantics during chart execution.

### **Do Not Export Functions**

You cannot export functions in a Moore chart.

### **Do Not Disable Inlining**

Moore chart semantics require inlining.

### **Do Not Enable Super Step Semantics**

You cannot use super step semantics in a Moore chart.

### **Do Not Use Messages**

You cannot use messages in a Moore chart.

### **Restrict Use of Events**

Limit the use of events in Moore charts:

- **Valid Uses:**
  - Use only one input event to trigger the chart.
  - Use event-based temporal logic to guard transitions.

The change in value of a temporal logic condition behaves like an event that the Moore chart schedules internally. At each time step, the number of ticks before the temporal event executes depends only on the state of the chart. For more information, see “Temporal Logic Operators” on page 16-36.

---

**Note** In Moore charts, the base event for temporal logic operators must be a predefined event such as `tick` (see “Implicit Events Based on Data and States” on page 14-26).

---

• **Invalid Uses:**

- You cannot broadcast an event of any type.
- You cannot use local events to guard transitions. Local events violate Moore semantics because they are not deterministic and can occur while the chart computes its outputs.
- You cannot use implicit events such as `chg(data_name)`, `en(state_name)`, or `ex(state_name)`.

**Do Not Use Moore Charts for Modeling Continuous-Time Systems**

In Moore charts, you cannot set the update method to `Continuous`. For modeling systems with continuous time in Stateflow, use `Classic` or `Mealy` charts.

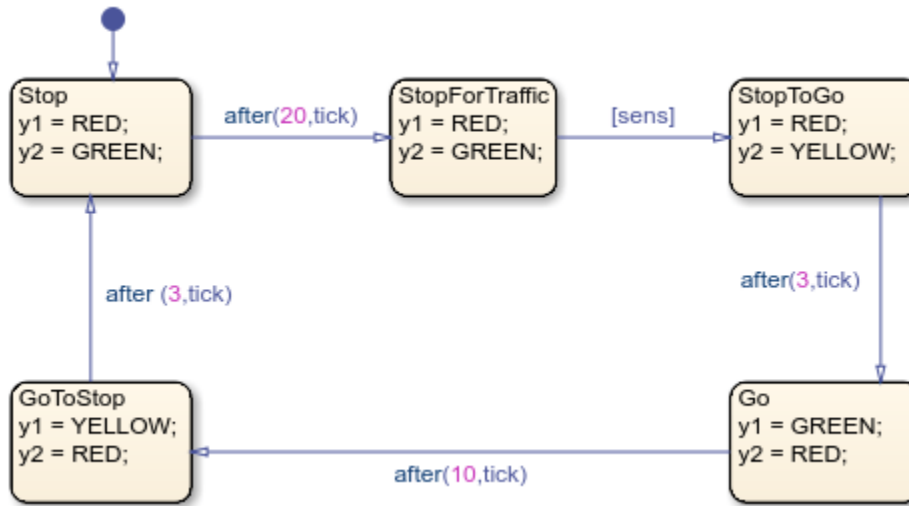
**See Also**

**More About**

- “Overview of Mealy and Moore Machines” on page 7-2
- “Model a Traffic Light by Using Moore Semantics” on page 7-12
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14

## Model a Traffic Light by Using Moore Semantics

This example shows how to use Moore semantics to model a traffic light.



### Logic of the Moore Traffic Light

In this example, the traffic light model contains a Moore chart called `Light_Controller`, which operates in five traffic states. Each state represents the color of the traffic light in two opposite directions, North-South and East-West, and the duration of the current color. The name of each state represents the operation of the light viewed from the North-South direction.

This chart uses temporal logic to regulate state transitions. The `after` operator implements a countdown timer, which initializes when the source state is entered. By default, the timer provides a longer green light in the East-West direction than in the North-South direction because the volume of traffic is greater on the East-West road. The green light in the East-West direction stays on for at least 20 clock ticks, but it can remain green as long as no traffic arrives in the North-South direction. A sensor detects whether cars are waiting at the red light in the North-South direction. If so, the light turns green in the North-South direction to keep traffic moving.

The `Light_Controller` chart behaves like a Moore machine because it updates its outputs based on current state before transitioning to a new state:

**When initial state `Stop` is active.** Traffic light is red for North-South, green for East-West.

- Sets output `y1 = RED` (North-South) based on current state.
- Sets output `y2 = GREEN` (East-West) based on current state.
- After 20 clock ticks, active state becomes `StopForTraffic`.

**In active state `StopForTraffic`.** Traffic light has been red for North-South, green for East-West for at least 20 clock ticks.

- Sets output `y1 = RED` (North-South) based on current state.
- Sets output `y2 = GREEN` (East-West) based on current state.
- Checks sensor.



- If sensor indicates cars are waiting (`[sens]` is true) in the North-South direction, active state becomes `StopToGo`.

**In active state `StopToGo`.** Traffic light must reverse traffic flow in response to sensor.

- Sets output `y1` = RED (North-South) based on current state.
- Sets output `y2` = YELLOW (East-West) based on current state.
- After 3 clock ticks, active state becomes `Go`.

**In active state `Go`.** Traffic light has been red for North-South, yellow for East-West for 3 clock ticks.

- Sets output `y1` = GREEN (North-South) based on current state.
- Sets output `y2` = RED (East-West) based on current state.
- After 10 clock ticks, active state becomes `GoToStop`.

**In active state `GoToStop`.** Traffic light has been green for North-South, red for East-West for 10 clock ticks.

- Sets output `y1` = YELLOW (North-South) based on current state.
- Sets output `y2` = RED (East-West) based on current state.
- After 3 clock ticks, active state becomes `Stop`.

### Design Rules in Moore Traffic Light

This example of a Moore traffic light illustrates these Moore design rules:

- The chart computes outputs in state actions.
- The chart tests inputs in conditions on transitions.
- The chart uses temporal logic, but no asynchronous events.
- The chart defines chart inputs (`sens`) and outputs (`y1` and `y2`).

## See Also

### More About

- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Moore Charts” on page 7-9
- “Convert Charts Between Mealy and Moore Semantics” on page 7-14
- “Model An Intersection Of One-Way Streets” on page 13-23
- “Model a Distributed Traffic Control System by Using Messages” on page 15-20

## Convert Charts Between Mealy and Moore Semantics

Mealy and Moore machines are often considered the basic, industry-standard paradigms for modeling finite-state machines. You can create charts that implement pure Mealy or Moore semantics as a subset of Stateflow chart semantics. Mealy and Moore semantics are supported only in Stateflow charts in Simulink models. For more information, see “Overview of Mealy and Moore Machines” on page 7-2.

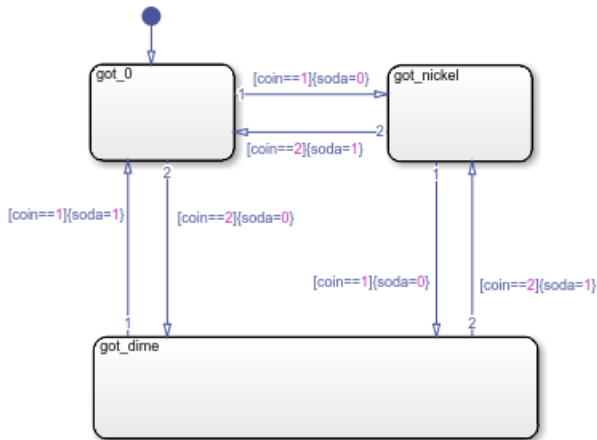
A best practice is to not change from one Stateflow chart type to another in the middle of development. You cannot automatically convert the semantics of the original chart to conform to the design rules of the new chart type. Changing chart type usually requires you to redesign your chart to achieve the equivalent behavior of the original chart, so that both charts produce the same sequence of outputs given the same sequence of inputs. Sometimes, however, there is no way to translate specific behaviors without violating chart definitions.

This table lists a summary of what happens when you change chart types mid-design.

From	To	Result
Mealy	Classic	Mealy charts retain their semantics when changed to Classic type.
Classic	Mealy	If the Classic chart defines its output at every time step and conforms to Mealy semantic rules, the Mealy chart exhibits behavior equivalent to the original Classic chart.
Moore	Classic	State actions in the Moore chart behave as <b>entry</b> and <b>during</b> actions because they are not labeled. The Classic chart exhibits behavior that is not equivalent to the original Moore chart. Requires redesign.
Classic	Moore	Actions that are unlabeled in the Classic chart ( <b>entry</b> and <b>during</b> actions by default) behave as <b>during</b> and <b>exit</b> actions. The Moore chart exhibits behavior that is not equivalent to the original Classic chart. Requires redesign.
Mealy	Moore	Mealy and Moore rules about placement of actions are mutually exclusive.
Moore	Mealy	Converting chart types between Mealy and Moore semantics does not produce equivalent behavior. Requires redesign.

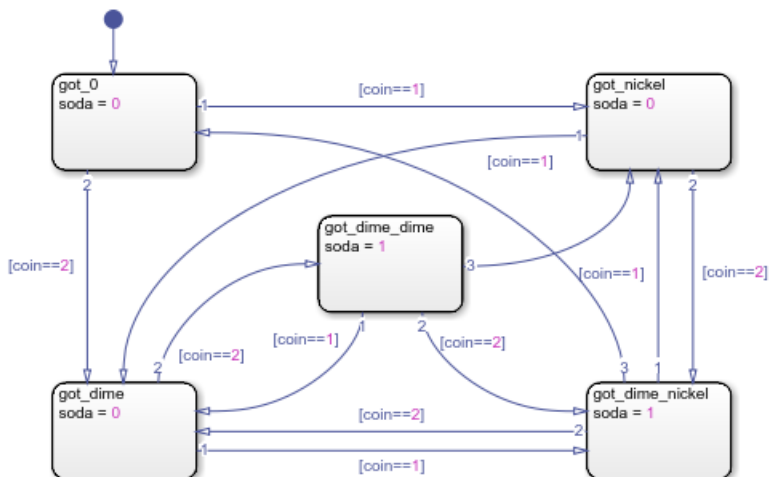
### Transform Chart from Mealy to Moore Semantics

This example shows how to use a Mealy chart to model a vending machine, as described in “Model a Vending Machine by Using Mealy Semantics” on page 7-7.



In the Mealy chart, each state represents one of the three possible coin inputs: nickel, dime, or no coin. Each condition action computes output (whether soda is released) based on input (the coin received) as the chart transitions to the next state. If you change the chart type to Moore, you get a compile-time diagnostic message indicating that the chart violates Moore chart semantics. According to Moore semantics, the chart output `soda` cannot depend on the value of the input `coin`.

To convert the chart to valid Moore semantics, redesign your chart by moving the logic that computes the output out of the transitions and into the states. In the Moore chart, each state must represent both coins received and the soda release condition (`soda = 0` or `soda = 1`). As a result, the redesigned chart requires more states.



Before considering the value of `coin`, the Moore chart must compute the value of `soda` according to the active state. As a result, there is a delay in releasing soda, even if the machine receives enough money to cover the cost.

### Compare Semantics of Vending Machines

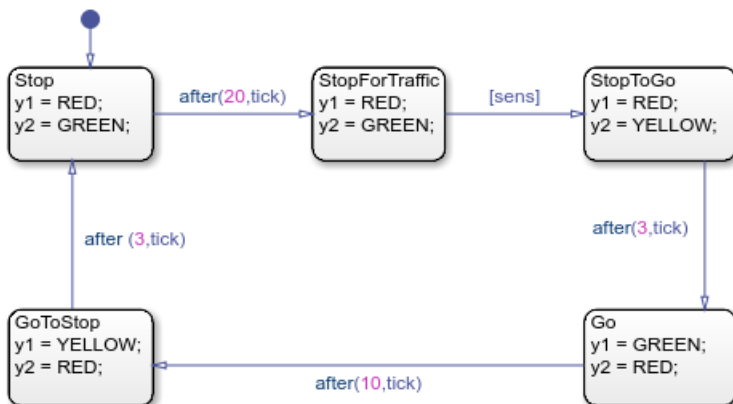
This table compares the semantics of the charts before and after the transformation.

Mealy Vending Machine	Moore Vending Machine
Uses three states	Uses five states
Computes outputs in condition actions	Computes outputs in state actions
Updates output based on input	Updates output before evaluating input, requiring an extra time step to produce the soda

For this vending machine, Mealy is a better modeling paradigm because there is no delay in releasing the soda once sufficient coins are received. By contrast, the Moore vending machine requires an extra time step before producing the soda. Therefore, it is possible for the Moore vending machine to produce a can of soda at the same time step that it accepts a coin toward the next purchase. In this situation, the delivery of a soda can appear to be in response to this coin, but actually occurs because the vending machine received the purchase price in previous time steps.

## Transform Chart from Moore to Mealy Semantics

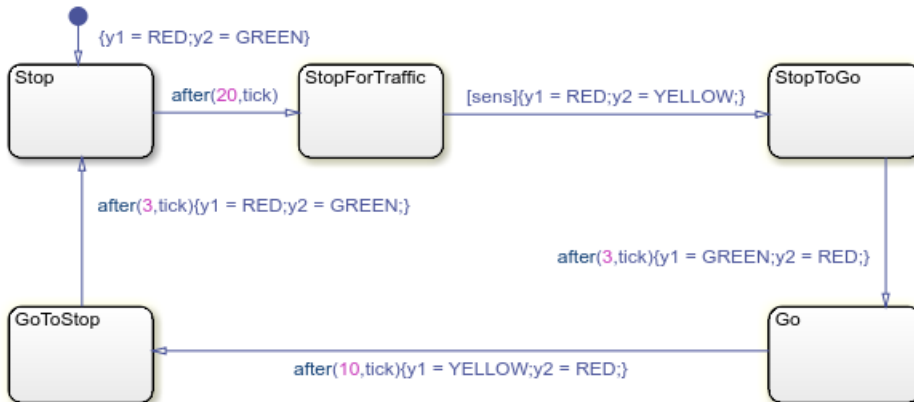
This example shows how to use a Moore chart to model a traffic light, as described in “Model a Traffic Light by Using Moore Semantics” on page 7-12.



In the Moore chart, each state represents the colors of the traffic light in two opposite directions and the duration of the current color. Each state action computes output (the colors of the traffic light) regardless of input (if there are cars waiting at a sensor). If you change the chart type to Mealy, you get a compile-time diagnostic message indicating that the chart violates Mealy chart semantics. According to Mealy semantics, the chart cannot compute its outputs in state actions.

To convert the chart to valid Mealy semantics, redesign your chart by moving the logic that computes the output out of the states and into the transitions. The redesigned Mealy chart consists of five states, just like the Moore chart. In most transitions, a temporal logic expression or the Boolean input `sens` guards a condition action computing the outputs `y1` and `y2`. The only exceptions are:

- The default transition, which computes the initial outputs without a guarding condition.
- The transition from the `Stop` state to the `StopForTraffic` state, which does not compute new outputs.



In the same time step, the Mealy chart evaluates the temporal logic expressions and the input signal `sens`, and computes the value of the outputs `y1` and `y2`. As a result, in the Mealy chart, the output changes one time step before the corresponding change occurs in the original Moore chart. In the Simulink model, you can compensate for the anticipated changes in output by adding a Delay block to each output signal.

### Compare Semantics of Traffic Light Controllers

This table compares the semantics of the charts before and after the transformation.

Moore Traffic Light Controller	Mealy Traffic Light Controller
Uses five states	Uses five states
Computes outputs in state actions	Computes outputs in condition actions
Updates output before evaluating input	Updates output based on input, requiring a Delay block in each output signal

### See Also

#### More About

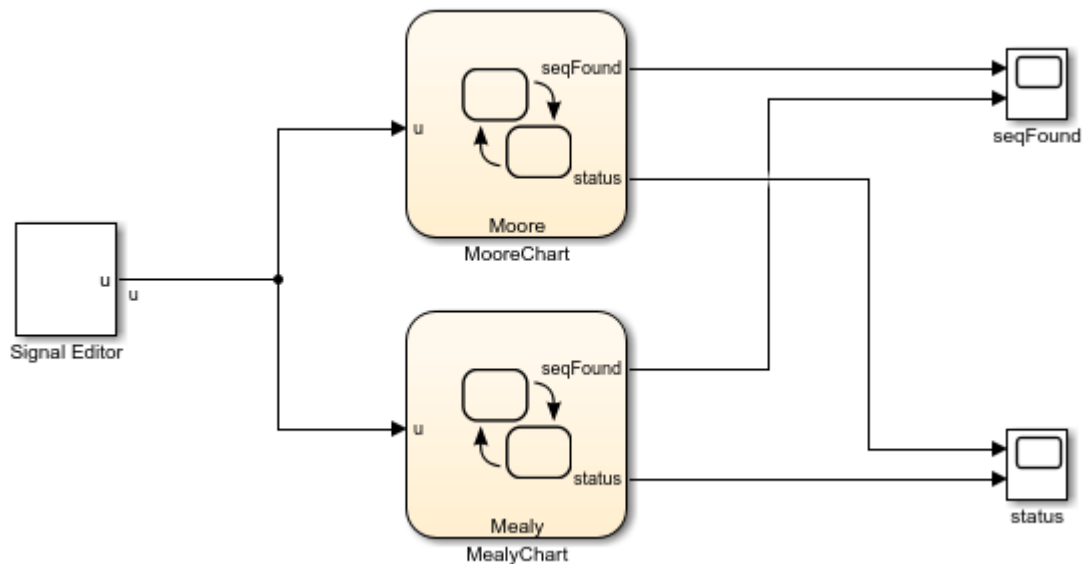
- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Mealy Charts” on page 7-5
- “Design Considerations for Moore Charts” on page 7-9
- “Model a Vending Machine by Using Mealy Semantics” on page 7-7
- “Model a Traffic Light by Using Moore Semantics” on page 7-12

## Sequence Recognition by Using Mealy and Moore Charts

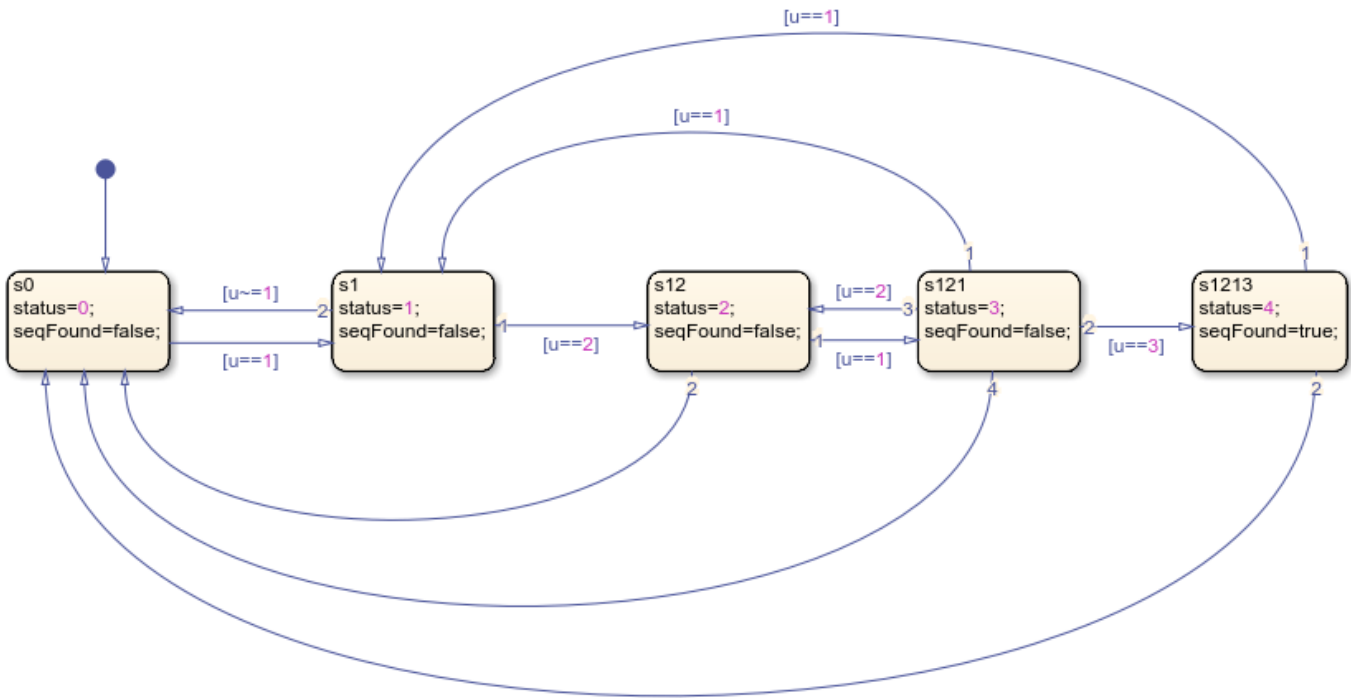
This example shows how to use Mealy and Moore machines for a sequence recognition application in signal processing. For more information, see “Overview of Mealy and Moore Machines” on page 7-2.

In this model, two Stateflow® charts use a different set of semantics to find the sequence 1,2,1,3 in the input signal from a Signal Editor (Simulink) block. Each chart contains an input data `u` and two output data:

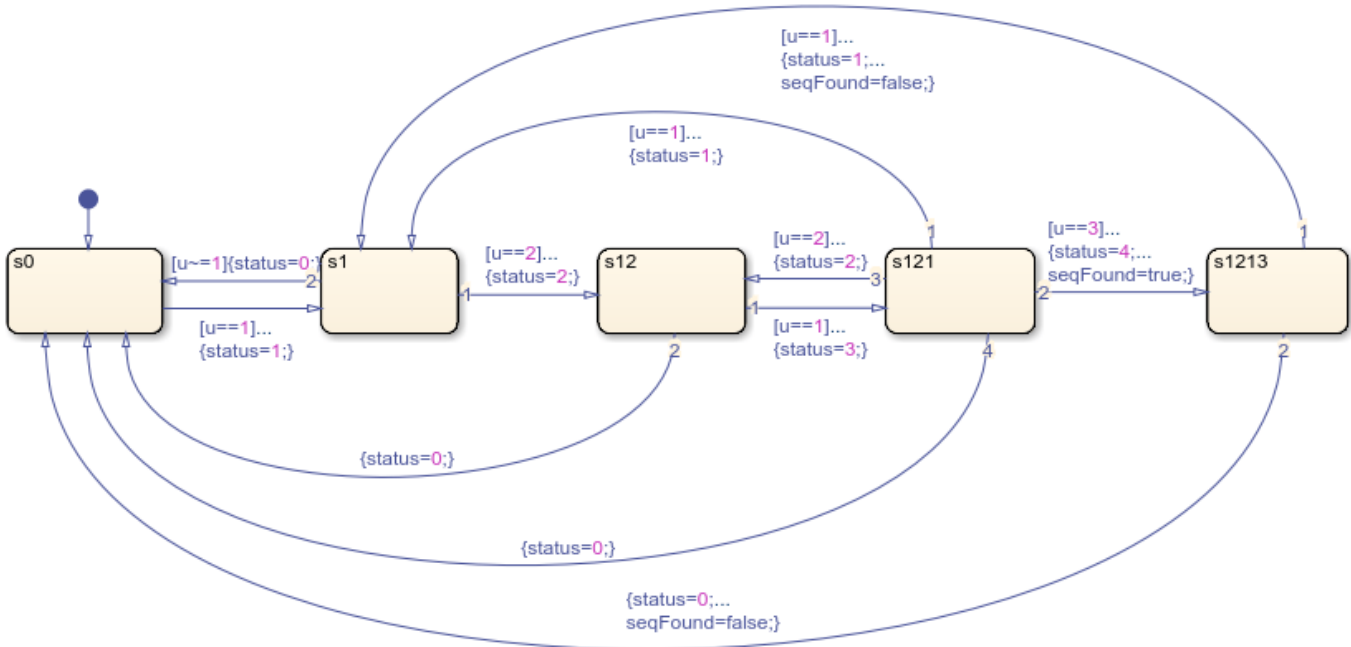
- `seqFound` indicates when the chart finds the sequence. A value of `false` means that the chart is still searching for the sequence. A value of `true` means that the chart has found the sequence.
- `status` records the status of the sequence recognition. This value ranges from 0 to 4 and indicates the number of symbols detected by the chart.



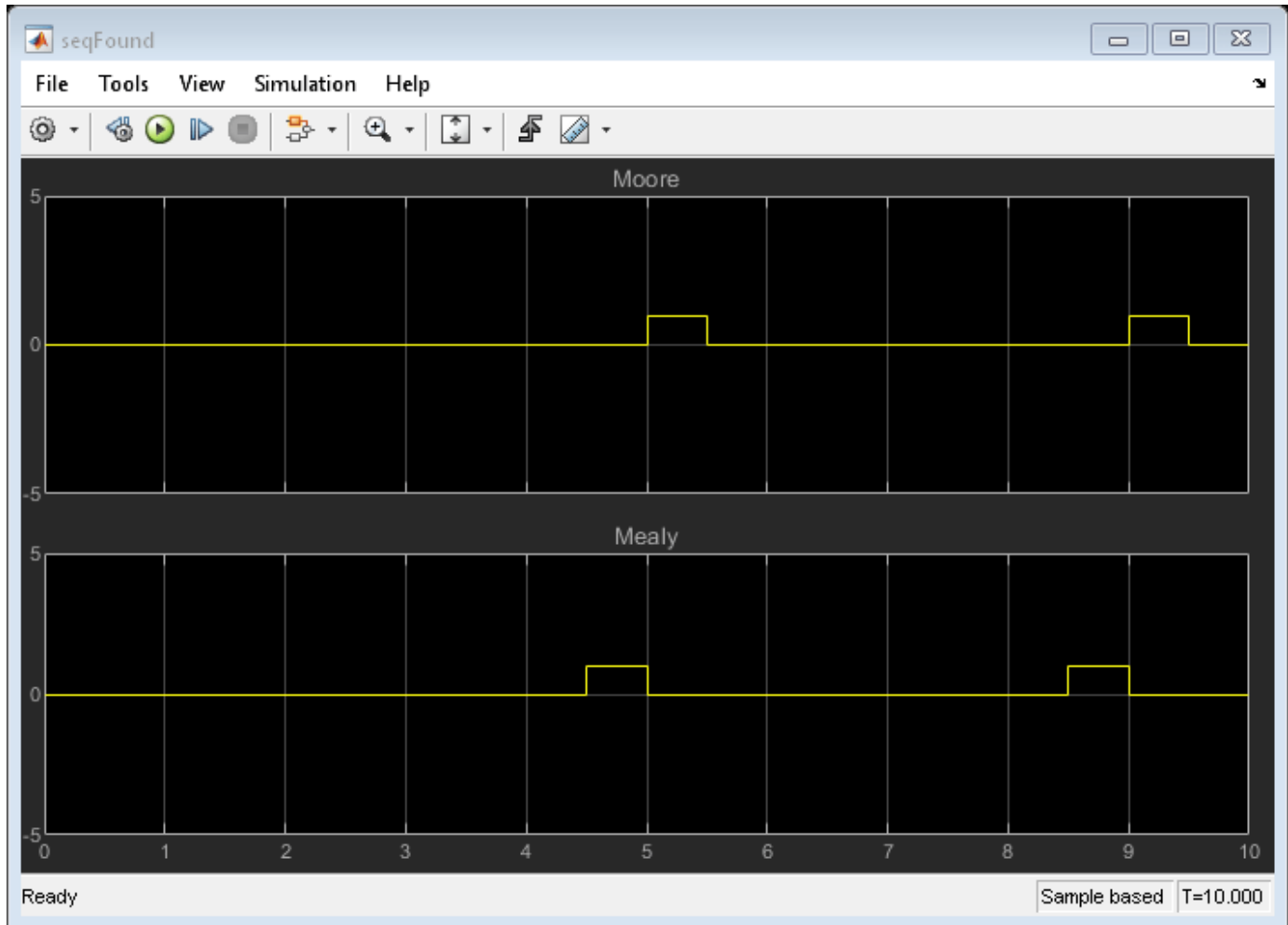
In the Moore chart, the outputs depend only on the current state of the chart. This chart computes its output values in the state actions. At each time step, the chart executes the actions for the current state, evaluates the input `u`, and makes the transition to a new state.



In the Mealy chart, the outputs depend on the current state of the chart and the input. This chart computes its output values in the condition actions of its transitions. At each time step, the chart evaluates the input  $u$ , makes the transition to a new state, and executes the corresponding condition actions.



When you simulate the model, the seqFound scope shows that the output of the Moore chart lags one time step behind the output of the Mealy chart. The delay is a result of the Moore semantics, in which the output is based on the state of the chart at the start of each time step and not on the current input.



### Reference

Katz, Bruce F. *Digital Design: From Gates to Intelligent Machines*, 2006.

### See Also

Signal Editor

### More About

- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Mealy Charts” on page 7-5
- “Design Considerations for Moore Charts” on page 7-9



## Karplus-Strong Algorithm by Using Moore Charts

This example shows a simple implementation of the Karplus-Strong algorithm for string synthesis by using Stateflow® charts with Moore semantics. For more information, see “Design Considerations for Moore Charts” on page 7-9.

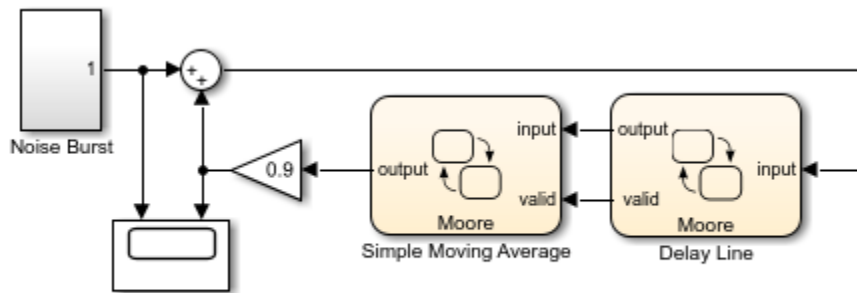
### Principle

The initial burst of white noise is produced by a Uniform Random Number block. It is fed back into a delay line of the same length. The moving average smooths the signal at each cycle, while the gain less than 1 maintains the stability of the feedback loop. They both model the string losses over each cycle.

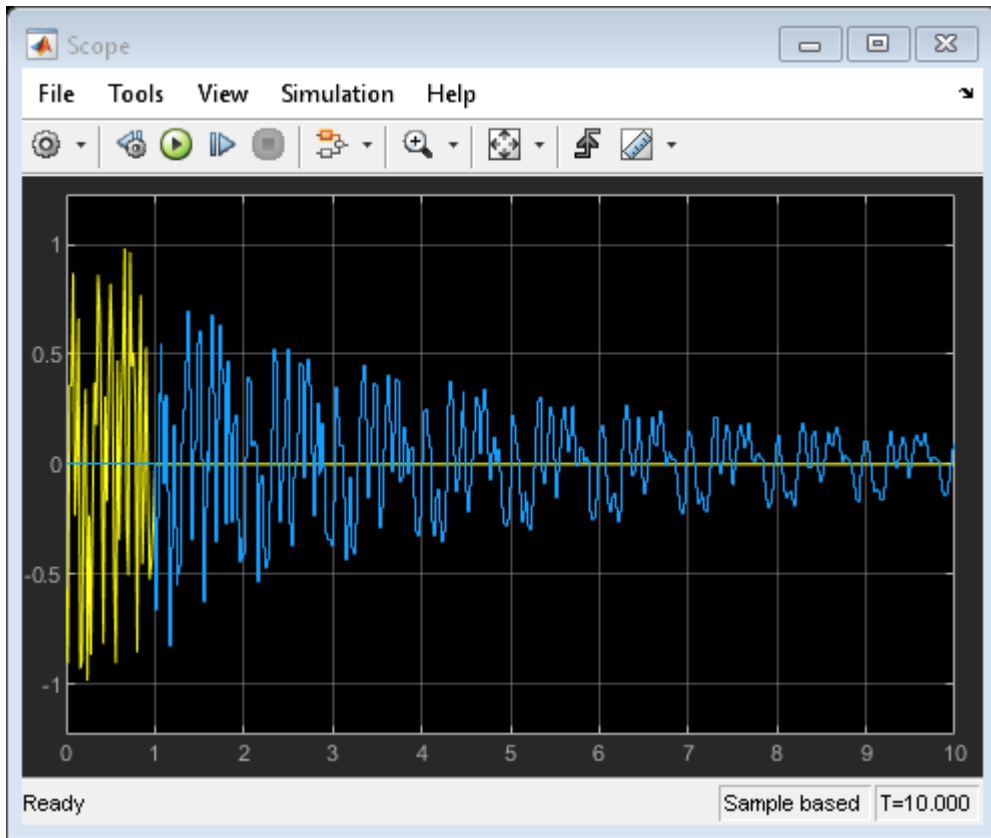
### Nondirect Feedthrough

This example illustrates the benefits of Moore Charts in loops. Moore semantics guarantees that outputs only depend on the current state, but neither on inputs nor the next state. Hence a Moore Chart has nondirect feedthrough and can safely be used in feedback loops. For more information, see “Algebraic Loop Concepts” (Simulink).

On the contrary, Classic or Mealy Charts provide direct feedthrough. These charts do not prevent algebraic loops, unless an external Delay block breaks cyclic dependencies. Simulation would issue an error if both charts were Classic or Mealy charts.



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## See Also

### More About

- “Overview of Mealy and Moore Machines” on page 7-2
- “Design Considerations for Moore Charts” on page 7-9
- “Algebraic Loop Concepts” (Simulink)

## Initialize Persistent Variables in MATLAB Functions

A persistent variable is a local variable in a MATLAB function that retains its value in memory between calls to the function. For code generation, functions must initialize a persistent variable if it is empty. For more information, see `persistent`.

When programming MATLAB functions in these situations:

- MATLAB Function blocks with no direct feedthrough
- MATLAB Function blocks in models that contain State Control blocks in Synchronous mode
- MATLAB functions in Stateflow charts that implement Moore machine semantics

The specialized semantics impact how a function initializes its persistent data. Because the initialization must be independent of the input to the function, follow these guidelines:

- The function initializes its persistent variables only by accessing constants.
- The control flow of the function does not depend on whether the initialization occurs.

For example, this function has a persistent variable `n`.

```
function y = fcn(u)
    persistent n

    if isempty(n)
        n = u;
        y = 1;
        return
    end

    y = n;
    n = n + u;
end
```

This type of initialization results in an error because the initial value of `n` depends on the input `u` and the `return` statement interrupts the normal control flow of the function.

To correct the error, initialize the persistent variable by setting it to a constant value and remove the `return` statement. For example, this function initializes the persistent variable without producing an error.

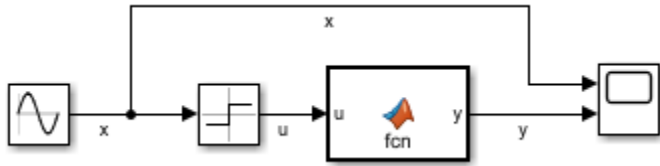
```
function y = fcn(u)
    persistent n

    if isempty(n)
        n = 1;
    end

    y = n;
    n = n + u;
end
```

### MATLAB Function Block With No Direct Feedthrough

This model contains a MATLAB function block that defines the function `fcn`, described previously. The input `u` is a square wave with values of 1 and -1.

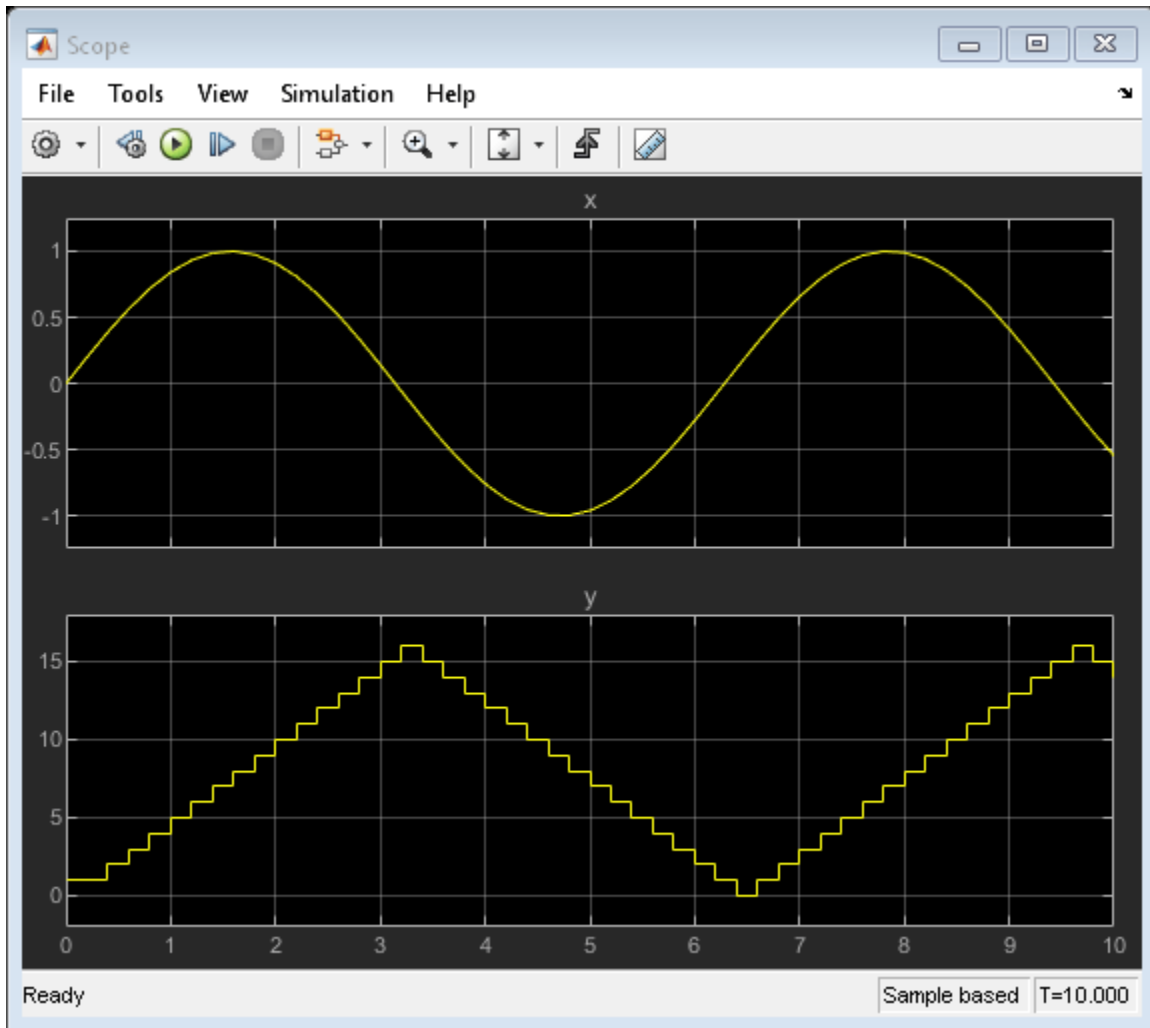


In the MATLAB function block:

- The initial value of the persistent variable  $n$  depends on the input  $u$ .
- The return statement interrupts the normal control flow of the function.

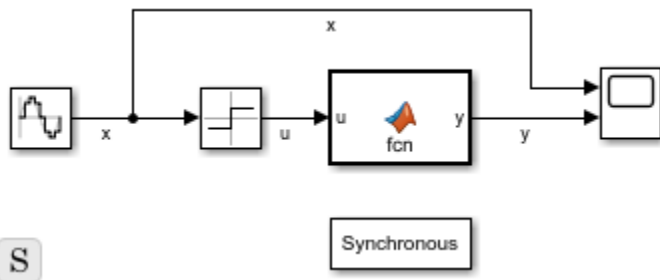
Because the **Allow direct feedthrough** check box is cleared, the initialization results in an error.

If you modify the function so it initializes  $n$  independently of the input, then you can simulate an error-free model.



## State Control Block in Synchronous Mode

This model contains a MATLAB function block that defines the function `fcn`, described previously. The input `u` is a square wave with values of 1 and -1.



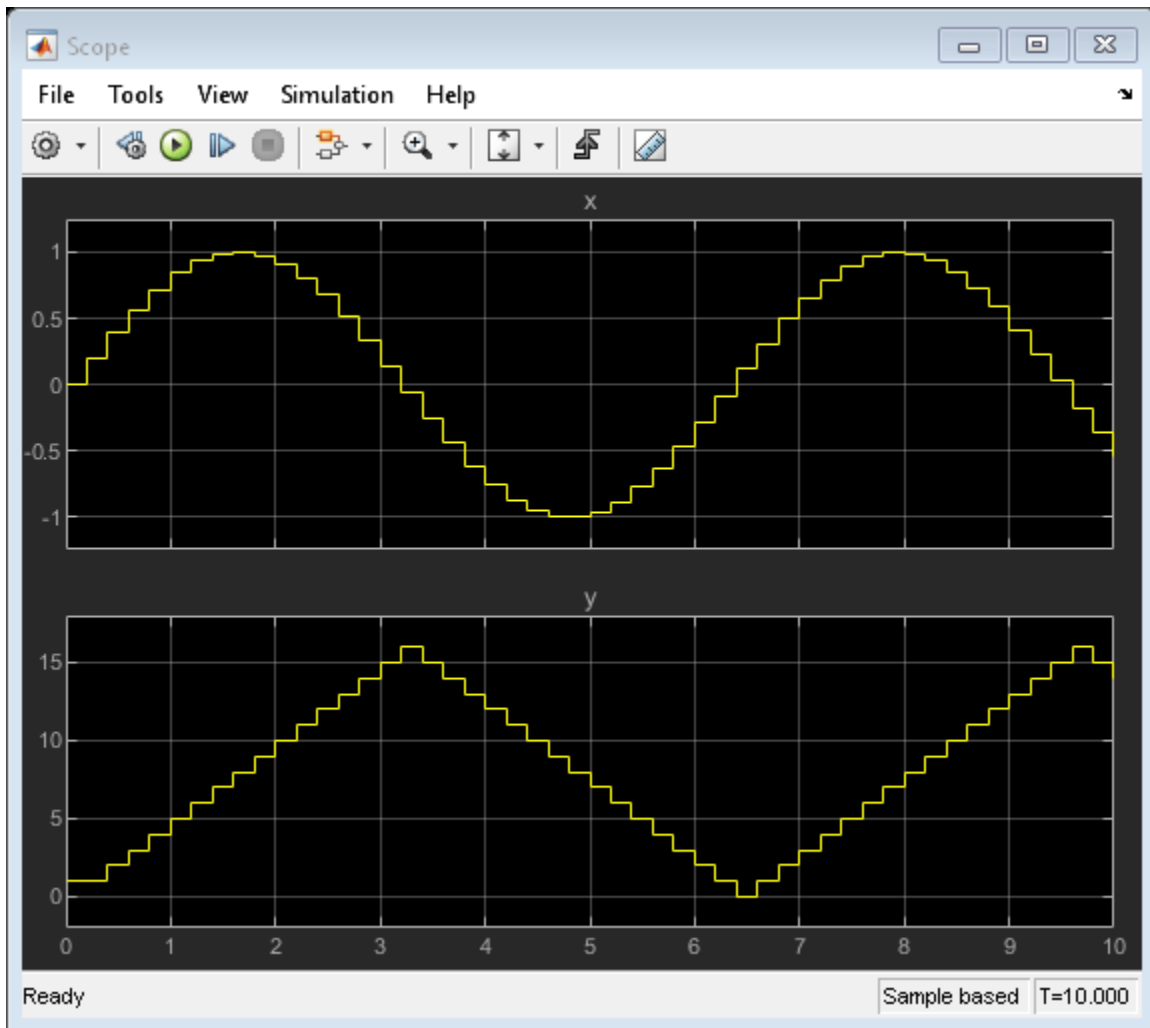
In the MATLAB function block:

- The initial value of the persistent variable `n` depends on the input `u`.

- The return statement interrupts the normal control flow of the function.

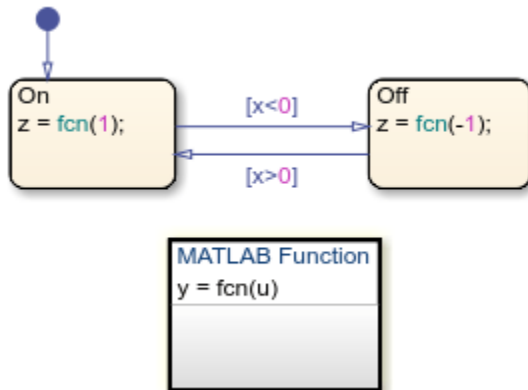
Because the model contains a State Control block in Synchronous mode, the initialization results in an error.

If you modify the function so it initializes  $n$  independently of the input, then you can simulate an error-free model.



## Stateflow Chart Implementing Moore Semantics

This model contains a Stateflow chart that implements Moore machine semantics. The chart contains a MATLAB function that defines the function `fcn`, described previously. The input  $u$  has values of 1 and -1 that depend on the state of the chart.

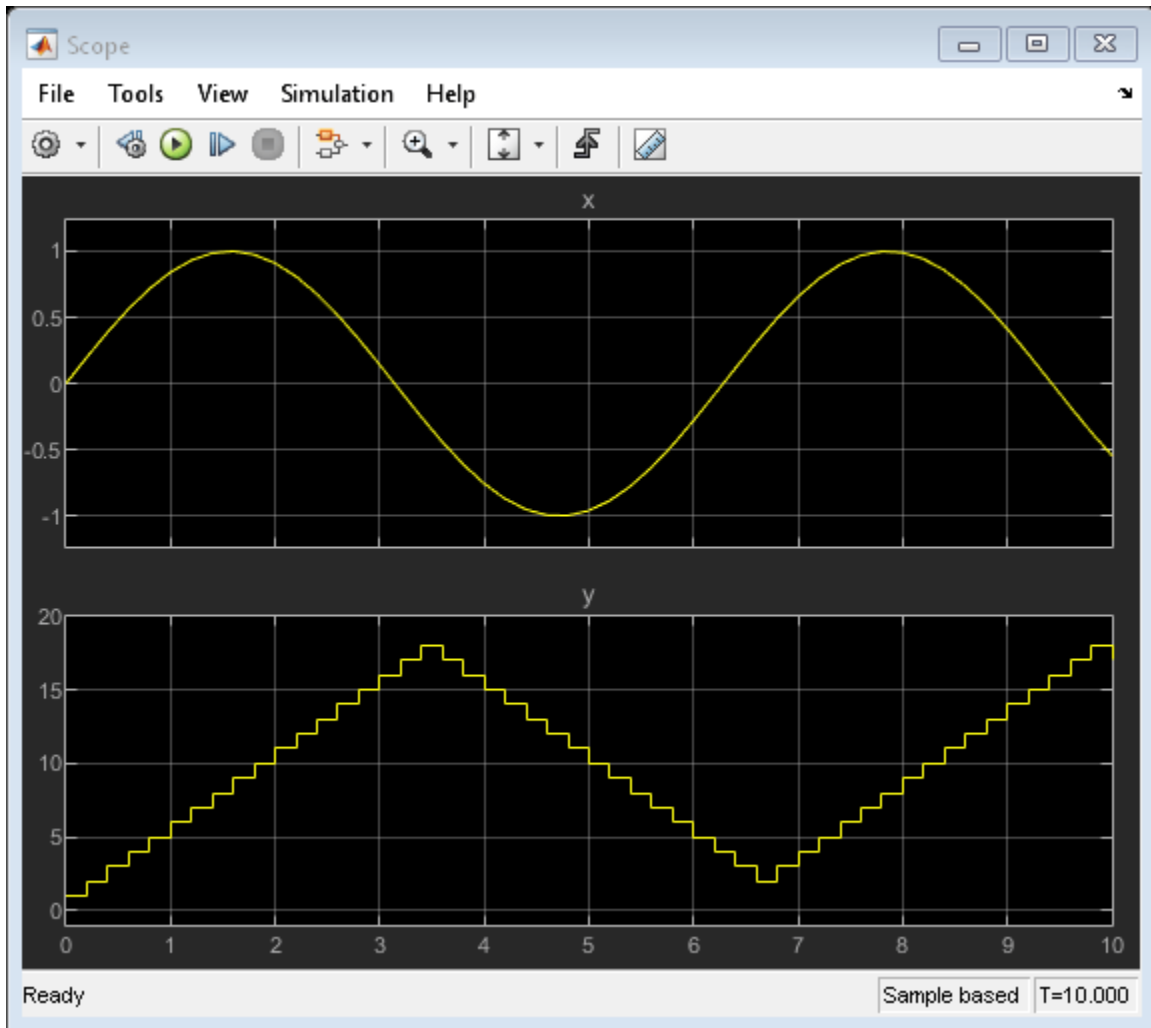


In the MATLAB function:

- The initial value of the persistent variable  $n$  depends on the input  $u$ .
- The return statement interrupts the normal control flow of the function.

Because the chart implements Moore semantics, the initialization results in an error.

If you modify the function so it initializes  $n$  independently of the input, then you can simulate an error-free model.



## See Also

Chart | MATLAB Function | State Control | persistent

## More About

- “Use Nondirect Feedthrough in a MATLAB Function Block” (Simulink)
- “Synchronous Subsystem Behavior with the State Control Block” (HDL Coder)
- “Design Considerations for Moore Charts” on page 7-9



# Techniques for Streamlining Chart Design

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- “Record State Activity by Using History Junctions” on page 8-2
- “Group Chart Objects by Using Boxes” on page 8-4
- “Encapsulate Modal Logic by Using Subcharts” on page 8-10
- “Move Between Levels of Hierarchy by Using Supertransitions” on page 8-13
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Export Stateflow Functions for Reuse” on page 8-23
- “Reuse Functions by Using Atomic Boxes” on page 8-28
- “Add Descriptive Comments in a Chart” on page 8-32

## Record State Activity by Using History Junctions

A history junction records the activity of substates inside superstates. Use a history junction in a superstate to indicate that its last active substate becomes active when the superstate becomes active. For more information, see “History Junctions” on page 2-41.

### Create a History Junction

To create a history junction, do the following:

- 1 In the editor toolbar, click the History Junction icon:



- 2 Move your pointer into the chart.
- 3 Click to place a history junction inside the state whose last active substate it records.

To create multiple history junctions, do the following:

- 1 In the editor toolbar, double-click the History Junction icon.

The button is now in multiple-object mode.

- 2 Click anywhere in the drawing area to place a history junction.
- 3 Move to and click another location to create an additional history junction.
- 4 Click the History Junction icon or press the **Esc** key to cancel the operation.

To move a history junction to a new location, click and drag it to the new position.

### Change History Junction Size

To change the size of junctions:

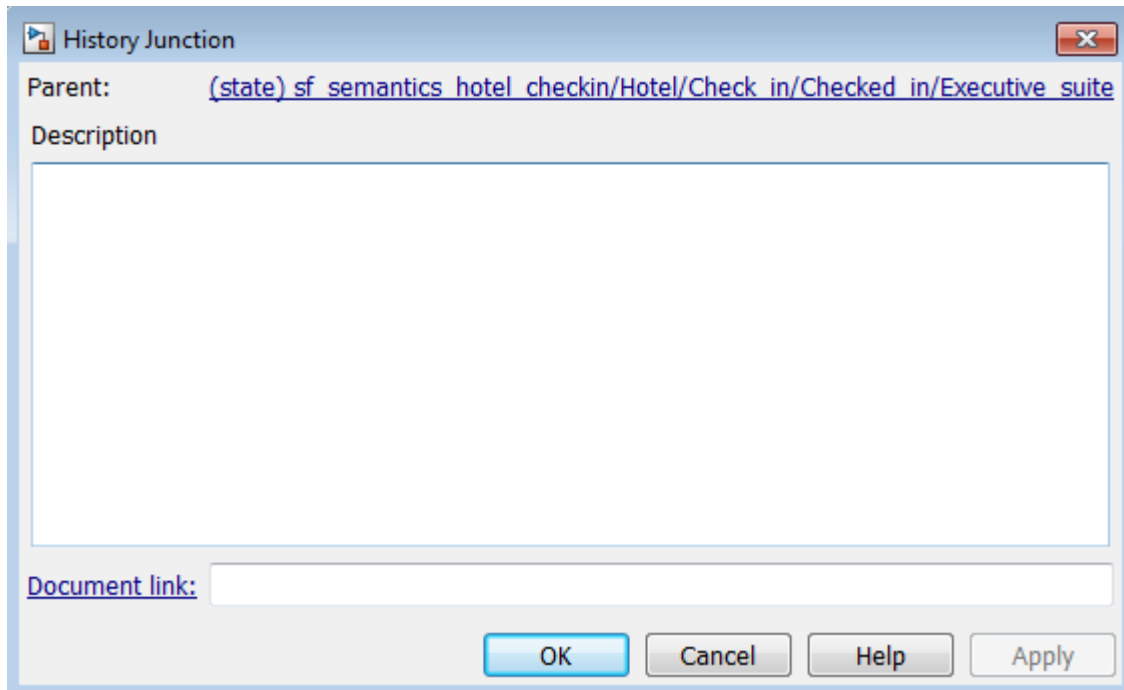
- 1 Select the history junctions whose size you want to change.
- 2 Right-click one of the junctions and select **Junction Size**.
- 3 Select a size from the list of junction sizes.

### Change History Junction Properties

To edit the properties for a junction:

- 1 Right-click a junction and select **Properties**.

The History Junction dialog box appears.



- 2 Edit the fields in the properties dialog box.

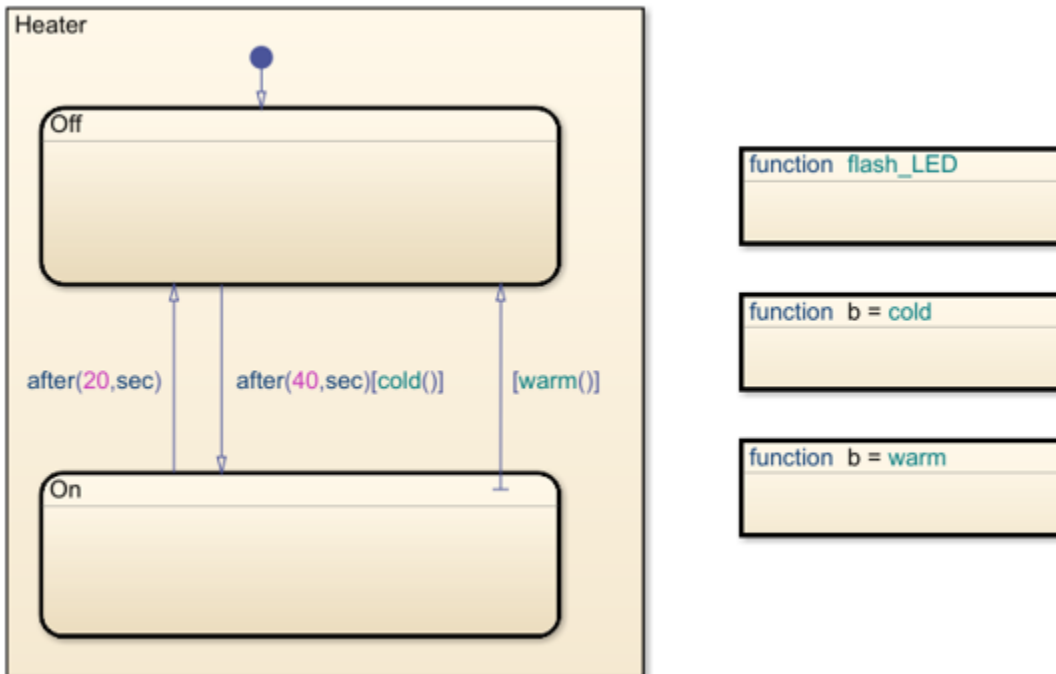
Field	Description
<b>Parent</b>	Parent of this history junction; read-only; click the hypertext link to bring the parent to the foreground.
<b>Description</b>	Textual description/comment.
<b>Document Link</b>	Enter a URL address or a general MATLAB command. Examples are <code>www.mathworks.com</code> , <code>mailto:email_address</code> , and <code>edit/spec/data/speed.txt</code> .

- 3 When finished editing, click one of the following buttons:
- **Apply** to save the changes
  - **Cancel** to cancel any changes
  - **OK** to save the changes and close the dialog box
  - **Help** to display the Stateflow online help in an HTML browser window

## Group Chart Objects by Using Boxes

A box is a graphical object that organizes other objects such as functions and states in your chart. You can use a box to encapsulate states and functions in a separate namespace. Boxes are supported only in Stateflow charts in Simulink models.

For example, in this chart, the box Heater groups together related states Off and On.



For more information about this example, see “Model Bang-Bang Temperature Control System” on page 16-52.

## Semantics of Stateflow Boxes

### Visibility of Graphical Objects in Boxes

Boxes add a level of hierarchy to Stateflow charts. This property affects visibility of functions and states inside a box to objects that reside outside of the box. If you refer to a box-parented function or state from a location outside of the box, you must include the box name in the path. See “Group Functions Using a Box” on page 8-7.

### Activation Order of Parallel States

Boxes affect the implicit activation order of parallel states in a chart. If your chart uses implicit ordering, parallel states within a box wake up before other parallel states that are lower or to the right in that chart. Within a box, parallel states wake up in top-down, left-right order. See “Group States Using a Box” on page 8-7.

**Note** To specify activation order explicitly on a state-by-state basis, select **User-specified state/transition execution order** in the Chart properties dialog box. This option is selected by default when you create a new chart. For details, see “Explicit Ordering of Parallel States” on page 3-60.

---

## Rules for Using Boxes

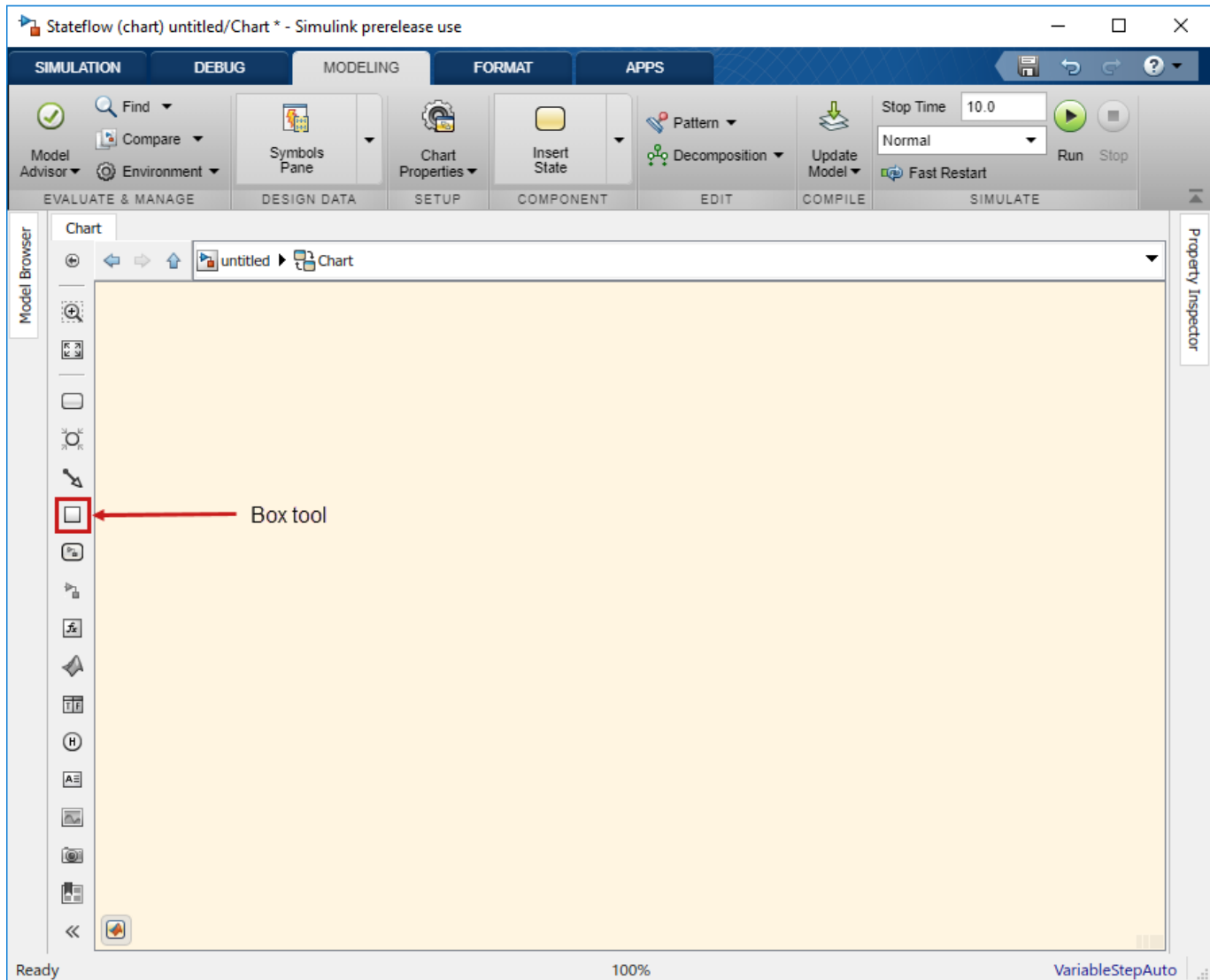
When you use a box, these rules apply:

- Include the box name in the path when you use dot notation to refer to a box-parented function or state from a location outside of the box.
- You can move or draw graphical objects inside a box, such as functions and states.
- You can add data to a box so that all the elements in the box can share the same data.
- You can group a box and its contents into a single graphical element. See “Group States” on page 4-6.
- You can subchart a box to hide its elements. See “Encapsulate Modal Logic by Using Subcharts” on page 8-10.
- You cannot define action statements for a box, such as `entry`, `during`, and `exit` actions.
- You cannot define a transition to or from a box. However, you can define a transition to or from a state within a box.

## Draw and Edit a Box

### Create a Box

You create boxes in your chart by using the box tool shown below.



- 1 Click the Box tool.
- 2 Move your pointer into the drawing area.
- 3 Click in any location to create a box.

The new box appears with a question mark (?) name in its upper left corner.

- 4 Click the question mark label.
- 5 Enter a name for the box and then click outside of the box.

#### Delete a Box

To delete a box, click to select it and press the **Delete** key.

## Examples of Using Boxes

### Group Functions Using a Box

This chart shows a box named `Status` that groups together MATLAB functions.

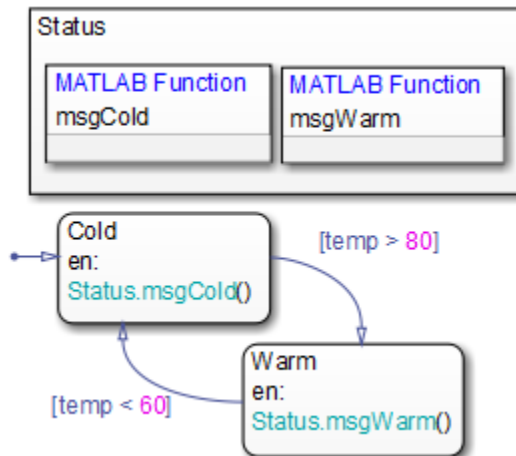


Chart execution takes place as follows:

- 1 The state `Cold` activates first.
- 2 Upon entry, the state `Cold` invokes the function `Status.msgCold`.

This function displays a status message that the temperature is cold.

---

**Note** Because the MATLAB function resides inside a box, the path of the function call must include the box name `Status`. If you omit this prefix, an error message appears.

---

- 3 If the value of the input data `temp` exceeds 80, a transition to the state `Warm` occurs.
- 4 Upon entry, the state `Warm` invokes the function `Status.msgWarm`.

This function displays a status message that the temperature is warm.

---

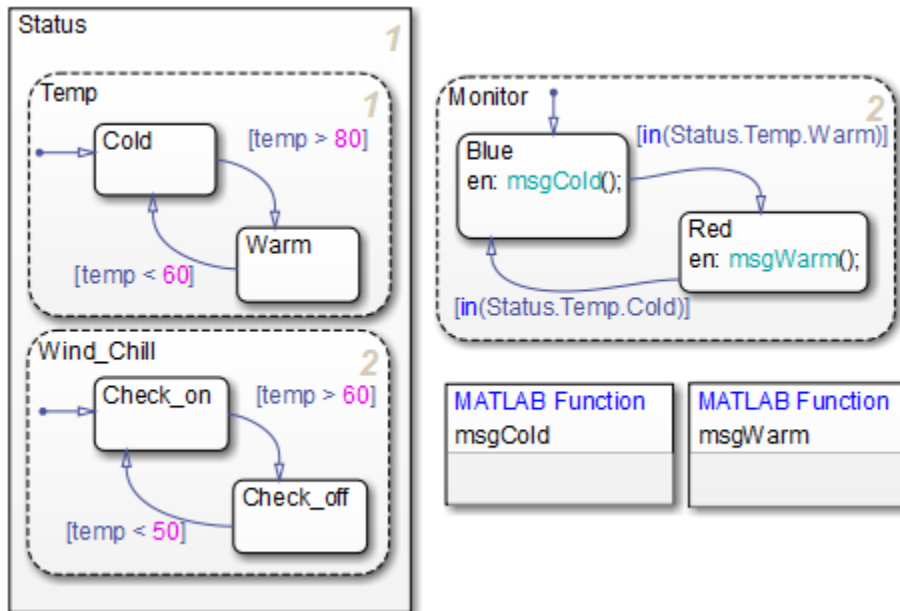
**Note** Because the MATLAB function resides inside a box, the path of the function call must include the box name `Status`. If you omit this prefix, an error message appears.

---

- 5 If the value of the input data `temp` drops below 60, a transition to the state `Cold` occurs.
- 6 Steps 2 through 5 repeat until the simulation ends.

### Group States Using a Box

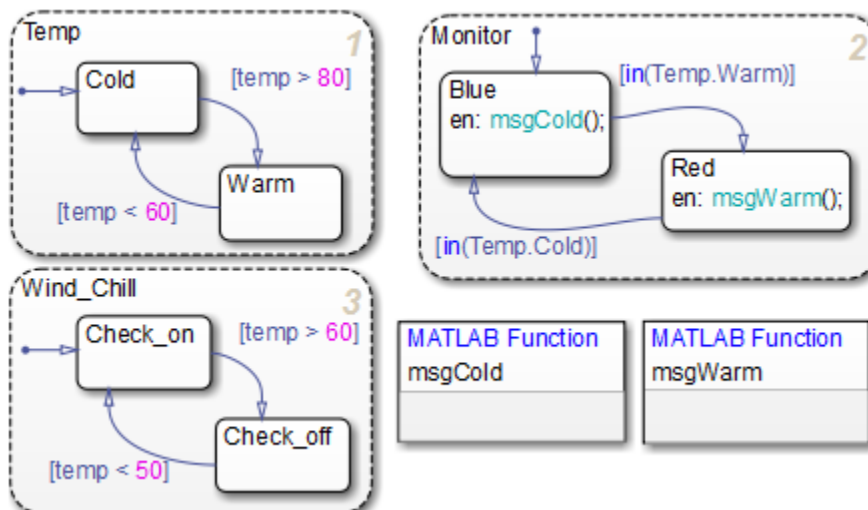
This chart shows a box named `Status` that groups together related states. The chart uses implicit ordering for parallel states, instead of the default explicit mode. (For details, see “Implicit Ordering of Parallel States” on page 3-61.)



The main ideas of this chart are:

- The state `Temp` wakes up first, followed by the state `Wind_Chill`. Then, the state `Monitor` wakes up.

**Note** This implicit activation order occurs because `Temp` and `Wind_Chill` reside in a box. If you remove the box, the implicit activation order changes, as shown, to: `Temp`, `Monitor`, `Wind_Chill`.



- Based on the input data `temp`, transitions between substates occur in the parallel states `Status.Temp` and `Status.Wind_Chill`.
- When the transition from `Status.Temp.Cold` to `Status.Temp.Warm` occurs, the transition condition `in(Status.Temp.Warm)` becomes true.



- When the transition from `Status.Temp.Warm` to `Status.Temp.Cold` occurs, the transition condition `in(Status.Temp.Cold)` becomes true.

---

**Note** Because the substates `Status.Temp.Cold` and `Status.Temp.Warm` reside inside a box, the argument of the `in` operator must include the box name `Status`. If you omit this prefix, an error message appears. For information about the `in` operator, see “Check State Activity by Using the `in` Operator” on page 13-17.

---

## Encapsulate Modal Logic by Using Subcharts

A subchart is a graphical object that can contain anything that a top-level chart can, including other subcharts. A subchart, or a subcharted state, is a superstate of the states that it contains. You can nest subcharts to any level in your chart design.

Using subcharts, you can reduce a complex chart to a set of simpler, hierarchically organized units. This design makes the chart easier to understand and maintain, without changing the chart behavior. Subchart boundaries do not apply during simulation and code generation.

The subchart appears as a block with its name in the block center. However, you can define actions and default transitions for subcharts just as you can for superstates. You can also create transitions to and from subcharts just as you can create transitions to and from superstates. You can create transitions between states residing outside a subchart and any state within a subchart. The term *supertransition* refers to a transition that crosses subchart boundaries in this way. See “Move Between Levels of Hierarchy by Using Supertransitions” on page 8-13 for more information.

Subcharts define a containment hierarchy within a top-level chart. A subchart or top-level chart is the *parent* of the states it contains at the first level and an *ancestor* of all the subcharts contained by its children and their descendants at lower levels.

Some subcharts can become *atomic* units if they meet certain modeling requirements. For more information, see “Restrictions for Converting to Atomic Subcharts” on page 19-9.

### Create a Subchart

You create a subchart by converting an existing state, box, or graphical function into the subchart. The object to convert can be one that you create for making a subchart or an existing object whose contents you want to turn into a subchart.

To convert a new or existing state, box, or graphical function to a subchart:

- 1 Right-click the object and select **Group & Subchart > Subchart**.
- 2 Confirm that the object now appears as a subchart.

To convert the subchart back to its original form, right-click the subchart. In the context menu, select **Group & Subchart > Subchart**.

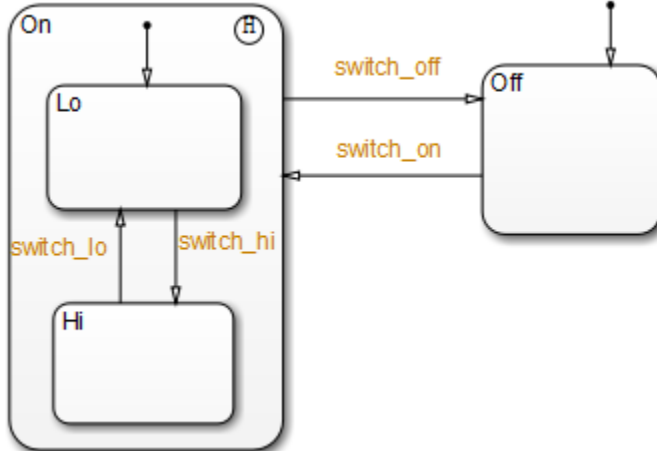
### Rules of Subchart Conversion

When you convert a box to a subchart, the subchart retains the attributes of a box. For example, the position of the resulting subchart determines its activation order in the chart if implicit ordering is enabled (see “Group Chart Objects by Using Boxes” on page 8-4 for more information).

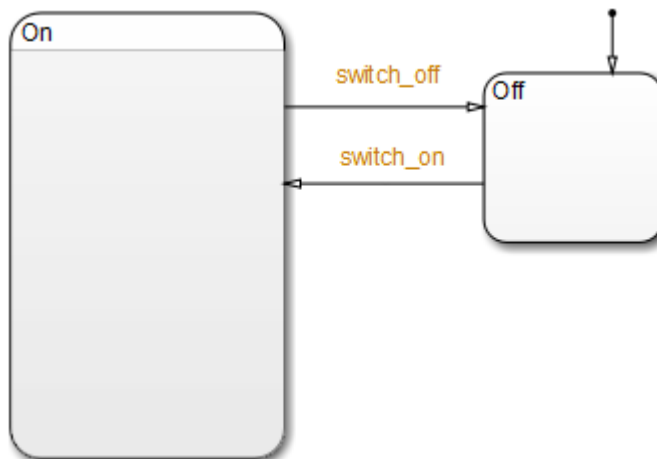
You cannot undo the operation of converting a subchart back to its original form. When you perform this operation, the undo and redo buttons are disabled from undoing and redoing any prior operations.

### Convert a State to a Subchart

Suppose that you have the following chart:



- 1 To convert the On state to a subchart, right-click the state and select **Group & Subchart > Subchart**.
- 2 Confirm that the On state now appears as a subchart.



## Manipulate Subcharts as Objects

Subcharts also act as individual objects. You can move, copy, cut, paste, relabel, and resize subcharts as you would states and boxes. You can also draw transitions to and from a subchart and any other state or subchart at the same or different levels in the chart hierarchy (see “Move Between Levels of Hierarchy by Using Supertransitions” on page 8-13).

## Open a Subchart

Opening a subchart allows you to view and change its contents. To open a subchart, do one of the following:

- Double-click anywhere in the box that represents the subchart.
- Select the box representing the subchart and press the **Enter** key.

## Edit a Subchart




After you open a subchart (see “Open a Subchart” on page 8-11), you can perform any editing operation on its contents that you can perform on a top-level chart. This means that you can create, copy, paste, cut, relabel, and resize the states, transitions, and subcharts in a subchart. You can also group states, boxes, and graphical functions inside subcharts.

You can also cut and paste objects between different levels in your chart. For example, to copy objects from a top-level chart to one of its subcharts, first open the top-level chart and copy the objects. Then open the subchart and paste the objects into the subchart.

Transitions from outside subcharts to states or junctions inside subcharts are called *supertransitions*. You create supertransitions differently than you do ordinary transitions. See “Move Between Levels of Hierarchy by Using Supertransitions” on page 8-13 for information on creating supertransitions.

## Navigate Subcharts

The Stateflow Editor toolbar contains a set of buttons for navigating the subchart hierarchy of a chart.

Tool	Description
	If the Stateflow Editor is displaying a subchart, clicking this button replaces the subchart with the parent of the subchart in the Stateflow Editor. If the Stateflow Editor is displaying a top-level chart, clicking this button replaces the chart with the Simulink model window containing that chart.
	Clicking this button shows the chart that you visited before the current chart, so that you can navigate up the hierarchy.
	Clicking this button shows the chart that you visited after visiting the current chart, so that you can navigate down the hierarchy.

---

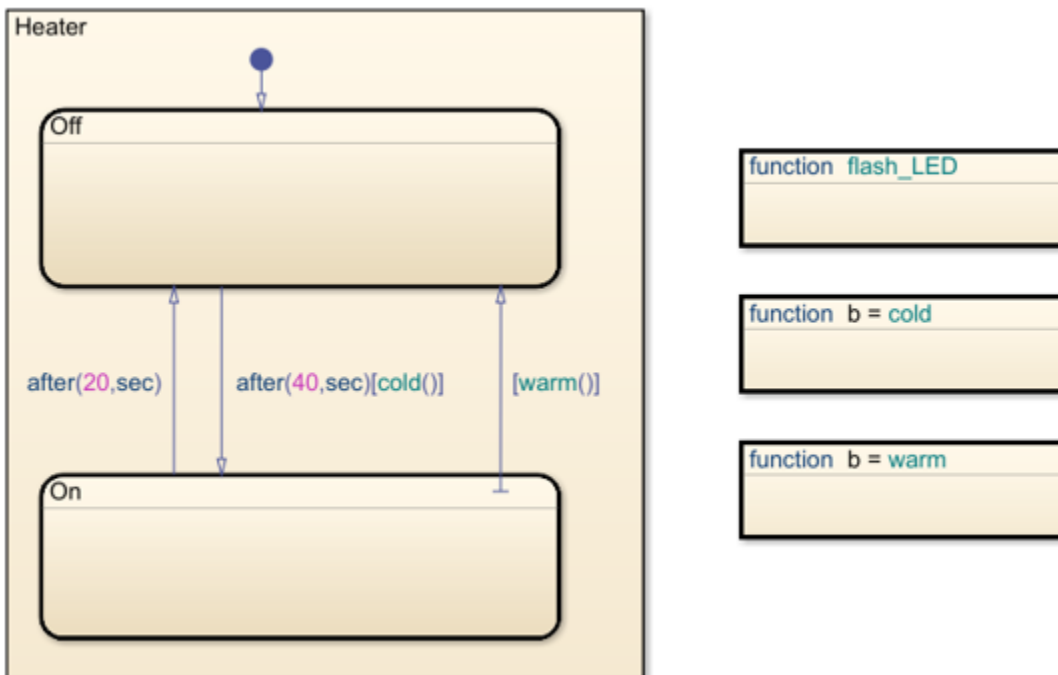
**Note** You can also use the **Escape** key to navigate up to the parent object for a subcharted state, box, or function.

---

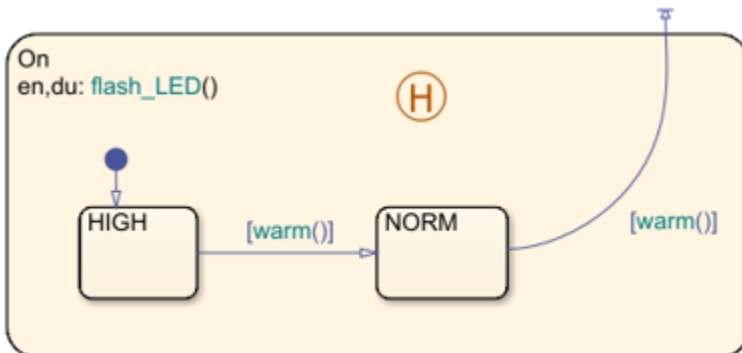
## Move Between Levels of Hierarchy by Using Supertransitions

A supertransition is a transition between different levels in a chart. A supertransition can be between a state in a top-level chart and a state in one of its substates, or between states residing in different substates. You can create supertransitions that span any number of levels in your chart, for example, from a state at the top level to a state that resides in a subchart several layers deep in the chart.

The point where a supertransition enters or exits a subchart is called a *slit*. Slits divide a supertransition into graphical segments. For example, this chart model shows a supertransition leaving the On subchart.



The same supertransition appears inside the subchart.



Both segments of the supertransition have the same label, `[warm()]`. For more information about this example, see "Model Bang-Bang Temperature Control System" on page 16-52.

## Draw a Supertransition Into a Subchart

Use the following steps to draw a supertransition from an object outside a subchart to an object inside the subchart.

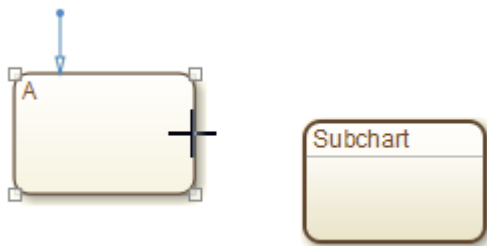
---

**Note** You cannot undo the operation of drawing a supertransition. When you perform this operation, the undo and redo buttons are disabled from undoing and redoing any prior operations.

---

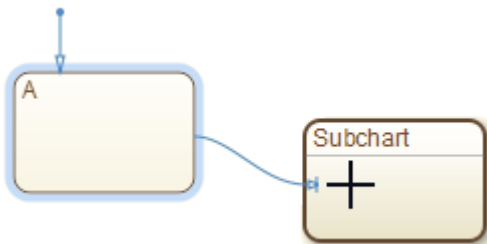
- 1 Position your cursor over the border of the state.

The cursor assumes the crosshairs shape.



- 2 Drag the mouse just inside the border of the subchart.

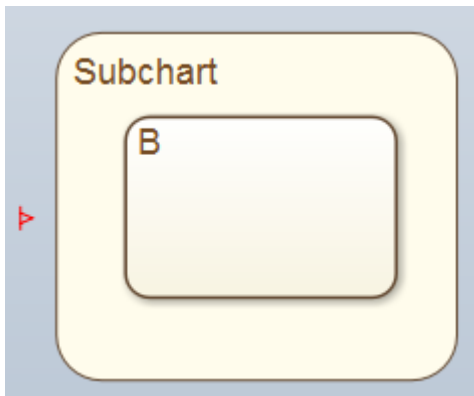
A supertransition appears, extending from the source state into the subchart with its arrowhead penetrating a slit in the subchart.



If you are not happy with the initial position of the slit, you can continue to drag the slit around the inside edge of the subchart to the desired location.

- 3 Double-click the subchart to open it.

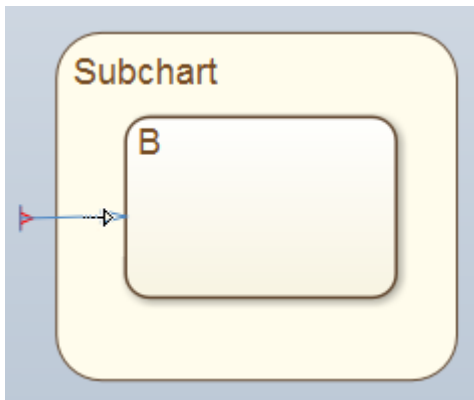
The tip of the arrowhead of the supertransition appears highlighted in red, entering the subchart.



- 4 Position your cursor over the arrowhead.

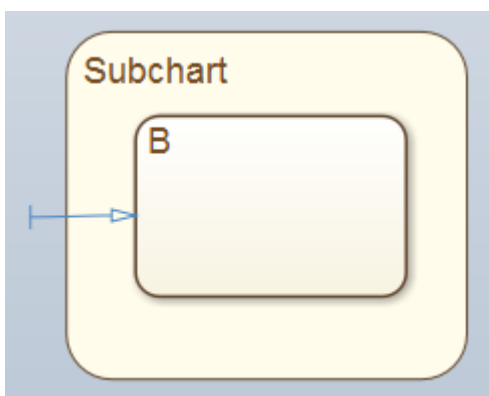
The cursor becomes an arrow.

- 5 Drag the cursor to the desired position in the subchart.



- 6 Release the cursor.

The supertransition terminates in the desired location.

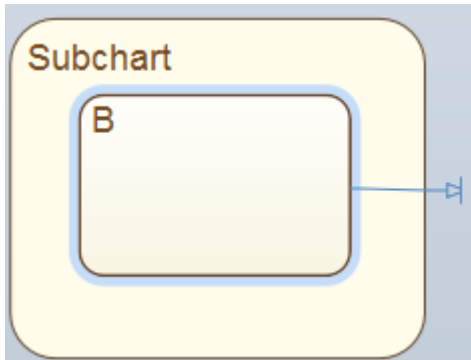


### **Draw a Supertransition Out of a Subchart**

Use the following steps to draw a supertransition out of a subchart.

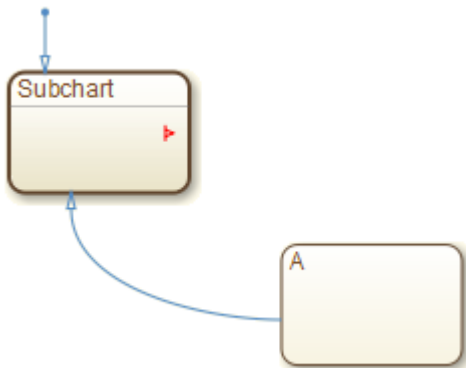
- 1** Draw an inner transition segment from the source object anywhere just outside the border of the subchart

A slit appears as shown.



- 2** Navigate up to the parent object.

The tip of the arrowhead of the supertransition appears highlighted in red, exiting the subchart.



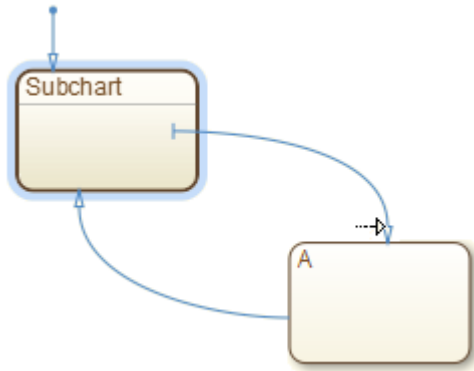
- 3** Position your cursor over the arrowhead.

The cursor becomes an arrow.

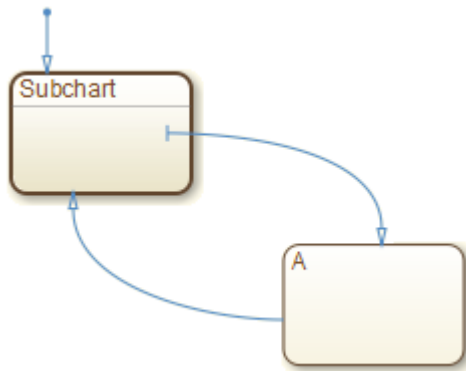
- 4** Drag the cursor to the desired position in the chart.

The parent of the subchart appears.





- 5 Release the cursor to complete the connection.




---

**Note** If the parent chart is itself a subchart and the terminating object resides at a higher level in the subchart hierarchy, repeat these steps until you reach the desired parent. In this way, you can connect objects separated by any number of layers in the subchart hierarchy.

---

## Label Supertransitions

A supertransition is displayed with multiple resulting transition segments for each layer of containment traversed. For example, if you create a transition between a state outside a subchart and a state inside a subchart of that subchart, you create a supertransition with three segments, each displayed at a different containment level.

You can label any one of the transition segments constituting a supertransition using the same procedure used to label a regular transition (see “Label Transitions” on page 4-14). The resulting label appears on all the segments that constitute the supertransition. Also, if you change the label on any one of the segments, the change appears on all segments.

## Reuse Logic Patterns by Defining Graphical Functions

A *graphical function* in a Stateflow chart is a graphical element that helps you reuse control-flow logic and iterative loops. You create graphical functions with flow charts that use connective junctions and transitions. You can call a graphical function in the actions of states and transitions. With graphical functions, you can:

- Create modular, reusable logic that you can call anywhere in your chart.
- Track simulation behavior visually during chart animation.

A graphical function can reside anywhere in a chart, state, or subchart. The location of the function determines the set of states and transitions that can call the function.

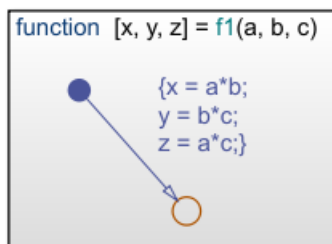
- If you want to call the function within one state or subchart and its substates, put your graphical function in that state or subchart. That function overrides any other functions of the same name in the parents and ancestors of that state or subchart.
- If you want to call the function anywhere in a chart, put your graphical function at the chart level.
- If you want to call the function from any chart in your model, put your graphical function at the chart level and enable exporting of chart-level functions. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

---


**Note** A graphical function can access chart and state data above it in the Stateflow hierarchy.

---

For example, this graphical function has the name `f1`. It takes three arguments (`a`, `b`, and `c`) and returns three output values (`x`, `y`, and `z`). The function contains a flow chart that computes three different products of the arguments.



### Define a Graphical Function

- 1 In the object palette, click the graphical function icon . Move your pointer to the location for the new graphical function in your chart.
- 2 Enter the signature label for the function.

The function signature label specifies a name for your function and the formal names for its arguments and return values. A signature label has this syntax:

```
[return_val1,return_val2,...] = function_name(arg1,arg2,...)
```

You can specify multiple return values and multiple input arguments. Each return value and input argument can be a scalar, vector, or matrix of values. For functions with only one return value, omit the brackets in the signature label.

You can use the same variable name for both arguments and return values. For example, a function with this signature label uses the variables `y1` and `y2` as both inputs and outputs:

```
[y1,y2,y3] = f(y1,u,y2)
```

If you export this function to C code, `y1` and `y2` are passed by reference (as pointers), and `u` is passed by value. Passing inputs by reference reduces the number of times that the generated code copies intermediate data, resulting in more optimal code.

---

**Note** Do not use the name of a chart symbol as a function argument or return value. For example, if either `x` or `y` are chart data, defining a function with the signature `y = f(x)` results in a run-time error.

---

- 3 To program the function, construct a flow chart inside the function box, as described in “Flow Charts in Stateflow” on page 5-2.

Because a graphical function must execute completely when you call it, you cannot use states. Connective junctions and transitions are the only graphical elements that you can use in a graphical function.

---

**Note** In a graphical function, do not broadcast events that can cause the active state to change. In a graphical function, the behavior of an event broadcast that causes an exit from the active state is unpredictable.

---

- 4 In the Model Explorer, expand the chart object and select the graphical function. The arguments and return values of the function signature appear as data items that belong to your function. Arguments have the scope `Input`. Return values have the scope `Output`.
- 5 In the Data properties dialog box for each argument and return value, specify the data properties, as described in “Set Data Properties” on page 12-5.
- 6 Create any additional data items required by your function. For more information, see “Add Data Through the Model Explorer” on page 12-3.

Your function can access its own data or data belonging to parent states or the chart. The data items in the function can have one of these scopes:

- **Constant** — Constant data retains its initial value through all function calls.
- **Parameter** — Parameter data retains its initial value through all function calls.
- **Local** — Local data persists across function calls throughout the simulation. Valid only in charts that use C as the action language.
- **Temporary** — Temporary data initializes at the start of every function call. Valid only in charts that use C as the action language.

In charts that use C as the action language, define local data when you want your data values to persist across function calls throughout the simulation. Define temporary data when you want to initialize data values at the start of every function call. For example, you can define a counter with `Local` scope if you want to track the number of times that you call the function. In contrast, you can designate a loop counter to have `Temporary` scope if you do not need the counter value to persist after the function completes.

In charts that use MATLAB as the action language, you do not need to define local or temporary function data. If you use an undefined variable, Stateflow creates a temporary variable that is available to the rest of the function. To store values that persist across function calls, your function can access local data at the chart level.

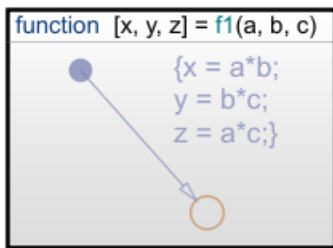
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**Tip** You can initialize local and temporary data in your function from the MATLAB workspace. For more information, see “Initialize Data from the MATLAB Base Workspace” on page 12-19.

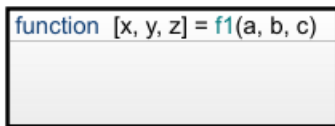
---

## Manage Large Graphical Functions

You can choose to make your graphical function as large as you want. If your function grows too large, you can hide its contents by right-clicking inside the function box and selecting **Group & Subchart > Subchart** from the context menu.



To make the graphical function box opaque, right-click the function and clear the **Content Preview** property from the context menu.



To dedicate the entire chart window to programming your function, access the flow chart in your subcharted graphical function by double-clicking the function box.

## Call Graphical Functions in States and Transitions

You can call graphical functions from the actions of any state or transition. You can also call graphical functions from other functions. If you export a graphical function, you can call it from any chart in the model.

To call a graphical function, use the function signature and include an actual argument value for each formal argument in the function signature. If the data types of the actual and formal arguments differ, the function casts the actual argument to the type of the formal argument.

## Specify Properties of Graphical Functions

You can specify properties for a graphical function in the Model Explorer or the Function properties dialog box.

- To use the Model Explorer:
  - 1 To open the Model Explorer, in the **Modeling** tab, select **Model Explorer**.
  - 2 In the **Model Hierarchy** pane, select the graphical function.
  - 3 In the **Function** pane, edit the graphical function properties.
- To use the Function properties dialog box:
  - 1 In the Stateflow Editor, right-click the graphical function.
  - 2 Select **Properties**.
  - 3 Edit the graphical function properties.

You can also specify graphical function properties programmatically by using `Stateflow.Function` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Name

Function name. Click the function name link to bring your function to the foreground in its native chart.

### Function Inline Option

Controls the inlining of your function in generated code:

- **Auto** — Determines whether to inline your function based on an internal calculation.
- **In line** — Inlines your function if you do not export it to other charts and it is not part of a recursion. (A recursion exists if your function calls itself directly or indirectly through another function call.)
- **Function** — Does not inline your function.

### Label

Signature label for your function. The function signature label specifies a name for your function and the formal names for its arguments and return values.

### Description

Function description. You can enter brief descriptions of functions in the hierarchy.

### Document Link

Link to online documentation for the function. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow displays the documentation.

### See Also

### More About

- “Flow Charts in Stateflow” on page 5-2

- “Create Flow Charts by Using Pattern Wizard” on page 5-5
- “Reusable Functions in Charts” on page 2-42
- “Export Stateflow Functions for Reuse” on page 8-23
- “Reuse Functions by Using Atomic Boxes” on page 8-28

## Export Stateflow Functions for Reuse

When you export chart-level functions, you extend the scope of your functions to other blocks in the Simulink model. For an example, see “Share Functions Across Simulink and Stateflow” on page 11-33. You can export these functions:

- Graphical functions
- MATLAB functions
- Truth tables

### How to Export Chart-Level Functions

- 1 Open the chart where your function resides.
- 2 In the Property Inspector, open the **Advanced** section.
- 3 Select **Export Chart Level Functions**.
- 4 If your function resides in a library chart, link that chart to your main model.

When you select **Export Chart Level Functions**, you can call exported functions by using Simulink Caller blocks with dot notation, *chartName.functionName*. To call the exported functions throughout the model from any Stateflow or Simulink Caller block, select **Treat Exported Functions as Globally Visible**. Do not use dot notation to call these functions. You cannot export functions with the same name.

Simulink functions can also be defined directly in the Simulink canvas. For more information, see Simulink Function.

### Rules for Exporting Chart-Level Functions

#### Link library charts to your main model to export chart-level functions from libraries

You must perform this step to export functions from library charts. Otherwise, a simulation error occurs.

#### Do not export chart-level functions that contain unsupported inputs or outputs

You cannot export a chart-level function when inputs or outputs have any of the following properties:

- Fixed-point data type with word length greater than 32 bits
- Variable size

#### Do not export Simulink functions

If you try to export Simulink functions, an error appears when you simulate your model. To avoid this behavior, clear the **Export chart level functions** check box in the Chart properties dialog box.

#### Do not export functions across model reference boundaries

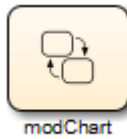
You cannot export functions from a referenced model and call the functions from a parent model.

## Export Chart-Level Functions

This example describes how to export functions in library charts to your main model.

### 1 Create these objects:

- Add a model named `main_model`, with a chart named `modChart`.



- Add a library model named `lib1`, with a chart named `lib1Chart`.

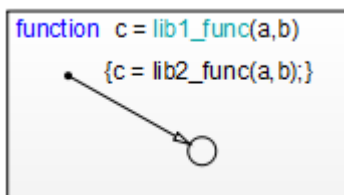


- Add a library model named `lib2`, with a chart named `lib2Chart`.

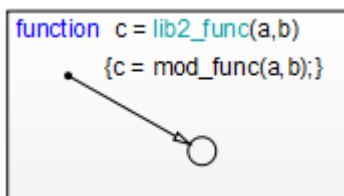


### 2 Create these graphical functions in the library charts:

- For `lib1Chart`, add this graphical function.



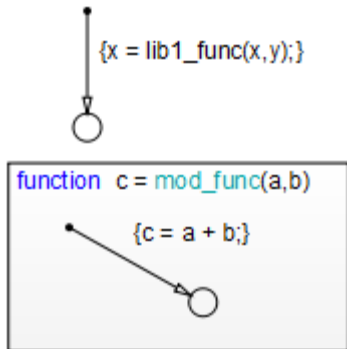
- For `lib2Chart`, add this graphical function.



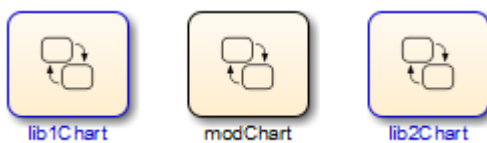
- In the Model Explorer, for each of the function inputs and outputs, `a`, `b`, and `c`, set these properties:
  - Size to 1



- Complexity to Off
  - Type to double
- 3 For modChart, add a graphical function and a default transition with a lib1\_func action.



- 4 For each chart, follow these steps:
- a In the Model Explorer, for each of the function inputs and outputs, a, b, and c, set:
    - Size to 1
    - Complexity to Off
    - Type to double
  - b Open the Chart properties dialog box.
  - c In the Chart properties dialog box, select **Export chart level functions** and **Treat exported functions as globally visible**.
  - d Click **OK**.
- 5 Drag lib1Chart and lib2Chart into main\_model from lib1 and lib2, respectively. Your main model should look something like this:



Each chart now defines a graphical function that any chart in main\_model can call.

- 6 Open the Model Explorer.
- 7 In the **Model Hierarchy** pane of the Model Explorer, navigate to main\_model.
- 8 Add the data x and y to the Stateflow machine:
  - a Select **Add > Data**.
  - b In the **Name** column, enter x.
  - c In the **Initial Value** column, enter 0.
  - d Use the default settings for other properties of x.
  - e Select **Add > Data**.
  - f In the **Name** column, enter y.

- g** In the **Initial Value** column, enter 1.
- h** Use the default settings for other properties of *y*.

This step ensures that input and output data are defined globally to support exported graphical functions.

- 9** Open the Model Configuration Parameters dialog box.
- 10** In the Model Configuration Parameters dialog box, go to the **Solver** pane.
- 11** In the **Solver selection** section, make these changes:
  - a** For **Type**, select **Fixed-step**.
  - b** For **Solver**, select **Discrete (no continuous states)**.
- 12** In the **Solver details** section, make these changes:
  - a** For **Fixed-step size**, enter 1.
  - b** Click **OK**.

This step ensures that when you simulate your model, a discrete solver is used. For more information, see “Compare Solvers” (Simulink).

### What Happens During Simulation

When you simulate the model, these actions take place during each time step.

Phase	The object...	Calls the graphical function...	Which...
1	modChart	lib1_func	Reads two input arguments <i>x</i> and <i>y</i>
2	lib1_func	lib2_func	Passes the two input arguments
3	lib2_func	mod_func	Adds <i>x</i> and <i>y</i> and assigns the sum to <i>x</i>

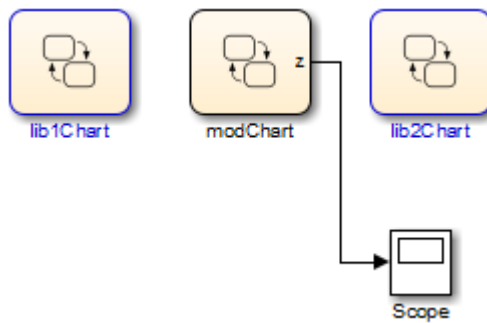
### How to View the Simulation Results

To view the simulation results, add a scope to your model. Follow these steps:

- 1** Open the Simulink Library Browser.
- 2** From the Simulink/Sinks Library, select the Scope block and add it to `main_model`.
- 3** Open the Model Explorer.
- 4** In the **Model Hierarchy** pane, navigate to `modChart`.
- 5** Add the output data *z* to the chart:
  - a** Select **Add > Data**.
  - b** In the **Name** column, enter *z*.
  - c** In the **Scope** column, select **Output**.
  - d** Use the default settings for other properties.
- 6** For `modChart`, update the default transition action to read as follows:
 

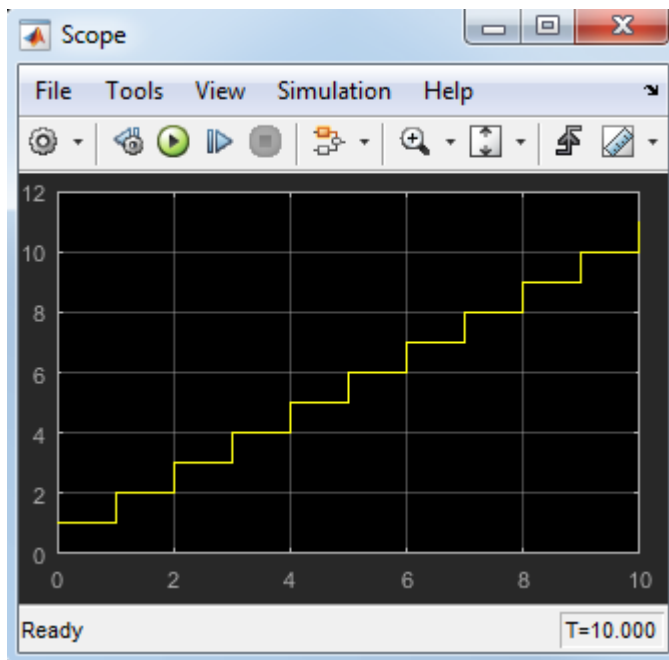
```
{x = lib1_func(x,y); z = x;}
```

- 7 In the model, connect the output from modChart to the inport of the Scope block.



- 8 Double-click the Scope block to open the display.
- 9 Start simulation.
- 10 After the simulation ends, right-click in the scope display and select **Autoscale**.

The results look something like this:



## Reuse Functions by Using Atomic Boxes

An atomic box is a graphical object that helps you encapsulate graphical, truth table, MATLAB, and Simulink functions in a separate namespace. Atomic boxes are supported only in Stateflow charts in Simulink models. Atomic boxes allow for:

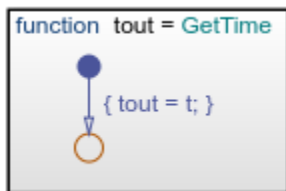
- Faster simulation after making small changes to a function in a chart with many states or levels of hierarchy
- Reuse of the same functions across multiple charts and models
- Ease of team development for people working on different parts of the same chart
- Manual inspection of generated code for a specific function in a chart

An atomic box looks opaque and includes the label **Atomic** in the upper left corner. If you use a linked atomic box from a library, the label **Link** appears in the upper left corner.

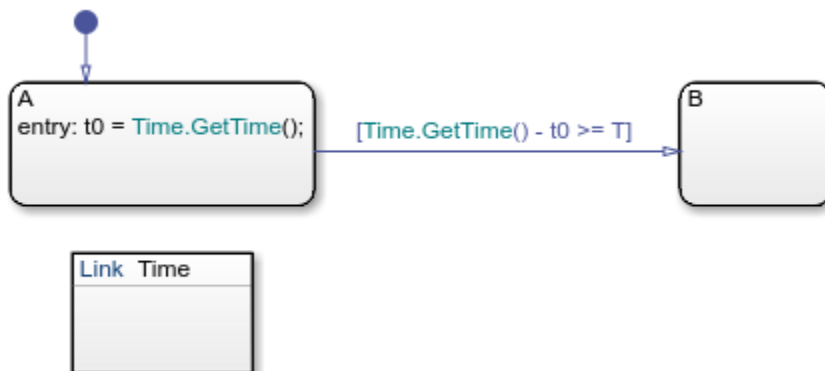
### Example of an Atomic Box

This example shows how to use a linked atomic box to reuse a graphical function across multiple charts and models.

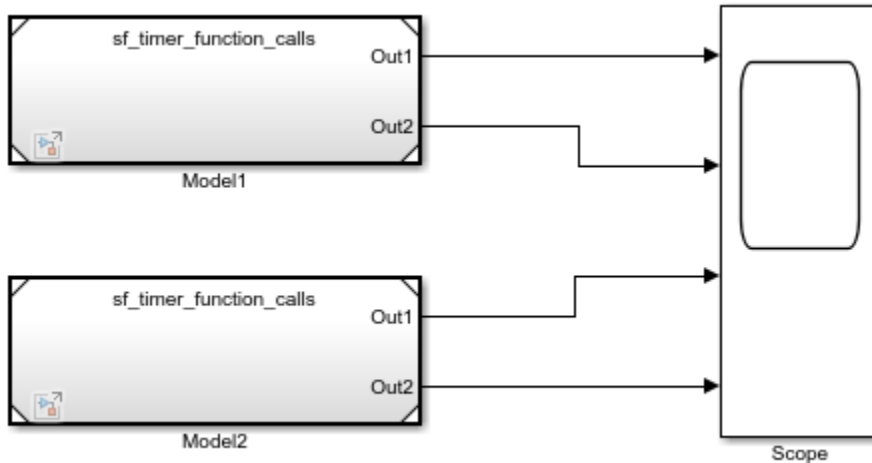
The function `GetTime` is defined in a chart in the library model `sf_timer_utils_lib`. The graphical function returns the simulation time in C charts where the equivalent MATLAB® function `getSimulationTime` is not available.



The model `sf_timer_function_calls` consists of two charts with a similar structure. Each chart contains a pair of states (A and B) and an atomic box (`Time`) linked from the library chart. The entry action in state A calls the function `GetTime` and stores its value as `t0`. The condition guarding the transition from A to B calls the function again and compares its output with the parameter `T`.



The top model `sf_timer_modelref` reuses the timer function in multiple referenced blocks. Because there are no exported functions, you can use more than one instance of the referenced block in the top model.



## Benefits of Using Atomic Boxes

Atomic boxes combine the functionality of normal boxes and atomic subcharts. Atomic boxes:

- Improve the organization and clarity of complex charts.
- Support usage as library links.
- Support the generation of reusable code.
- Allow mapping of inputs, outputs, parameters, data store memory, and input events.

Atomic boxes contain only functions. They cannot contain states. Adding a state to an atomic box results in a compilation-time error.

To call a function that resides in an atomic box from a location outside the atomic box, use dot notation to specify its full path:

```
atomic_box_name.function_name
```

Using the full path for the function call:

- Makes clear the dependency on the function in the linked atomic box.
- Avoids pollution of the global namespace.
- Does not affect the efficiency of generated code.

## Create an Atomic Box

You can create an atomic box by converting an existing box or by linking a chart from a library model. After creating the atomic box, update the mapping of variables by right-clicking the atomic box and selecting **Subchart Mappings**. For more information, see “Map Variables for Atomic Subcharts and Boxes” on page 19-11.

### Convert a Normal Box to an Atomic Box

To create a container for your functions that allows for faster debugging and code generation workflows, convert an existing box into an atomic box. In your chart, right-click a normal box and select **Group & Subchart > Atomic Subchart**. The label **Atomic** appears in the upper left corner of the box.

The conversion process gives the atomic box its own copy of every data object that the box accesses in the chart. Local data is copied as data store memory. The scope of other data, including input and output data, does not change.

---

**Note** If a box contains any states or messages, you cannot convert it to an atomic box.

---

### Link an Atomic Box from a Library

To create a collection of functions for reuse across multiple charts and models, create a link from a library model. Copy a chart in a library model and paste it to a chart in another model. If the library chart contains only functions and no states, it appears as a linked atomic box with the label **Link** in the upper left corner.

This modeling method minimizes maintenance of reusable functions. When you modify the atomic box in the library, your changes propagate to the links in all charts and models.

If the library chart contains any states, then it appears as a linked atomic subchart in the chart. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Convert an Atomic Box to a Normal Box

Converting an atomic box back to a normal box removes all of its variable mappings by merging subchart-parented data objects with the chart-parented data to which they map.

- 1 If the atomic box is a library link, right-click the atomic box and select **Library Link > Disable Link**.
- 2 To convert an atomic box to a subcharted box, right-click the atomic box and clear the **Group & Subchart > Atomic Subchart** check box.
- 3 To convert the subcharted box back to a normal box, right-click the subchart and clear the **Group & Subchart > Subchart** check box.
- 4 If necessary, rearrange graphical objects in your chart.

You cannot convert an atomic box to a normal box if:

- The atomic box maps a parameter to an expression other than a single variable name. For example, mapping a parameter `data1` to one of these expressions prevents the conversion of an atomic box to a normal box:
  - 3
  - `data2(3)`
  - `data2 + 3`
- Both of these conditions are true:
  - The atomic box contains MATLAB functions or truth table functions that use MATLAB as the action language.

- The atomic box does not map each variable to a variable of the same name in the main chart.

## When to Use Atomic Boxes

### Debug Functions Incrementally

Suppose that you want to test a sequence of changes to a library of functions. The functions are part of a chart that contains many states or several levels of hierarchy, so recompiling the entire chart can take a long time. If you define the functions in an atomic box, recompilation occurs for only the box and not for the entire chart. For more information, see “Reduce the Compilation Time of a Chart” on page 19-29.

### Reuse Functions

Suppose that you have a set of functions for use in multiple charts and models. The functions reside in the library model to enable easier configuration management. To use the functions in another model, you can either:

- Configure the library chart to export functions and create a link to the library chart in the model.
- Link the library chart as an atomic box in each chart of the model.

Models that use these functions can appear as referenced blocks in a top model. When the functions are exported, you can use only one instance of that referenced block for each top model. For more information, see “Model Reference Requirements and Limitations” (Simulink).

With atomic boxes, you can avoid this limitation. Because there are no exported functions in the charts, you can use more than one instance of the referenced block in the top model.

### Develop Charts Used by Multiple People

Suppose that multiple people are working on different parts of a chart. If you store each library of functions in a linked atomic box, different people can work on different libraries without affecting the other parts of the chart. For more information, see “Divide a Chart into Separate Units” on page 19-32.

### Inspect Generated Code

Suppose that you want to inspect code generated by Simulink Coder or Embedded Coder manually for a specific function. You can specify that the code for an atomic box appears in a separate file to avoid searching through unrelated code. For more information, see “Generate Code from Atomic Subcharts” on page 32-14.

## See Also

### More About

- “Group Chart Objects by Using Boxes” on page 8-4
- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11

## Add Descriptive Comments in a Chart

You can enter comments or annotations in any location on a Stateflow chart. Annotations can contain any combination of:

- Text.
- Images.
- Equations using TeX commands.
- Hyperlinks that open a website or perform MATLAB functions. See “Describe Models Using Notes and Annotations” (Simulink).

To create an annotation:

- 1 Double-click in the desired location of the chart. An annotation box opens.
- 2 In the annotation box, type your comments. To start a new line, press the **Enter** key.
- 3 After you finish typing, click outside the annotation box.

## Change Annotation Properties

You can change the style of an existing annotation by using the annotation formatting toolbar, the annotation context menu, or the Annotation properties dialog box.

- To access the annotation formatting toolbar, double-click the annotation text. Buttons on the formatting toolbox enable you to change font styles, text alignment, colors, and other options. For more information, see “Describe Models Using Notes and Annotations” (Simulink).



- To open the annotation context menu, right-click the annotation text and select one of these options:
  - **Format** — choose font size, style (bold or italics), and whether to display a drop shadow around the annotation text.
  - **Text Alignment** — choose between left, center, and right justified text.
  - **Enable TeX Commands** — include TeX formatting commands in the annotation text. See “Include TeX Formatting Instructions” on page 8-33.
- To open the Annotation properties dialog box, right-click the annotation text and select **Properties**. You can specify the layout of the annotation, including:
  - Fixed height and width options.
  - Text and background color.
  - Text alignment.
  - Margins between the text and the border of the annotation.



## Include TeX Formatting Instructions

In your annotations, you can embed a subset of TeX commands to produce special characters such as Greek letters and mathematical symbols. For example, suppose that you enter this annotation text:

```
\it{\omega_N = e^{\{-2\pii\}/N}}
```

When you select the **Enable TeX Commands** annotation property, the chart renders this annotation like this:

$$\omega_N = e^{(-2\pi)/N}$$

For a list of more information on using TeX commands in annotations, see “Describe Models Using Notes and Annotations” (Simulink).

## See Also

### More About

- “Describe Models Using Notes and Annotations” (Simulink)



# MATLAB Functions in Stateflow Charts

---

- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
- “Program a MATLAB Function in a Chart” on page 9-6
- “Connect Structures in MATLAB Functions to Simulink Bus Signals” on page 9-12
- “Debug a MATLAB Function in a Chart” on page 9-15

## Reuse MATLAB Code by Defining MATLAB Functions

A MATLAB function in a Stateflow chart is a graphical element that you use to write algorithms that are easier to implement by calling built-in MATLAB functions. Typical applications include:

- Matrix-oriented calculations
- Data analysis and visualization

This type of function is useful for coding algorithms that are more easily expressed by using MATLAB instead of the graphical Stateflow constructs. MATLAB functions also provide optimizations for generating efficient, production-quality C code for embedded applications.

A MATLAB function can reside anywhere in a chart, state, or subchart. The location of the function determines the set of states and transitions that can call the function.

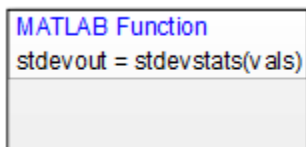
- If you want to call the function within one state or subchart and its substates, put your MATLAB function in that state or subchart. That function overrides any other functions of the same name in the parents and ancestors of that state or subchart.
- If you want to call the function anywhere in a chart, put your MATLAB function at the chart level.
- If you want to call the function from any chart in your model, put your MATLAB function at the chart level and enable exporting of chart-level functions. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

---

**Note** A MATLAB function can access chart and state data above it in the Stateflow hierarchy.

---

For example, this MATLAB function has the name `stdevstats`. It takes an argument `vals` and returns an output value `stdevout`.



To compute the standard deviation of the values in `vals`, the function uses this code.


```
function stdevout = stdevstats(vals)
%#codegen

% Calculates the standard deviation for vals

len = length(vals);
stdevout = sqrt(sum(((vals-avg(vals,len)).^2))/len);

function mean = avg(array,size)
mean = sum(array)/size;
```

### Define a MATLAB Function in a Chart

- 1 In the object palette, click the MATLAB function icon . Move your pointer to the location for the new MATLAB function in your chart.

- 2 Enter the signature label for the function.

The function signature label specifies a name for your function and the formal names for its arguments and return values. A signature label has this syntax:

```
[return_val1,return_val2,...] = function_name(arg1,arg2,...)
```

You can specify multiple return values and multiple input arguments. Each return value and input argument can be a scalar, vector, or matrix of values. For functions with only one return value, omit the brackets in the signature label.

You can use the same variable name for both arguments and return values. For example, a function with this signature label uses the variables `y1` and `y2` as both inputs and outputs:

```
[y1,y2,y3] = f(y1,u,y2)
```

If you export this function to C code, `y1` and `y2` are passed by reference (as pointers), and `u` is passed by value. Passing inputs by reference reduces the number of times that the generated code copies intermediate data, resulting in more optimal code.

---

**Note** Do not use the name of a chart symbol as a function argument or return value. For example, if either `x` or `y` are chart data, defining a function with the signature `y = f(x)` results in a run-time error.

---

- 3 To program the function, open the MATLAB editor by double-clicking the function box.
- 4 In the MATLAB editor, enter the MATLAB code implementing your function. For more information, see “Program a MATLAB Function in a Chart” on page 9-6.
- 5 In the Model Explorer, expand the chart object and select the MATLAB function. The arguments and return values of the function signature appear as data items that belong to your function. Arguments have the scope **Input**. Return values have the scope **Output**.
- 6 In the Data properties dialog box for each argument and return value, specify the data properties, as described in “Set Data Properties” on page 12-5.
- 7 Create any additional data items required by your function. For more information, see “Add Data Through the Model Explorer” on page 12-3.

Your function can access its own data or data belonging to parent states or the chart. The data items in the function can have one of these scopes:

- **Constant** — Constant data retains its initial value through all function calls.
- **Parameter** — Parameter data retains its initial value through all function calls.

In MATLAB functions, you do not need to create local or temporary function data explicitly. If you use an undefined variable, Stateflow creates a temporary variable that is available to the rest of the function. To store values that persist across function calls, use the keyword `persistent`.

## Call MATLAB Functions in States and Transitions

You can call MATLAB functions from the actions of any state or transition. You can also call MATLAB functions from other functions. If you export a MATLAB function, you can call it from any chart in the model.

To call a MATLAB function, use the function signature and include an actual argument value for each formal argument in the function signature. If the data types of the actual and formal arguments differ, the function casts the actual argument to the type of the formal argument.

## Specify Properties of MATLAB Functions

You can specify properties for a MATLAB function in the Model Explorer or the MATLAB Function properties dialog box.

- To use the Model Explorer:
  - 1 To open the Model Explorer, in the **Modeling** tab, select **Model Explorer**.
  - 2 In the **Model Hierarchy** pane, select the MATLAB function.
  - 3 In the **MATLAB Function** pane, edit the MATLAB function properties.
- To use the MATLAB Function properties dialog box:
  - 1 In the Stateflow Editor, right-click the MATLAB function.
  - 2 Select **Properties**.
  - 3 Edit the MATLAB function properties.

You can also specify MATLAB function properties programmatically by using `Stateflow.EMFunction` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Name

Function name. Click the function name link to open your function in the MATLAB editor.

### Function Inline Option

Controls the inlining of your function in generated code:

- **Auto** — Determines whether to inline your function based on an internal calculation.
- **InLine** — Inlines your function if you do not export it to other charts and it is not part of a recursion. (A recursion exists if your function calls itself directly or indirectly through another function call.)
- **Function** — Does not inline your function.

### Label

Signature label for your function. The function signature label specifies a name for your function and the formal names for its arguments and return values.

### Saturate on Integer Overflow

Specifies whether integer overflows saturate in the generated code. For more information, see “Handle Integer Overflow for Chart Data” on page 12-36.

This property applies only to MATLAB functions in charts that use C as the action language. In charts that use MATLAB as the action language, the behavior of data depends on the value of the “Saturate on integer overflow” on page 28-5 property for the chart.

## MATLAB Function fimath

Defines the `fimath` properties for the MATLAB function. The `fimath` properties specified are associated with all `fi` and `fimath` objects constructed in the MATLAB function. Choose one of these options:

- **Same as MATLAB** — The function uses the same `fimath` properties as the current global `fimath`. The edit box appears dimmed and displays the current global `fimath` in read-only form. For more information on the global `fimath` and `fimath` objects, see the Fixed-Point Designer™ documentation.
- **Specify Other** — Specify your own `fimath` object by one of these methods:
  - Construct the `fimath` object inside the edit box.
  - Construct the `fimath` object in the MATLAB or model workspace and enter its variable name in the edit box.

This property applies only to MATLAB functions in charts that use C as the action language. In charts that use MATLAB as the action language, the behavior of data depends on the value of the “MATLAB Chart `fimath`” on page 28-6 property for the chart.

### Description

Function description. You can enter brief descriptions of functions in the hierarchy.

### Document Link

Link to online documentation for the function. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow displays the documentation.

### See Also

#### More About

- “Program a MATLAB Function in a Chart” on page 9-6
- “Reusable Functions in Charts” on page 2-42
- “Export Stateflow Functions for Reuse” on page 8-23
- “Reuse Functions by Using Atomic Boxes” on page 8-28
- “Enhance Code Readability for MATLAB Function Blocks” (Embedded Coder)

## Program a MATLAB Function in a Chart

A MATLAB function in a Stateflow chart is a graphical element that you use to write algorithms that are easier to implement by calling built-in MATLAB functions. This type of function is useful for coding algorithms that are more easily expressed by using MATLAB instead of the graphical Stateflow constructs. For more information, see “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2.

Inside a MATLAB function, you can call these types of functions:

- Local functions defined in the body of the MATLAB function.
- Graphical, Simulink, truth table, and other MATLAB functions in the chart.
- Built-in MATLAB functions that support code generation. These functions generate C code for building targets that conform to the memory and data type requirements of embedded environments.
- Extrinsic MATLAB functions that do not support code generation. These functions execute only in the MATLAB workspace during simulation of the model. For more information, see “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40.
- Simulink Design Verifier™ functions for property proving and test generation. These functions include:
  - `sldv.prove`
  - `sldv.assume`
  - `sldv.test`
  - `sldv.condition`

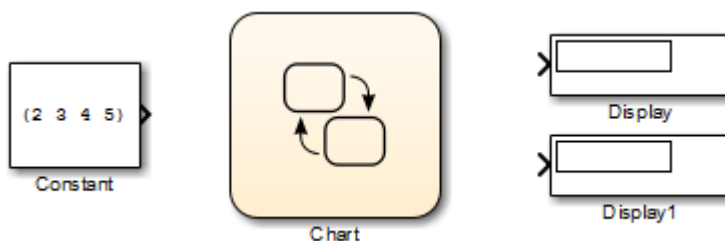
This example shows how to create a model with a Stateflow chart that calls two MATLAB functions, `meanstats` and `stdevstats`:

- `meanstats` calculates the mean of the values in `vals`.
- `stdevstats` calculates a standard deviation for the values in `vals`.

### Build Model

Follow these steps:

- 1 Create a new model with the following blocks:



- 2 Save the model as `call_stats_function_stateflow`.
- 3 In the model, double-click the Chart block.

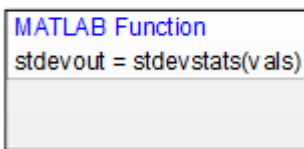
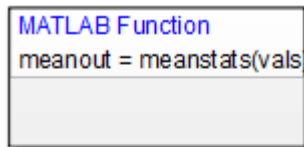


- 4 Drag two MATLAB functions into the empty chart using this icon from the toolbar:



A text field with a flashing cursor appears in the middle of each MATLAB function.

- 5 Label each function as shown:



You must label a MATLAB function with its signature. Use the following syntax:

```
[return_val1, return_val2, ...] = function_name(arg1, arg2, ...)
```

You can specify multiple return values and multiple input arguments, as shown in the syntax. Each return value and input argument can be a scalar, vector, or matrix of values.

---

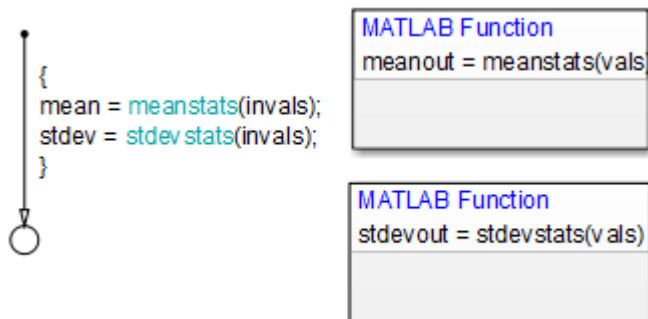
**Tip** For MATLAB functions with only one return value, you can omit the brackets in the signature label.

---

- 6 In the chart, draw a default transition into a terminating junction with this condition action:

```
{
mean = meanstats(invals);
stdev = stdevstats(invals);
}
```

The chart should look something like this:

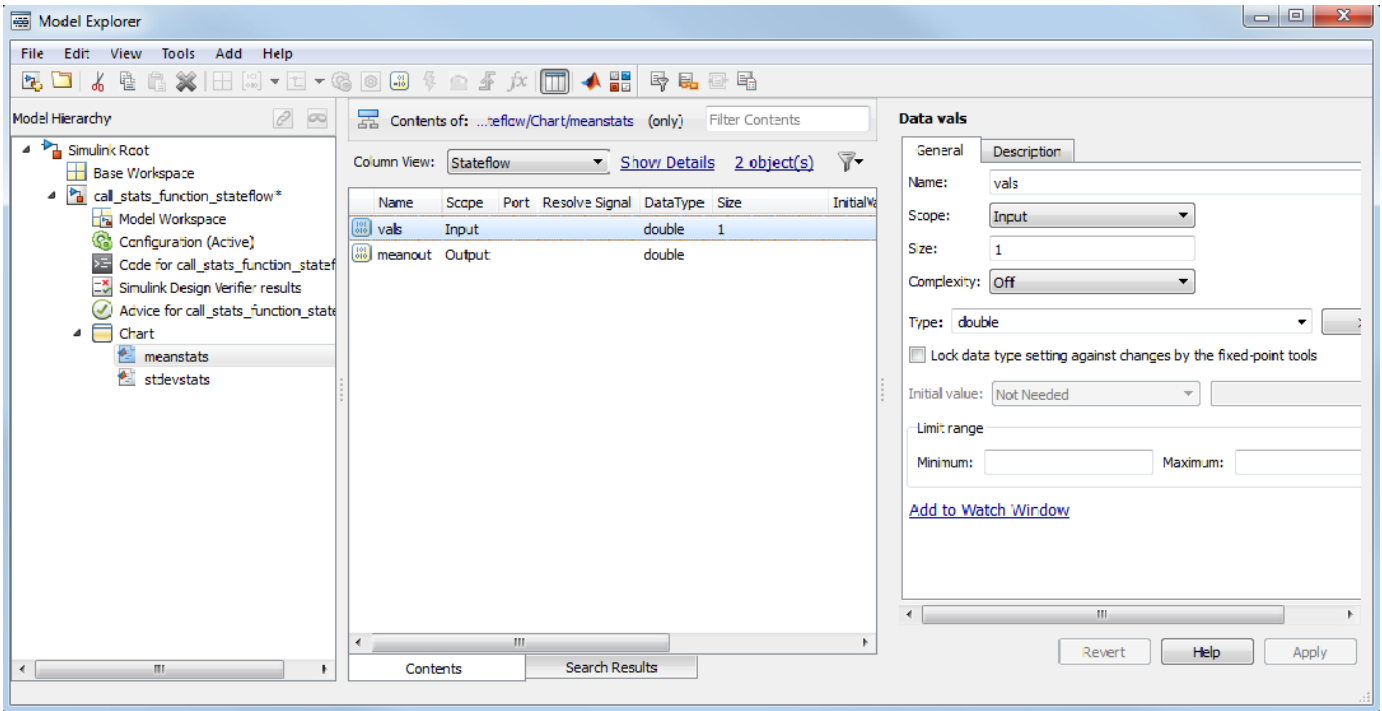



---

**Tip** If the formal arguments of a function signature are scalars, verify that inputs and outputs of function calls follow the rules of scalar expansion. For more information, see “Assign Values to All Elements of a Matrix” on page 21-6.

---

- 7 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
- 8 In the **Model Hierarchy** pane of the Model Explorer, select the function **meanstats**.

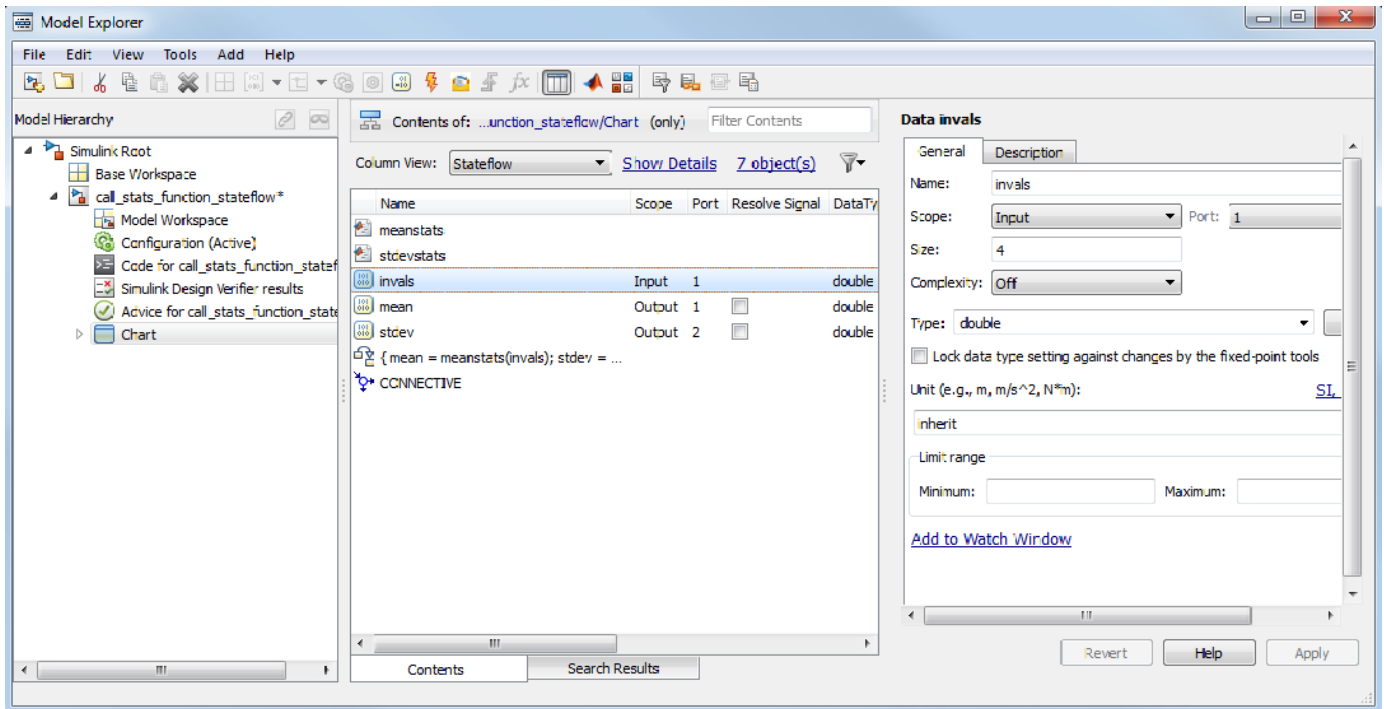


The **Contents** pane displays the input argument **vals** and output argument **meanout**. Both are scalars of type **double** by default.

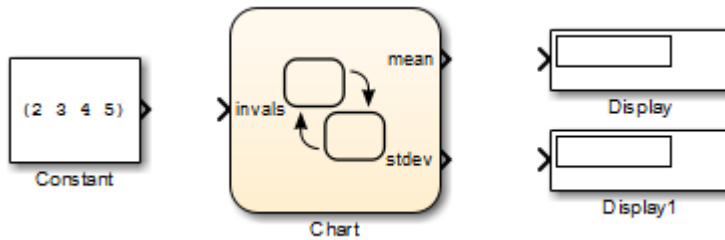
- 9 Double-click the **vals** row under the **Size** column to set the size of **vals** to 4.
- 10 In the **Model Hierarchy** pane of the Model Explorer, select the function **stdevstats** and repeat the previous step.
- 11 In the **Model Hierarchy** pane of the Model Explorer, select **Chart** and add the following data:

Name	Scope	Size
invals	Input	4
mean	Output	Scalar (no change)
stdev	Output	Scalar (no change)

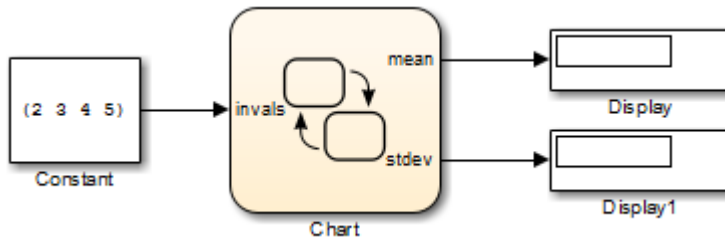
You should now see the following data in the Model Explorer.



After you add the data `invals`, `mean`, and `stdev` to the chart, the corresponding input and output ports appear on the Stateflow block in the model.



- 12 Connect the Constant and Display blocks to the ports of the Chart block and save the model.



## Program MATLAB Functions

To program the functions `meanstats` and `stdevstats`, follow these steps:

- 1 Open the chart in the model `call_stats_function_stateflow`.

- 2 In the chart, open the function `meanstats`.

The function editor appears with the header:

```
function meanout = meanstats(vals)
```

This header is taken from the function label in the chart. You can edit the header directly in the editor, and your changes appear in the chart after you close the editor.

- 3 On the line after the function header, enter:

```
%#codegen
```

The `%#codegen` compilation directive helps detect compile-time violations of syntax and semantics in MATLAB functions supported for code generation.

- 4 Enter a line space and this comment:

```
% Calculates the statistical mean for vals
```

- 5 Add the line:

```
len = length(vals);
```

The function `length` is an example of a built-in MATLAB function that is supported for code generation. You can call this function directly to return the vector length of its argument `vals`. When you build a simulation target, the function `length` is implemented with generated C code. Functions supported for code generation appear in “Functions and Objects Supported for C/C++ Code Generation” (MATLAB Coder).

The variable `len` is an example of implicitly declared local data. It has the same size and type as the value assigned to it — the value returned by the function `length`, a scalar `double`. To learn more about declaring variables, see “Data Definition Basics” (MATLAB Coder).

The MATLAB function treats implicitly declared local data as temporary data, which exists only when the function is called and disappears when the function exits. You can declare local data for a MATLAB function in a chart to be persistent by using the `persistent` construct.

- 6 Enter this line to calculate the value of `meanout`:

```
meanout = avg(vals, len);
```

The function `meanstats` stores the mean of `vals` in the Stateflow data `meanout`. Because these data are defined for the parent Stateflow chart, you can use them directly in the MATLAB function.

Two-dimensional arrays with a single row or column of elements are treated as vectors or matrices in MATLAB functions. For example, in `meanstats`, the argument `vals` is a four-element vector. You can access the fourth element of this vector with the matrix notation `vals(4,1)` or the vector notation `vals(4)`.

The MATLAB function uses the functions `avg` and `sum` to compute the value of `mean`. `sum` is a function supported for code generation. `avg` is a local function that you define later. When resolving function names, MATLAB functions in your chart look for local functions first, followed by functions supported for code generation.

---

**Note** If you call a function that the MATLAB function cannot resolve as a local function or a function for code generation, you must declare the function to be extrinsic.

---

- 7** Now enter this statement:

```
coder.extrinsic('plot');
```

- 8** Enter this line to plot the input values in `vals` against their vector index.

```
plot(vals, '-+');
```

Recall that you declared `plot` to be an extrinsic function because it is not supported for code generation. When the MATLAB function encounters an extrinsic function, it sends the call to the MATLAB workspace for execution during simulation.

- 9** Now, define the local function `avg`, as follows:

```
function mean = avg(array,size)
mean = sum(array)/size;
```

The header for `avg` defines two arguments, `array` and `size`, and a single return value, `mean`. The local function `avg` calculates the average of the elements in `array` by dividing their sum by the value of argument `size`.

The complete code for the function `meanstats` looks like this:

```
function meanout = meanstats(vals)
%#codegen

% Calculates the statistical mean for vals

len = length(vals);
meanout = avg(vals,len);

coder.extrinsic('plot');
plot(vals, '-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

- 10** Save the model.

- 11** Back in the chart, open the function `stdevstats` and add code to compute the standard deviation of the values in `vals`. The complete code should look like this:

```
function stdevout = stdevstats(vals)
%#codegen

% Calculates the standard deviation for vals

len = length(vals);
stdevout = sqrt(sum(((vals-avg(vals,len)).^2))/len);

function mean = avg(array,size)
mean = sum(array)/size;
```

- 12** Save the model again.

## Connect Structures in MATLAB Functions to Simulink Bus Signals

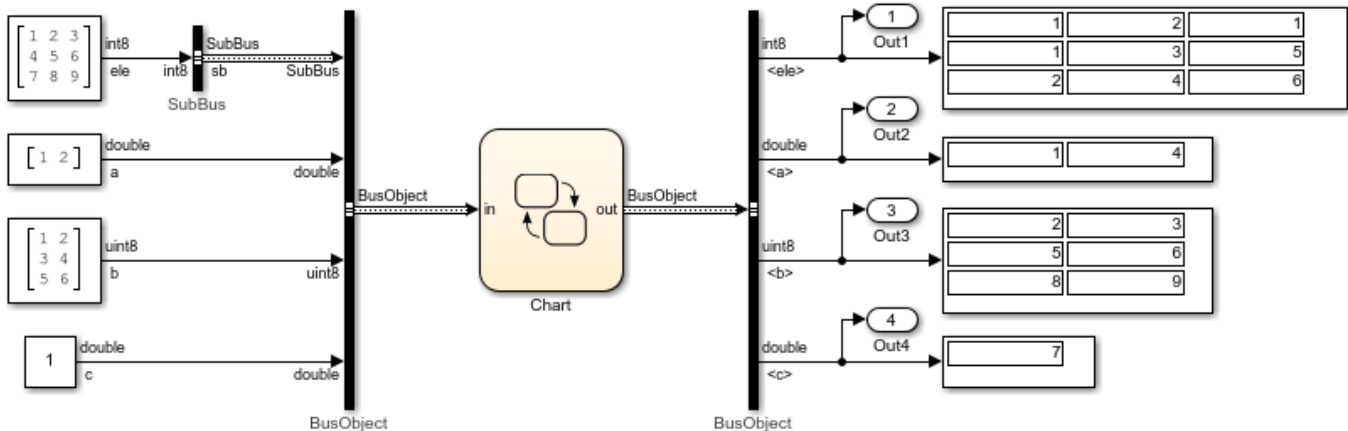
This example shows how to use MATLAB® structures in a Stateflow® chart. MATLAB structures enable you to bundle data of different sizes and types together into a single variable in a MATLAB function. You can create a MATLAB structure to:

- Store related data in a local or persistent variable of a MATLAB function
- Read from or write to a local Stateflow structure
- Interface with a Simulink® bus signal at an input or output port

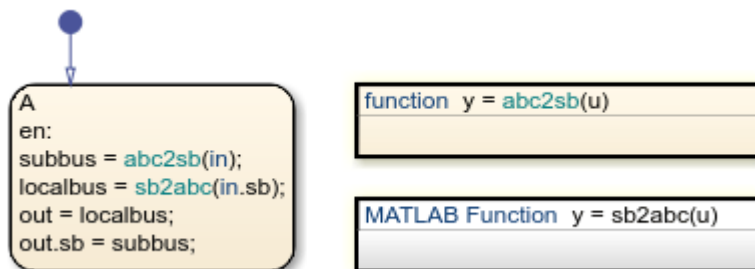
MATLAB functions support nonvirtual buses only. For more information, see “Types of Composite Signals” (Simulink).

### Define Structures in MATLAB Functions

In this example, a Stateflow chart processes data from one Simulink bus signal and outputs the result to another Simulink bus signal. Both the input and output bus signals are defined by the Simulink.Bus (Simulink) object BusObject. These buses have four fields: sb, a, b, and c. The field sb is also a bus signal defined by the Simulink.Bus object SubBus. It has one field called ele.



In the chart, the Simulink bus signals interface with the Stateflow structures in and out. The functions `abc2sb` and `sb2abc` extract information from the input structure and store it in the local Stateflow structures `localbus` and `subbus`. Then, the chart writes to the output structure by combining the values of these local structures. For more information on Stateflow structures, see “Access Bus Signals Through Stateflow Structures” on page 29-2.



The MATLAB® function `sb2abc` takes a Stateflow structure of type `SubBus` and returns a Stateflow structure of type `BusObject`. The function decomposes the value of the field `ele` from its input into three components: a vector, a 3-by-2 matrix, and a scalar. The function stores these components in the local MATLAB struct `Y` that has the same structure as the Simulink.Bus object `BusObject`. Then, the function assigns the value of the MATLAB struct `Y` to the output structure `y`.

```
function y = sb2abc(u)

% extract data from input structure

E = int8(magic(3));
A = double(u.ele(1:2,1));
B = uint8(u.ele(:,2:3));
C = double(u.ele(3,1));

% create local structure

X = struct('ele',E);
Y = struct('sb',X,'a',A,'b',B,'c',C);

% assign value to output structure

y = Y;
end
```

### Define Input and Output Structures

In a MATLAB function, access a local Stateflow structure or interface with a Simulink bus signal by defining input and output structures for the function:

- 1 In the base workspace, create a `Simulink.Bus` object that defines the structure data type.
- 2 In the Symbols pane, select the function input or output.
- 3 In the Property Inspector, set the **Type** property to `Bus: <object name>`. Replace `<object name>` with the name of the `Simulink.Bus` object that defines the Stateflow structure.

For example, in the function `sb2abc`:

- The **Type** property of the input structure `u` is specified as `Bus: SubBus`.
- The **Type** property of the output structure `y` is specified as `Bus: BusObject`.

For more information, see “Define Stateflow Structures” on page 29-2.

### Define Local and Persistent Structure Variables

To store related data in a single variable inside a MATLAB function, you can create a MATLAB struct as a local or persistent variable. For example, the function `sb2abc` defines two local MATLAB structures to temporarily store the data extracted from the input structure `u` before writing to the output structure `y`:

- `X` is a scalar struct with a single field called `ele`. This field contains a 3-by-3 matrix of type `int8`, which matches the structure of the `Simulink.Bus` object `SubBus`.
- `Y` is a scalar struct with four fields: `sb` is a substructure of type `SubBus`, `a` is a two-dimensional vector of type `double`, `b` is a 3-by-2 matrix of type `uint8`, and `c` is a scalar of type `double`. These fields match the structure of the `Simulink.Bus` object `BusObject`.

For more information, see “Define Scalar Structures for Code Generation” (Simulink).

## **See Also**

Simulink.Bus | struct

## **More About**

- “Access Bus Signals Through Stateflow Structures” on page 29-2
- “Index and Assign Values to Stateflow Structures” on page 29-7
- “Identify Data by Using Dot Notation” on page 12-39
- “Define Scalar Structures for Code Generation” (Simulink)



## Debug a MATLAB Function in a Chart

### Check MATLAB Functions for Syntax Errors

Before you can build a simulation application for a model, you must fix syntax errors. Follow these steps to check the MATLAB function `meanstats` for syntax violations:

- 1 Open the function `meanstats` inside the chart in the `call_stats_function_stateflow` model that you constructed in “Program a MATLAB Function in a Chart” on page 9-6.

The editor automatically checks your function code for errors and recommends corrections.

- 2 In the **Apps** tab, click **Simulink Coder**. In the **C Code** tab, click **Build**.

If there are no errors or warnings, the Builder window appears and reports success. Otherwise, it lists errors. For example, if you change the name of local function `avg` to a nonexistent local function `aug` in `meanstats`, errors appear in the Diagnostic Viewer.

- 3 The diagnostic message provides details of the type of error and a link to the code where the error occurred. The diagnostic message also contains a link to a diagnostic report that provides links to your MATLAB functions and compile-time type information for the variables and expressions in these functions. If your model fails to build, this information simplifies finding sources of error messages and aids understanding of type propagation rules. For more information about this report, see “MATLAB Function Reports” (Simulink).
- 4 In the diagnostic message, click the link after the function name `meanstats` to display the offending line of code.

The offending line appears highlighted in the editor.

- 5 Correct the error by changing `aug` back to `avg` and recompile. No errors are found and the compile completes successfully.

### Run-Time Debugging for MATLAB Functions in Charts

You use simulation to test your MATLAB functions for run-time errors that are not detectable by Stateflow. When you simulate your model, your MATLAB functions undergo diagnostic tests for missing or undefined information and possible logical conflicts as described in “Check MATLAB Functions for Syntax Errors” on page 9-15. If no errors are found, the simulation of your model begins.

Follow these steps to simulate and debug the `meanstats` function during run-time conditions:

- 1 In the function editor, click the dash (-) character in the left margin of this line:

```
len = length(vals);
```

A small red ball appears in the margin of this line, indicating that you have set a breakpoint.

- 2 Start simulation for the model.

If you get any errors or warnings, make corrections before you try to simulate again. Otherwise, simulation pauses when execution reaches the breakpoint you set. A small green arrow in the left margin indicates this pause.

- 3 To advance execution to the next line, select **Step**.

Notice that this line calls the local function `avg`. If you select **Step** here, execution advances past the execution of the local function `avg`. To track execution of the lines in the local function `avg`, select **Step In** instead.

- 4 To advance execution to the first line of the called local function `avg`, select **Step In**.

Once you are in the local function, you can advance through one line at a time with the **Step** tool. If the local function calls another local function, use the **Step In** tool to step into it. To continue through the remaining lines of the local function and go back to the line after the local function call, select **Step Out**.

- 5 Select **Step** to execute the only line in `avg`.

When `avg` finishes its execution, you see a green arrow pointing down under its last line.

- 6 Select **Step** to return to the function `meanstats`.

Execution advances to the line after the call to `avg`.

- 7 To display the value of the variable `len`, place your pointer over the text `len` in the function editor for at least a second.

The value of `len` appears adjacent to your pointer.

You can display the value for any data in the MATLAB function in this way, no matter where it appears in the function. For example, you can display the values for the vector `vals` by placing your pointer over it as an argument to the function `length`, or as an argument in the function header.

You can also report the values for MATLAB function data in the MATLAB Command Window during simulation. When you reach a breakpoint, the `debug>>` command prompt appears in the MATLAB Command Window (you may have to press **Enter** to see it). At this prompt, you can inspect data defined for the function by entering the name of the data, as shown in this example:

```
debug>> len
len =
     4
debug>>
```

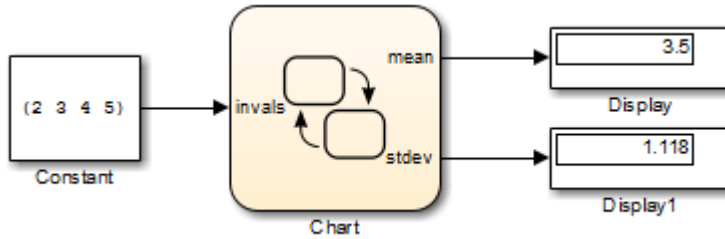
As another debugging alternative, you can display the execution result of a function line by omitting the terminating semicolon. If you do, execution results appear in the MATLAB Command Window during simulation.

- 8 To leave the function until it is called again and the breakpoint is reached, select **Continue**.

At any point in a function, you can advance through the execution of the remaining lines of the function with the **Continue** tool. If you are at the end of the function, selecting **Step** does the same thing.

- 9 Click the breakpoint to remove it and select **Quit Debugging** to complete the simulation.

In the model, the computed values of `mean` and `stdev` now appear in the Display blocks.



## Check for Data Range Violations

To control data range checking, set **Simulation range checking** in the **Diagnostics: Data Validity** pane of the Model Configuration Parameters dialog box.

### Specify a Range

To specify a range for input and output data, follow these steps:

- 1 In the Model Explorer, select the MATLAB function input or output of interest.

The Data properties dialog box opens in the **Dialog** pane of the Model Explorer.

- 2 In the Data properties dialog box, click the **General** tab and enter a limit range, as described in "Limit Range" on page 12-10.



# Truth Table Functions for Decision-Making Logic

---

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Program a Truth Table” on page 10-8
- “Debug Errors in a Truth Table” on page 10-21
- “View Generated Content for Stateflow Truth Tables” on page 10-28
- “Correct Overspecified and Underspecified Truth Tables” on page 10-34
- “Home Climate Control Using the Truth Table Block” on page 10-38

## Use Truth Tables to Model Combinatorial Logic

Truth tables implement combinatorial logic design in a concise, tabular format. Typical applications for truth tables include decision making for:

- Fault detection and management
- Mode switching

Truth tables are supported only in Simulink.

You can add a Truth Table block directly to your Simulink model, or you can define a truth table function in a Stateflow chart, state, or subchart. Truth Table blocks in a Simulink model execute as a Simulink block, while truth table functions in a Stateflow chart execute only when you call the truth table function. The location of the function determines the set of states and transitions that can call the function.

- If you want to call the function from within one state or subchart and its substates, put your truth table function in that state or subchart. That function overrides any other functions of the same name in the parents and ancestors of that state or subchart.
- If you want to call the function anywhere in a chart, put your truth table function at the chart level.
- If you want to call the function from any chart in your model, put your truth table at the chart level and enable exporting of chart-level functions. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

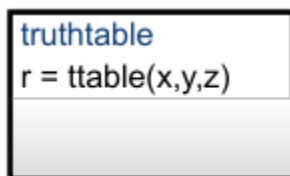
---

**Note** A truth table function can access chart and state data above it in the Stateflow hierarchy.

---

### Layout of a Truth Table

This truth table function has the name `ttable`. It takes three arguments (`x`, `y`, and `z`) and returns one output value (`r`).



The function consists of this arrangement of conditions, decisions, and actions.

Condition	Decision 1	Decision 2	Decision 3	Decision 4
<code>x == 1</code>	T	F	F	-
<code>y == 1</code>	F	T	F	-
<code>z == 1</code>	F	F	T	-
<b>Action</b>	<code>r = 1</code>	<code>r = 2</code>	<code>r = 3</code>	<code>r = 4</code>

Each of the conditions entered in the **Condition** column must evaluate to true (nonzero value) or false (zero value). Outcomes for each condition are specified as T (true), F (false), or - (true or false).

Each of the decision columns combines an outcome for each condition with a logical AND into a compound condition, which is referred to as a decision.


You evaluate a truth table one decision at a time, starting with **Decision 1**. The **Decision 4** covers all possible remaining decisions. If one of the decisions is true, the table perform the associated action, and then the truth table execution is complete.

For example, if conditions  $x == 1$  and  $y == 1$  are false and condition  $z == 1$  is true, then **Decision 3** is true and the variable  $r$  is set equal to 3. The remaining decisions are not tested and evaluation of the truth table is finished. If the first three decisions are false, then the default decision is automatically true and its action ( $r=4$ ) is executed. This table lists pseudocode corresponding to the evaluation of this truth table example.

Pseudocode	Description
if ((x == 1) & !(y == 1) & !(z == 1)) r = 1;	If <b>Decision 1</b> is true, then set r=1.
elseif (!(x == 1) & (y == 1) & !(z == 1)) r = 2;	If <b>Decision 2</b> is true, then set r=2.
elseif (!(x == 1) & !(y == 1) & (z == 1)) r = 3;	If <b>Decision 3</b> is true, then set r=3.
else r = 4; endif	If all other decisions are false, then default decision is true. Set r=4.

## Define a Truth Table Function

To define a truth table function:

- 1 In the object palette, click the truth table function icon . Move your pointer to the location for the new truth table function in your chart.
- 2 Enter the signature label for the function.

The function signature label specifies a name for your function and the formal names for its arguments and return values. A signature label has this syntax:

```
[return_val1,return_val2,...] = function_name(arg1,arg2,...)
```

You can specify multiple return values and multiple input arguments. Each return value and input argument can be a scalar, vector, or matrix of values. For functions with only one return value, omit the brackets in the signature label.

You can use the same variable name for both arguments and return values. For example, a function with this signature label uses the variables  $y1$  and  $y2$  as both inputs and outputs:

```
[y1,y2,y3] = f(y1,u,y2)
```

If you export this function to C code,  $y1$  and  $y2$  are passed by reference (as pointers), and  $u$  is passed by value. Passing inputs by reference reduces the number of times that the generated code copies intermediate data, resulting in more optimal code.

---

**Note** Do not use the name of a chart symbol as a function argument or return value. For example, if either  $x$  or  $y$  are chart data, defining a function with the signature  $y = f(x)$  results in a run-time error.

---

- 3 To program the function, open the truth table editor by double-clicking the function box.
- 4 In the truth table editor, add conditions, decisions, and actions. For more information, see “Program a Truth Table” on page 10-8.
- 5 In the Model Explorer, expand the chart object and select the truth table function. The arguments and return values of the function signature appear as data items that belong to your function. Arguments have the scope **Input**. Return values have the scope **Output**.
- 6 In the Data properties dialog box for each argument and return value, specify the data properties, as described in “Set Data Properties” on page 12-5.
- 7 Create any additional data items required by your function. For more information, see “Add Data Through the Model Explorer” on page 12-3.

Your function can access its own data or data belonging to parent states or the chart. The data items in the function can have one of these scopes:

- **Constant** — Constant data retains its initial value through all function calls.
- **Parameter** — Parameter data retains its initial value through all function calls.
- **Local** — Local data persists from one function call to the next function call. Valid only for truth tables that use **C** as the action language.
- **Temporary** — Temporary data initializes at the start of every function call. Valid only for truth tables that use **C** as the action language.

In truth table functions that use **C** as the action language, define local data when you want your data values to persist across function calls throughout the simulation. Define temporary data when you want to initialize data values at the start of every function call. For example, you can define a counter with **Local** scope if you want to track the number of times that you call the function. In contrast, you can designate a loop counter to have **Temporary** scope if you do not need the counter value to persist after the function completes.

In truth table functions that use **MATLAB** as the action language, you do not need to define local or temporary function data. If you use an undefined variable, Stateflow creates a temporary variable that is available to the rest of the function. To store values that persist across function calls, your function can access local data at the chart level.

---

**Tip** You can initialize local and temporary data in your function from the **MATLAB** workspace. For more information, see “Initialize Data from the **MATLAB** Base Workspace” on page 12-19.

---

## Call Truth Table Functions in States and Transitions

You can call truth table functions from the actions of any state or transition. You can also call truth table functions from other functions. If you export a truth table function, you can call it from any chart in the model. For more information about exporting functions, see “Export Stateflow Functions for Reuse” on page 8-23.

The syntax for a call to a truth table function is the same as the function signature, with actual arguments replacing the formal ones specified in a signature. If the data types of an actual and formal argument differ, a function casts the actual argument to the type of the formal argument.



To call a truth table function, use the function signature and include an actual argument value for each formal argument in the function signature. If the data types of the actual and formal arguments differ, the function casts the actual argument to the type of the formal argument.

## Specify Properties of Truth Table Functions

You can specify properties for a truth table function in the Model Explorer or the Truth Table properties dialog box.

- To use the Model Explorer:
  - 1 To open the Model Explorer, in the **Modeling** tab, select **Model Explorer**.
  - 2 In the **Model Hierarchy** pane, select the truth table function.
  - 3 In the **Truth Table** pane, edit the truth table function properties.
- To use the Truth Table properties dialog box:
  - 1 In the Stateflow Editor, right-click the truth table function.
  - 2 Select **Properties**.
  - 3 Edit the truth table function properties.

You can also specify truth table function properties programmatically by using `Stateflow.TruthTable` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Name

Function name. Click the function name link to bring your function to the foreground in its native chart.

### Function Inline Option

Controls the inlining of your function in generated code:

- **Auto** — Determines whether to inline your function based on an internal calculation.
- **InLine** — Inlines your function if you do not export it to other charts and it is not part of a recursion. (A recursion exists if your function calls itself directly or indirectly through another function call.)
- **Function** — Does not inline your function.

### Label

Signature label for your function. The function signature label specifies a name for your function and the formal names for its arguments and return values.

### Underspecification

Controls the level of diagnostics for underspecification in your truth table function. For more information, see “Correct Overspecified and Underspecified Truth Tables” on page 10-34.

### Overspecification

Controls the level of diagnostics for overspecification in your truth table function. For more information, see “Correct Overspecified and Underspecified Truth Tables” on page 10-34.

## Action Language

Controls the action language for your Stateflow truth table function. Choose between MATLAB or C. For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

## Description

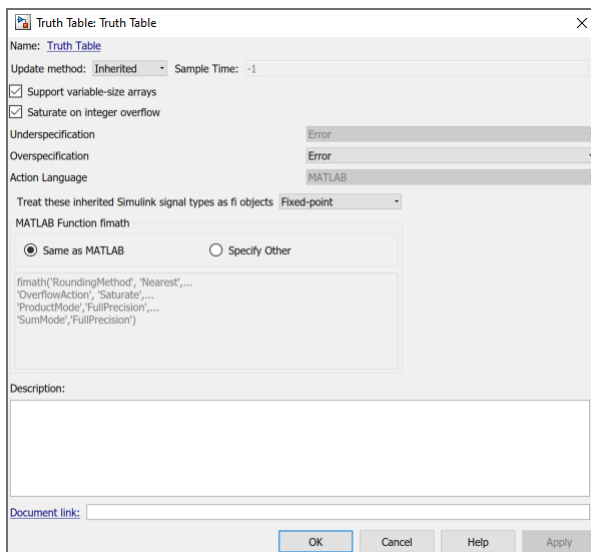
Function description. You can enter brief descriptions of functions in the hierarchy.

## Document Link

Link to online documentation for the function. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow displays the documentation.

## Specify Properties for Truth Table Blocks

To open the Truth Table properties dialog box, in the **Modeling** tab, click **Table Properties**.



The properties for Truth Table blocks are a combination of properties of truth table functions and charts that use MATLAB as the action language. For a description of each property, see “Specify Properties of Truth Table Functions” on page 10-5 and “Specify Properties for Stateflow Charts” on page 28-2.

You can also specify Truth Table block properties programmatically by using `Stateflow.TruthTableChart` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

## See Also

Truth Table

## **More About**

- “Program a Truth Table” on page 10-8
- “Differences Between MATLAB and C as Action Language Syntax” on page 17-5
- “Reusable Functions in Charts” on page 2-42
- “Export Stateflow Functions for Reuse” on page 8-23
- “Reuse Functions by Using Atomic Boxes” on page 8-28

## Program a Truth Table

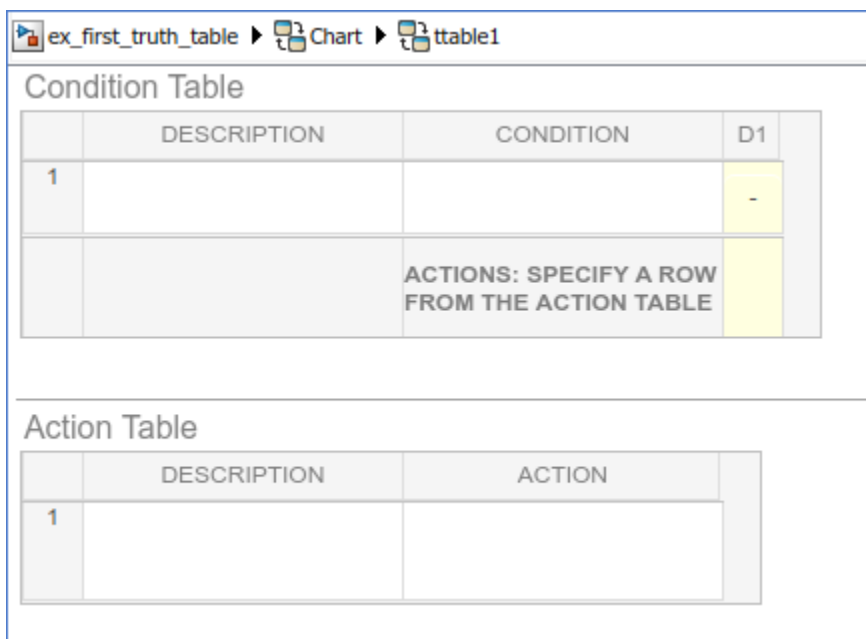
Once you've created a new truth table, you can program it to execute according to your specifications. To program a truth table you add conditions, decisions, and actions. For more information about creating a truth table, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

Truth tables are supported only in Simulink models. For more information, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

### Open a Truth Table for Editing

After you create and label a truth table in a chart or Simulink model, you specify its logical behavior. These specifications apply to both the truth table block in a Simulink model and the truth table function in a Stateflow chart. In this example, you specify the behavior of a truth table function.

To open the truth table, double-click the truth table function, `ttable`, that you created in “Use Truth Tables to Model Combinatorial Logic” on page 10-2.



By default, a truth table contains a **Condition Table** and an **Action Table**, each with one row. The **Condition Table** contains a single decision column, **D1**, and a single action row.

### Select an Action Language

If the truth table is inside a Stateflow chart that uses C as the action language, you can specify the action language for your Stateflow truth table:

- 1 Open the Property Inspector. In the **Modeling** tab, under **Design Data**, select **Property Inspector**.
- 2 Under the **Properties** section, select **C** or **MATLAB** as the Action Language.

Truth tables inside a Stateflow chart that uses C as the action language must also use C as the action language.

## Enter Truth Table Conditions

Conditions are the starting point for specifying logical behavior in a truth table. Open your new truth table, `ttable`, for editing. You start programming the behavior of `ttable` by specifying conditions.

You enter conditions in the **Condition** column of the **Condition Table**. For each condition that you enter, you can enter an optional description in the **Description** column. To enter conditions for the truth table `ttable`:

- 1 Click the row on the **Condition Table** that you want to append.

- 2 Click the **Append Row** button  on the side panel twice.

The truth table appends two rows to the bottom of the **Condition Table**.

- 3 Click and drag the bar that separates the **Condition Table** and the **Action Table** panes down to enlarge the **Condition Table** pane.

- 4 In the **Condition Table**, click the top cell of the **Description** column.

A flashing text cursor appears in the cell, which appears highlighted.

- 5 Enter this text:

```
x is equal to 1
```

Condition descriptions are optional, but appear as comments in the generated code for the truth table.

- 6 Click the next cell on the right, in the **Condition** column..

- 7 In the first cell of the **Condition** column, enter:

```
XEQ1:
```

This text is an optional label that you can include with the condition. Each label must begin with an alphabetic character ([a-z] [A-Z]) followed by any number of alphanumeric characters ([a-z] [A-Z] [0-9]) or an underscore (\_).

- 8 Press **Enter** and this text:

```
x == 1
```

This text is the actual condition. Each condition that you enter must evaluate to zero (false) or nonzero (true). You can use optional brackets in the condition (for example, `[x == 1]`).

In truth table conditions, you can use data that passes to the truth table function through its arguments. The preceding condition tests whether the argument `x` is equal to 1. You can also use data defined for parent objects of the truth table, including the chart.

- 9 Repeat the preceding steps to enter the other two conditions.

The screenshot shows a software window titled 'ex\_first\_truth\_table' with a 'Chart' button and a 'ttable' button. The main area is divided into two sections: 'Condition Table' and 'Action Table'.

**Condition Table**


	DESCRIPTION	CONDITION	D1
1	x is equal to 1	XEQ1: x == 1	-
2	y is equal to 1	YEQ1: y == 1	-
3	z is equal to 1	ZEQ1: z == 1	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE			

**Action Table**

	DESCRIPTION	ACTION
1		

## Enter Truth Table Decisions

Each decision column (**D1**, **D2**, and so on) binds a group of condition outcomes together with an AND relationship into a decision. The possible values for condition outcomes in a decision are T (true), F (false), and - (true or false). In “Enter Truth Table Conditions” on page 10-9, you entered conditions for the truth table `ttable`. Continue by entering values in the decision columns:

- 1 Click the decision column of the **Condition Table** that you want to append.
- 2 Click the **Append Column** button  on the side panel three times.
- 3 Click the top cell in decision column **D1**.
- 4 Press the space bar until a value of T appears.

Pressing the space bar toggles through the possible values of F, T, and -. You can also enter these characters directly. Pressing 1 sets the value to T, while pressing 0 sets the value to F. Pressing x sets the value to -.

- 5 Enter the remaining values for the decision columns:

Condition Table						
	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE						

Action Table	
	ACTION
1	

During execution of the truth table, decision testing occurs in left-to-right order. The order of testing for individual condition outcomes within a decision is undefined. Truth tables evaluate the conditions for each decision in top-down order (first condition 1, then condition 2, and so on). Because this implementation is subject to change in the future, do not rely on a specific evaluation order.

### The Default Decision Column


The last decision column in `ttable`, **D4**, is the default decision for this truth table. The default decision covers any decisions not tested for in preceding decision columns. Create a default decision by entering - in every cell of the farthest right decision column. This entry represents any outcome for the condition, T or F. The default decision column must be the last column on the right in the **Condition Table**.

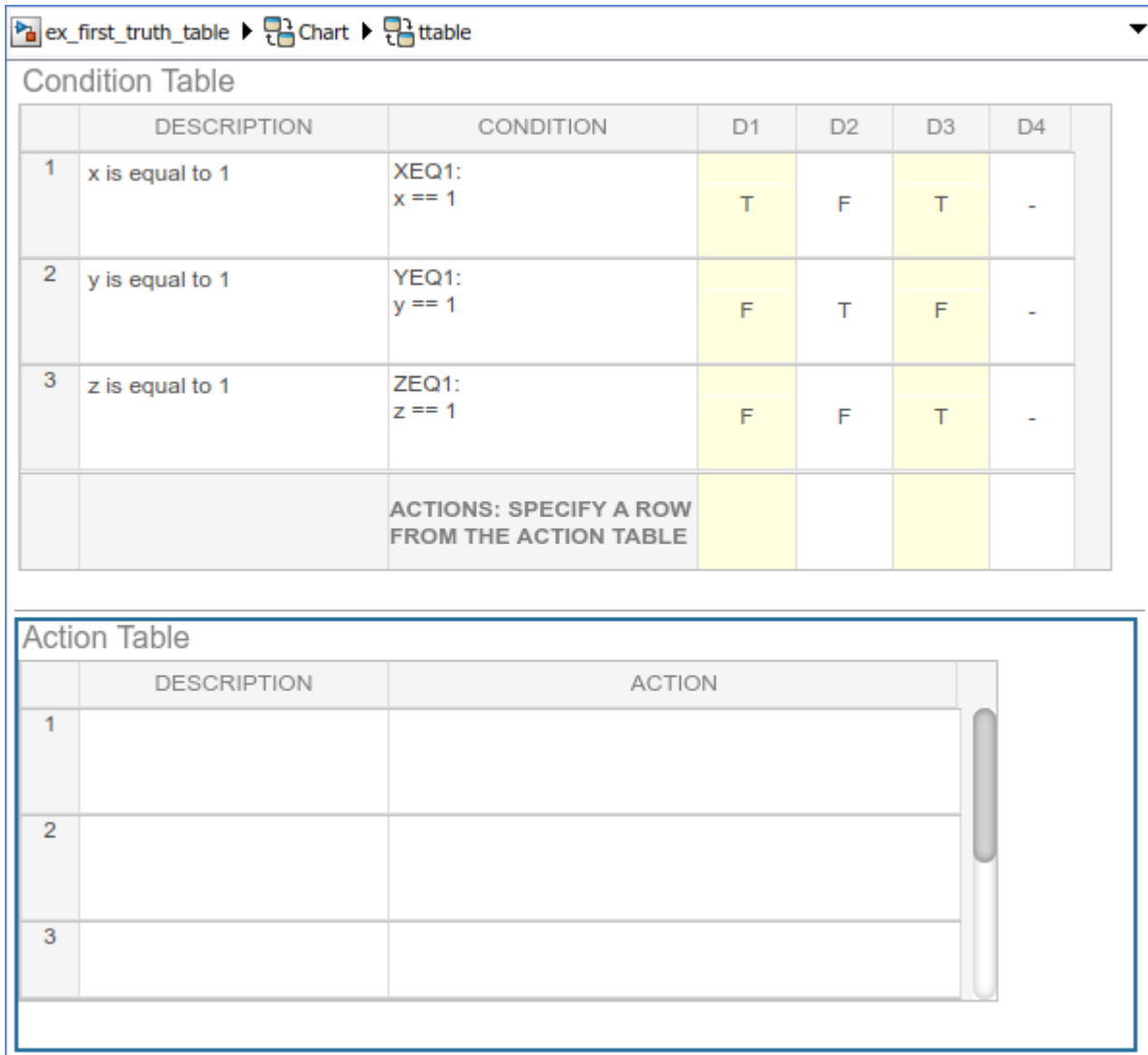
### Enter Truth Table Actions

During execution of the truth table, decision testing occurs in left-to-right order. When a decision match occurs, the action in the **Action Table** that is specified in the **Actions** row for that decision column executes. Then the truth table exits.

In “Enter Truth Table Decisions” on page 10-10, you entered decisions in the truth table. The next step is to enter actions you want to occur for each decision in the **Action Table**. Later, you assign these actions to their decisions in the **Actions** row of the **Condition Table**.

### Set Up the Action Table

- 1 Click the row **Action Table** that you want to append.
- 2 Click the **Append Row** button  on the side panel three times.



The screenshot shows a software interface with two tables. The top table is titled "Condition Table" and has columns for "DESCRIPTION", "CONDITION", and four decision variables "D1", "D2", "D3", and "D4". It contains three rows of conditions and a final row for actions.

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	T	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE				

The bottom table is titled "Action Table" and has columns for "DESCRIPTION" and "ACTION". It is currently empty with three rows.

	DESCRIPTION	ACTION
1		
2		
3		

- 3 Program the actions for the truth table.

### Program Actions of a Truth Table

For truth tables that use MATLAB as the action language, you can write MATLAB code to program your actions. Using this code, you can add control flow logic and call MATLAB functions directly. In the following procedure, you program an action in the truth table `ttable`, using the following features of MATLAB syntax:

- Persistent variables
- `if ... else ... end` control flows



- for loop

Follow these steps:

- 1 Click the top cell in the **Description** column of the **Action Table**.

A flashing text cursor appears in the cell, which appears highlighted.

- 2 Enter this description:

```
Maintain a counter and a circular
vector of values of length 6.
Every time this action is called,
output r takes the next value of
the vector.
```

Action descriptions are optional, but appear as comments in the generated code for the truth table.

- 3 Press the right arrow key to select the next cell on the right, in the **Action** column.
- 4 Enter the following text:

A1:

You begin an action with an optional label followed by a colon (:). Later, you enter these labels in the **Actions** row of the **Condition Table** to specify an action for each decision column. Like condition labels, action labels must begin with an alphabetic character ([a-z] [A-Z]) followed by any number of alphanumeric characters ([a-z] [A-Z] [0-9]) or an underscore (\_).

- 5 Press **Enter** and enter the following text:

```
persistent values counter;
cycle = 6;

coder.extrinsic('plot');

if isempty(counter)
    % Initialize counter to be zero
    counter = 0;
else
    % Otherwise, increment counter
    counter = counter + 1;
end

if isempty(values)
    % Values is a vector of 1 to cycle
    values = zeros(1, cycle);
    for i = 1:cycle
        values(i) = i;
    end

    % For debugging purposes, call the MATLAB
    % function "plot" to show values
    plot(values);
end

% Output r takes the next value in values vector
r = values( mod(counter, cycle) + 1);
```

In truth table actions, you can use data that passes to the truth table function through its arguments and return value. The preceding action sets the return value `r` equal to the next value of the vector `values`. You can also specify actions with data defined for a parent object of the truth table, including the chart. Truth table actions can also broadcast or send events that are defined for the truth table, or for a parent, such as the chart itself.

- 6 Enter the remaining actions in the **Action Table**, as shown:

The screenshot shows a software interface with a breadcrumb trail: `ex_first_truth_table` > `Chart` > `ttable`. Below the breadcrumb, there are two tables.

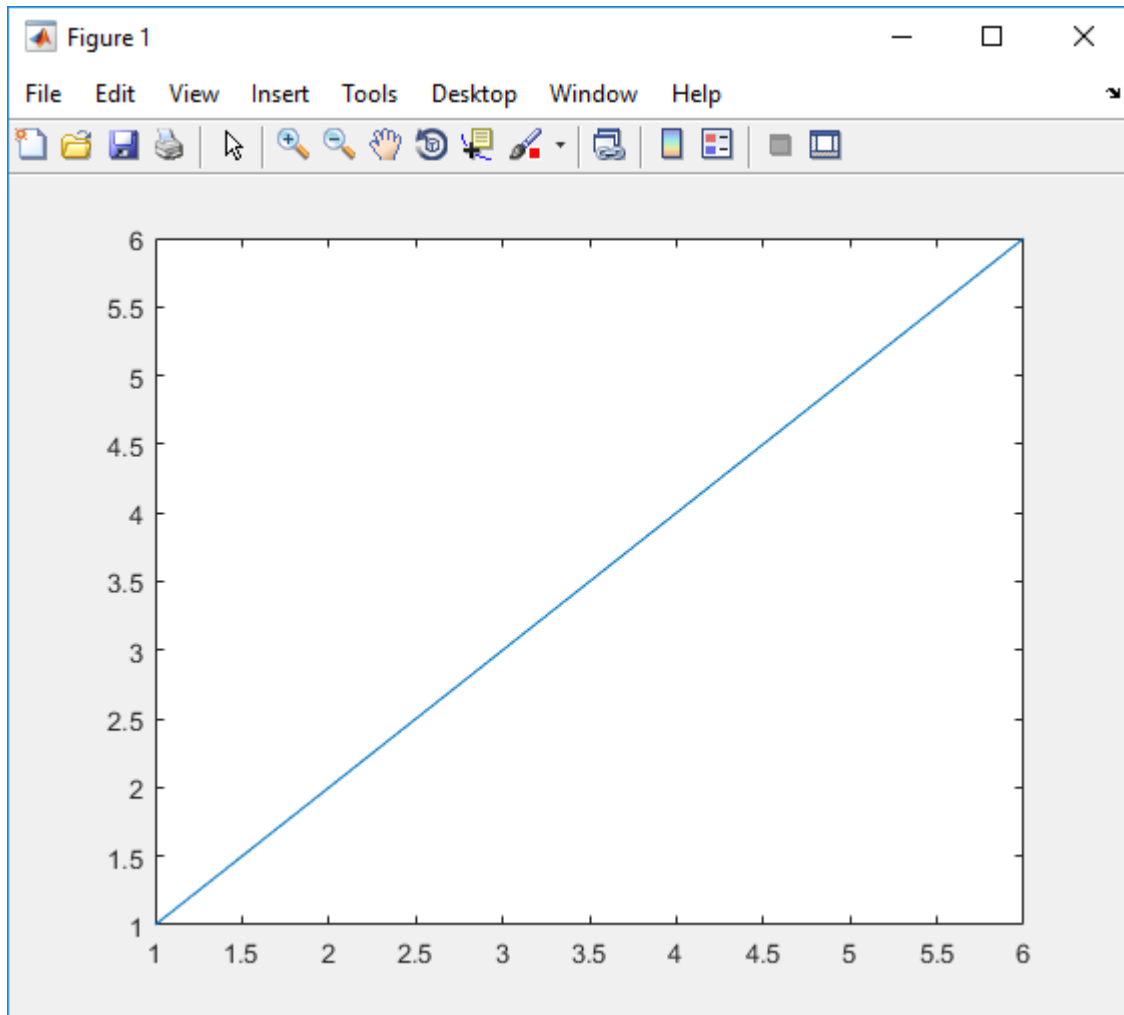
**Condition Table**

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE						

**Action Table**

	DESCRIPTION	ACTION
1	Maintain a counter and a circular vector of values of length 6. Every time this	A1: persistent values counter; cycle = 6;
2	set r to 1	A2: r=1;
3	set r to 2	A3: r=2;
4	set r to 3	A4: r=3;

If action A1 executes during simulation, a plot of the `values` vector appears:



Now you are ready to assign actions to decision.

## Assign Truth Table Actions to Decisions

You must assign at least one action from the **Action Table** to each decision in the **Condition Table**. The truth table uses this association to determine what action to execute when a decision tests as true.

### Rules for Assigning Actions to Decisions

The following rules apply when you assign actions to decisions in a truth table:

- You specify actions for decisions by entering a row number or a label in the **Actions** row cell of a decision column.

If you use a label specifier, the label must appear with the action in the **Action Table**.

- You must specify at least one action for each decision.

Actions for decisions are not optional. Each decision must have at least one action specifier that points to an action in the **Action Table**. If you want to specify no action for a decision, specify a row that contains no action statements.

- You can specify multiple actions for a decision with multiple specifiers separated by a comma, semicolon, or space.

For example, for the decision column **D1**, you can specify **A1, A2, A3** or **1; 2; 3** to execute the first three actions when decision **D1** is true.

- You can mix row number and label action specifiers interchangeably in any order.

The following example uses both row and label action specifiers.

The screenshot shows a software window titled 'ex\_first\_truth\_table' with a 'table' tab selected. It contains two tables:

**Condition Table**

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE			A1	2	A3	4

**Action Table**

	DESCRIPTION	ACTION
1	set r to 1	A1: r=1;
2	set r to 2	A2: r=2;
3	set r to 3	A3: r=3;
4	set r to 4	A4: r=4;

- You can specify the same action for more than one decision, as shown:

The screenshot shows a software window titled 'ex\_first\_truth\_table' with a 'Chart' button and a 'ttable' button. The window contains two tables:

**Condition Table**

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE			A1	1	A2	2

**Action Table**

	DESCRIPTION	ACTION
1	set r to 1	A1: r=1;
2	set r to 2	A2: r=2;

- Row number action specifiers in the **Actions** row of the **Condition Table** automatically adjust to changes in the row order of the **Action Table**.

### How to Assign Actions to Decisions

This section describes how to assign actions to decisions in the truth table `ttable`. In this example, the **Actions** row cell for each decision column contains a label specified for each action in the **Action Table**. Follow these steps:

- 1 Click the bottom cell in decision column **D1**, the first cell of the **Actions** row of the **Condition Table**.
- 2 Enter the action specifier **A1** for decision column **D1**.

When **D1** is true, action **A1** in the **Action Table** executes.

- 3 Enter the action specifiers for the remaining decision columns:

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		<b>ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE</b>	<b>A1</b>	<b>A2</b>	<b>A3</b>	<b>A4</b>

### Action Table

	DESCRIPTION	ACTION
1	set r to 1	A1: r=1;
2	set r to 2	A2: r=2;
3	set r to 3	A3: r=3;
4	set r to 4	A4: r=4;

Now you are ready to perform the final step in programming a truth table.

## Add Initial and Final Actions

In addition to actions for decisions, you can add initial and final actions to the truth table function. Initial actions specify an action that executes before any decision testing occurs. Final actions specify an action that executes as the last action before the truth table exits. To specify initial and final actions for a truth table, use the action labels **INIT** and **FINAL** in the **Action Table**.

Use this procedure to add initial and final actions that display diagnostic messages in the MATLAB Command Window before and after execution of the truth table `ttable`:

- 1 In the truth table, right-click row 1 of the **Action Table** and select **Insert Row**.

A blank row appears at the top of the **Action Table**.

- 2 In the **Modeling** tab, select **Append Row**.

A blank row appears at the bottom of the **Action Table**.

- 3 Click and drag the bottom border of the truth table to show all six rows of the **Action Table**:

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		<b>ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE</b>	<b>A1</b>	<b>A2</b>	<b>A3</b>	<b>A4</b>

### Action Table

	DESCRIPTION	ACTION
1		
2	set r to 1	A1: r=1;
3	set r to 2	A2: r=2;
4	set r to 3	A3: r=3;
5	set r to 4	A4: r=4;
6		

- 4 Add the initial action in row 1 as follows:


Description	Action
Initial action:	INIT:
Display message	<code>coder.extrinsic('disp');</code> <code>disp('truth table ttable entered');</code>

- 5 Add the final action in row 6 as follows:

Description	Action
Final action:	FINAL:
Display message	<code>coder.extrinsic('disp');</code> <code>disp('truth table ttable exited');</code>

Although the initial and final actions for the preceding truth table example appear in the first and last rows of the **Action Table**, you can enter these actions in any row. You can also assign initial and final actions to decisions by using the action specifier INIT or FINAL in the **Actions** row of the **Condition Table**.

## Generate Content for Truth Tables

When you have simulated your model, Stateflow generates content for your truth table. To see the generated content, click the View Generated Content  button. For truth tables that use C as the action language, content is generated as a graphical function. For truth tables that use MATLAB as the action language, content is generated as MATLAB code. For more information, see “View Generated Content for Stateflow Truth Tables” on page 10-28.

## See Also

### More About

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Export Stateflow Functions for Reuse” on page 8-23




## Debug Errors in a Truth Table

Once you completely specify your truth tables, you begin the process of debugging them. The first step is to run diagnostics to check truth tables for syntax errors including overspecification and underspecification, as described in “Correct Overspecified and Underspecified Truth Tables” on page 10-34. Additionally, you can add breakpoints directly into your truth table to debug during simulation.

Truth tables are supported only in Simulink. For more information, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

### Find Syntax Errors by Running Diagnostics

To check for syntax errors:

- 1 Double-click the truth table.
- 2 In the truth table, click **Run Diagnostics** .

For example, if you change the action for decision column **D4** to an action that does not exist, you get an error message in the Diagnostic Viewer.

Truth table diagnostics run automatically when you simulate a model with a new or modified truth table. If no errors exist, the diagnostic window does not appear and simulation starts immediately.



### Debug Logic by Using Breakpoints





You can use breakpoints in a Stateflow truth table to pause simulation and debug your logic. Once a breakpoint causes the simulation to pause, you can step through the actions and examine the data values at that specific point in the simulation.

With truth tables, you can set these different breakpoint types:

- Condition tested
- Decision tested
- Decision valid
- Action executed

After simulation stops at a breakpoint, you can continue chart execution on the Stateflow Editor toolbar, at the MATLAB command prompt, or by selecting a keyboard shortcut.

Toolbar Icon	Option	Command	Description	Keyboard Shortcut
	Continue	dbcont	Continue the simulation to the next breakpoint.	<b>Ctrl+T</b>
	Step Over	dbstep	Advance to the next step in the truth table execution.	<b>F10</b>

Toolbar Icon	Option	Command	Description	Keyboard Shortcut
	Step In	dbstep in	From a state or transition action that calls a function, advance to the first executable statement in the function.  From a statement in a function containing another function call, advance to the first executable statement in the second function.  Otherwise, advance to the next step in the truth table execution. (See Step Over.)	<b>F11</b>
	Step Out	dbstep out	From a function call, return to the statement calling the function.  Otherwise, continue simulation to the next breakpoint. (See Continue.)	<b>Shift+F11</b>
	Step Forward		Exit debug mode and pause simulation before next time step.	
	Stop	dbquit	Exit debug mode and stop simulation.	<b>Ctrl+Shift+T</b>

### Condition Breakpoints

To set a breakpoint when a condition is tested, right-click the condition cell and select **Set Breakpoint (Condition Tested)**. A red badge appears on the far left of the table next to the number of the condition. When you run the model, the simulation pauses when the condition is tested. Stateflow highlights the condition row being tested. Place your cursor over the data in the truth table to see its current value.

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	A4

### Action Table

	DESCRIPTION	ACTION
1	Initial action: Display message	INIT: ml.disp('truth table ttable entered');
2	set t to 1	A1: t=1;
3	set t to 2	A2: t=2;
4	set t to 3	A3: t=3;
5	set t to 4	A4: t=4;
6	Final action: Display message	FINAL: ml.disp('truth table ttable exited');

## Decision Breakpoints

To set a breakpoint when a decision is tested, right-click the top of the decision column and select **Set Breakpoint (Decision Tested)**. A red badge appears on the top of the decision column next to the number of the decision. When you run the model, the simulation pauses when the decision is tested. Stateflow highlights the decision column being tested. Place your cursor over the data in the truth table to see its current value.

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	A4

### Action Table

	DESCRIPTION	ACTION
1	Initial action: Display message	INIT: ml.disp('truth table ttable entered');
2	set t to 1	A1: t=1;
3	set t to 2	A2: t=2;
4	set t to 3	A3: t=3;
5	set t to 4	A4: t=4;
6	Final action: Display message	FINAL: ml.disp('truth table ttable exited');

To set a breakpoint when a decision is valid, right-click the action cell at the bottom of the decision column and select **Set Breakpoint (Decision Valid)**. A red badge appears on the top of the cell next to the action number. When you run the model, the simulation pauses when the action is valid. Stateflow highlights the valid decision. Place your cursor over the data in the truth table to see its current value.

If there is more than one action to take when a decision is valid, the breakpoint is set for the first executable. In truth tables that use MATLAB as the action language, you can set a breakpoint on any line of executable code by setting breakpoints in the generated content. See “Debugging Generated Truth Table Content” on page 10-27.

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	A4

### Action Table

	DESCRIPTION	ACTION
1	Initial action: Display message	INIT: ml disp('truth table ttable entered');
2	set t to 1	A1: t=1;
3	set t to 2	A2: t=2;
4	set t to 3	A3: t=3;
5	set t to 4	A4: t=4;
6	Final action: Display message	FINAL: ml disp('truth table ttable exited');

### Action Breakpoints

To set a breakpoint when an action is executed, right-click the action cell and select **Set Breakpoint (Action Executed)**. A red badge appears on the far left of the table next to the number of the action. When you run the model, the simulation pauses when the action is executed. Stateflow highlights the action row being tested. Place your cursor over the data in the truth table to see its current value.

If there is more than one action within the action cell, the breakpoint is set for the first action. In truth tables that use MATLAB as the action language, you can set a breakpoint on any line of

executable code by setting breakpoints in the generated content. See “Debugging Generated Truth Table Content” on page 10-27.

ex\_first\_truth\_table ▶ Chart ▶ ttable

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	x is equal to 1	XEQ1: x == 1	T	F	F	-
2	y is equal to 1	YEQ1: y == 1	F	T	F	-
3	z is equal to 1	ZEQ1: z == 1	F	F	T	-
		<b>ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE</b>	<b>A1</b>	<b>A2</b>	<b>A3</b>	<b>A4</b>

---

### Action Table

	DESCRIPTION	ACTION
1	Initial action: Display message	INIT: ml.disp("truth table ttable entered");
2	<input checked="" type="radio"/> set t to 1	A1: t=1;
3	set t to 2	A2: t=2;
4	set t to 3	A3: t=3;
5	set t to 4	A4: t=4;
6	Final action: Display message	FINAL: ml.disp("truth table ttable exited");

## Edit Breakpoints

Click the breakpoint to open the **Edit Breakpoint** dialog box. From this window you can disable the breakpoint by clearing the **Enable Breakpoint** check box.

When you add a condition to a breakpoint, the breakpoint pauses the simulation only when its associated condition is true.

## Debugging Generated Truth Table Content

You can use breakpoints on the generated content for truth tables that use MATLAB or C as the action language.

For truth tables that use MATLAB as the action language, content is generated as MATLAB code. To set a breakpoint in the code, click the breakpoint alley next to the executable line where you want simulation to pause. See “Debug a MATLAB Program”. When you add an element to your truth table that changes the generated content, all breakpoints are regenerated.

For truth tables that use C as the action language, content is generated as a graphical function. To set a breakpoint in the graphical function, right-click the transition where you want to set a breakpoint and select **Set Breakpoint**. When you add an element to your truth table that changes the generated content, all breakpoints are regenerated if you recompile your truth table.


## See Also

### More About

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Program a Truth Table” on page 10-8
- “Correct Overspecified and Underspecified Truth Tables” on page 10-34
- “Debugging a MATLAB Function Block” (Simulink)

## View Generated Content for Stateflow Truth Tables

You generate content for a truth table when you simulate your model. Content regenerates whenever a truth table changes. To view the generated content of a truth table, click the **View Generated**

**Content** button . Stateflow charts that use C as the action language generate content as a graphical function. Stateflow charts that use MATLAB as the action language generate content as MATLAB code.

### How Stateflow Software Generates Graphical Functions for Truth Tables

This section describes how Stateflow software translates the logic of a C truth table into a graphical function.

In the following example, a C truth table has three conditions, four decisions and actions, and initial and final actions.



ex\_truhtable\_view\_generated\_content ▶ Chart ▶ xyz

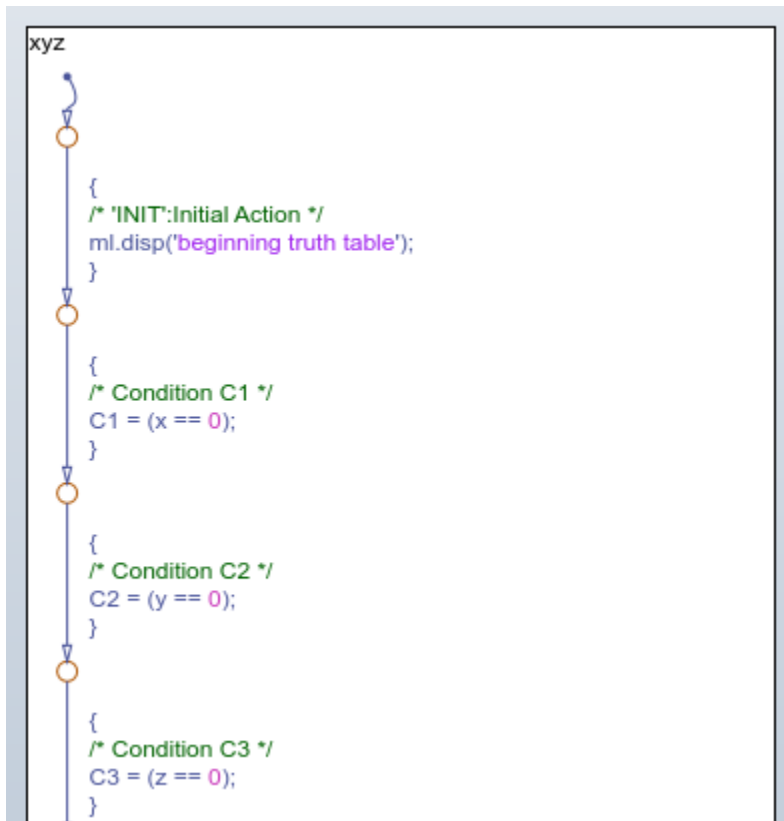
### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	Condition C1	C1: x == 0	T	F	F	-
2	Condition C2	C2: y == 0	-	T	F	-
3	Condition C3	C3: z == 0	-	-	T	-
ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE			A1	A2	A3	DA

### Action Table

	DESCRIPTION	ACTION
1	Initial Action	INIT: ml.disp('beginning truth table');
2	Action 1	A1: x = 1;
3	Action 2	A2: y = 1;
4	Action 3	A3: z = 1;
5	Default Action	DA: x = 0; y = 0; z = 0;
6	Final Action	FINAL: ml.disp('ending truth table');

Stateflow software generates a graphical function for the preceding truth table. The top half of the flow chart looks like this:

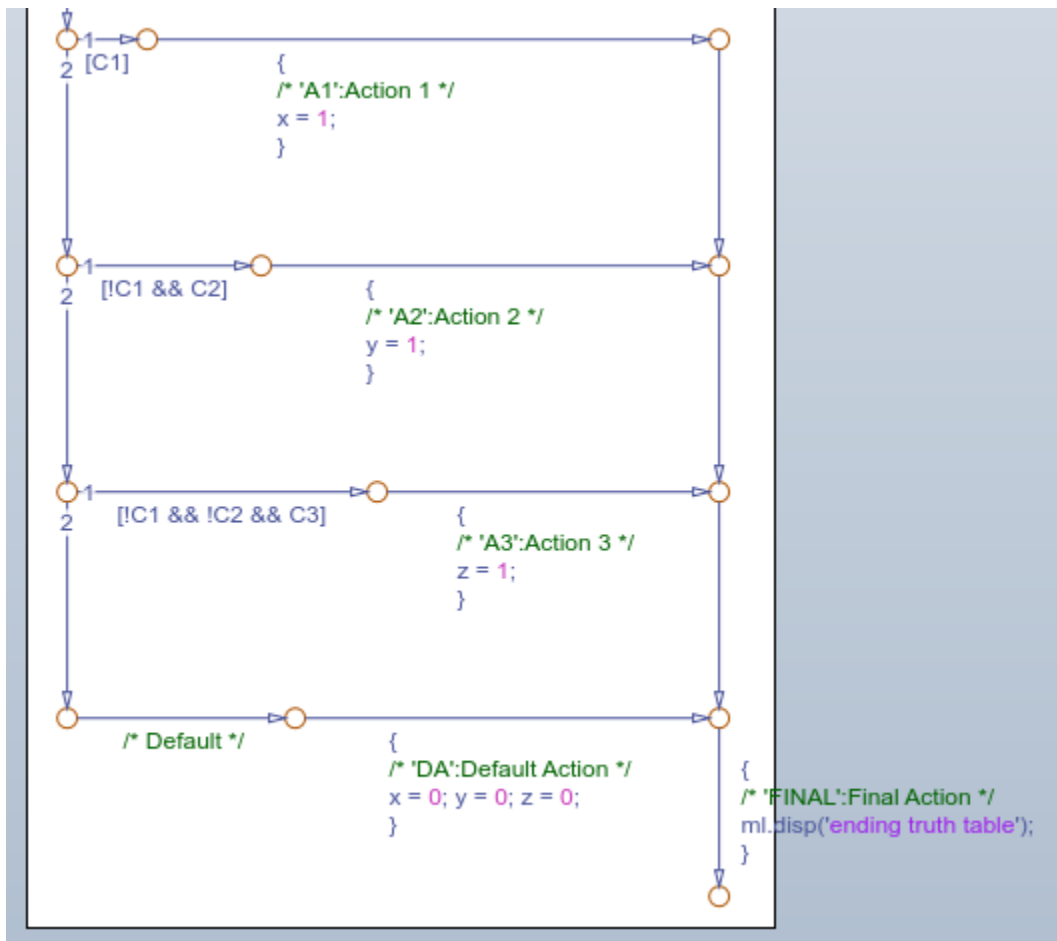


The top half of the flow chart executes as follows:

- Performs initial actions
- Evaluates the conditions and stores the results in temporary data variables

The temporary data for storing conditions is based on the labels that you enter for the conditions. If you do not specify the labels, temporary data variables appear.

The bottom half of the flow chart looks like this:



In the bottom half of the flow chart, the stored values for conditions determine which decision is true and what action to perform. Each decision appears as a fork from a connective junction with one of two possible paths:

- A transition segment with a decision followed by a segment with the consequent action

The action appears as a condition action that leads to the **FINAL** action and termination of the flow chart.

- A transition segment that flows to the next fork for an evaluation of the next decision

This transition segment has no condition or action.

This implementation continues from the first decision through the remaining decisions in left-to-right column order. When a decision match occurs, the action for that decision executes as a condition action of its transition segment. After the action executes, the flow chart performs the final action for the truth table and terminates. Therefore, only one action results from a call to a truth table graphical function. This behavior also means that no data dependencies are possible between different decisions.

## How Stateflow Software Generates MATLAB Code for Truth Tables

Stateflow software generates the content of MATLAB truth tables as MATLAB code that represents each action as a *nested* function inside the main truth table function.

Nested functions offer these advantages:

- Nested functions are independent of one another. Variables are local to each function and not subject to naming conflicts.
- Nested functions can access all data from the main truth table function.

The generated content appears in the function editor, which provides tools for simulation and debugging.

Here is the generated content for the MATLAB truth table described in “Program Actions of a Truth Table” on page 10-12:

- Main truth table function

```
function r = ttable(x,y,z)

% Initialize condition vars to logical scalar
XEQ1 = false;
YEQ1 = false;
ZEQ1 = false;

% Condition #1, "XEQ1"
% x is equal to 1
XEQ1 = logical(x == 1);

% Condition #2, "YEQ1"
% y is equal to 1
YEQ1 = logical(y == 1);

% Condition #3, "ZEQ1"
% z is equal to 1
ZEQ1 = logical(z == 1);

if (XEQ1 && ~YEQ1 && ~ZEQ1) % D1
    A1();
elseif (~XEQ1 && YEQ1 && ~ZEQ1) % D2
    A2();
elseif (~XEQ1 && ~YEQ1 && ZEQ1) % D3
    A3();
else % Default
    A4();
end
```

- Action A1

```
function A1()
% Action #1, "A1"
% Maintain a counter and a circular vector of length 6.
% Every time this action is called,
% output t takes the next value of the vector.

persistent values counter;
```

```

cycle = 6;

if isempty(counter)
    % Initialize counter to be zero
    counter = 0;
else
    % Otherwise, increment counter
    counter = counter + 1;
end

if isempty(values)
    % Values is a vector of 1 to cycle
    values = zeros(1, cycle);
    for i = 1:cycle
        values(i) = i;
    end

    % For debugging purposes, call the MATLAB
    % function "plot" to show values
    plot(values);
end

% Output r takes the next value in values vector
r = values( mod(counter, cycle) + 1);

```

- Actions A2, A3, and A4

```

function A2()
% Action #2, "A2"
% set r to 2

r=2;

%=====
function A3()
% Action #3, "A3"
% set r to 3

r=3;

%=====
function A4()
% Action #4, "A4"
% set r to 4

r=4;

```

## See Also

### More About

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Program a Truth Table” on page 10-8

## Correct Overspecified and Underspecified Truth Tables

When programming your truth table, you might program an overspecified or underspecified truth table. An overspecified truth table contains at least one true or false combination that is specified by another decision column. When this happens, the action associated with that decision column never executes. An underspecified truth table occurs when your truth table does not have enough decision columns to account for all possible true or false combinations.

By default, Stateflow reports an error for overspecified and underspecified truth tables. To adjust the error settings for truth tables, open your truth table. After opening the truth table, in the **Modeling** tab, click **Table Properties** and change the settings for **Underspecification** or **Overspecification**.

Truth tables are supported only in a Simulink model. For more information, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

### Example of an Overspecified Truth Table

An overspecified truth table contains at least one decision that never executes because a previous decision specifies it in the **Condition Table**. The following example shows the **Condition Table** of an overspecified truth table.

	DESCRIPTION	CONDITION	D1	D2	D3
1	Condition C1	C1: x == 0	F	T	-
2	Condition C2	C2: y == 0	T	-	T
3	Condition C3	C3: z == 0	T	T	T
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3

The decision in column **D3** (-TT) specifies the decisions FTT and TTT. These decisions are duplicates of decisions **D1** (FTT) and **D2** (TTT and TFT). Therefore, column **D3** is an overspecification.

The following example shows the **Condition Table** of a truth table that appears to be overspecified, but is not.

ex\_truthtable\_not\_overspecified ▶ Chart ▶ xyz

Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	Condition C1	C1: x == 0	F	T	T	-
2	Condition C2	C2: y == 0	T	F	T	T
3	Condition C3	C3: z == 0	T	T	F	T
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	A4

In this case, the decision **D4** specifies two decisions (TTT and FTT). FTT also appears in decision **D1**, but TTT is not a duplicate. Therefore, this **Condition Table** is not overspecified.

## Example of an Underspecified Truth Table

An underspecified truth table includes undefined behavior because it lacks decisions that cover every combination of the specified conditions.. The following example shows the **Condition Table** of an underspecified truth table.

ex\_truthtable\_underspecified ▶ Chart ▶ xyz

Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3
1	Condition C1	C1: x == 0	T	T	F
2	Condition C2	C2: y == 0	T	F	T
3	Condition C3	C3: z == 0	F	T	T
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3

Complete coverage of the conditions in the preceding truth table requires a **Condition Table** with every possible decision:

ex\_truthtable\_completely\_specified ▶ Chart ▶ xyz

Condition Table			D1	D2	D3	D4	D5	D6	D7	D8
1	Condition C1	C1: x == 0	T	T	F	T	F	T	F	F
2	Condition C2	C2: y == 0	T	F	T	T	F	F	T	F
3	Condition C3	C3: z == 0	F	T	T	T	F	F	F	T
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	A4	A5	A6	A7	A8

To avoid underspecification specify an action for all other possible decisions through a default decision, named DA:

ex\_truthtable\_default\_action ▶ Chart ▶ xyz

Condition Table			D1	D2	D3	D4
1	Condition C1	C1: x == 0	T	T	F	-
2	Condition C2	C2: y == 0	T	F	T	-
3	Condition C3	C3: z == 0	F	T	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	A1	A2	A3	DA

The last decision column, **D4**, is the default decision for the truth table. The default decision covers any remaining decisions not tested in the preceding decision columns. See “The Default Decision Column” on page 10-11 for an example and more complete description of the default decision column for a **Condition Table**.



## **See Also**

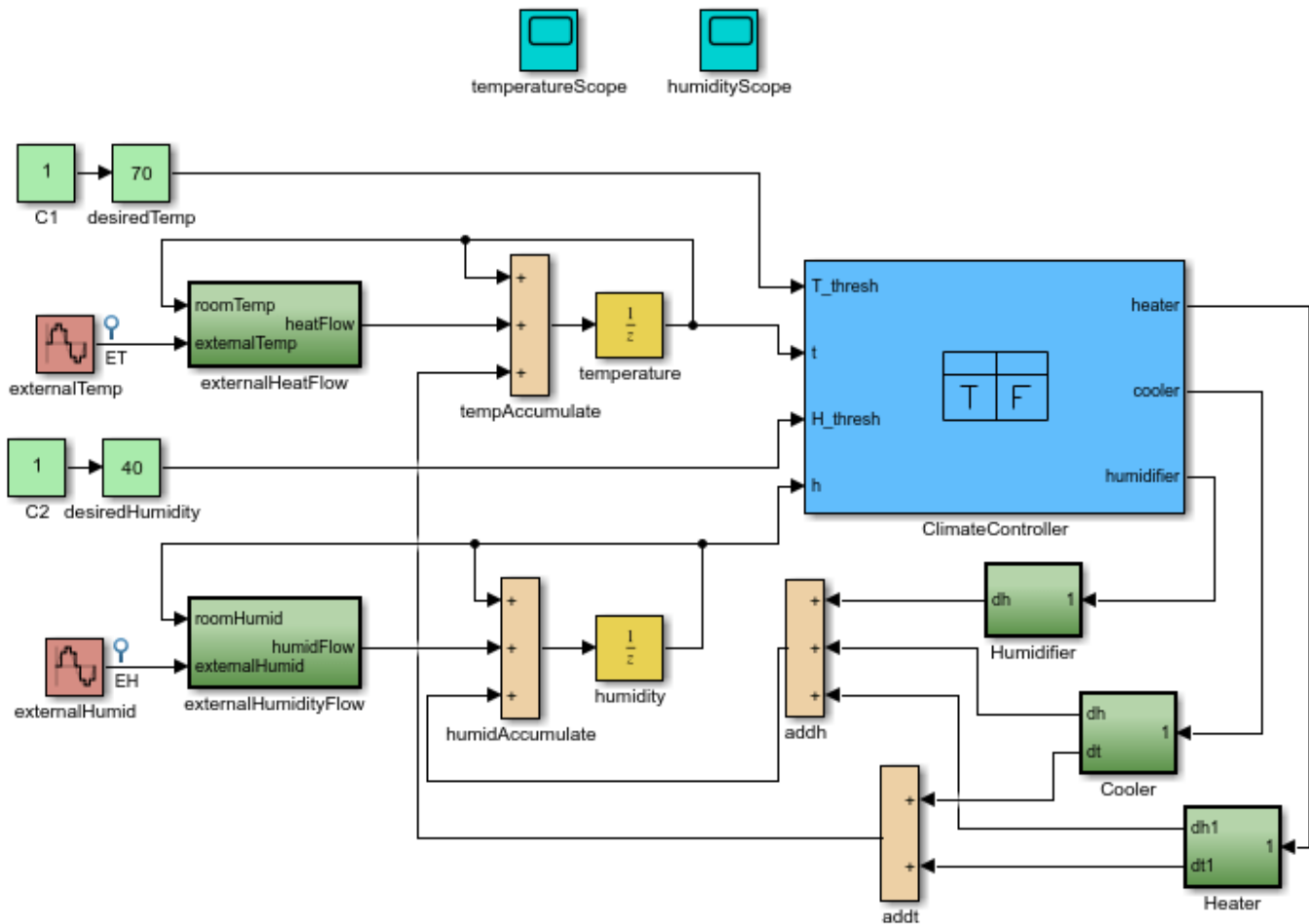
### **More About**

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Program a Truth Table” on page 10-8
- “Debug Errors in a Truth Table” on page 10-21

## Home Climate Control Using the Truth Table Block

This example models a home climate control system by using a Truth Table block. Homes rarely maintain a constant climate without a climate control system in place, and occupants usually rely on automated systems to maintain a desired climate. Because temperature and humidity are dynamic, maintaining desired conditions requires consistent monitoring and adjusting. To model how a home activates different subsystems that maintain a desired climate, this model uses a Truth Table block to manage logical decision making.

Home climate (temperature and humidity) controller using Truth Table



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### Examine the Truth Table

In this example, the Truth Table block labeled ClimateController controls all of the physical subsystem outputs. The block uses four inputs: the desired temperature  $T\_thresh$ , the actual home temperature  $t$ , the desired humidity  $H\_thresh$ , and the actual home humidity  $h$ . Double-click the

block to see how the block uses the inputs to produce the outputs. The ClimateController block includes two tables: the Condition Table and the Action Table.

The Condition Table shows how the inputs are logically evaluated, and illustrates the two comparisons made by the block and the four actions that can be taken. To execute the first action, the two conditions must be True. If either condition is not True, the block tests the conditions outlined in the next decision column, which requires only the first condition to be True. This evaluation continues from left to right until a decision is made or the last decision column is reached, which then executes. In this example, the - entries function like False conditions. As a result, the block would behave the same way if the - conditions were explicitly defined as False. However, automatically generated code using only True and False conditions may produce suboptimal code coverage. To avoid that issue, this example uses - conditions.

In the first row, the block compares the home temperature to the desired temperature, and the home cooler and heater are controlled using the CoolOn and HeatOn actions, respectively. When  $t > T\_thresh$ , the block activates the CoolOn action. If this condition is not True, the block activates the HeatOn action. In the second row, the block compares the home humidity to the desired humidity, and the humidifier is controlled using the HumidOn action. When  $h < H\_thresh$ , the block activates the HumidOn action.

Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4
1	Hot	$t > T\_thresh$	T	T	-	-
2	Dry	$h < H\_thresh$	T	-	T	-
		ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	CoolOn,HumidOn	CoolOn	HeatOn,HumidOn	HeatOn

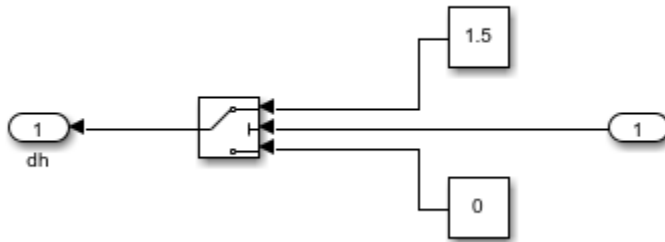
The Action Table defines the block outputs associated with each logical action. In the first row, CoolOn sets the value of cooler to 1 and the value of heater to 0. In the second row, HeatOn sets the value of heater to 1 and the value of cooler to 0. By default, the humidifier is 0 unless the block enables HumidOn.

Action Table

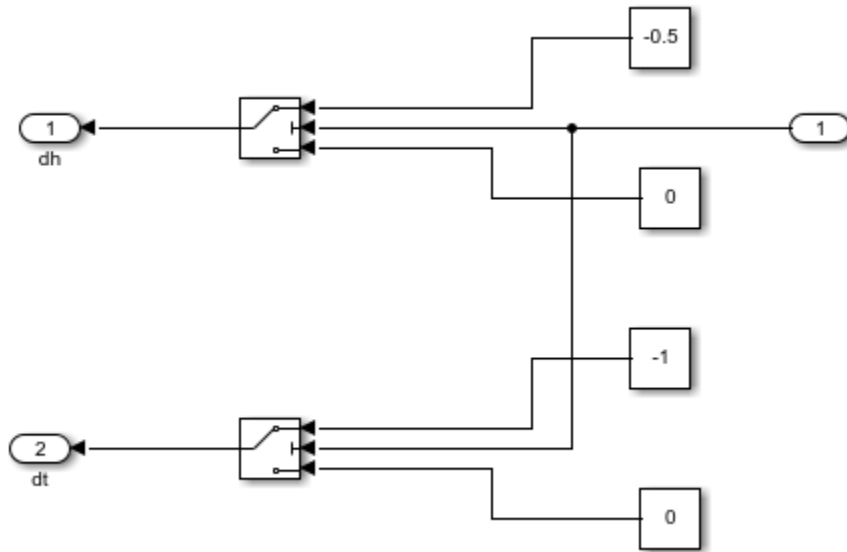
	DESCRIPTION	ACTION
1	Turn On Cooling (This implicitly reduces humidity)	CoolOn: cooler = 1; heater = 0; humidifier = 0;
2	Turn On Heater (This implicitly reduces humidity)	HeatOn: heater = 1; cooler = 0; humidifier = 0;
3	Turn On Humidifier	HumidOn: humidifier = 1;

**Examine the Home Subsystems**

In the model, the green blocks labeled Humidifier, Cooler, and Heater represent the physical subsystems that regulate the climate of the home. The Humidifier subsystem includes a Switch block that engages from the output of the ClimateController block. If the input to the Humidifier subsystem is 1, the subsystem outputs 1.5. Otherwise, the subsystem outputs a value of 0.



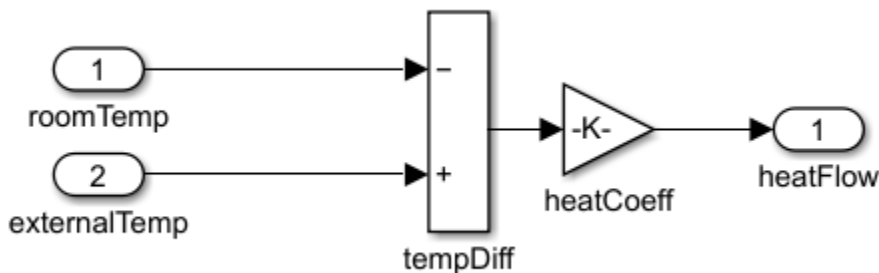
The Heater and Cooler subsystems work on similar principles. They each include two Switch blocks. One Switch block outputs a value that affects the temperature, which is the output at the **dt** and **dt1** ports for the Cooler and Heater, respectively. The other Switch block outputs a value that affects the humidity, which is output at the **dh** and **dh1** ports for the Cooler and Heater, respectively. If cooler = 1, the Cooler subsystem activates, and if heater = 1, the Heater subsystem activates. When engaged, the Heater subsystem outputs 1 at **dt1**, and the Cooler outputs -1 at **dt**. Both subsystems output -0.5 at **dh** and **dh1** when engaged.



Due to how the ClimateController block is configured, the Cooler and Heater subsystems will not activate at the same time.

### Examine the External Subsystems

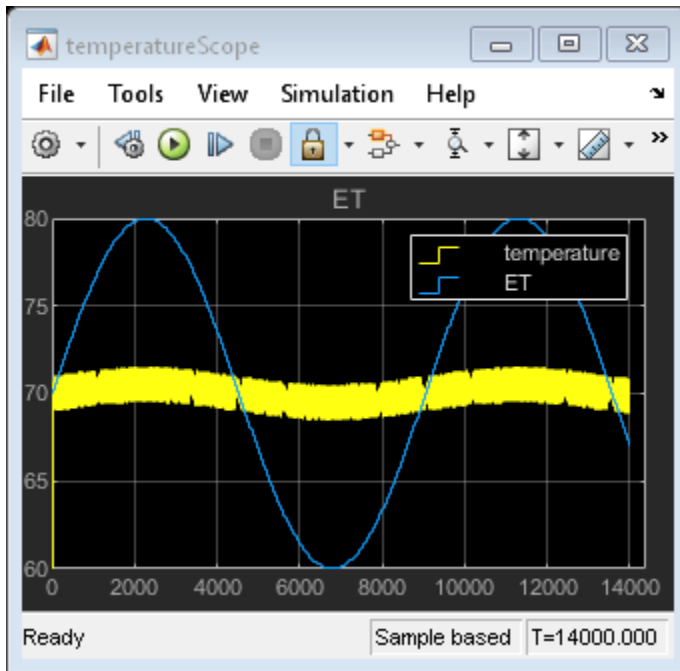
External heat and humidity also affect the climate of the home. The model represents the effect of these conditions as heat and humidity flow. The externalHeatFlow subsystem models external heat flow, and the externalHumidityFlow subsystem models external humidity flow. The externalHeatFlow subsystem takes the difference between the external and internal temperatures and multiplies the difference by a coefficient.



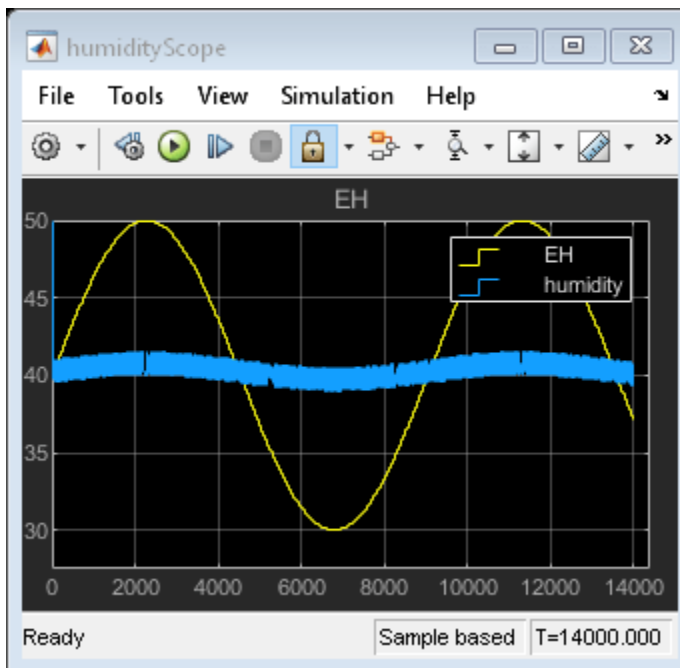
Higher values of the coefficient represent larger heat flows, which occur in less insulated homes. Although the externalHumidityFlow subsystem represents a different physical behavior than externalHeatFlow, the externalHumidityFlow subsystem uses the same arrangement of blocks and connections. The externalHumidityFlow subsystem takes the difference between between the external and internal humidities and multiplies the difference by a coefficient.

### Simulate the Model

Running the model populates the two Floating Scope blocks. The Scope block labeled temperatureScope displays the external temperature (ET) and the home temperature (temperature).



The Scope block labeled humidityScope plots the external humidity (EH) and the home humidity (humidity).



The simulation is configured to run indefinitely. To stop the simulation, you can stop it manually by pressing the **Stop** button or by adjusting the stop time before running the simulation.

### **Explore and Modify the Model**

You can adjust the external temperature by using a different external temperature signal or by modifying the signal amplitude. Try adjusting the amplitude of the Sine Wave blocks, externalTemp and externalHumid, and observe how the model responds.

Other homes may not be as insulated or might have more effective climate control subsystems. These physical differences affect the outputs of the subsystems. Try adjusting the Heater or Cooler subsystem outputs by changing the Constant block values.

### **See Also**

Truth Table

### **More About**

- “Use Truth Tables to Model Combinatorial Logic” on page 10-2





# Simulink Functions in Stateflow Charts

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- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Bind a Simulink Function to a State” on page 11-6
- “Improve Chart Design by Using Simulink Functions” on page 11-11
- “Schedule Execution of Multiple Controllers” on page 11-19
- “Schedule Simulink Algorithms by Using Stateflow” on page 11-26
- “Design Switching Controllers by Using Simulink Functions” on page 11-28
- “Share Functions Across Simulink and Stateflow” on page 11-33
- “Why Use a Simulink Function in a Stateflow Chart?” on page 11-35

## Reuse Simulink Components in Stateflow Charts

A Simulink function is a graphical object that enables you to call a Simulink subsystem in the actions of states and transitions. Simulink functions are supported only in Stateflow charts in Simulink models.

Simulink functions can improve the efficiency of your design and increase the readability of your model. Typical applications include:

- Defining a function that requires Simulink blocks
- Scheduling execution of multiple controllers

A Simulink function can reside anywhere in a chart, state, or subchart. The location of a function determines the set of states and transitions that can call the function.

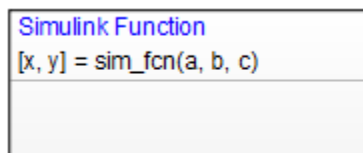
- If you want to call the function within one state or subchart and its substates, put your Simulink function in that state or subchart. That function overrides any other functions of the same name in the parents and ancestors of that state or subchart.
- If you want to call the function anywhere in a chart, put your Simulink function at the chart level.
- If you want to call the function from any chart in your model, use a Simulink Function block to define the function directly in the Simulink canvas. For more information, see “Simulink Functions Overview” (Simulink).

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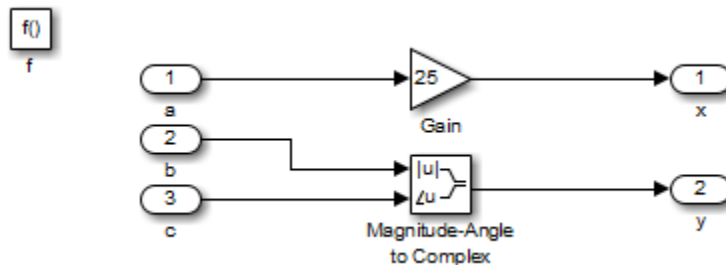
**Note** A Simulink function cannot access chart or state data in the Stateflow hierarchy.

---


For example, this Simulink function has the name `sim_fcn`. It takes three arguments (a, b, and c) and returns two output values (x and y).



The function contains a Simulink subsystem that multiplies the first argument times a gain of 25 and combines the other two arguments into a complex output signal.



## Define a Simulink Function

- 1 In the object palette, click the Simulink function icon . Move your pointer to the location for the new Simulink function in your chart.
- 2 Enter the signature label for the function.

The function signature label specifies a name for your function and the formal names for its arguments and return values. A signature label has this syntax:

```
[return_val1,return_val2,...] = function_name(arg1,arg2,...)
```

You can specify multiple return values and multiple input arguments. Each return value and input argument can be a scalar, vector, or matrix of values. For functions with only one return value, omit the brackets in the signature label.

You must use unique variable names for all arguments and return values.

- 3 To program the function, open the Simulink editor by double-clicking the function box. Initially, the editor contains a function-call Trigger block and Inport and Outport blocks that match the function signature. You cannot delete the Trigger block.
- 4 In the Simulink editor, add blocks and connect them to the Inport and Outport blocks.
- 5 Configure the Inport and Outport blocks.
  - a Double-click each block to open the Block Parameters dialog box.
  - b In the **Signal Attributes** tab, enter the **Data type** and **Port dimensions** of the input parameter or return value.
  - c Click **OK**.

---

**Note** An Inport block in a Simulink function cannot inherit its **Data type** and **Port dimensions**. For more information, see “Explicitly Set the Properties of Inport Blocks” on page 11-4.

---

## Call Simulink Functions in States and Transitions

You can call Simulink functions from the actions of any state or transition. You can also call Simulink functions from other functions.

To call a Simulink function, use the function signature and include an actual argument value for each formal argument in the function signature. If the data types of the actual and formal arguments differ, the function casts the actual argument to the type of the formal argument.

## Specify Properties of Simulink Functions

You can specify properties for a Simulink function in the Model Explorer or the Block Parameters dialog box.

- To use the Model Explorer:
  - 1 To open the Model Explorer, in the **Modeling** tab, select **Model Explorer**.
  - 2 In the **Model Hierarchy** pane, select the Simulink function.
  - 3 In the **Block Parameters** pane, edit the Simulink function properties.

- To use the Block Parameters dialog box:
  - 1 In the Stateflow Editor, right-click the Simulink function.
  - 2 Select **Properties**.
  - 3 Edit the Simulink function properties.

For a description of the Simulink function properties, see Subsystem, Atomic Subsystem, CodeReuse Subsystem.

You can specify additional properties of Simulink functions programmatically by using `Stateflow.SLFunction` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

## Guidelines for Using Simulink Functions

### Use Alphanumeric Characters and Underscores in Argument Names

This guideline ensures that the names of Inport and Output blocks are compatible with the identifier naming rules of Stateflow charts.

### Explicitly Set the Properties of Inport Blocks

The Inport blocks in a Simulink function cannot inherit their data types and sizes. Therefore, you must set the **Data type** and **Port dimensions** of each Inport block that is not a scalar of type `double`.

The Output blocks in a Simulink function can inherit sizes and data types based on the connections inside the subsystem. Therefore, you can specify the **Data type** and **Port dimensions** of these blocks as inherited.

---

**Tip** To make it easier to update the properties of Inport blocks, you can specify data types and sizes as parameters.

---

### Convert Discontiguous Signals to Contiguous Signals

Output blocks in Simulink functions do not support discontiguous signals. If your function contains a block that outputs a discontiguous signal, insert a Signal Conversion block between the discontiguous output and the Output block. This action ensures that the output signal is contiguous.

Blocks that can output a discontiguous signal include the Bus Creator block and the Mux block. For the Bus Creator block, the output is discontiguous when the block outputs a virtual bus. If you select **Output as nonvirtual bus**, the output signal is contiguous and no conversion is necessary.

### Do Not Export Simulink Functions

Exporting a Simulink function results in a run-time error during simulation. To avoid this error, open the Chart properties dialog box and clear the **Export Chart Level Functions** check box.

### Do Not Use Simulink Functions in Moore Charts

You cannot use Simulink functions in Moore charts. This restriction prevents violations of Moore semantics during chart execution.

### **Do Not Call Simulink Functions in Default Transitions That Execute During Chart Initialization**

If you select the chart property **Execute (enter) Chart At Initialization**, you cannot call Simulink functions in default transitions that execute the first time that the chart awakens. Otherwise, the chart generates a run-time error during simulation.

### **Do Not Call Simulink Functions in State During Actions Or Transition Conditions of Continuous-time Charts**

In continuous-time charts, you cannot call Simulink functions during minor time steps. Instead, call Simulink functions in actions that occur during major time steps: state entry or exit actions and transition actions. Calling Simulink functions in state during actions or transition conditions results in a run-time error during simulation.

### **Do Not Generate HDL Code for Simulink Functions**

Simulink functions do not support HDL code generation. Generating HDL code for charts that contain Simulink functions results in a run-time error during simulation.

### **Pass Arguments by Value**

Passing an argument to a Simulink function by reference results in a run-time error during simulation.

### **See Also**

Bus Creator | Inport | Mux | Outport | Signal Conversion | Simulink Function | Trigger

### **More About**

- “Export Stateflow Functions for Reuse” on page 8-23
- “Simulink Functions Overview” (Simulink)
- “Simulink functions: Simulink Function block, exported Stateflow graphical and MATLAB functions” (Simulink)
- “Share Functions Across Simulink and Stateflow” on page 11-33

## Bind a Simulink Function to a State

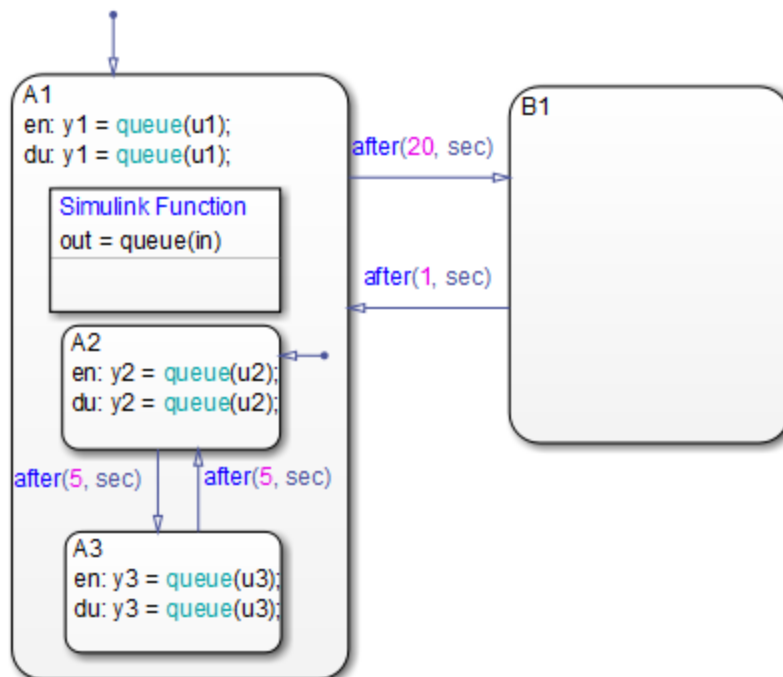
A Simulink function is a graphical object that you fill with Simulink blocks and call in the actions of states and transitions. Simulink functions are supported only in Stateflow charts in Simulink models. For more information, see “Reuse Simulink Components in Stateflow Charts” on page 11-2.

### Bind Behavior of a Simulink Function

When a Simulink function resides inside a state, the function binds to that state. Binding results in the following behavior:

- Function calls can occur only in state actions and on transitions within the state and its substates.
- When the state is entered, the function is enabled.
- When the state is exited, the function is disabled.

For example, the following Stateflow chart shows a Simulink function that binds to a state.



Because the function `queue` resides in state A1, the function binds to that state.

- State A1 and its substates A2 and A3 can call `queue`, but state B1 cannot.
- When state A1 is entered, `queue` is enabled.
- When state A1 is exited, `queue` is disabled.

### Control Subsystem Variables When the Simulink Function Is Disabled

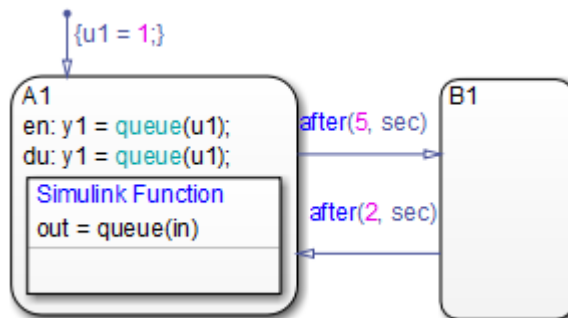
If a Simulink function binds to a state, you can hold the subsystem variables at their values from the previous execution or reset the variables to their initial values. Follow these steps:

- 1 In the Simulink function, double-click the trigger port to open the Block Parameters dialog box.
- 2 Select an option for **States when enabling**.

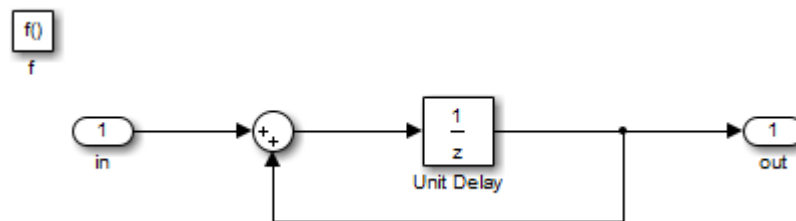
Option	Description	Reference Section
held	Holds the values of the subsystem variables from the previous execution	“How the Function Behaves When Variables Are Held” on page 11-9
reset	Resets the subsystem variables to their initial values	“How the Function Behaves When Variables Are Reset” on page 11-10

## Example of Binding a Simulink Function to a State

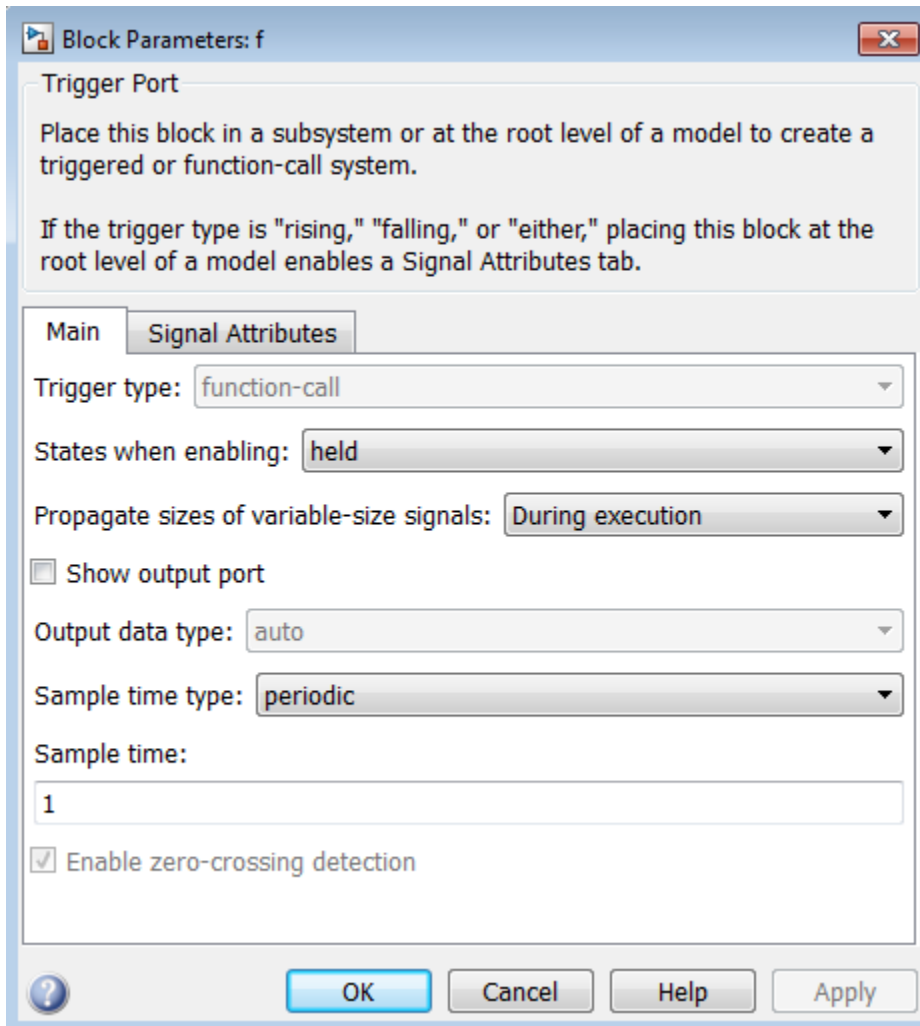
This example shows how a Simulink function behaves when bound to a state.



The function `queue` contains a block diagram that increments a counter by 1 each time the function executes.



The Block Parameters dialog box for the trigger port appears as follows.



In the dialog box, setting **Sample time type** to periodic enables the **Sample time** field, which defaults to 1. These settings tell the function to execute for each time step specified in the **Sample time** field while the function is enabled.

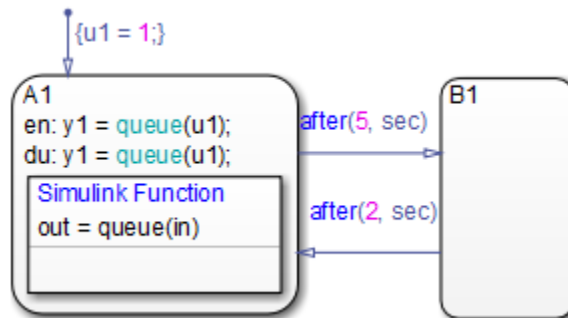
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**Note** If you use a fixed-step solver, the value in the **Sample time** field must be an integer multiple of the fixed-step size. This restriction does not apply to variable-step solvers. (For more information, see "Compare Solvers" (Simulink).)

---



### Simulation Behavior of the Chart

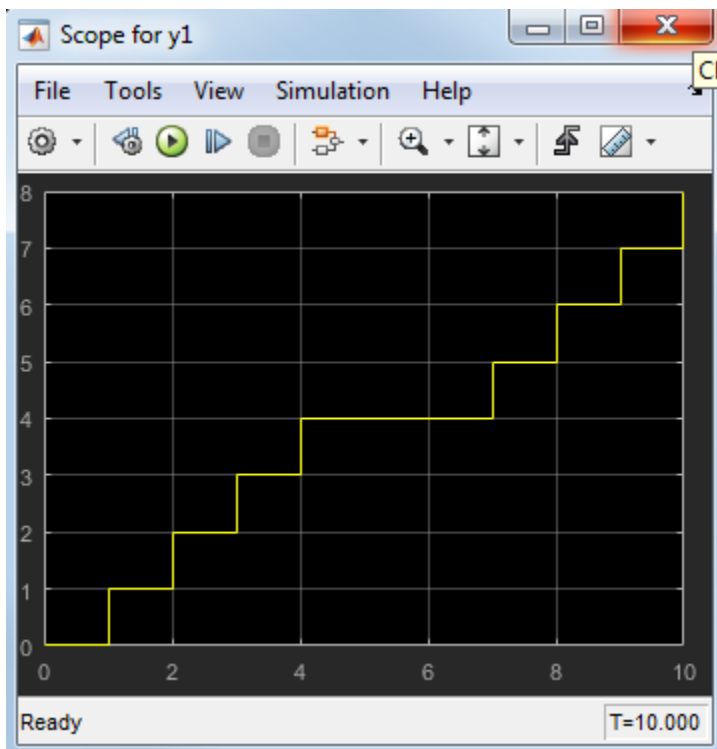


When you simulate the chart, the following actions occur:

- 1 The default transition to state A1 occurs, which includes setting local data `u1` to 1.
- 2 When A1 is entered, the function `queue` is enabled.
- 3 Function calls to `queue` occur until the condition `after(5, sec)` is true.
- 4 The transition from state A1 to B1 occurs.
- 5 When A1 is exited, the function `queue` is disabled.
- 6 After two more seconds pass, the transition from B1 to A1 occurs.
- 7 Steps 2 through 6 repeat until the simulation ends.

### How the Function Behaves When Variables Are Held

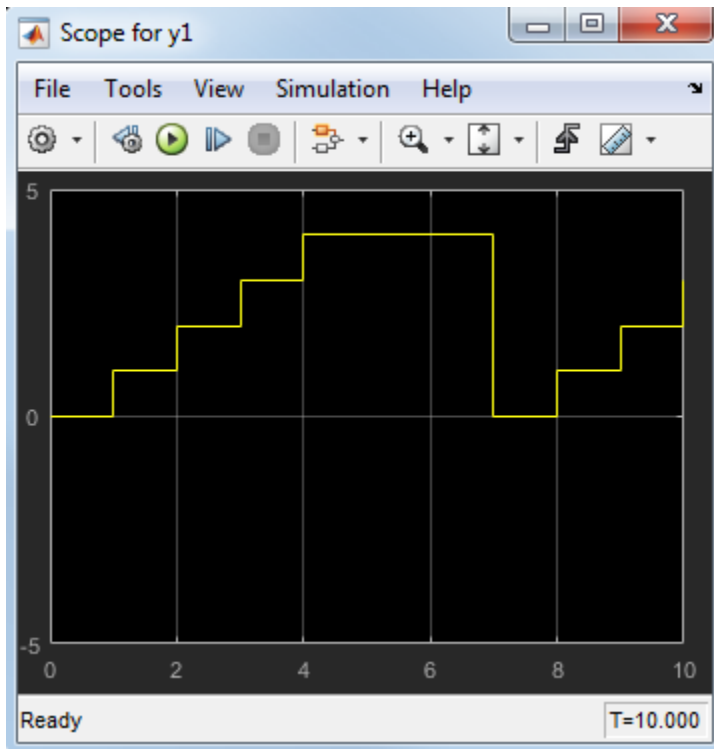
If you set **States when enabling** to held, the output `y1` is as follows.



When state A1 becomes inactive at  $t = 5$ , the Simulink function holds the counter value. When A1 is active again at  $t = 7$ , the counter has the same value as it did at  $t = 5$ . Therefore, the output  $y1$  continues to increment over time.

### How the Function Behaves When Variables Are Reset

If you set **States when enabling** to reset, the output  $y1$  is as follows.



When state A1 becomes inactive at  $t = 5$ , the Simulink function does *not* hold the counter value. When A1 is active again at  $t = 7$ , the counter resets to zero. Therefore, the output  $y1$  resets too.

### See Also

#### More About

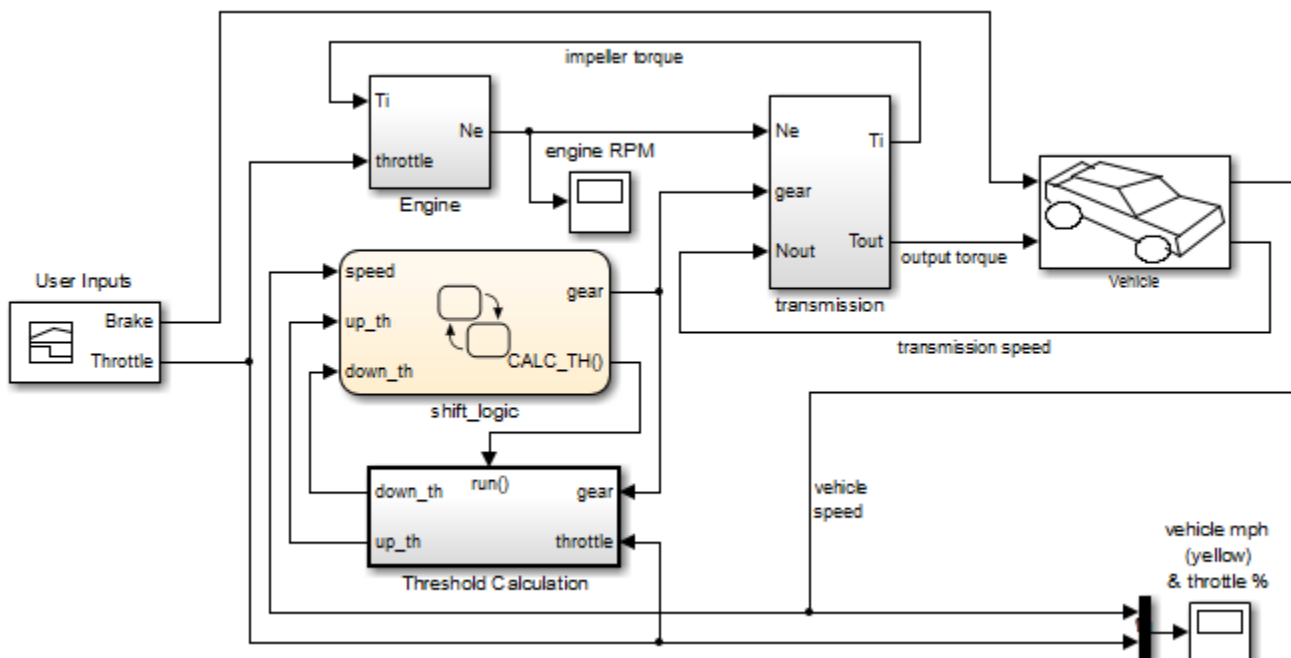
- "Reuse Simulink Components in Stateflow Charts" on page 11-2
- "Why Use a Simulink Function in a Stateflow Chart?" on page 11-35

## Improve Chart Design by Using Simulink Functions

A Simulink function is a graphical object that you fill with Simulink blocks and call in the actions of states and transitions. Simulink functions are supported only in Stateflow charts in Simulink models. For more information, see “Reuse Simulink Components in Stateflow Charts” on page 11-2.

### Goal of the Tutorial

The goal of this tutorial is to use a Simulink function in a Stateflow chart to improve the design of a model named `old_sf_car`.



### Rationale for Improving the Model Design

The `old_sf_car` model contains a function-call subsystem named `Threshold Calculation` and a Stateflow chart named `shift_logic`. The two blocks interact as follows:

- The chart broadcasts the output event `CALC_TH` to trigger the function-call subsystem.
- The subsystem uses lookup tables to interpolate two values for the `shift_logic` chart.
- The subsystem outputs (`up_th` and `down_th`) feed directly into the chart as inputs.

No other blocks in the model access the subsystem outputs.

You can replace a function-call subsystem with a Simulink function in a chart when:

- The subsystem performs calculations required by the chart.
- Other blocks in the model do not need access to the subsystem outputs.

## Edit a Model to Use a Simulink Function

The sections that follow describe how to replace a function-call subsystem in a Simulink model with a Simulink function in a Stateflow chart. This procedure reduces the number of objects in the model while retaining the same simulation results.

Step	Task	Reference
1	Open the model.	"Open the Model" on page 11-12
2	Move the contents of the function-call subsystem into a Simulink function in the chart.	"Add a Simulink Function to the Chart" on page 11-14
3	Change the scope of specific chart-level data to <code>Local</code> .	"Change the Scope of Chart Data" on page 11-16
4	Replace the event broadcast with a function call.	"Update State Action in the Chart" on page 11-16
5	Verify that function inputs and outputs are defined.	"Add Data to the Chart" on page 11-17
6	Remove unused items in the model.	"Remove Unused Items in the Model" on page 11-17

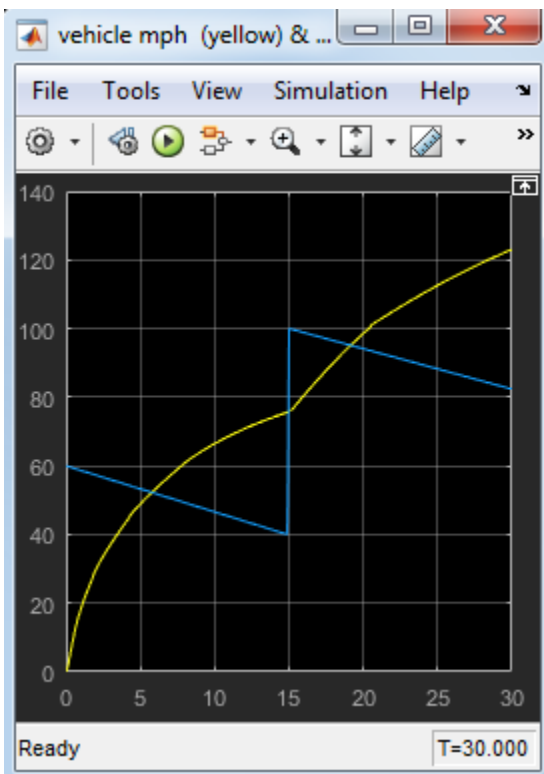
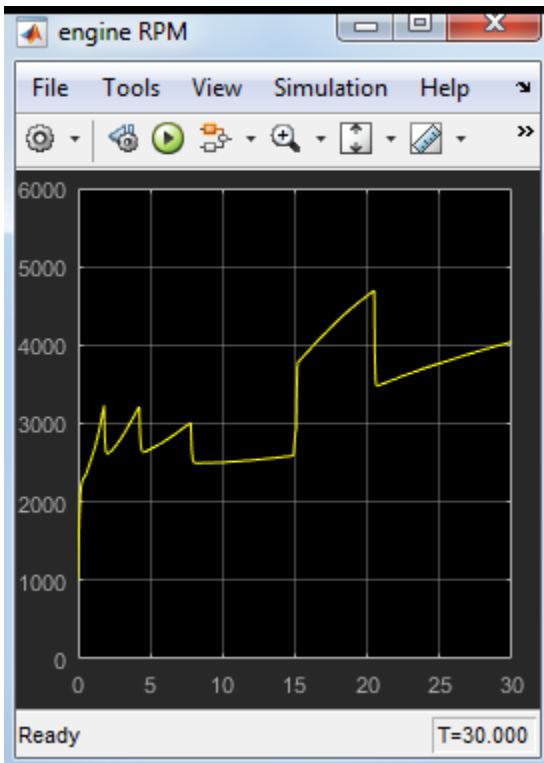
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**Note** To skip the conversion steps, open the model `sf_car`.

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### Open the Model

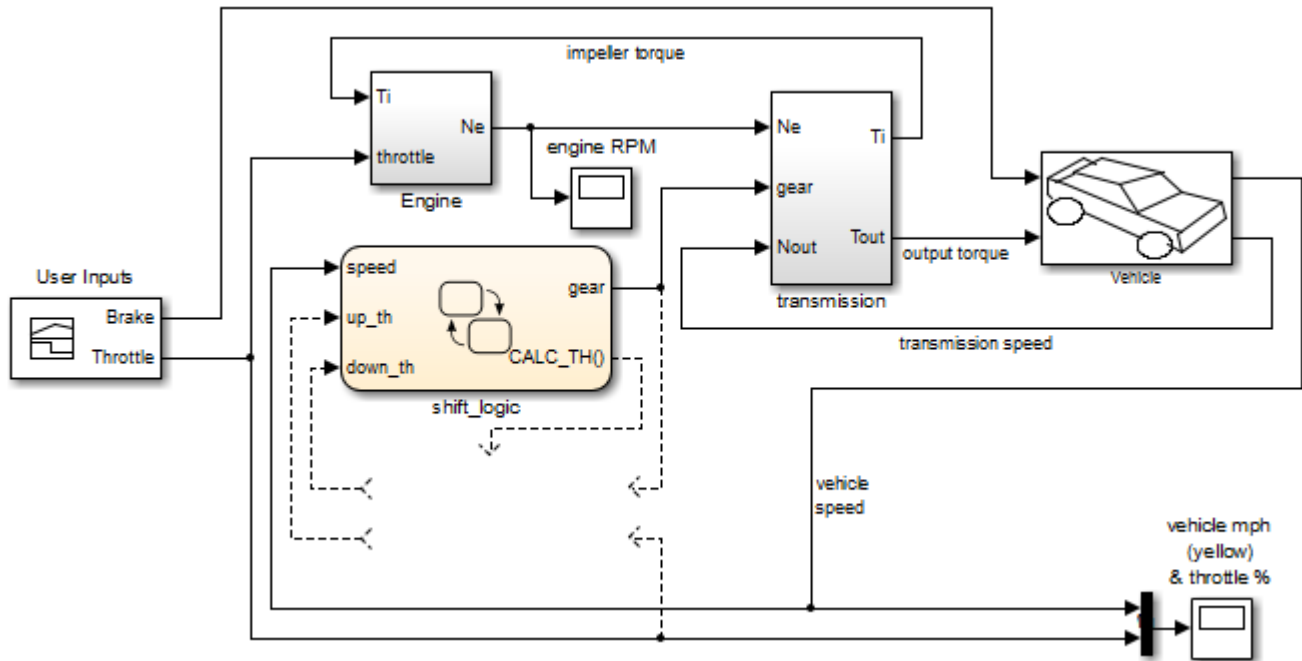
Open the model `old_sf_car`. If you simulate the model, you see these results in the two scopes.



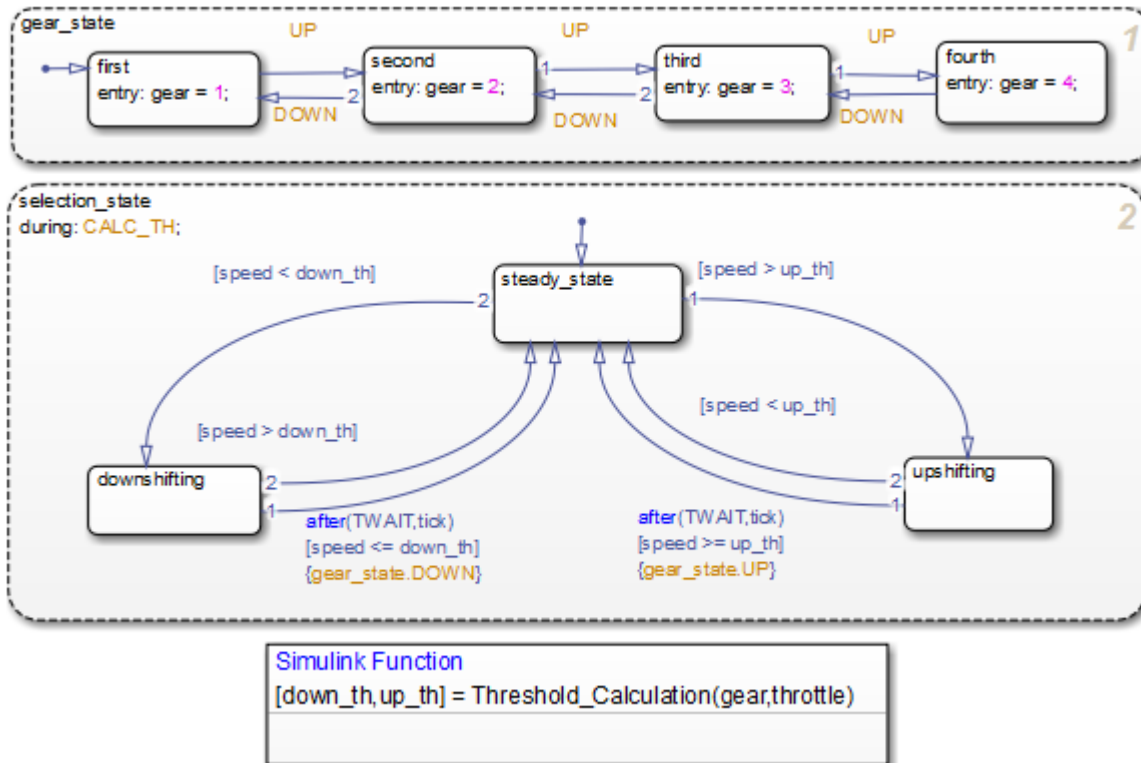
### Add a Simulink Function to the Chart

Follow these steps to add a Simulink function to the shift\_logic chart.

- 1 In the Simulink model, right-click the Threshold Calculation block in the lower left corner and select **Cut** from the context menu.

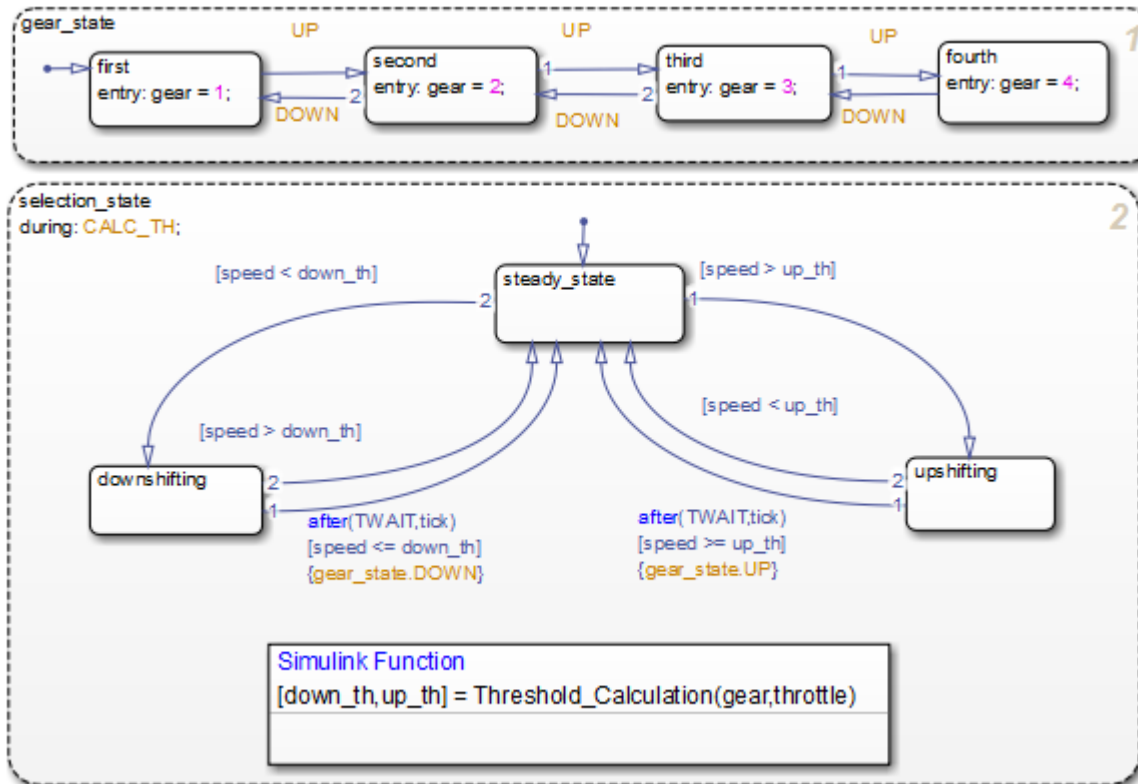


- 2 Open the shift\_logic chart.
- 3 In the chart, right-click below selection\_state and select **Paste** from the context menu.
- 4 Expand the new Simulink function so that the signature fits inside the function box.



**Tip** To change the font size of a function, right-click the function box and select a new size from the **Font Size** menu.

- Expand the border of `selection_state` to include the new function.



**Note** The function resides in this state instead of the chart level because no other state in the chart requires the function outputs `up_th` and `down_th`. See “Bind a Simulink Function to a State” on page 11-6.

- 6 Rename the Simulink function from `Threshold_Calculation` to `calc_threshold` by entering `[down_th, up_th] = calc_threshold(gear, throttle)` in the function box.

### Change the Scope of Chart Data

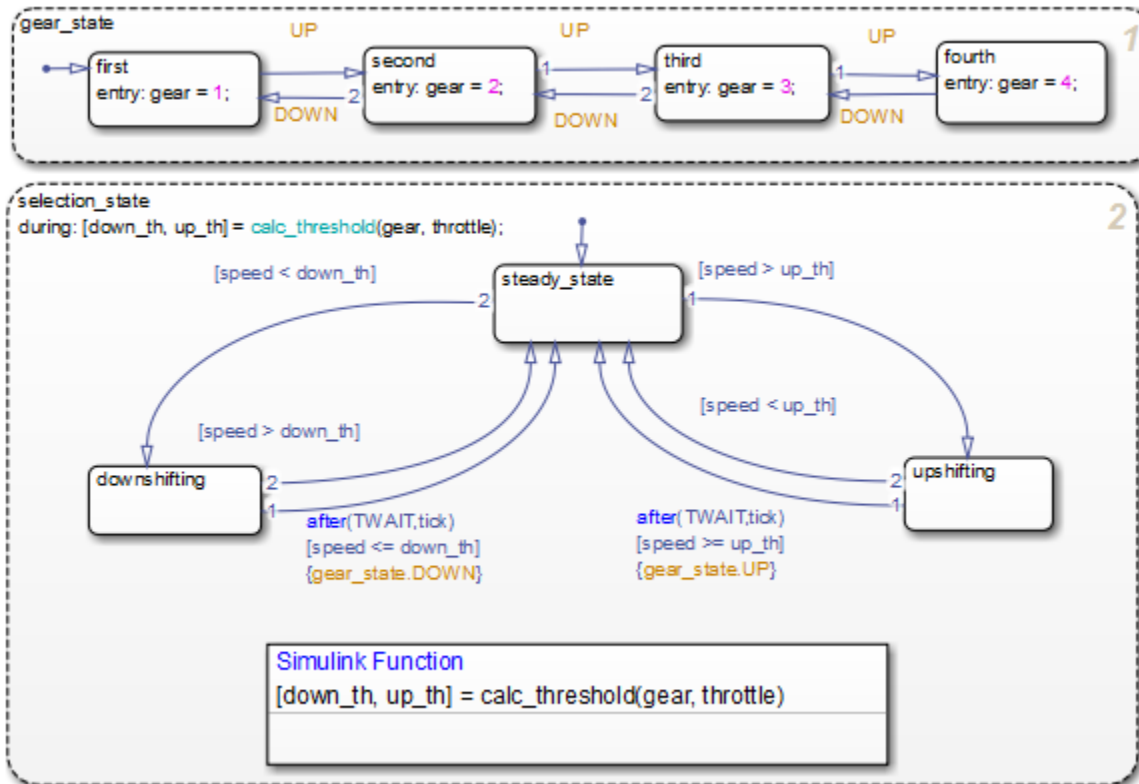
In the Model Explorer, change the scope of chart-level data `up_th` and `down_th` to `Local` because calculations for those data now occur inside the chart.

### Update State Action in the Chart

In the Stateflow Editor, change the `during` action in `selection_state` to call the Simulink function `calc_threshold`.

```
during: [down_th, up_th] = calc_threshold(gear, throttle);
```





### Add Data to the Chart

Because the function `calc_threshold` takes `throttle` as an input, you must define that data as a chart input. (For details, see “Add Stateflow Data” on page 12-2.)

- 1 Add input data `throttle` to the chart with a **Port** property of 1.

Using port 1 prevents signal lines from overlapping in the Simulink model.

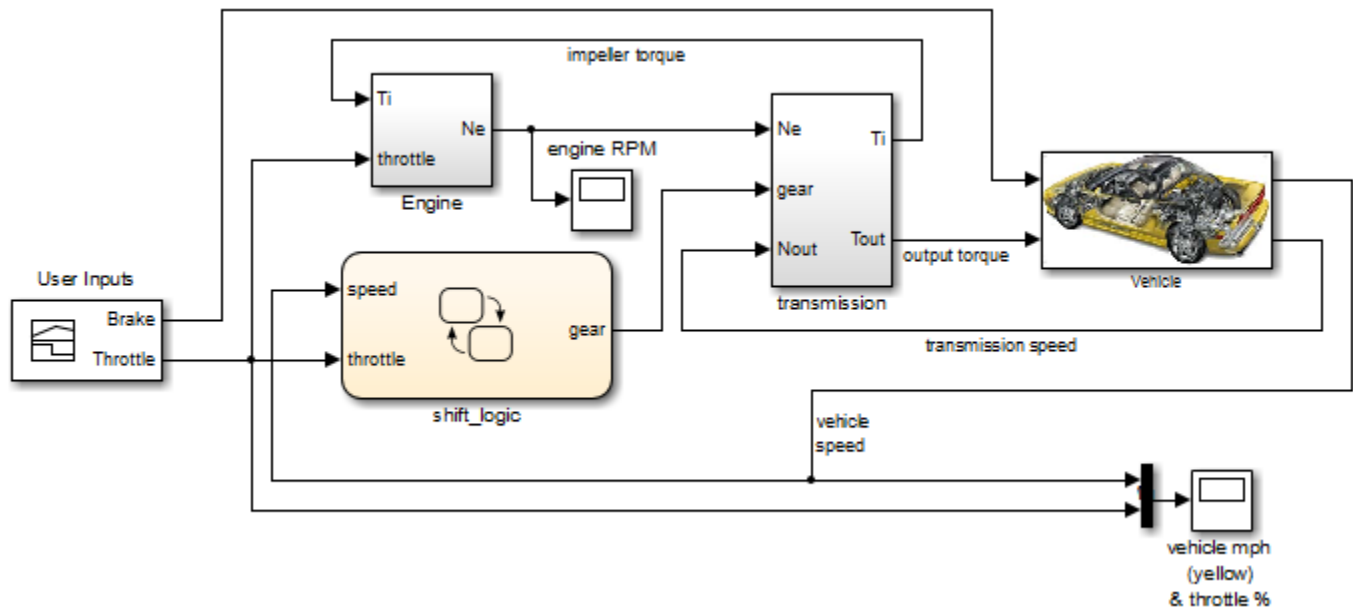
- 2 In the Simulink model, add a signal line for `throttle` between the inport of the Engine block and the inport of the shift\_logic chart.

### Remove Unused Items in the Model

- 1 In the Model Explorer, delete the function-call output event `CALC_TH` because the Threshold Calculation block no longer exists.
- 2 Delete any dashed signal lines from your model.

### Run the New Model

Your new model looks something like this:



If you simulate the new model, the results match those of the original design.

## See Also

### More About

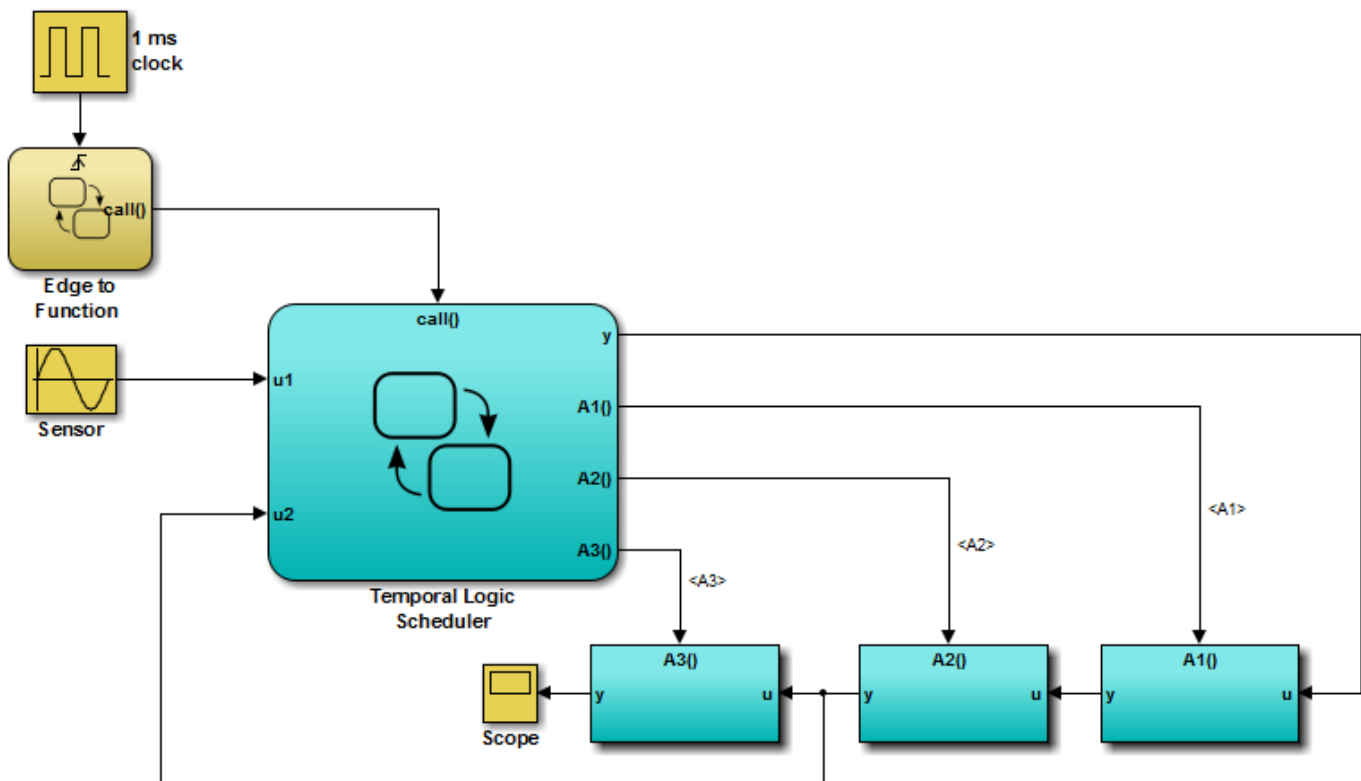
- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Define a Simulink Function” on page 11-3

## Schedule Execution of Multiple Controllers

A Simulink function is a graphical object that you fill with Simulink blocks and call in the actions of states and transitions. Simulink functions are supported only in Stateflow charts in Simulink models. For more information, see “Reuse Simulink Components in Stateflow Charts” on page 11-2.

### Goal of the Tutorial

The goal of this tutorial is to use Simulink functions in a Stateflow chart to improve the design of a model named `sf_temporal_logic_scheduler`.



### Rationale for Improving the Model Design

The `sf_temporal_logic_scheduler` model contains a Stateflow chart and three function-call subsystems. These blocks interact as follows:

- The chart broadcasts the output events A1, A2, and A3 to trigger the function-call subsystems.
- The subsystems A1, A2, and A3 execute at different rates defined by the chart.
- The subsystem outputs feed directly into the chart.

No other blocks in the model access the subsystem outputs.

You can replace function-call subsystems with Simulink functions inside a chart when:

- The subsystems perform calculations required by the chart.

- Other blocks in the model do not need access to the subsystem outputs.

## Edit a Model to Use Simulink Functions

The sections that follow describe how to replace function-call subsystem blocks in a Simulink model with Simulink functions in a Stateflow chart. This procedure reduces the number of objects in the model while retaining the same simulation results.

Step	Task	Reference
1	Open the model.	"Open the Model" on page 11-20
2	Move the contents of the function-call subsystems into Simulink functions in the chart.	"Add Simulink Functions to the Chart" on page 11-21
3	Change the scope of specific chart-level data to <code>Local</code> .	"Change the Scope of Chart Data" on page 11-23
4	Replace event broadcasts with function calls.	"Update State Actions in the Chart" on page 11-23
5	Verify that function inputs and outputs are defined.	"Add Data to the Chart" on page 11-24
6	Remove unused items in the model.	"Remove Unused Items in the Model" on page 11-24

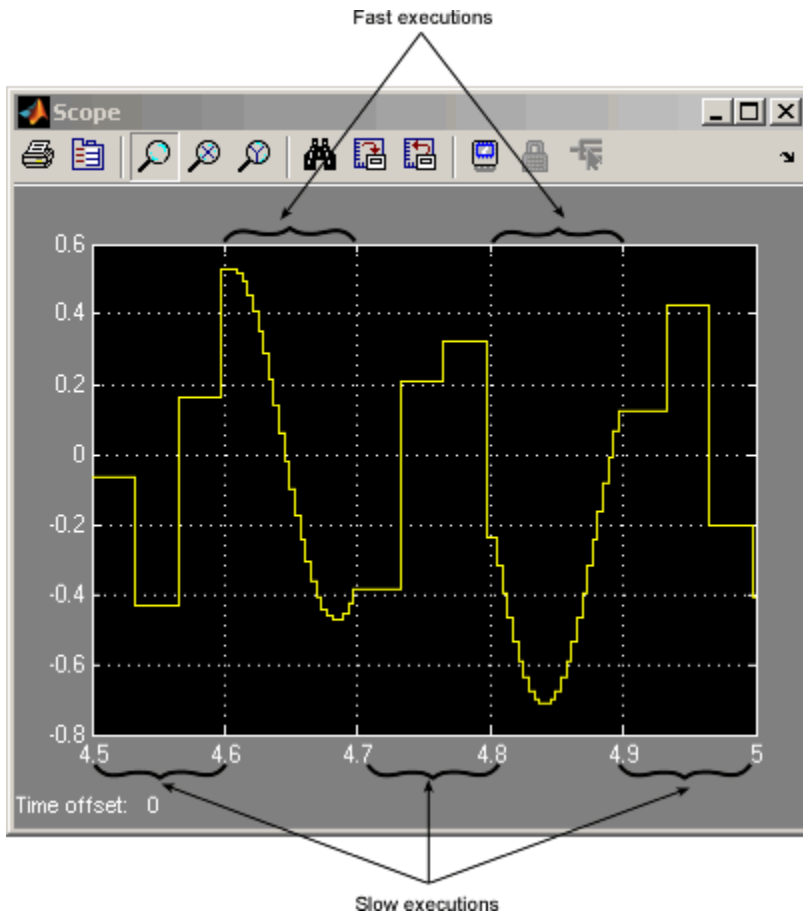
---

**Note** To skip the conversion steps, you can access the new model directly.

---

### Open the Model

Open the `sf_temporal_logic_scheduler` model. If you simulate the model, you see this result in the scope.

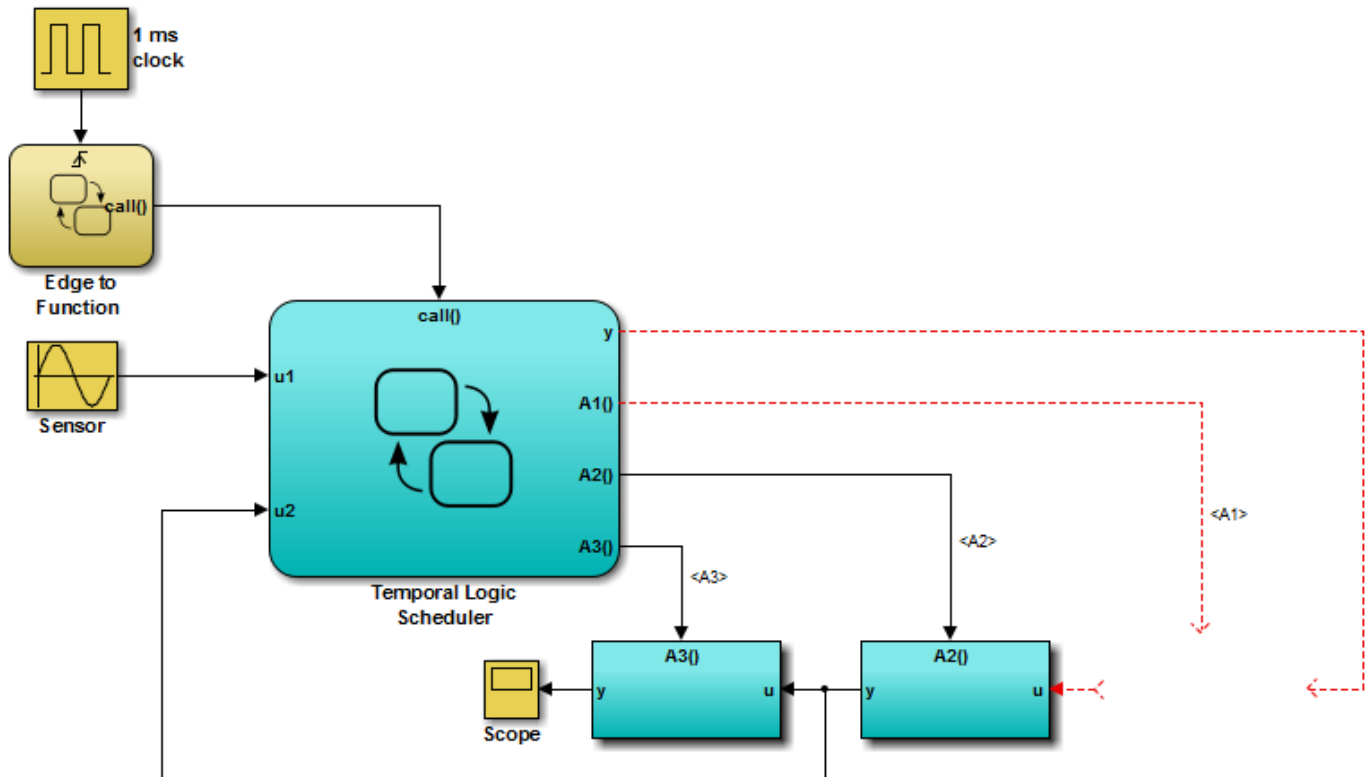


For more information, see “Schedule Subsystems to Execute at Specific Times” on page 30-9.

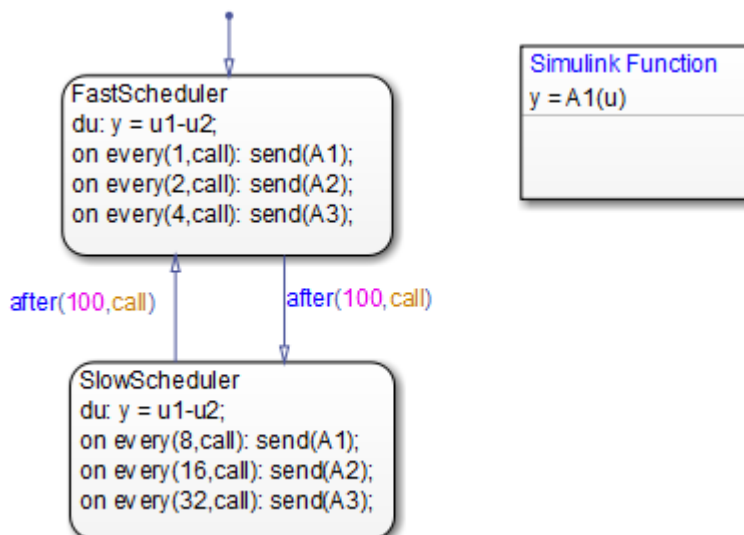
### Add Simulink Functions to the Chart

Follow these steps to add Simulink functions to the Temporal Logic Scheduler chart.

- 1 In the Simulink model, right-click the A1 block in the lower right corner and select **Cut** from the context menu.

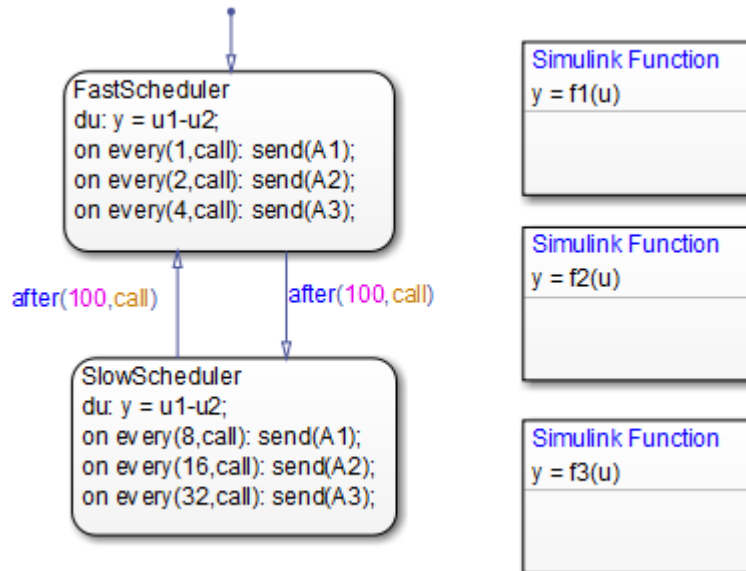


- 2 Open the Temporal Logic Scheduler chart.
- 3 In the chart, right-click outside any states and select **Paste** from the context menu.
- 4 Expand the new Simulink function so that the signature fits inside the function box.



**Tip** To change the font size of a function, right-click the function box and select a new size from the **Font Size** menu.

- 5 Rename the Simulink function from A1 to f1 by entering  $y = f1(u)$  in the function box.
- 6 Repeat steps 1 through 5 for these cases:
  - Copying the contents of A2 into a Simulink function named f2.
  - Copying the contents of A3 into a Simulink function named f3.




---

**Note** The new functions reside at the chart level because both states `FastScheduler` and `SlowScheduler` require access to the function outputs.

---

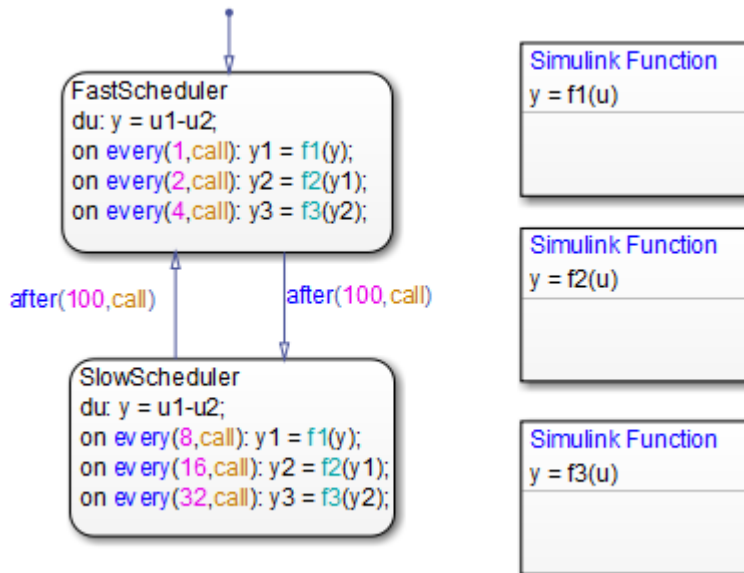
### Change the Scope of Chart Data

In the Model Explorer, change the scope of chart-level data `y` to `Local` because the calculation for that data now occurs inside the chart.

### Update State Actions in the Chart

In the Stateflow Editor, you can replace event broadcasts in state actions with function calls.

- 1 Edit the state actions in `FastScheduler` and `SlowScheduler` to call the Simulink functions `f1`, `f2`, and `f3`.



- 2 In both states, update each during action as follows.

du:  $y = u1 - y2$ ;

### Add Data to the Chart

For the on every state actions of FastScheduler and SlowScheduler, define three data. (For details, see “Add Stateflow Data” on page 12-2.)

- 1 Add local data  $y1$  and  $y2$  to the chart.
- 2 Add output data  $y3$  to the chart.
- 3 In the model, connect the output for  $y3$  to the input of the scope.

---

**Tip** To flip the Scope block, right-click and select **Rotate & Flip > Flip Block** from the context menu.

---

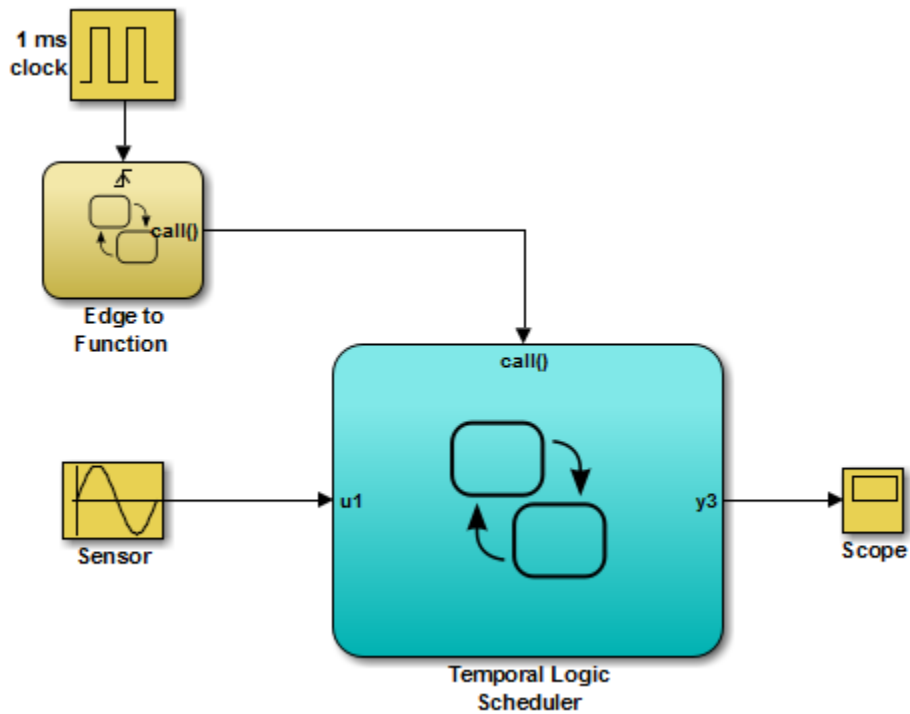
### Remove Unused Items in the Model

- 1 In the Model Explorer, delete output events A1, A2, and A3 and input data  $u2$  because the function-call subsystems no longer exist.
- 2 Delete any dashed signal lines from your model.

### Run the New Model

Your new model looks something like this:





If you simulate the new model, the results match those of the original design.

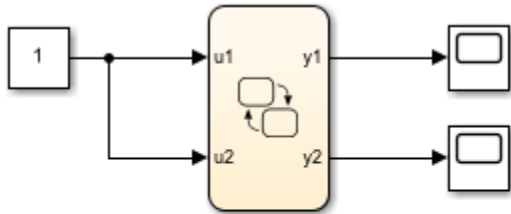
## See Also

### More About

- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Define a Simulink Function” on page 11-3

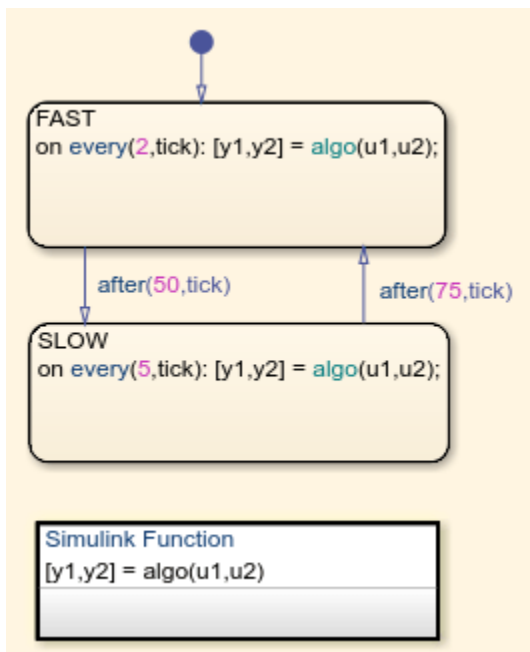
## Schedule Simulink Algorithms by Using Stateflow

This model shows how you can schedule a Simulink® algorithm using Stateflow®.

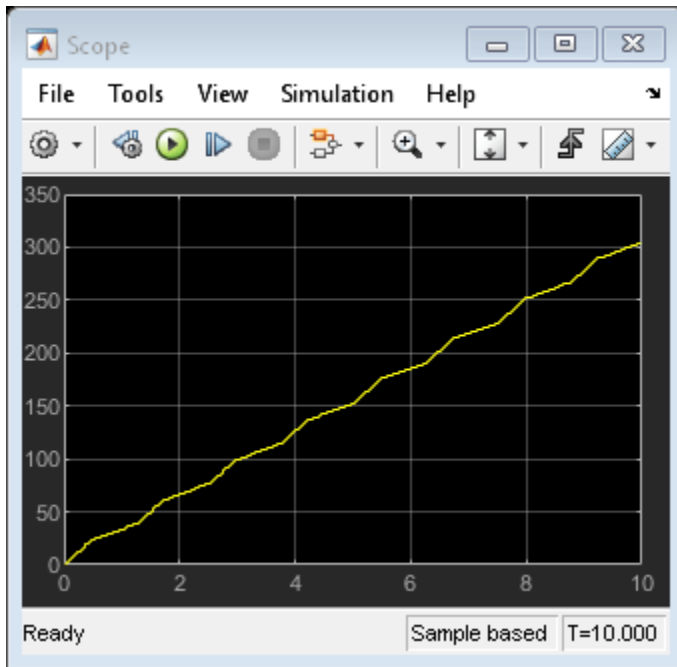


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The Stateflow chart in this model consists of a Simulink algorithm which runs at different rates at different times in the simulation. Stateflow is ideally suited to designing the transition logic which determines when these rate transitions happen. The Simulink algorithm on the other hand is used for the actual data processing. The chart merely passes inputs and outputs to the Simulink subsystem. For the purposes of this example, the Simulink algorithm adds the input to the output each time the chart calls it.



Upon running the simulation, we see the counter counting at varying rates:



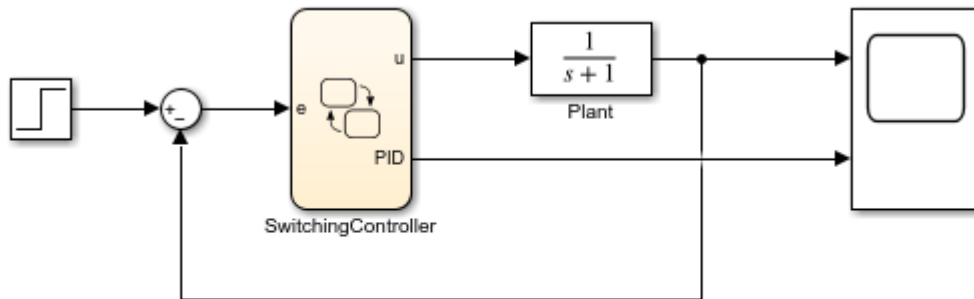
## See Also

## More About

- "Reuse Simulink Components in Stateflow Charts" on page 11-2

## Design Switching Controllers by Using Simulink Functions

This model shows how you can design switching controllers by combining the power of Stateflow® and Simulink® functions.

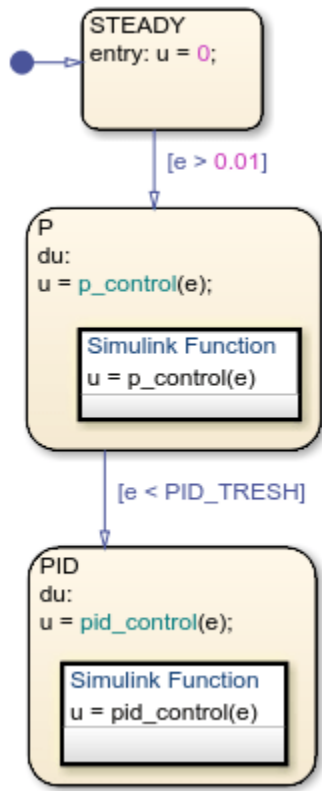


Copyright 2009-2018 The MathWorks, Inc.

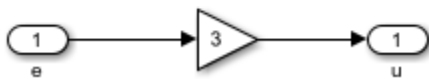
The Stateflow chart `SwitchingController` implements a simple switching controller which switches between three states: `STEADY`, `P` and `PID`. When in `STEADY` state, we produce zero control output. When in `P` or `PID`, we delegate to Simulink function call subsystems in order to compute the required control effort.

The **Create data for monitoring** option for the state `PID` is checked. Therefore, in addition to the control output `u`, the Stateflow chart also produces a logging output with the same name as the state `PID`.

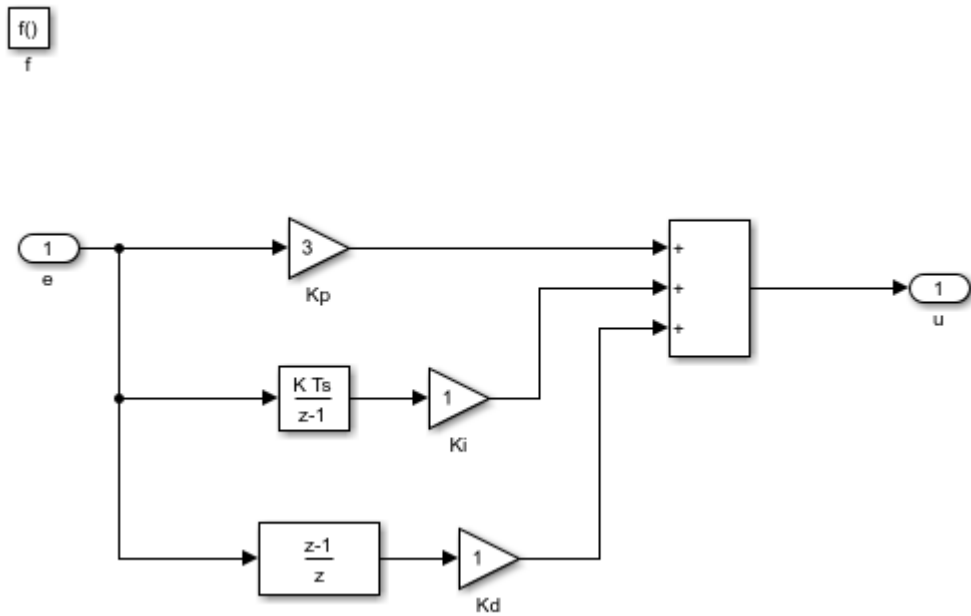
The condition for switching from `P` to `PID` is based on the error being low enough [`e < PID_TRESH`]. `PID_TRESH` is a variable defined in the Model Workspace with a value of 0.3.



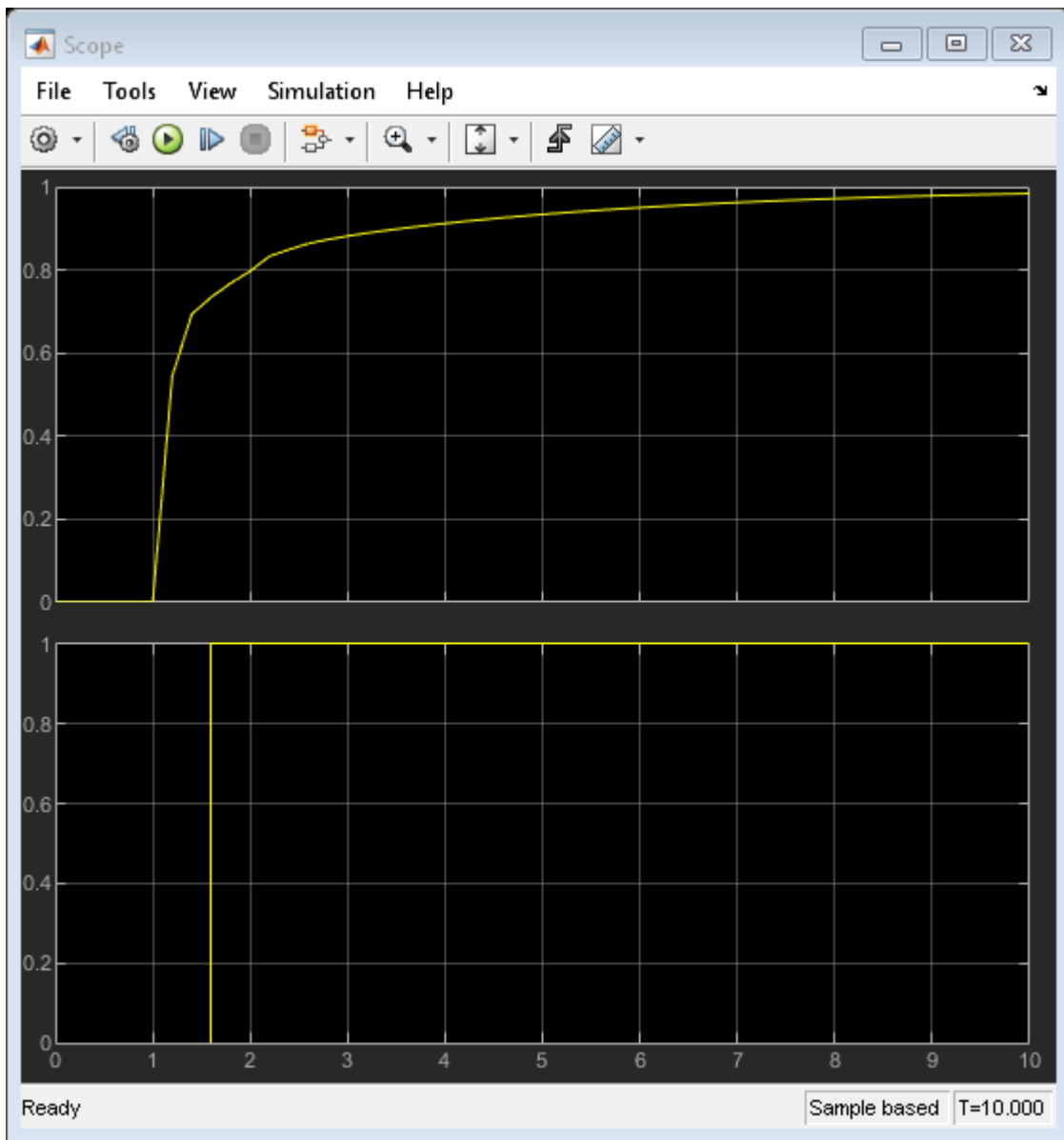
The Simulink subsystem `SwitchingController/P.p_control` implements a very simple proportional control with a gain of 3. If we had continued to stay in the state P, the steady state gain of the closed-loop system would be  $3/4 = 0.75$ . Therefore, we would get an error of 0.25.



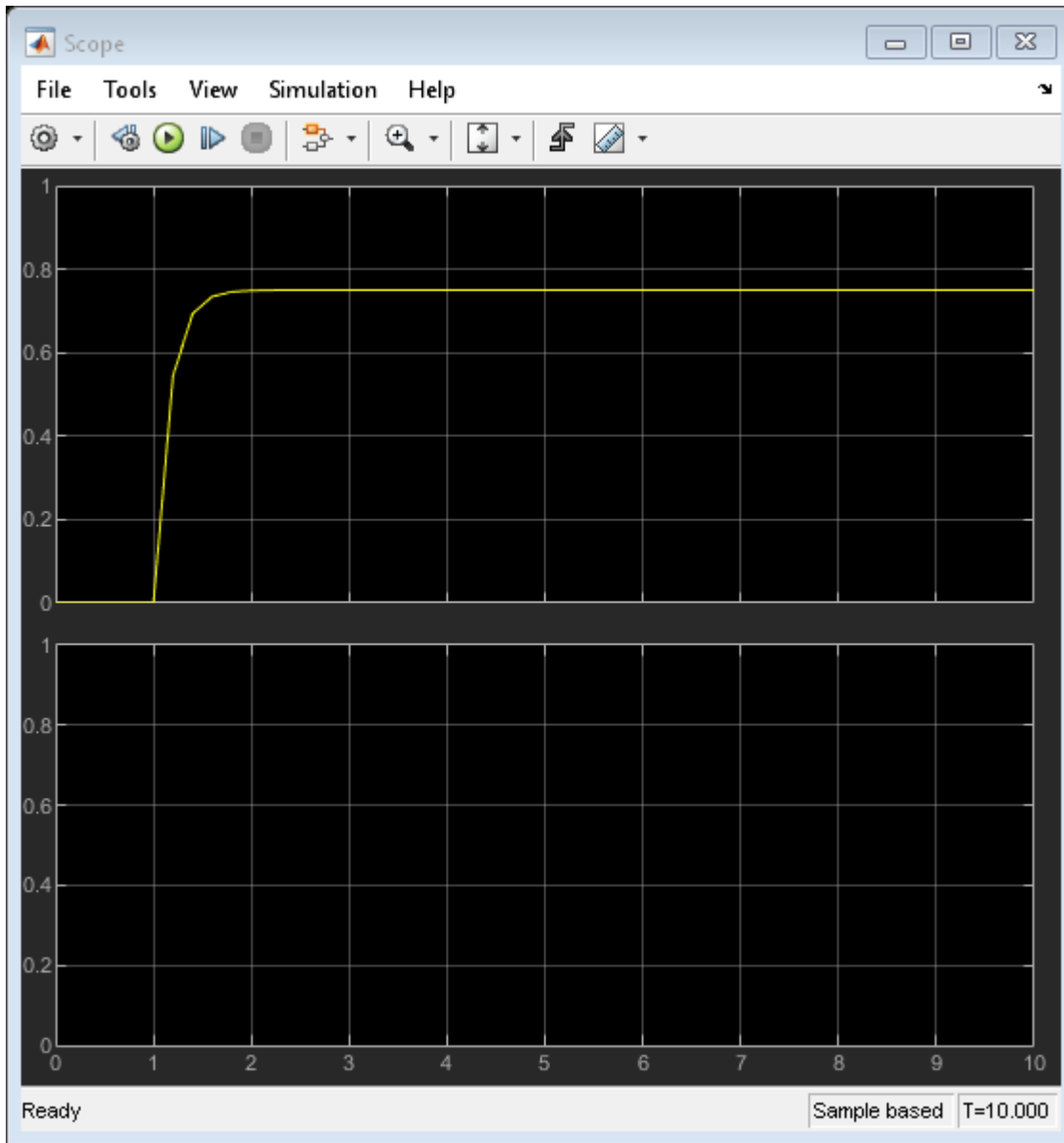
The Simulink subsystem `SwitchingController/PID.pid_control` implements a simple PID control strategy. The proportional gain is the same as in P thereby ensuring a smooth transition in the control effort.



When we simulate the model, we notice that the steady state error approaches zero.



In the absence of the PID control, we would have had a steady state error of 0.25. If we change `PID_TRESH` to 0.1, we will *never* get to PID, because the error will never get below 0.25 as long as we are in state P.



## See Also

### More About

- “Reuse Simulink Components in Stateflow Charts” on page 11-2



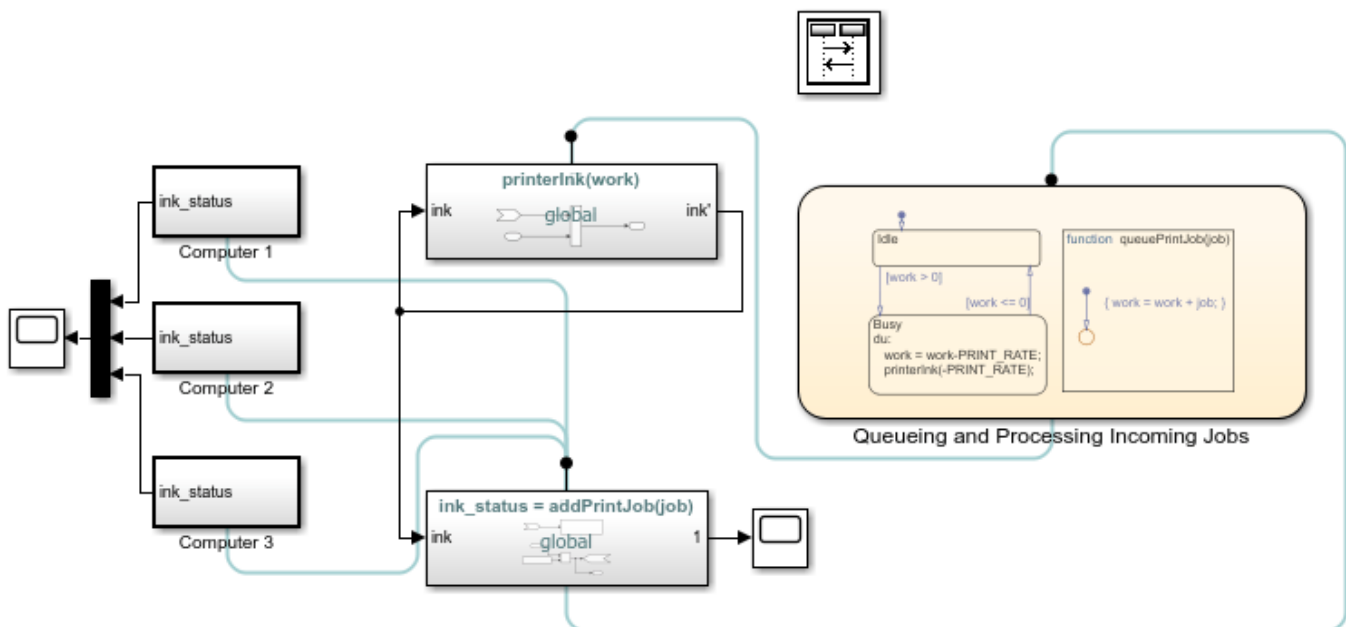
## Share Functions Across Simulink and Stateflow

This example shows how to call functions across Simulink® and Stateflow®. The `slexPrinterExample` model consists of three computer clients that share a printer. Each computer creates print jobs by calling the Simulink function `addPrintJob`.

### Communicate and Share Resources with Functions

In this example, the Stateflow chart communicates with the model by:

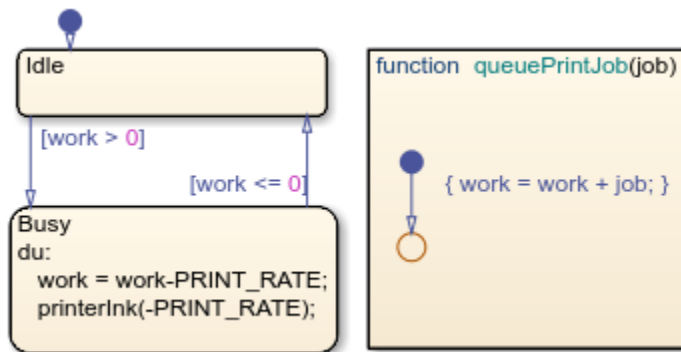
- Defining and exporting a graphical function that is called by Simulink.
- Calling a Simulink function that is defined in Simulink.



Each computer client invokes the printer server with a call to the Simulink function, `addPrintJob`. The `addPrintJob` function calls the Stateflow graphical function `queuePrintJob` to add the print job to the work load. The chart processes the work and calls the Simulink function `printerInk` to model usage of printer `ink`.

### Call a Simulink Function from Stateflow

The function `printerInk` is defined in a Simulink Function block at the top level of the model. The function interface `printerInk(work)` defines one input argument. The Simulink Function, `printerInk`, also interacts with the model with signal lines through the inport `ink` and outport `ink'`. The state `Busy` matches the function signature for `printerInk(work)` by passing one input argument.



### Export Stateflow Functions to Simulink

In the chart *Queuing and Processing Incoming Jobs*, the properties **Export chart level functions** and **Treat exported functions as globally visible** are selected. These properties allow the Simulink function `addPrintJob` to call the chart graphical function, `queuePrintJob`.

### See Also

Simulink Function

### More About

- “Export Stateflow Functions for Reuse” on page 8-23
- “Simulink Functions Overview” (Simulink)
- “Model Reference Basics” (Simulink)

## Why Use a Simulink Function in a Stateflow Chart?

In this section...
“Advantages of Using Simulink Functions in a Stateflow Chart” on page 11-35
“Benefits of Using a Simulink Function to Access Simulink Blocks” on page 11-35
“Benefits of Using a Simulink Function to Schedule Execution of Multiple Controllers” on page 11-37

### Advantages of Using Simulink Functions in a Stateflow Chart

When you define a function that uses Simulink function-call subsystem blocks or schedule execution of multiple controllers without Simulink functions, the model requires these elements:

- Simulink function-call subsystem blocks
- Stateflow chart with function-call output events
- Signal lines between the chart and each function-call subsystem port

Simulink functions in a Stateflow chart provide these advantages:

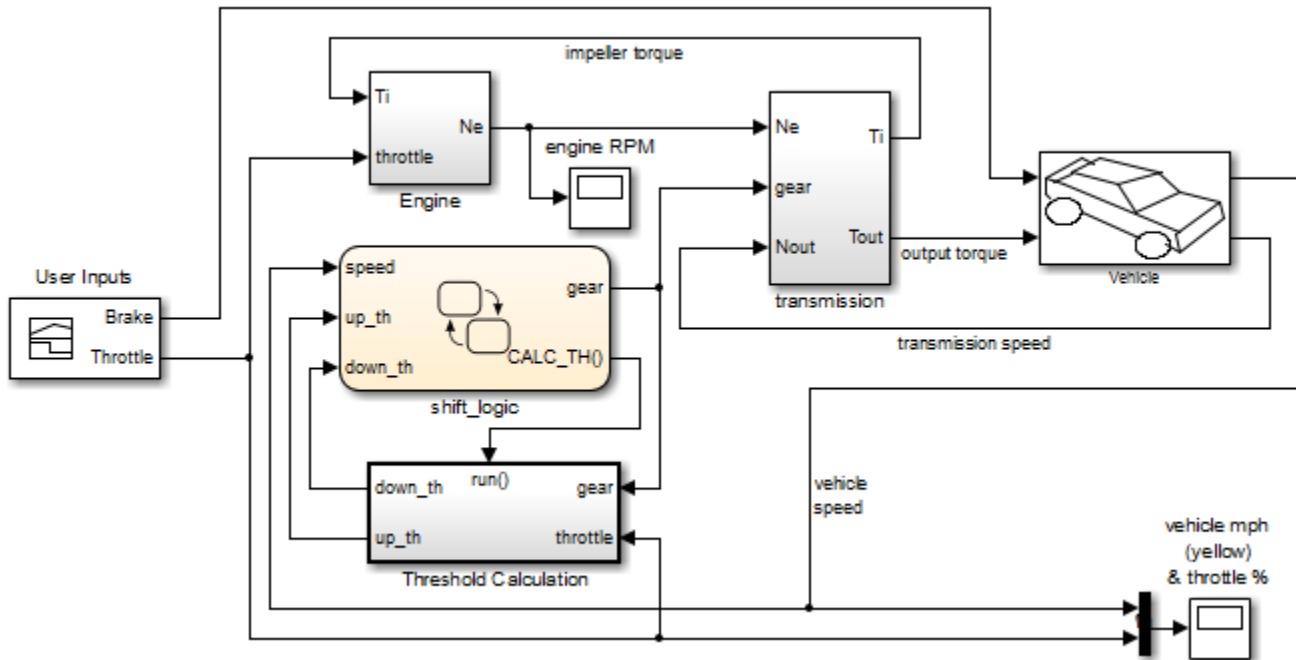
- No function-call subsystem blocks
- No output events
- No signal lines

### Benefits of Using a Simulink Function to Access Simulink Blocks

The sections that follow compare two ways of defining a function that uses Simulink blocks.

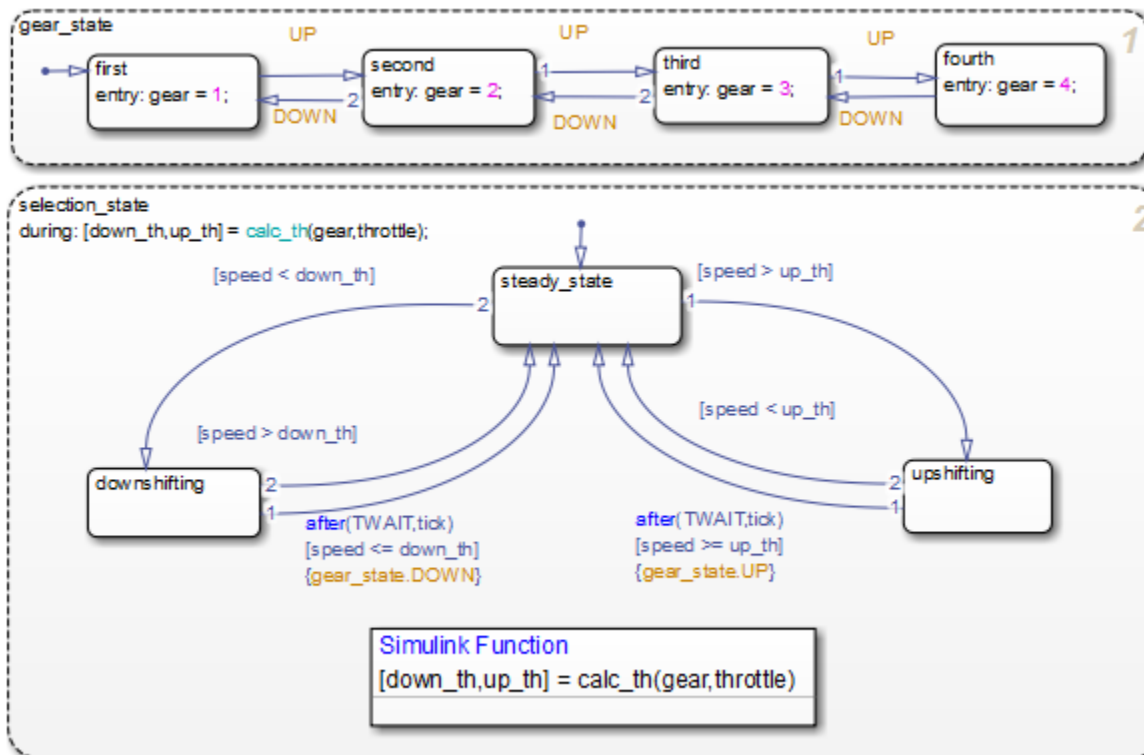
#### Model Method Without a Simulink Function

You define a function-call subsystem in the Simulink model (see “Using Function-Call Subsystems” (Simulink)). Use an output event in a Stateflow chart to call the subsystem, as shown.



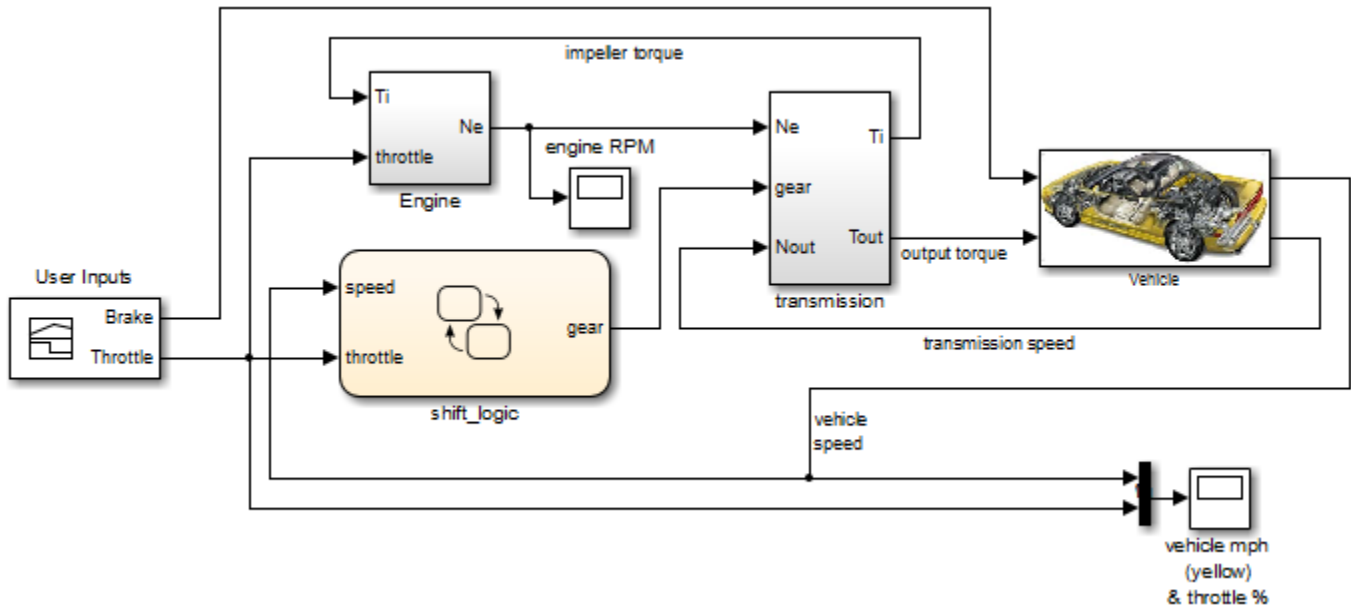
### Model Method With a Simulink Function

You place one or more Simulink blocks in a Simulink function of a Stateflow chart. Use a function call to execute the blocks in that function, as shown.



In the chart, the during action in `selection_state` contains a function call to `calc_th`, which is a function that contains Simulink blocks.

This modeling method minimizes the objects in your model.



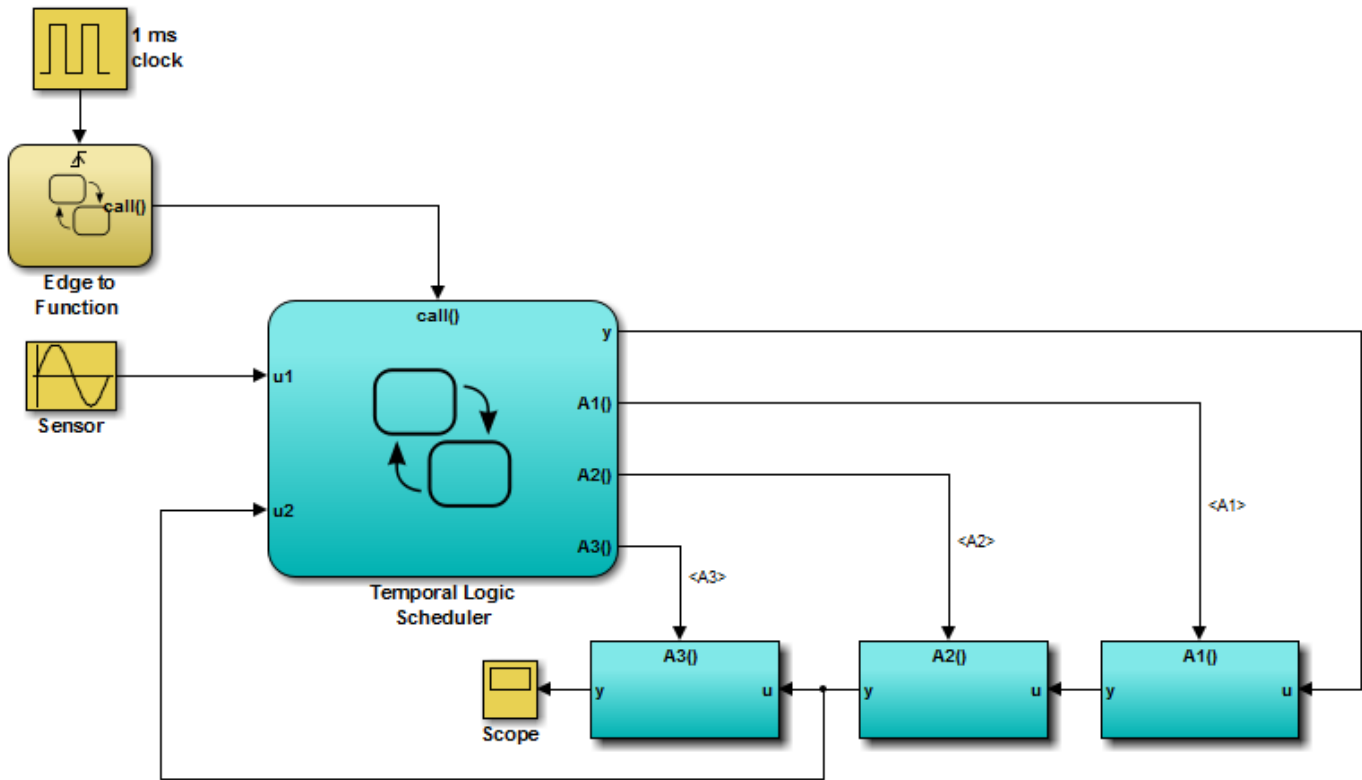
For more information, see “Improve Chart Design by Using Simulink Functions” on page 11-11.

## Benefits of Using a Simulink Function to Schedule Execution of Multiple Controllers

The sections that follow compare two ways of scheduling execution of multiple controllers.

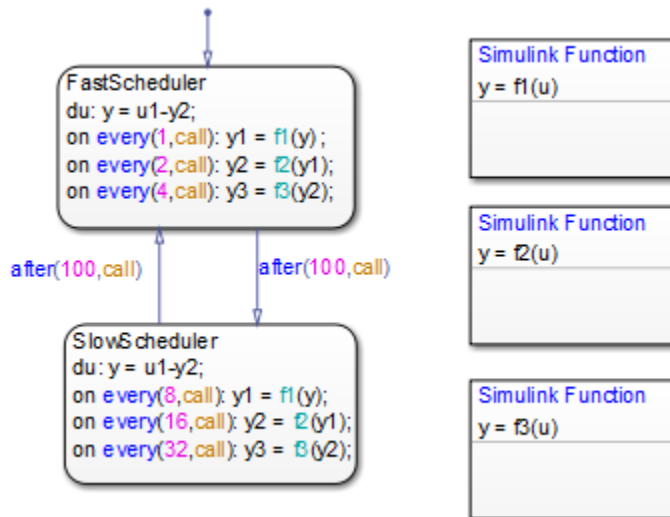
### Model Method Without Simulink Functions

You define each controller as a function-call subsystem block and use output events in a Stateflow chart to schedule execution of the subsystems, as shown in the `sf_temporal_logic_scheduler` model.

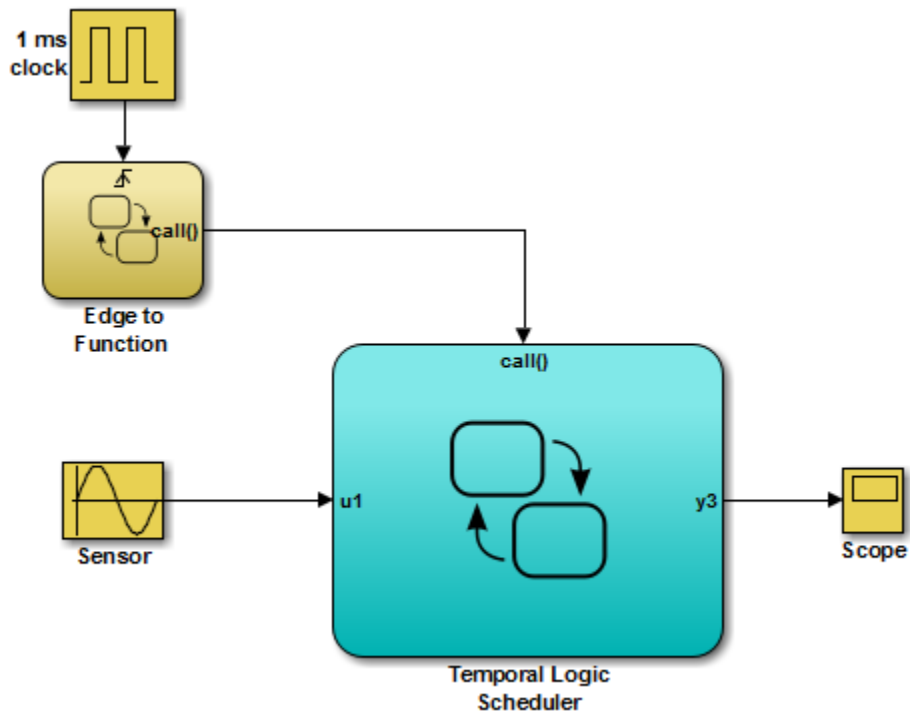


### Model Method With Simulink Functions

You define each controller as a Simulink function in a Stateflow chart and use function calls to schedule execution of the subsystems, as shown in the `sf_temporal_logic_scheduler_with_sl_fcns` model.



This modeling method minimizes the objects in your model.



## See Also

### More About

- “Benefits of Using a Simulink Function to Access Simulink Blocks” on page 11-35
- “Benefits of Using a Simulink Function to Schedule Execution of Multiple Controllers” on page 11-37
- “Schedule Execution of Multiple Controllers” on page 11-19





# Define Data

---

- “Add Stateflow Data” on page 12-2
- “Set Data Properties” on page 12-5
- “Share Data with Simulink and the MATLAB Workspace” on page 12-19
- “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21
- “Access Data Store Memory from a Chart” on page 12-23
- “Specify Type of Stateflow Data” on page 12-27
- “Specify Size of Stateflow Data” on page 12-33
- “Handle Integer Overflow for Chart Data” on page 12-36
- “Identify Data by Using Dot Notation” on page 12-39
- “Resolve Data Properties from Simulink Signal Objects” on page 12-43

## Add Stateflow Data

When you want to store values that are visible at a specific level of the Stateflow hierarchy, add data to your chart.

Data defined in a Stateflow chart is visible by multiple Stateflow objects in the chart, including states, transitions, MATLAB functions, and truth tables. To determine what data is used in a state or transition, right-click the state or transition and select **Explore**. A context menu lists the names and scopes of all resolved symbols in the state or transition. Selecting a symbol from the context menu displays its properties in the Model Explorer. Selecting an output event from the context menu opens the Simulink subsystem or Stateflow chart associated with the event.


---

**Note** Stateflow data is not available to Simulink functions within a Stateflow chart.

---

You can add data to a Stateflow chart by using the Symbols pane, the Stateflow Editor menu, or the Model Explorer.

### Add Data Through the Symbols Pane

- 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane**.
- 2 Click the **Create Data** icon .
- 3 In the row for the new data, under **TYPE**, click the icon and choose:
  - Input Data
  - Local Data
  - Output Data
  - Constant
  - Data Store Memory
  - Parameter
  - Temporary
- 4 Edit the name of the data.
- 5 For input and output data, click the **PORT** field and choose a port number.
- 6 To specify properties for data, open the Property Inspector. In the Symbols pane, right-click the row for the symbol and select **Explore**. For more information, see “Stateflow Data Properties” on page 12-5.

### Add Data by Using the Stateflow Editor Menu

- 1 In a Stateflow chart in a Simulink model, select the menu option corresponding to the scope of the data that you want to add.

Scope	Menu Option
Input	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Data Input</b> .
Output	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Data Output</b> .

Scope	Menu Option
Local	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Local</b> .
Constant	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Constant</b> .
Parameter	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Parameter</b> .
Data Store Memory	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Data Store</b> .

- In the Data dialog box, specify data properties. For more information, see “Stateflow Data Properties” on page 12-5.

## Add Data Through the Model Explorer

To add machine or state-parented data to Stateflow charts in Simulink models, use the Model Explorer:

- In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
- In the **Model Hierarchy** pane, select the object in the Stateflow hierarchy where you want to make the new data visible. The object that you select becomes the parent of the new data.
- In the Model Explorer menu, select **Add > Data**. The new data with a default definition appears in the **Contents** pane of the Model Explorer.
- In the **Data** pane, specify the properties of the data. For more information, see “Stateflow Data Properties” on page 12-5.

## Best Practices for Using Data in Charts

### Avoid Inheriting Output Data Properties from Simulink Blocks

Stateflow output data should not inherit properties from output signals, because the values back propagate from Simulink blocks and can be unpredictable.

### Restrict Use of Machine-Parented Data

Avoid using machine-parented data. The presence of machine-parented data in a model prevents reuse of generated code and other code optimizations. This type of data is also incompatible with many Simulink and Stateflow features.

For example, the following features do not support machine-parented data:

- Enumerated data
- Simulink functions
- Chart operating point
- Implicit change events
- Detection of unused data
- Parameters binding to a `Simulink.Parameter` object in the base workspace
- Model referencing (see “Model Reference Requirements and Limitations” (Simulink) )
- Use of code replacement libraries in code generated by Embedded Coder. For more information, see “Code You Can Replace From Simulink Models” (Embedded Coder).

- Code generation by Simulink PLC Coder™ software
- Analysis by Simulink Design Verifier software

To make Stateflow data accessible to other charts and blocks in a model, use data store memory. For details, see “Access Data Store Memory from a Chart” on page 12-23.

### **See Also**

#### **More About**

- “Set Data Properties” on page 12-5
- “Specify Type of Stateflow Data” on page 12-27
- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2
- “Resolve Undefined Symbols in Your Chart” on page 31-37

## Set Data Properties

When you create Stateflow charts in Simulink, you can specify data properties in either the Property Inspector or the Model Explorer.

- To use the Property Inspector:
  - 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane** and **Property Inspector**.
  - 2 In the Symbols pane, select the data object.
  - 3 In the Property Inspector pane, edit the data properties.
- To use the Model Explorer:
  - 1 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
  - 2 In the **Contents** pane, select the data object.
  - 3 In the **Message** pane, edit the data properties.

You can also specify data properties programmatically by using `Stateflow.Data` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

Properties vary according to the scope and type of the data object. For many data properties, you can enter expressions or parameter values. Using parameters to set properties for many data objects simplifies maintenance of your model because you can update multiple properties by changing a single parameter.

### Stateflow Data Properties

You can set these data properties in:

- The main and **Advanced** sections of the Property Inspector.
- The **General** tab of the Model Explorer.

#### Name

Name of the data object. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

#### Scope

Location where data resides in memory, relative to its parent.

Setting	Description
Local	Data defined in the current chart only.
Constant	Read-only constant value that is visible to the parent Stateflow object and its children.
Parameter	Constant whose value is defined in the MATLAB base workspace or derived from a Simulink block parameter that you define and initialize in the parent masked subsystem. The Stateflow data object must have the same name as the MATLAB variable or the Simulink parameter. For more information, see “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21.

Setting	Description
Input	Input argument to a function if the parent is a graphical function, truth table, or MATLAB function. Otherwise, the Simulink model provides the data to the chart through an input port on the Stateflow block. For more information, see “Share Input and Output Data with Simulink” on page 12-19.
Output	Return value of a function if the parent is a graphical function, truth table, or MATLAB function. Otherwise, the chart provides the data to the Simulink model through an output port on the Stateflow block. For more information, see “Share Input and Output Data with Simulink” on page 12-19.
Data Store Memory	Data object that binds to a Simulink data store, which is a signal that functions like a global variable. All blocks in a model can access that signal. This binding allows the chart to read and write to the Simulink data store, sharing global data with the model. The Stateflow object must have the same name as the Simulink data store. For more information, see “Access Data Store Memory from a Chart” on page 12-23.
Temporary	Data that persists during only the execution of a function. For C charts, you can define temporary data only for a graphical function, truth table, or MATLAB function.
Exported	Data from the Simulink model that is made available to external code defined in the Stateflow hierarchy. You can define exported data only for a Stateflow machine.
Imported	Data parented by the Simulink model that you define in external code embedded in the Stateflow machine. You can define imported data only for a Stateflow machine.

**Port**

Index of the port associated with the data object. This property applies only to input and output data. See “Share Input and Output Data with Simulink” on page 12-19.

**Update Method**

Specifies whether a variable updates in discrete or continuous time. This property applies only when the chart is configured for continuous-time simulation. See “Continuous-Time Modeling in Stateflow” on page 25-2.

**Data Must Resolve to Signal Object**

Specifies that output or local data explicitly inherits properties from `Simulink.Signal` objects of the same name in the MATLAB base workspace or the Simulink model workspace. The data can inherit these properties:

- Size
- Complexity
- Type
- Unit
- Minimum value

- Maximum value
- Initial value
- Storage class
- Sampling mode (for Truth Table block output data)

This option is available only when you set the model configuration parameter **Signal resolution** to a value other than **None**. For more information, see “Resolve Data Properties from Simulink Signal Objects” on page 12-43.

## Size

Size of the data object. The size can be a scalar value or a MATLAB vector of values.

- To specify a scalar, set the **Size** property to 1 or leave the field blank.
- To specify an  $n$ -by-1 column vector, set the **Size** property to  $n$ .
- To specify a 1-by- $n$  row vector, set the **Size** property to  $[1 \ n]$ .
- To specify an  $n$ -by- $m$  matrix, set the **Size** property to  $[n \ m]$ .
- To specify an  $n$ -dimensional array, set the **Size** property to  $[d_1 \ d_2 \ \dots \ d_n]$ , where  $d_i$  is the size of the  $i^{\text{th}}$  dimension.
- To configure a Stateflow data object to inherit its size from the corresponding Simulink signal or from its definition in the chart, specify a size of  $-1$ .

The scope of the data object determines what sizes you can specify. Stateflow data store memory inherits all its properties, including its size, from the Simulink data store to which it is bound. For all other scopes, size can be scalar, vector, or a matrix of  $n$ -dimensions. For more information, see “Specify Size of Stateflow Data” on page 12-33.

You can specify data size through a MATLAB expression that evaluates to a valid size specification. For more information, see “Specify Data Size by Using Expressions” on page 12-34 and “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

## Variable Size

Specifies that the data object changes dimensions during simulation. This option is available for input and output data only when you enable the chart property **Support variable-size arrays**. For more information, see “Declare Variable-Size Data in Stateflow Charts” on page 22-2.

## Complexity

Specifies whether the data object accepts complex values.

Setting	Description
Off	Data object does not accept complex values.
On	Data object accepts complex values.
Inherited	Data object inherits the complexity setting from a Simulink block.

The default value is **Off**. For more information, see “Complex Data in Stateflow Charts” on page 27-2.

**First Index**


Index of the first element of the data array. The first index can be any integer. The default value is 0. This property is available only for C charts.

**Type**

Type of data object. To specify the data type:

- From the **Type** drop-down list, select a built-in type.
- In the **Type** field, enter an expression that evaluates to a data type. Use one of these expressions:
  - A call to the `fixdt` function to create a `Simulink.NumericType` object that describes a fixed-point or floating-point data type. See “Specify Fixed-Point Data” on page 26-2.
  - A call to the `type` operator to specify the type of previously defined data. See “Derive Data Types from Other Data Objects” on page 12-30.
  - A `Simulink.AliasType` object that defines a data type alias in the MATLAB base workspace. See “Specify Data Types by Using a Simulink Alias” on page 12-31.

For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

Additionally, in the Model Explorer, you can open the Data Type Assistant by clicking the **Show data type assistant** button . Specify a data **Mode**, and then specify the data type based on that mode. For more information, see “Specify Type of Stateflow Data” on page 12-27.

---

**Note** If you enter an expression for a fixed-point data type, you must specify scaling explicitly. For example, you cannot enter an incomplete specification such as `fixdt(1,16)` in the **Type** field. If you do not specify scaling explicitly, an error appears when you try to simulate your model.

---

**Lock Data Type Against Fixed-Point Tools**

Prevents replacement of the current fixed-point type with an autoscaled type chosen by the Fixed-Point Tool (Fixed-Point Designer). For more information, see “Autoscaling Using the Fixed-Point Tool” (Fixed-Point Designer).

**Unit (e.g., m, m/s<sup>2</sup>, N\*m)**

Specifies physical units for input and output data. For more information, see “Specify Units for Stateflow Data” on page 28-17.

**Initial Value**

Initial value of the data object. For constant data, this property is called **Constant value**. The options for specifying this property depend on the scope of the data object.



Scope	Specify for Initial Value
Local	<p>Expression or parameter defined in the Stateflow hierarchy, MATLAB base workspace, or Simulink masked subsystem. To specify the initial value when you leave the <b>Initial value</b> field blank, open the Model Explorer or the Data properties dialog box and set the <b>Initial value</b> drop-down list to Expression or Parameter.</p> <ul style="list-style-type: none"> <li>• <b>Expression</b> — Numeric data resolves to a default value of 0. For enumerated data, the default value typically is the first one listed in the <b>enumeration</b> section of the definition. You can specify a different default enumerated value in the <b>methods</b> section of the definition. For more information, see “Define Enumerated Data Types” on page 23-5.</li> <li>• <b>Parameter</b> — The data object resolves to a variable in the base workspace with the same name.</li> </ul> <p>The default setting is Expression.</p>
Constant	<p>Constant value or expression. The expression is evaluated when you update the chart. The resulting value is used as a constant for running the chart.</p> <p>When you leave the <b>Constant value</b> field blank, numeric data resolves to a default value of 0. For enumerated data, the default value typically is the first one listed in the <b>enumeration</b> section of the definition. You can specify a different default enumerated value in the <b>methods</b> section of the definition. For more information, see “Define Enumerated Data Types” on page 23-5.</p>
Parameter	<p>You cannot enter a value. The chart inherits the initial value from the parameter.</p>
Input	<p>You cannot enter a value. The chart inherits the initial value from the Simulink input signal at the designated port.</p>
Output	<p>Expression or parameter defined in the Stateflow hierarchy, MATLAB base workspace, or Simulink masked subsystem. To specify the initial value when you leave the <b>Initial value</b> field blank, open the Model Explorer or the Data properties dialog box and set the <b>Initial value</b> drop-down list to Expression or Parameter.</p> <ul style="list-style-type: none"> <li>• <b>Expression</b> — Numeric data resolves to a default value of 0. For enumerated data, the default value typically is the first one listed in the <b>enumeration</b> section of the definition. You can specify a different default enumerated value in the <b>methods</b> section of the definition. For more information, see “Define Enumerated Data Types” on page 23-5.</li> <li>• <b>Parameter</b> — The data object resolves to a variable in the base workspace with the same name.</li> </ul> <p>The default setting is Expression.</p>
Data Store Memory	<p>You cannot enter a value. The chart inherits the initial value from the Simulink data store to which it resolves.</p>

For more information on using an expression to specify an initial value, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

### Limit Range

Range of acceptable values for this data object. Stateflow charts use this range to validate the data object during simulation.

- **Minimum** — The smallest value allowed for the data item during simulation. You can enter an expression or parameter that evaluates to a numeric scalar value.
- **Maximum** — The largest value allowed for the data item during simulation. You can enter an expression or parameter that evaluates to a numeric scalar value.

The smallest value that you can set for **Minimum** is `-inf`. The largest value that you can set for **Maximum** is `inf`.

You can specify the minimum and maximum values through a MATLAB expression. For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

---

**Note** A Simulink model uses the **Limit range** properties to calculate best-precision scaling for fixed-point data types. Before you select **Calculate Best-Precision Scaling**, specify a minimum or maximum value. For more information, see “Calculate Best-Precision Scaling” on page 12-13.

---

### Add to Watch Window

Enables watching the data values in the Stateflow Breakpoints and Watch window. For more information, see “View Data in the Breakpoints and Watch Window” on page 33-11.

### Fixed-Point Data Properties

In the Model Explorer, when you set the Data Type Assistant **Mode** to **Fixed point**, the Data Type Assistant displays fields for specifying additional information about your fixed-point data.

### Signedness

Specifies whether the fixed-point data is Signed or Unsigned. Signed data can represent positive and negative values. Unsigned data represents positive values only. The default setting is Signed.

### Word Length

Specifies the bit size of the word that holds the quantized integer. Large word sizes represent large values with greater precision than small word sizes. The default value is 16.

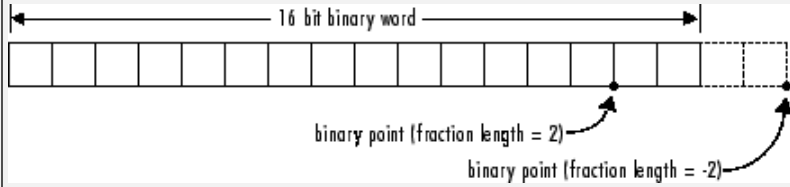
- Word length can be any integer from 0 through 128 for chart-level data of these scopes:
  - Input

- Output
- Parameter
- Data Store Memory
- For other Stateflow data, word length can be any integer from 0 through 32.

You can specify the word length through a MATLAB expression. For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

### Scaling

Specifies the method for scaling your fixed-point data to avoid overflow conditions and minimize quantization errors. The default method is Binary point scaling.

Setting	Description
Binary point	<p>If you select this mode, the Data Type Assistant displays the <b>Fraction length</b> field, which specifies the binary point location.</p> <p><b>Fraction length</b> can be any integer. The default value is 0. A positive integer moves the binary point left of the rightmost bit by that amount. A negative integer moves the binary point farther right of the rightmost bit.</p>  <p>The diagram shows a horizontal row of 16 boxes representing bits. Above the boxes, a double-headed arrow spans the entire row and is labeled "16 bit binary word". Below the boxes, two arrows point to specific bit positions. The first arrow points to the 14th bit from the left (the 3rd bit from the right) and is labeled "binary point (fraction length = 2)". The second arrow points to the 2nd bit from the right and is labeled "binary point (fraction length = -2)".</p>
Slope and bias	<p>If you select this mode, the Data Type Assistant displays fields for entering the <b>Slope</b> and <b>Bias</b> for the fixed-point encoding scheme.</p> <p><b>Slope</b> can be any positive real number. The default value is 1.0.</p> <p><b>Bias</b> can be any real number. The default value is 0.0.</p> <p>You can enter slope and bias as expressions that contain parameters you define in the MATLAB base workspace.</p>

Whenever possible, use binary-point scaling to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data that use binary-point scaling are performed with simple bit shifts and eliminate expensive code implementations required for separate slope and bias values. For more information about fixed-point scaling, see “Scaling” (Fixed-Point Designer).

You can specify **Fraction length**, **Slope**, and **Bias** through a MATLAB expression. For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

### Data Type Override

Specifies whether to inherit the data type override setting of the Fixed-Point Tool that applies to this model. If the data does not inherit the model-wide setting, the specified data type applies.

### Calculate Best-Precision Scaling

Specifies whether to calculate the best-precision values for **Binary point** and **Slope** and **bias** scaling, based on the values in the **Minimum** and **Maximum** fields in the **Limit range** section.

To calculate best-precision scaling values:

- 1 Specify **Limit range** properties.
- 2 Click **Calculate Best-Precision Scaling**.

The best-precision scaling values are displayed in the **Fraction length** field or the **Slope** and **Bias** fields. For more information, see “Maximize Precision” (Fixed-Point Designer).

---

**Note** The **Limit range** properties do not apply to **Constant** and **Parameter** scopes. For **Constant**, Simulink software calculates the scaling values based on the **Initial value** setting. The software cannot calculate best-precision scaling for data of **Parameter** scope.

---

### Show Fixed-Point Details

Displays information about the fixed-point data type that is defined in the Data Type Assistant:

- **Minimum** and **Maximum** show the same values that appear in the corresponding **Minimum** and **Maximum** fields in the **Limit range** section.
- **Representable minimum**, **Representable maximum**, and **Precision** show the minimum value, maximum value, and precision that the fixed-point data type can represent.

If the value of a field cannot be determined without first compiling the model, the **Fixed-point details** subpane shows the value as **Unknown**.

**Data data**

General | Logging | Description

Name: data

Scope: Local

Data must resolve to signal object

Size:

Complexity: Off

Type: fixdt(1,16,0) <<

**Data Type Assistant**

Mode: Fixed point Signedness: Signed Word length: 16

Scaling: Binary point Fraction length: 0

Data type override: Inherit Calculate Best-Precision Scaling

**Fixed-point details**

Representable maximum: 32767

Maximum: 10000

Minimum: -20

Representable minimum: -32768

Precision: 1 Refresh Details

Lock data type against Fixed-Point tools

Initial value: Expression

Limit range

Minimum: -20 Maximum: 10000

[Add to Watch Window](#)

OK Cancel Help Apply

The values displayed by the **Fixed-point details** subpane *do not* automatically update if you change the values that define the fixed-point data type. To update the values shown in the **Fixed-point details** subpane, click **Refresh Details**.

Clicking **Refresh Details** does not modify the model. It changes only the display. To apply the displayed values, click **Apply** or **OK**.

The **Fixed-point details** subpane indicates any error resulting from the fixed-point data type specification. For example, this figure shows two errors.

The screenshot shows the 'Data data' dialog box with the 'General' tab selected. The 'Name' is 'data', 'Scope' is 'Local', and 'Complexity' is 'Off'. The 'Type' is 'fixdt(1,16,0)'. The 'Data Type Assistant' section shows 'Mode' as 'Fixed point', 'Signedness' as 'Signed', 'Word length' as '16', 'Scaling' as 'Binary point', and 'Fraction length' as '0'. The 'Fixed-point details' section is expanded, showing the following information:

Representable maximum:	32767	
Maximum:	50000	Outside representable range by 17233 (17233 x precision)
Minimum:	MySymbol	Cannot evaluate
Representable minimum:	-32768	

The 'Precision' is 1. A 'Refresh Details' button is visible. At the bottom, there are 'OK', 'Cancel', 'Help', and 'Apply' buttons.

The row labeled **Maximum** indicates that the value specified in the **Maximum** field of the **Limit range** section is not representable by the fixed-point data type. To correct the error, make one of these modifications so the fixed-point data type can represent the maximum value:

- Decrease the value in the **Maximum** field of the **Limit range** section.
- Increase **Word length**.
- Decrease **Fraction length**.

The row labeled **Minimum** shows the error `Cannot evaluate` because evaluating the expression `MySymbol`, specified in the **Minimum** field of the **Limit range** section, does not return a numeric value. When an expression does not evaluate successfully, the **Fixed-point details** subpane shows the unevaluated expression (truncating to 10 characters as needed) in place of the unavailable value. To correct this error, define `MySymbol` in the base workspace to provide a numeric value. If you click **Refresh Details**, the error indicator and description are removed and the value of `MySymbol` appears in place of the unevaluated text.

## Logging Properties

You can set logging properties for data in:

- The **Logging** section of the Property Inspector.
- The **Logging** tab of the Model Explorer.

### Log Signal Data

Saves the data value to the MATLAB base workspace during simulation. For more information, see “Log Simulation Output for States and Data” on page 33-43.

### Test Point

Designates the data as a test point. A test point is a signal that you can observe in a Floating Scope block in a model. Data objects can be test points if:

- Scope is `Local`.
- Parent is not a Stateflow machine.
- Data type is not `mL`.

For more information, see “Monitor Test Points in Stateflow Charts” on page 33-39.

### Logging Name

Specifies the name associated with logged signal data. Simulink software uses the signal name as its logging name by default. To specify a custom logging name, select `Custom` from the list box and enter the new name in the adjacent edit field.

### Limit Data Points to Last

Limits the amount of data logged to the most recent samples.

### Decimation

Limits the amount of data logged by skipping samples. For example, a decimation factor of 2 saves every other sample.

## Additional Properties

You can set additional data properties in:



- The **Info** tab of the Property Inspector.
- The **Description** tab of the Model Explorer.

### Save Final Value to Base Workspace

Assigns the value of the data object to a variable of the same name in the MATLAB base workspace at the end of simulation. This option is available only in the Model Explorer for charts that use C as the action language. For more information, see “Model Workspaces” (Simulink).

### Units

Units of measurement associated with the data object. The unit in this field resides with the data object in the Stateflow hierarchy. This property is available only in the Model Explorer for C charts.

### Description

Description of the data object. You can enter brief descriptions of data in the hierarchy.

### Document Link

Link to online documentation for the data object. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow evaluates the link and displays the documentation.

## Default Data Property Values

When you leave a property field blank, Stateflow assumes a default value.

Property		Default Value
“Size” on page 12-7		-1 (inherited), for inputs, parameters, and function outputs 1 (scalar), for other data objects
“First Index” on page 12-8		0
“Initial Value” on page 12-8		0.0
“Limit Range” on page 12-10	<b>Minimum</b>	-inf
	<b>Maximum</b>	inf
“Fixed-Point Data Properties” on page 12-10	<b>Word length</b>	16
	<b>Fraction length</b>	0
	<b>Slope</b>	1.0
	<b>Bias</b>	0.0

## Specify Data Properties by Using MATLAB Expressions

In the Property Inspector and Model Explorer, you can enter MATLAB expressions as values for these properties:

- “Size” on page 12-7
- “Type” on page 12-8
- “Initial Value” on page 12-8
- “Limit Range” on page 12-10: **Minimum** and **Maximum**
- “Fixed-Point Data Properties” on page 12-10: **Word length**, **Fraction length**, **Slope**, and **Bias**

Expressions can contain a mix of numeric values, constants, parameters, variables, arithmetic operations, parameters, constants, arithmetic operators, and calls to MATLAB functions. For example, you can use these functions to specify data properties.

Property	Function	Description
<b>Size</b>	size	Returns the size of a data object
<b>Type</b>	type on page 12-30	Returns the type of a data object
	fixdt	Returns a Simulink.NumericType object that describes a fixed-point or floating-point data type
	fi	Returns a fixed-point numeric object
<b>Minimum</b>	min	Returns the smallest element or elements of an array
<b>Maximum</b>	max	Returns the largest element or elements of an array

For more information, see “Specify Data Size by Using Expressions” on page 12-34 and “Derive Data Types from Other Data Objects” on page 12-30.

## See Also

Simulink.AliasType | Simulink.NumericType | fi | fixdt | max | min | size

## More About

- “Add Stateflow Data” on page 12-2
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Specify Type of Stateflow Data” on page 12-27
- “Specify Size of Stateflow Data” on page 12-33

## Share Data with Simulink and the MATLAB Workspace

Stateflow charts interface with the other blocks in a Simulink model by:

- Sharing data through input and output connections.
- Importing initial data values from the MATLAB base workspace.
- Saving final data values to the MATLAB base workspace.

Charts also can access Simulink parameters and data stores. For more information, see “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21 and “Access Data Store Memory from a Chart” on page 12-23.

### Share Input and Output Data with Simulink

Data flows from Simulink into a Stateflow chart through input ports. Data flows from a Stateflow chart into Simulink through output ports.

To define input or output data in a chart:

- 1 Add a data object to the chart, as described in “Add Stateflow Data” on page 12-2.
- 2 Set the **Scope** property for the data object.
  - To define input data, set **Scope** to **Input Data**. An input port appears on the left side of the chart block.
  - To define output data, set **Scope** to **Output Data**. An output port appears on the right side of the chart block.

By default, **Port** values appear in the order in which you add data objects. You can change these assignments by modifying the **Port** property of the data. When you change the **Port** property for an input or output data object, the **Port** values for the remaining input or output data objects automatically renumber.

- 3 Set the data type of the data object, as described in “Specify Type of Stateflow Data” on page 12-27.
- 4 Set the size of the data object, as described in “Specify Size of Stateflow Data” on page 12-33.

---

**Note** You cannot set the type or size of Stateflow input data to accept frame-based data from Simulink.

---

### Initialize Data from the MATLAB Base Workspace

You can import the initial value of a data symbol by defining it in the MATLAB base workspace and in the Stateflow hierarchy.

- 1 Define and initialize a variable in the MATLAB base workspace.
- 2 In the Stateflow hierarchy, define a data object with the same name as the MATLAB variable.
- 3 Select the **Allow initial value to resolve to a parameter** property for the data object.

When the simulation starts, data resolution occurs. During this process, the Stateflow data object gets its initial value from the associated MATLAB variable.

One-dimensional Stateflow arrays are compatible with MATLAB row and column vectors of the same size. For example, a Stateflow vector of size 5 is compatible with a MATLAB row vector of size [1, 5] or column vector of size [5, 1]. Each element of the Stateflow array initializes to the same value as the corresponding element of the array in the MATLAB base workspace.

The time of initialization depends on the data parent and scope of the Stateflow data object.

Data Parent	Scope	Initialization Time
Machine	Local, Exported	Start of simulation
	Imported	Not applicable
Chart	Input	Not applicable
	Output, Local	Start of simulation or when chart reinitializes as part of an enabled Simulink subsystem
State with History Junction	Local	Start of simulation or when chart reinitializes as part of an enabled Simulink subsystem
State without History Junction	Local	State activation
Function (graphical, truth table, and MATLAB functions)	Input, Output	Function-call invocation
	Local	Start of simulation or when chart reinitializes as part of an enabled Simulink subsystem

## Save Data to the MATLAB Base Workspace

At the end of simulation, a Stateflow chart that uses C as the action language can save the final value of a data object to the MATLAB base workspace.

- 1 Open the Model Explorer. In the **Modeling** tab, select **Model Explorer**.
- 2 Double-click the data object in the **Contents** pane.
- 3 In the **Description** pane of the Data properties dialog box, select **Save final value to base workspace**.

This option is available for data symbols of all scopes except Constant and Parameter.

## See Also

### More About

- “Add Stateflow Data” on page 12-2
- “Set Data Properties” on page 12-5
- “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21
- “Access Data Store Memory from a Chart” on page 12-23

## Share Parameters with Simulink and the MATLAB Workspace

A parameter is a constant data object that you can:

- Define in the MATLAB base workspace.
- Derive from a Simulink block parameter that you define and initialize in a mask.

Use parameters to avoid hard-coding data values and properties. Share Simulink parameters with charts to maintain consistency with your Simulink model.

You can access parameter values in multiple Stateflow objects in a chart such as states, MATLAB functions, and truth tables. You can include parameters in expressions defining data properties such as:

- Size
- Type
- Initial Value
- Minimum and Maximum
- Fixed-Point Data Properties

For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17

### Initialize Parameters from the MATLAB Base Workspace

You can initialize a parameter by defining it in the MATLAB base workspace and in the Stateflow hierarchy.

- 1 Define and initialize a variable in the MATLAB base workspace.
- 2 In the Stateflow hierarchy, define a data object with the same name as the MATLAB variable.
- 3 Set the scope of the Stateflow data object to **Parameter**.

When the simulation starts, data resolution occurs. During this process, the Stateflow parameter gets its value from the associated MATLAB variable.

### Share Simulink Parameters with Charts

You can share a parameter from a Simulink subsystem containing a Stateflow chart by creating a mask for the subsystem.

- 1 In the Simulink mask editor for the parent subsystem, define and initialize a Simulink parameter.
- 2 In the Stateflow hierarchy, define a data object with the same name as the Simulink parameter.
- 3 Set the scope of the Stateflow data object to **Parameter**.

When the simulation starts, Simulink tries to resolve the Stateflow data object to a parameter at the lowest-level masked subsystem. If unsuccessful, Simulink moves up the model hierarchy to resolve the data object to a parameter at higher-level masked subsystems.

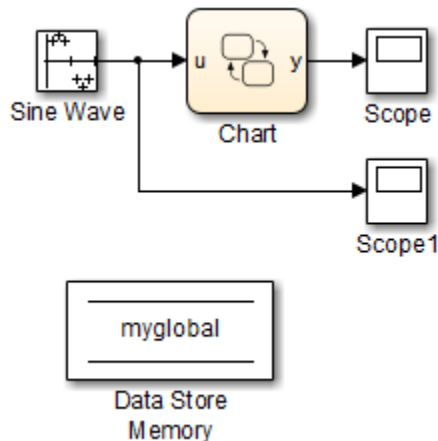
### See Also

### More About

- “Create a Mask to Share Parameters with Simulink” on page 28-14
- “Add Stateflow Data” on page 12-2
- “Set Data Properties” on page 12-5

## Access Data Store Memory from a Chart

A Simulink model implements global variables as data stores, either as Data Store Memory blocks or as instances of Simulink.Signal objects. You can use data stores to share data between multiple Simulink blocks without explicit input or output connections to pass data from one block to another. Stateflow charts share global data with Simulink models by reading from and writing to data store memory symbolically.



To access global data from a chart, bind a Stateflow data object to a Simulink data store. After you create the binding, the Stateflow data object becomes a symbolic representation of the Simulink data store memory. You can then use this symbolic object to store and retrieve global data.

### Local and Global Data Store Memory

Stateflow charts can interface with local and global data stores.

- Local data stores are visible to all blocks in one model. To interact with a local data store, a chart must reside in the model where you define the local data store. You can define a local data store by adding a Data Store Memory block to a model or by creating a Simulink signal object.
- Global data stores have a broader scope that crosses model reference boundaries. To interact with global data stores, a chart must reside in the top model where you define the global data store or in a model that the top model references. You implement global data stores as Simulink signal objects.

For more information, see “Local and Global Data Stores” (Simulink).

### Bind Stateflow Data to Data Stores

- 1 To define the Simulink data store memory, add a Data Store Memory block to your model or create a Simulink signal object. For more information, see “Data Stores with Data Store Memory Blocks” (Simulink) and “Data Stores with Signal Objects” (Simulink).
- 2 Add a data object to the Stateflow chart, as described in “Add Stateflow Data” on page 12-2.
- 3 Set the **Name** property as the name of the Simulink data store memory to which you want to bind the Stateflow data object.

#### 4 Set the **Scope** property to Data Store Memory.

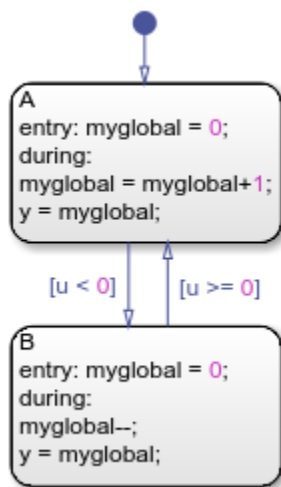
The Stateflow data object inherits all additional properties from the data store memory to which you bind the object.

Multiple local and global data stores with the same name can exist in the same model hierarchy. In this situation, the Stateflow data object binds to the data store that is the nearest ancestor.

## Store and Retrieve Global Data

After binding a Stateflow data object to a Simulink data store, you can store and retrieve global data in state and transition actions. The data object acts as a global variable that you reference by its symbolic name. When you store numeric values in this variable, you are writing to the Simulink data store memory. When you retrieve numeric values from this variable, you are reading from the data store memory.

For example, in this chart, the state actions read from and write to a Data Store Memory block called `myglobal`.



## Best Practices for Using Data Stores

### Data Store Properties in Charts

When you bind a Stateflow data object to a data store, the Stateflow object inherits all of its properties from the data store. To ensure that properties propagate correctly, when you create the Simulink data stores:

- Specify a data type other than `auto`.
- Minimize the use of automatic-mode properties.

### Share Data Store Memory Across Multiple Models

To access a global data store from multiple models:

- Verify that your models do not contain any Data Store Memory blocks. You can include Data Store Read and Data Store Write blocks.



- In the MATLAB base workspace, create a `Simulink.Signal` object with these attributes:
  - Set **Data type** to an explicit data type. The data type cannot be `Auto`.
  - Fully specify **Dimensions**. The signal dimensions cannot be `-1` or `Inherited`.
  - Fully specify **Complexity**. The complexity cannot be `Auto`.
  - Set **Storage class** to `ExportedGlobal`.
- In each chart that shares the data, bind a Stateflow data object to the Simulink data store.

### Write to Data Store Memory Before Reading

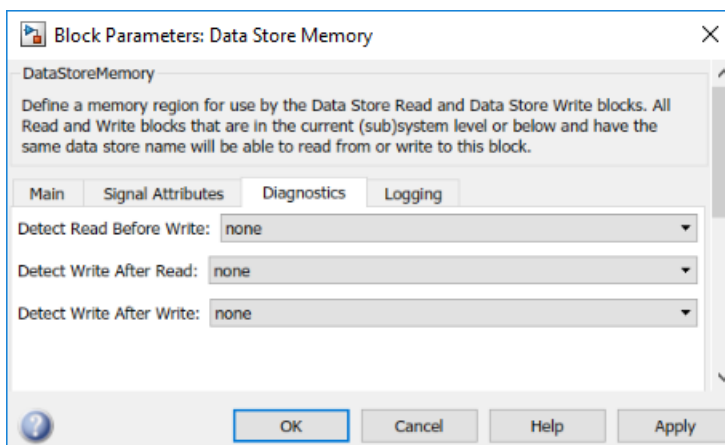
To avoid algorithm latency, write to data store memory before reading from it. Otherwise, the read actions retrieve the value that was stored in the previous time step, rather than the value computed and stored in the current time step. When unconnected blocks share global data while running at different rates:

- Segregate read actions into separate blocks from write actions.
- Assign priorities to blocks so that your model invokes write blocks before read blocks. For more information, see “Control and Display Execution Order” (Simulink).

To avoid situations when multiple reads and writes occur unintentionally in the same time step, enable the Data Store Memory block diagnostics to:

- **Detect Read Before Write**
- **Detect Write After Read**
- **Detect Write After Write**

If you use a data store memory block as a persistent global storage area for accumulating values across time steps, avoid unnecessary warnings by disabling the Data Store Memory block diagnostics. For more information, see “Data Store Diagnostics” (Simulink).



### See Also

Data Store Read | Data Store Write | Data Store Memory | `Simulink.Signal`

### More About

- “Add Stateflow Data” on page 12-2

- “Data Store Basics” (Simulink)
- “Model Global Data by Creating Data Stores” (Simulink)
- “Data Store Diagnostics” (Simulink)
- “Control and Display Execution Order” (Simulink)


## Specify Type of Stateflow Data

The term data type refers to how computers represent information in memory. The data type determines the amount of storage allocated to data, the method of encoding a data value as a pattern of binary digits, and the operations available for manipulating the data.

### Specify Data Type by Using the Data Type Assistant

You can specify the type of a data object in either the Property Inspector or the Model Explorer. In the **Type** field, select a type from the drop-down list or enter an expression that evaluates to a data type. For more information, see “Set Data Properties” on page 12-5.

Alternatively, use the Data Type Assistant to specify a data **Mode** and select the data type based on that mode:

- 1 In the Model Explorer, on the **Data** pane, click the **Show data type assistant** button .
- 2 Select a **Mode** from the drop-down list. The list of available modes depends on the scope of the data object.

Scope	Modes
Local	Inherit (available only in charts that use MATLAB as the action language), Built in, Fixed point, Enumerated, Bus object, Expression
Constant	Built in, Fixed point, Expression
Parameter	Inherit, Built in, Fixed point, Enumerated, Bus object, Expression
Input	Inherit, Built in, Fixed point, Enumerated, Bus object, Expression
Output	Inherit, Built in, Fixed point, Enumerated, Bus object, Expression
Data Store Memory	Inherit

- 3 Specify additional information based on the mode. The Data Type Assistant populates the **Type** field based on your specification.

Mode	Data Types
Inherit	<p>You cannot specify a data type. You inherit the data type based on the scope that you select for the data object:</p> <ul style="list-style-type: none"> <li>• For charts that use MATLAB as the action language, if scope is <code>Local</code>, the data infers its type from the context of the MATLAB code in the chart.</li> <li>• If the scope is <code>Parameter</code>, the data inherits its type from the associated parameter, which you can define in the Simulink model or in the MATLAB base workspace. See “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21.</li> <li>• If the scope is <code>Input</code>, the data inherits its type from the Simulink input signal on the designated input port. See “Share Input and Output Data with Simulink” on page 12-19.</li> <li>• If the scope is <code>Output</code>, the data inherits its type from the Simulink output signal on the designated output port. See “Share Input and Output Data with Simulink” on page 12-19.</li> </ul> <hr/> <p><b>Note</b> Avoid inheriting data types from output signals. See “Avoid Inheriting Output Data Properties from Simulink Blocks” on page 12-3.</p> <ul style="list-style-type: none"> <li>• If the scope is <code>Data Store Memory</code>, the data inherits its type from the Simulink data store to which you bind the data object. See “Access Data Store Memory from a Chart” on page 12-23.</li> </ul> <p>For more information, see “Inherit Data Types from Simulink Objects” on page 12-30.</p>

Mode	Data Types
Built in	<p>Specify a data type from the drop-down list of supported data types:</p> <ul style="list-style-type: none"> <li>• <b>double</b>: 64-bit double-precision floating point.</li> <li>• <b>single</b>: 32-bit single-precision floating point.</li> <li>• <b>half</b>: A half-precision data type occupies 16 bits of memory, but its floating-point representation enables it to handle wider dynamic ranges than integer or fixed-point data types of the same size. See “The Half-Precision Data Type in Simulink” (Fixed-Point Designer).</li> <li>• <b>int64</b>: 64-bit signed integer.</li> <li>• <b>int32</b>: 32-bit signed integer.</li> <li>• <b>int16</b>: 16-bit signed integer.</li> <li>• <b>int8</b>: 8-bit signed integer.</li> <li>• <b>uint64</b>: 64-bit unsigned integer.</li> <li>• <b>uint32</b>: 32-bit unsigned integer.</li> <li>• <b>uint16</b>: 16-bit unsigned integer.</li> <li>• <b>uint8</b>: 8-bit unsigned integer.</li> <li>• <b>boolean</b>: Boolean (1 = true; 0 = false).</li> <li>• <b>ml</b>: Typed internally with the MATLAB array <code>mxArray</code>. Supported only in charts that use C as the action language. The <code>ml</code> data type provides Stateflow data with the benefits of the MATLAB environment, including the ability to assign the Stateflow data object to a MATLAB variable or pass it as an argument to a MATLAB function. <code>ml</code> data cannot have a scope outside the Stateflow hierarchy. That is, it cannot have a scope of <code>Input</code> or <code>Output</code>. For more information, see “<code>ml</code> Data Type” on page 16-23.</li> <li>• <b>string</b>: String. Supported only in charts that use C as the action language. For more information, see “Manage Textual Information by Using Strings” on page 24-2.</li> </ul>
Fixed point	<p>Specify this information about the fixed-point data:</p> <ul style="list-style-type: none"> <li>• <b>Signedness</b>: Whether the data is signed or unsigned</li> <li>• <b>Word Length</b>: Bit size of the word that holds the quantized integer. Large word sizes represent large values with greater precision than small word sizes. The default value is 16.</li> <li>• <b>Scaling</b>: Method for scaling your fixed-point data to avoid overflow conditions and minimize quantization errors. The default method is <code>Binary point</code>.</li> </ul> <p>For information, see “Fixed-Point Data Properties” on page 12-10.</p>
Enumerated	<p>Specify the class name for the enumerated data type. For more information, see “Define Enumerated Data Types” on page 23-5.</p>
Bus object	<p>Specify the name of a <code>Simulink.Bus</code> object to associate with the Stateflow bus object structure. Click <b>Edit</b> to create or edit a bus object in the Bus Editor. You can also inherit bus object properties from Simulink signals.</p>

Mode	Data Types
Expression	<p>Specify an expression that evaluates to a data type. Use one of these expressions:</p> <ul style="list-style-type: none"> <li>• A call to the <code>fixdt</code> function to create a <code>Simulink.NumericType</code> object that describes a fixed-point or floating-point data type. See “Specify Fixed-Point Data” on page 26-2.</li> <li>• A call to the <code>type</code> operator to specify the type of previously defined data. See “Derive Data Types from Other Data Objects” on page 12-30.</li> <li>• A <code>Simulink.AliasType</code> object that defines a data type alias in the MATLAB base workspace. See “Specify Data Types by Using a Simulink Alias” on page 12-31.</li> </ul> <p>For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.</p>

- 4 To save the data type settings, click **Apply**.

The Data Type Assistant is available only through the Model Explorer.

## Inherit Data Types from Simulink Objects

When you select **Inherit: Same as Simulink** from the **Type** drop-down list, data objects of scope **Input**, **Output**, **Parameter**, and **Data Store Memory** inherit their data types from Simulink objects.

Scope	Description
Input	Inherits type from the Simulink input signal connected to corresponding input port in chart.
Output	Inherits type from the Simulink output signal connected to corresponding output port in chart.  Avoid inheriting data types from output signals. Values that back-propagate from Simulink blocks can be unpredictable.
Parameter	Inherits type from the corresponding MATLAB base workspace variable or Simulink parameter in a masked subsystem.
Data Store Memory	Inherits type from the corresponding Simulink data store.

To determine the data types that the objects inherit:

- 1 Build the Simulink model.
- 2 Open the Model Explorer.
- 3 In the **Contents** pane, examine the **CompiledType** column.

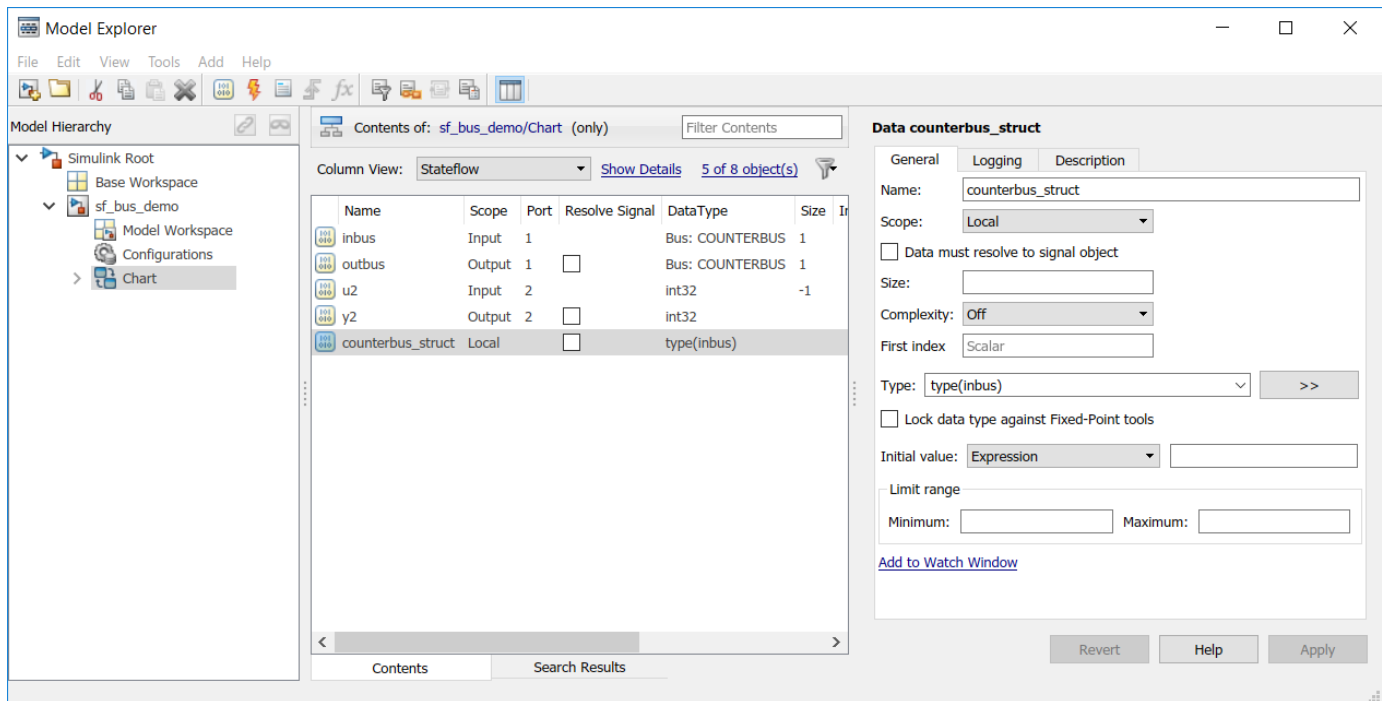
## Derive Data Types from Other Data Objects

You can use the `type` operator to derive data types from other Stateflow data objects:

```
type(data_obj)
```

For example, in the model `sf_bus_demo`, the expression `type(inbus)` returns the data type of the input structure `inbus`. Because `inbus` derives its type from the `Simulink.Bus` object `COUNTERBUS`,

the data type of the local structure `counterbus_struct` also derives its data type from `COUNTERBUS`.



After you build your model, the **CompiledType** column of the Model Explorer shows the type used in the compiled simulation application.

## Specify Data Types by Using a Simulink Alias

You can specify the type of Stateflow data by using a Simulink data type alias. For more information, see `Simulink.AliasType`.

For example, suppose that you want to define a data type alias `MyFloat` that corresponds to the built-in data type `single`. At the MATLAB command prompt, enter:

```
MyFloat = Simulink.AliasType;
MyFloat.BaseType = 'single';
```

To use this alias to specify the type of a data object, select the object in the Property Inspector or the Model Explorer. In the **Type** field, enter the alias name `MyFloat`.

After you build your model, the **CompiledType** column of the Model Explorer shows the type used in the compiled simulation application.

## Strong Data Typing with Simulink Inputs and Outputs

By default, the **Use Strong Data Typing with Simulink I/O** chart property allows C charts to interface directly with signals from Simulink models. The chart accepts only input signals whose data type matches the type of the corresponding Stateflow data object. Otherwise, a type mismatch error occurs. For example, by selecting **Use Strong Data Typing with Simulink I/O**, you can flag

mismatches between input or output fixed-point data in charts and their counterparts in Simulink models. For more information, see “Specify Properties for Stateflow Charts” on page 28-2.

If you clear the **Use Strong Data Typing with Simulink I/O** chart property, the chart converts inputs signals of type `double` to the type of the corresponding input data object in the chart. The chart converts output data objects to type `double` before exporting them as output signals to Simulink models.

---

**Note** The **Use Strong Data Typing with Simulink I/O** chart property is provided for backward compatibility. Clearing this check box can produce unpredictable results and is not recommended.

---

### See Also

`Simulink.AliasType` | `Simulink.NumericType` | `fixdt`

### More About

- “Set Data Properties” on page 12-5
- “Specify Properties for Stateflow Charts” on page 28-2
- “About Data Types in Simulink” (Simulink)



## Specify Size of Stateflow Data

In a Stateflow chart in a Simulink model, you specify the size of a data object by:

- Setting the **Size** property, as described in “Set Data Properties” on page 12-5. For more information, see “Size” on page 12-7.
- Setting the `Props.Array.Size` property through the Stateflow API. For more information, see `Stateflow.Data`.

Use one of these methods to specify the size:

- Inherit the size from a Simulink signal or from its definition in the Stateflow chart.
- Enter a numeric value.
- Enter a MATLAB expression.

Support for each sizing method depends on the scope of your data.

Scope of Data	Method for Sizing Data		
	Inherit the Size	Use Numeric Values	Use MATLAB Expressions
Local	Only in charts that use MATLAB as the action language	Yes	Yes
Constant	No	Yes	Yes
Parameter	Yes	Yes	Yes
Input	Yes	Yes	Yes
Output	Yes	Yes	Yes
Data store memory	Yes	No	No

### Inherit Data Size

To configure a Stateflow data object to inherit its size from the corresponding Simulink signal or its definition in the chart, specify a size of `-1`. After you simulate or build your model, you can find the inherited size of the data in the Model Explorer, under the **Compiled Size** column.

---

**Note** Charts cannot inherit data sizes from Simulink frame-based signals. For more information, see “Sample- and Frame-Based Concepts” (DSP System Toolbox).

---

### Specify Data Size by Using Numeric Values

When you specify data size by entering a numeric value, follow these guidelines:

- To specify a scalar, enter 1 or leave the field blank.
- To specify an  $n$ -by-1 column vector, enter  $n$ .
- To specify a 1-by- $n$  row vector, enter  $[1 \ n]$ .
- To specify an  $n$ -by- $m$  matrix, enter  $[n \ m]$ .

- To specify an  $n$ -dimensional array, enter  $[d_1 \ d_2 \ \dots \ d_n]$ , where  $d_i$  is the size of the  $i^{\text{th}}$  dimension.

In charts that use C as the action language, one-dimensional Stateflow vectors are compatible with Simulink row or column vectors of the same size. For example, a Stateflow input data of size 3 is compatible with a Simulink row vector of size  $[1 \ 3]$  or a column vector of size  $[3 \ 1]$ .

## Specify Data Size by Using Expressions

You can specify data size by entering a MATLAB expression that evaluates to one of the size specifications described in “Specify Data Size by Using Numeric Values” on page 12-33. These guidelines also apply:

- Expressions can contain a mix of numeric values, constants, parameters, variables, arithmetic operations, and calls to MATLAB functions.
- Expressions that specify the size of a dimension must evaluate to a positive integer value.
- Expressions can only combine compatible values. For example, integers can only be combined with other integers of the same type or with scalar doubles.
- If the expression contains an enumerated value, you must include the type prefix for consistency with MATLAB naming rules. For example, `Colors.Red` is valid but `Red` is not. For more information, see “Notation for Enumerated Values” on page 23-3.
- You cannot use a MATLAB expression to:
  - Specify inherited data size. Do not use expressions that evaluate to `-1`.
  - Specify the size of Stateflow input data that accepts frame-based data from Simulink. For more information, see “Sample- and Frame-Based Concepts” (DSP System Toolbox).

### Examples of Valid Data Size Expressions

These examples are valid MATLAB expressions for specifying data size in your chart:

- `K+3`, where `K` is a chart-level Stateflow constant or parameter.
- `N/2`, where `N` is a variable in the MATLAB base workspace.
- `[P Q]`, where `P` and `Q` are Simulink parameters. Charts that use C as the action language propagate these symbolic dimensions throughout the model. See “Propagate Symbolic Dimensions of Stateflow Data” on page 12-35.
- `2*Colors.Red`, where `Red` is an enumerated value of type `Colors`.
- `size(u)`, where `u` is a chart-level variable. The function `size` enables you to specify the size of one data object based on the size of another data object. This type of expression is useful in a library chart that you reuse with data of different sizes. In other situations, you can improve the clarity of your chart by avoiding the `size` function and specifying the size of the data directly.
- `floor((a*b)/c)`, where `a` and `c` are scalars of type `int16` and `b` is a scalar of type `double`.
- `[fi(2,1,16,2) fi(4,1,16,2)]`. This expression specifies a data size of  $[2 \ 4]$  by calling the function `fi`. This function returns signed fixed-point numbers with a word length of 16 and a fraction length of 2.

### Avoid Variables That Can Lead to Naming Conflicts

When a model contains multiple variables with identical names, the variable with the highest priority is used to specify size.

Priority	Variable
1	Mask parameter
2	Model workspace variable
3	MATLAB base workspace variable
4	Stateflow data

To avoid confusion, do not specify data size by using a variable name that you define in multiple levels of your model.

### Propagate Symbolic Dimensions of Stateflow Data

When you select the model configuration parameter **Allow symbolic dimension specification**, charts that use C as the action language can propagate the symbolic dimensions of Stateflow data throughout the model. If you have Embedded Coder, the symbolic dimensions go into the generated code for ERT targets. Specify the size of the symbolic dimensions by using Simulink parameters with one of these storage classes:

- Define or ImportedDefine with a specified header file
- CompilerFlag
- A user-defined custom storage class that defines data as a macro in a specified header file

For more information, see “Allow symbolic dimension specification” (Simulink) and “Implement Dimension Variants for Array Sizes in Generated Code” (Embedded Coder).

Stateflow charts that use MATLAB as the action language do not support symbolic dimension propagation. To specify data size by using Simulink parameters, clear the **Allow symbolic dimension specification** check box.

### See Also

fi | size

### More About

- “Vectors and Matrices in Stateflow Charts” on page 21-2
- “Stateflow Data Properties” on page 12-5
- “Reference Values by Name by Using Enumerated Data” on page 23-2

## Handle Integer Overflow for Chart Data

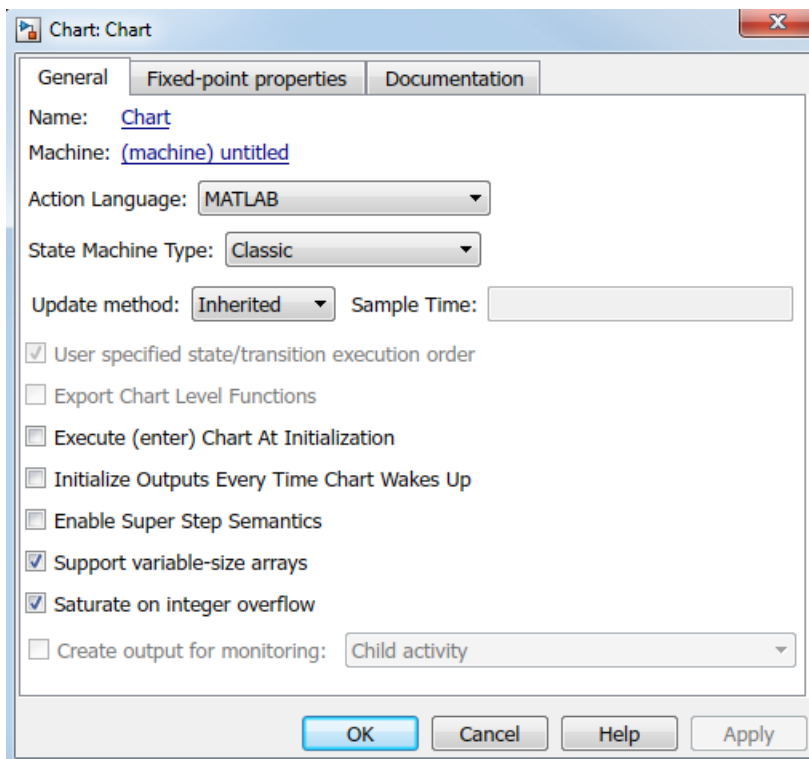
### When Integer Overflow Can Occur

For some arithmetic operations, a processor may need to take an  $n$ -bit fixed-point value and store it in  $m$  bits, where  $m \neq n$ . If  $m < n$ , the reduced range of the value can cause an overflow for an arithmetic operation. Some processors identify this overflow as Inf or NaN. Other processors, especially digital signal processors (DSPs), handle overflows by saturating or wrapping the value.

For more information about saturation and wrapping for integer overflow, see “Saturation and Wrapping” (Fixed-Point Designer).

### Support for Handling Integer Overflow in Charts

For Stateflow charts in Simulink models, you can control whether or not saturation occurs for integer overflow. Use the chart property, **Saturate on integer overflow**, to control overflow handling.



Check Box	When to Use This Setting	Overflow Handling	Example of the Result
Selected	Overflow is possible for data in your chart and you want explicit saturation protection in the generated code.	Overflows saturate to either the minimum or maximum value that the data type can represent.	An overflow associated with a signed 8-bit integer saturates to -128 or +127 in the generated code.

Check Box	When to Use This Setting	Overflow Handling	Example of the Result
Cleared	You want to optimize efficiency of the generated code.	The handling of overflows depends on the C compiler that you use for generating code.	The number 130 does not fit in a signed 8-bit integer and wraps to -126 in the generated code.

Arithmetic operations for which you can enable saturation protection are:

- Unary minus: `-a`
- Binary operations: `a + b`, `a - b`, `a * b`, `a / b`, `a ^ b`
- Assignment operations: `a += b`, `a -= b`, `a *= b`, `a /= b`
- In C charts, increment and decrement operations: `++`, `--`

When you select **Saturate on integer overflow**, be aware that:

- Saturation applies to all intermediate operations, not just the output or final result.
- The code generator can detect some cases when overflow is not possible. In these cases, the generated code does not include saturation protection.

To determine whether clearing the **Saturate on integer overflow** check box is a safe option, perform a careful analysis of your logic, including simulation if necessary. If saturation is necessary in only some sections of the logic, encapsulate that logic in atomic subcharts or MATLAB functions and define a different set of saturation settings for those units.

## Effect of Integer Promotion Rules on Saturation

Charts use ANSI<sup>®</sup> C rules for integer promotion.

- All arithmetic operations use a data type that has the same word length as the target word size. Therefore, the intermediate data type in a chained arithmetic operation can be different from the data type of the operands or the final result.
- For operands with integer types smaller than the target word size, promotion to a larger type of the same word length as the target size occurs. This implicit cast occurs before any arithmetic operations take place.

For example, when the target word size is 32 bits, an implicit cast to `int32` occurs for operands with a type of `uint8`, `uint16`, `int8`, or `int16` before any arithmetic operations occur.

Suppose that you have the following expression, where `y`, `u1`, `u2`, and `u3` are of `uint8` type:

```
y = (u1 + u2) - u3;
```

Based on integer promotion rules, that expression is equivalent to the following statements:

```
uint8_T u1, u2, u3, y;
int32_T tmp, result;
tmp = (int32_T) u1 + (int32_T) u2;
result = tmp - (int32_T) u3;
y = (uint8_T) result;
```

For each calculation, the following data types and saturation limits apply.

Calculation	Data Type	Saturation Limits
tmp	int32	(MIN_INT32, MAX_INT32)
result	int32	(MIN_INT32, MAX_INT32)
y	uint8	(MIN_UINT8, MAX_UINT8)

Suppose that u1, u2, and u3 are equal to 200. Because the saturation limits depend on the intermediate data types and not the operand types, you get the following values:

- tmp is 400.
- result is 200.
- y is 200.

### Impact of Saturation on Error Checks

Suppose that you set **Wrap on overflow** in the **Diagnostics: Data Validity** pane of the Model Configuration Parameters dialog box to error or warning. When you select **Saturate on integer overflow**, Stateflow does not flag cases of integer overflow during simulation. However, Stateflow continues to flag the following situations:

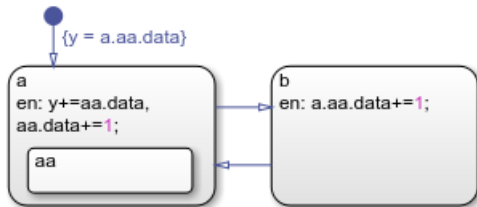
- Out-of-range data violations based on minimum and maximum range checks
- Division-by-zero operations

## Identify Data by Using Dot Notation

To specify the path from the parent state to a data object, a qualified data name uses dot notation. Dot notation is a way to identify data at a specific level of the Stateflow chart hierarchy. The first part of a qualified data name identifies the parent object. Subsequent parts identify the children along a hierarchical path.

For example, in this chart, the symbol `data` resides in the substate `aa` of the state `a`. The state and transition actions use qualified data names to refer to this symbol.

- In the default transition, the action uses the qualified data name `a.aa.data` to specify a path from the chart to the top-level state `a`, to the substate `aa`, and finally to `data`.
- In state `a`, the entry action uses the qualified data name `aa.data` to specify a path from the substate `aa` to `data`.
- In state `b`, the entry action uses the qualified data name `a.aa.data` to specify a path from the chart to the state `a`, to the substate `aa`, and then to `data`.



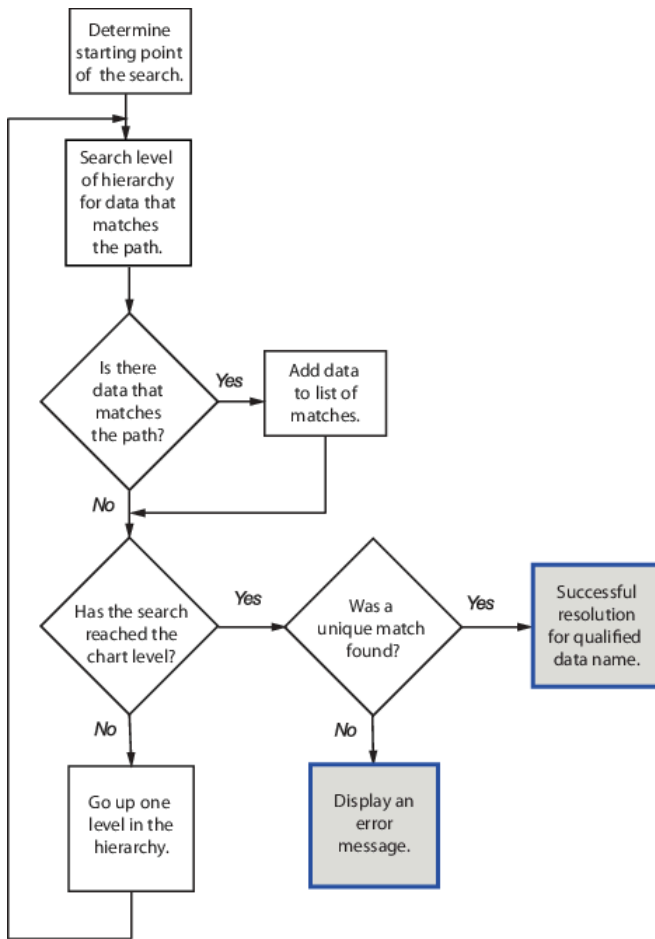
## Resolution of Qualified Data Names

During simulation, Stateflow resolves the qualified data name by performing a localized search of the chart hierarchy for a matching data object. The search begins at the hierarchy level where the qualified data name appears:

- For a state action, the starting point is the state containing the action.
- For a transition label, the starting point is the parent of the transition source.

The resolution process searches each level of the chart hierarchy for a path to the data. If a data object matches the path, the process adds that data object to the list of possible matches. Then, the process continues the search one level higher in the hierarchy. The resolution process stops after it searches the chart level of the hierarchy. If a unique match exists, the qualified data name resolves to the matching path. Otherwise, the resolution process fails. Simulation stops, and you see an error message.

This flow chart illustrates the different stages in the process for resolving qualified data names.



## Best Practices for Using Dot Notation

Resolving qualified data names:

- Does not perform an exhaustive search of all data.
- Does not stop after finding the first match.

To improve the chances of finding a unique search result when resolving qualified data names:

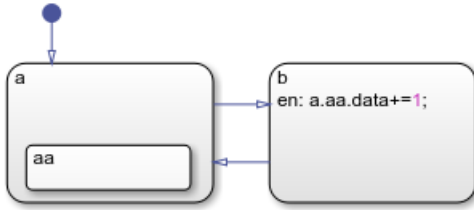
- Use specific paths in qualified data names.
- Give states unique names.
- Use states and boxes as enclosures to limit the scope of the path resolution search.

## Examples of Qualified Data Name Resolution

### Search Produces No Matches

In this chart, the entry action in state **b** contains the qualified data name `aa.data`. If the symbol `data` resides in state `aa`, then Stateflow cannot resolve the qualified data name.





This table lists the different stages in the resolution process for the qualified data name `aa.data`.

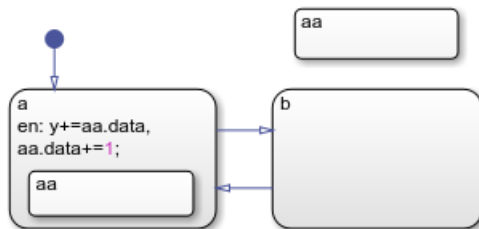
Stage	Description	Result
1	Starting in state <code>b</code> , search for an object <code>aa</code> that contains <code>data</code> .	No match found.
2	Move up to the next level of the hierarchy (the chart level). Search for an object <code>aa</code> that contains <code>data</code> .	No match found.

The search ends at the chart level with no match found for `aa.data`, resulting in an error.

To avoid this error, in the entry action of state `b`, specify the data with the more specific qualified data name `a.aa.data`.

### Search Produces Multiple Matches

In this chart, the entry action in state `a` contains two instances of the qualified data name `aa.data`. If both states named `aa` contain a data object named `data`, then Stateflow cannot resolve the qualified data name.



This table lists the different stages in the resolution process for the qualified data name `aa.data`.

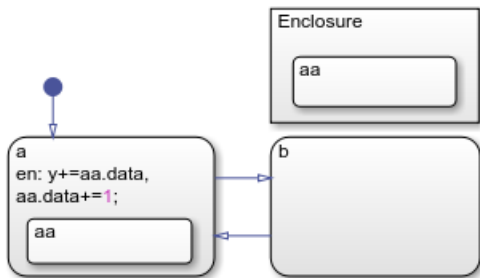
Stage	Description	Result
1	Starting in state <code>a</code> , search for an object <code>aa</code> that contains <code>data</code> .	Match found.
2	Move up to the next level of the hierarchy (the chart level). Search for an object <code>aa</code> that contains <code>data</code> .	Match found.

The search ends at the chart level with two matches found for `aa.data`, resulting in an error.

To avoid this error:

- Use a more specific qualified data name. For instance:
  - To specify the data object in the substate of state `a`, use the qualified data name `a.aa.data`.

- To specify the data object in the top-level state `aa`, use the qualified data name `/aa.data`.
- Rename one of the states containing data.
- Enclose the top-level state `aa` in a box or in another state. Adding an enclosure prevents the search process from detecting data in the top-level state.



### See Also

### More About

- “States” on page 2-8
- “Transitions” on page 2-21
- “State Hierarchy” on page 2-17

## Resolve Data Properties from Simulink Signal Objects

Stateflow® local and output data in charts can explicitly inherit properties from `Simulink.Signal` objects in the model workspace or base workspace. This process is called signal resolution and requires that the resolved signal have the same name as the chart output or local data.

For information about Simulink® signal resolution, see “Symbol Resolution” (Simulink) and “Symbol Resolution Process” (Simulink).

### Inherited Properties

When Stateflow local or output data resolve to Simulink signal objects, they inherit these properties:

- Size
- Complexity
- Type
- Minimum value
- Maximum value
- Initial value
- Storage class

Storage class controls the appearance of chart data in the generated code. See “Organize Parameter Data into a Structure by Using Struct Storage Class” (Embedded Coder).

### Enable Signal Resolution

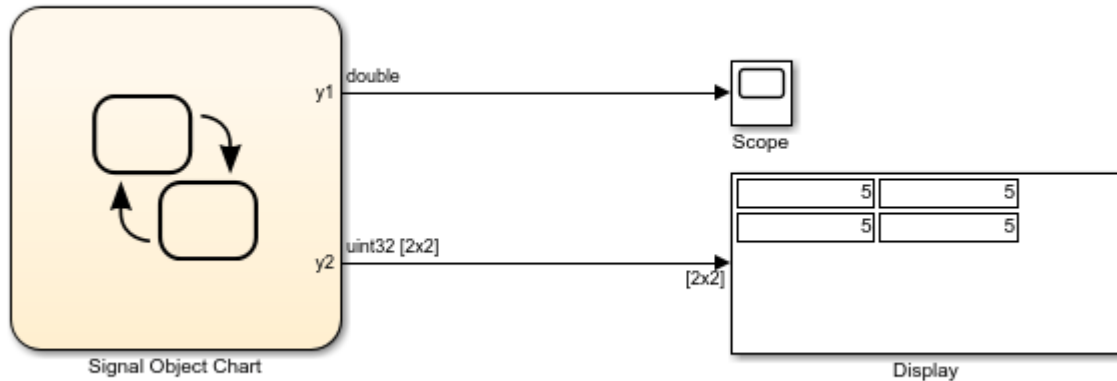
To enable explicit signal resolution, follow these steps:

- 1** Set **Configuration Parameters > Diagnostics > Data Validity > Signal resolution** to a value other than **None**. For more information about the other options, see “Signal resolution” (Simulink).
- 2** In the model workspace, base workspace, or data dictionary, define a `Simulink.Signal` object with the properties you want your Stateflow data to inherit. For more information about creating Simulink signals, see `Simulink.Signal` (Simulink).
- 3** Add output or local data to a chart.
- 4** Enter a name for your data that matches the name of the `Simulink.Signal` object.
- 5** In the data properties, select the **Data must resolve to signal object** check box. After you select this check box, the dialog box removes or dims the properties that your data inherits from the signal.

### A Simple Example

This model shows how a chart resolves local and output data to `Simulink.Signal` objects.

## Resolve Signal Object



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In the base workspace, there are three Simulink.Signal objects, each with a different set of properties.

- y1 has these properties: **Type** = double, **Dimensions** = 1, and **Storage Class** = Model default.
- y2 has these properties: **Type** = uint32, **Dimensions** = [2 2], and **Storage Class** = Auto.
- local has these properties: **Type** = single, **Dimensions** = 1, and **Storage Class** = ExportedGlobal.

The chart contains three data objects — two outputs and a local variable — that will resolve to a signal with the same name.

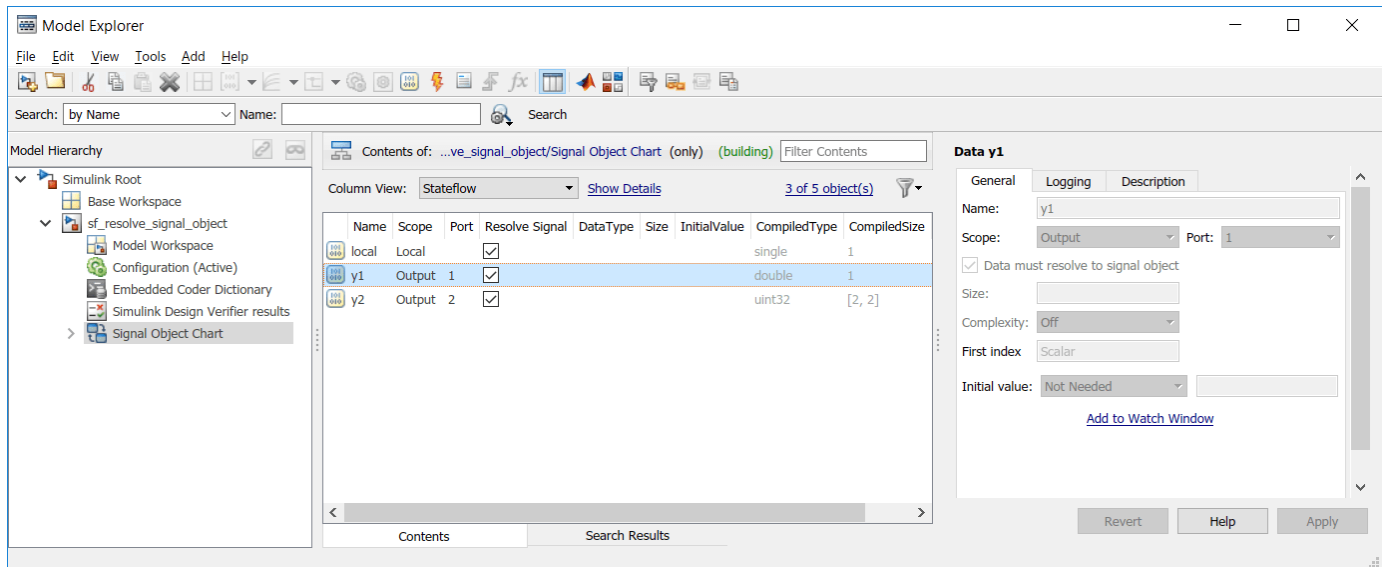
The screenshot shows the Simulink Model Explorer interface. The 'Model Hierarchy' on the left shows the 'Signal Object Chart' selected. The 'Contents' pane shows a table with the following data:

Name	Scope	Port	Resolve Signal	Data Type	Size	Initial Value	Compiled Type	Compiled Size
local	Local		<input checked="" type="checkbox"/>				unknown	
y1	Output	1	<input checked="" type="checkbox"/>				unknown	
y2	Output	2	<input checked="" type="checkbox"/>				unknown	

The 'Data y1' pane on the right shows the following properties:

- Name: y1
- Scope: Output
- Port: 1
- Data must resolve to signal object
- Size: (empty)
- Complexity: Off
- First index: Scalar
- Initial value: Not Needed

When you build the model, each data object inherits the properties of the identically named signal.



The generated code declares the data based on the storage class that the data inherits from the associated Simulink signal. For example, the header file below declares local to be an exported global variable:

```

/*
 * Exported States
 *
 * Note: Exported states are block states with an exported
 * global storage class designation.
 */
extern real32_T local;                /* '<Root>/Signal Object Chart' */

```

## See Also

Simulink.Signal

## More About

- “Symbol Resolution” (Simulink)
- “Organize Parameter Data into a Structure by Using Struct Storage Class” (Embedded Coder)



# Active State Data

---

- “Monitor State Activity Through Active State Data” on page 13-2
- “Simplify Stateflow Charts by Incorporating Active State Output” on page 13-7
- “View State Activity by Using the Simulation Data Inspector” on page 13-11
- “View Stateflow States in the Logic Analyzer” on page 13-14
- “Check State Activity by Using the in Operator” on page 13-17
- “Model An Intersection Of One-Way Streets” on page 13-23

## Monitor State Activity Through Active State Data

Active state data can simplify the design of some Stateflow charts because you do not have to maintain data that is highly correlated to the chart hierarchy. When you enable active state data, Stateflow reports state activity through an output port to Simulink or as local data in your chart. Using active state data, you can:

- Avoid manual data updates reflecting chart activity.
- View chart activity by using a scope, the Simulation Data Inspector, or the Logic Analyzer.
- Log chart activity for diagnostics.
- Drive other Simulink subsystems.

### Types of Active State Data

When you enable active state data, Stateflow creates a Boolean or enumerated data object to match the activity type.

Activity Type	Active State Data Type	Description
Self activity	Boolean	Is the state active?
Child activity	Enumeration	Which child is active?
Leaf state activity	Enumeration	Which leaf state is active?

For self-activity of a chart or state, the data value is `true` when active and `false` when inactive. For child and leaf state activity, the data is an enumerated type. Stateflow can define the enumeration class or you can create the definition manually. For more information, see “Define State Activity Enumeration Type” on page 13-3.

You can enable active state data for a Stateflow chart, state, state transition table, or atomic subchart. This table lists the activity types supported by each kind of Stateflow object.

Stateflow Object	Self-Activity	Child Activity	Leaf State Activity
Charts	Not supported	Supported	Supported
States with exclusive (OR) decomposition	Supported	Supported	Supported
States with parallel (AND) decomposition	Supported	Not supported	Not supported
Atomic subcharts	Supported at the container level	Supported inside the subchart	Supported inside the subchart
State transition tables	Not supported	Supported	Supported

### Enable Active State Data

You can enable active state data in either the Property Inspector or the Model Explorer.

- Property Inspector
  - 1 To open the Property Inspector, in the **Modeling** tab, click **Property Inspector**.



- 2 In the Stateflow Editor canvas, select the Stateflow object to monitor.
  - 3 In the **Monitoring** section of the Property Inspector, select the **Create output for monitoring** check box and edit the active state data properties.
- Model Explorer
    - 1 To open the Model Explorer, in the **Modeling** tab, click **Model Explorer**.
    - 2 In the **Model Hierarchy** pane, double-click the Stateflow object to monitor.
    - 3 In the Stateflow object pane, select the **Create output for monitoring** check box and edit the active state data properties.

## Active State Data Properties

### Activity Type

Type of state activity to monitor. Choose from these options:

- Self activity
- Child activity
- Leaf state activity

### Data Name

Name of the active state data object. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

### Enum Name

Name of the enumerated data type for the active state data object. This property applies only to child and leaf state activity.

### Define Enumerated Type Manually

Specifies whether you define the enumerated data type manually. This property applies only to child and leaf state activity. For more information, see “Define State Activity Enumeration Type” on page 13-3.

## Set Scope for Active State Data

By default, active state data has a scope of **Output**. Stateflow creates an output port on the chart block in the Simulink model.

To access active state data inside a Stateflow chart, change the scope to **Local** in the Symbols pane or in the Model Explorer. For more information, see “Set Data Properties” on page 12-5.

You can specify information for code generation by binding the local active state data to a `Simulink.Signal` object. Modify the properties of the object through the `CoderInfo` property. For more information, see `Simulink.CoderInfo`.

## Define State Activity Enumeration Type

By default, Stateflow defines the enumeration data type for child and leaf activity. If you select the **Define enumerated type manually** check box and no enumeration data type definition exists, then

Stateflow provides a link to create a definition. Clicking the **Create enum definition from template** link generates a customizable definition.

The screenshot shows the configuration for the 'gear\_state' activity. The 'Info' tab is active. The 'Execution order' is set to 1. Under the 'Monitoring' section, the checkbox 'Create output for monitoring' is checked, and the 'Child activity' dropdown is set to 'gear'. The 'Data name' field contains 'gear' and the 'Enum name' field contains 'gearType'. The checkbox 'Define enumerated type manually' is also checked. At the bottom, there is a blue link labeled 'Create enum definition from template'.

The enumeration data type definition contains one enumerated value for each state name. The definition also contains an enumerated value that serves as the default value for the enumeration data type and indicates that no substate is active. For example, in the model `sf_car`, the state `gear_state` contains four child states that correspond to the gears in a car: `first`, `second`, `third`, `fourth`. The model specifies the child activity data type with this enumeration class definition:

```
classdef gearType < Simulink.IntEnumType
    enumeration
        None(0),
        first(1),
        second(2),
        third(3),
        fourth(4)
    end
    ...
end
```

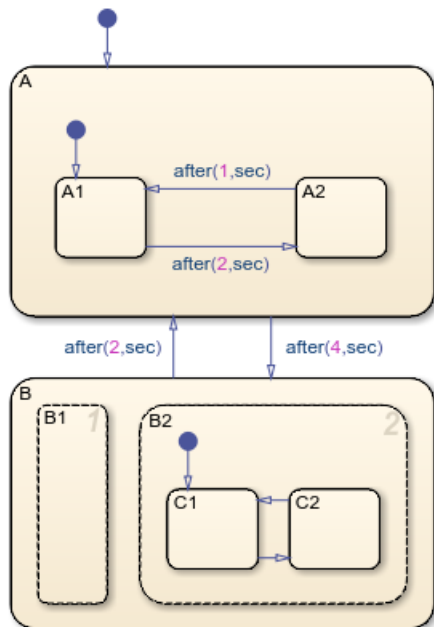
You can customize this definition by reordering the enumerated values or renaming the default value. Do not rename the enumerated values that correspond to states or use the `getDefaultvalue` method to specify a different default value. For more information, see “Define Enumerated Data Types” on page 23-5.

**Tip** The base storage type for automatically created enumerations defaults to `Native Integer`. For a smaller memory footprint, in the **Optimization** pane of the Configuration Parameters dialog box, change the value of the **Base storage type for automatically created enumerations** field. For more information, see “Base storage type for automatically created enumerations” (Simulink Coder).

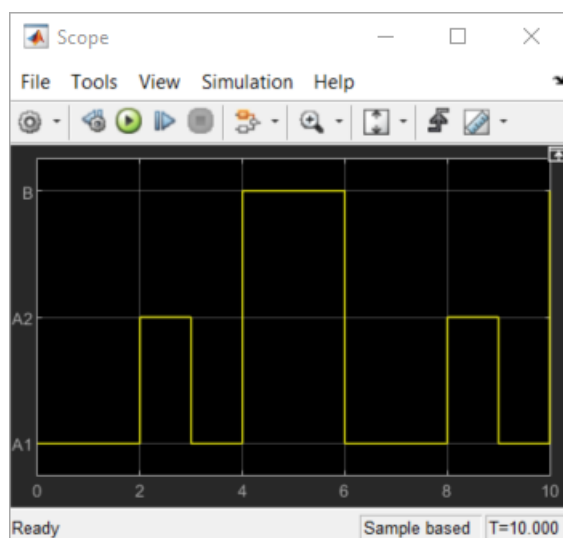
## State Activity and Parallel States

In states with parallel (AND) decomposition, child activity and leaf state activity are not available because the parallel substates are active simultaneously.

When you enable leaf state activity in a chart or state, a substate with parallel (AND) decomposition is treated as a leaf state. For example, suppose that you enable leaf state activity for this chart. Because state B has parallel decomposition, its substates B1 and B2 are active simultaneously so B is treated as a leaf state of the chart.



During simulation, a scope connected to the active state output data shows the enumerated values for the leaf states A1, A2, and B.



## Limitations for Active State Data

- Enabling child activity output for states that have no children results in an error at compilation and run time.
- You cannot enable child or leaf state activity in charts or states with parallel decomposition. To check state activity in substates of parallel states, use the `in` operator. For more information, see “Check State Activity by Using the `in` Operator” on page 13-17.
- Active state data is not supported in charts that use classic or Mealy semantics when the chart property **Initialize outputs every time chart wakes up** is enabled. For more information, see “Initialize outputs every time chart wakes up” on page 28-5.

## See Also

`Simulink.Signal` (Simulink) | `Simulink.CoderInfo` (Simulink)

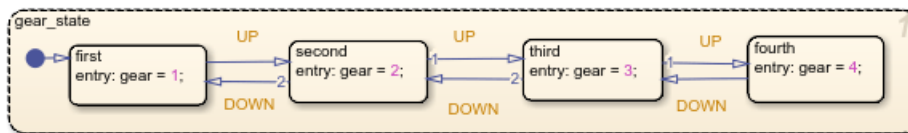
## More About

- “Simplify Stateflow Charts by Incorporating Active State Output” on page 13-7
- “View State Activity by Using the Simulation Data Inspector” on page 13-11
- “Check State Activity by Using the `in` Operator” on page 13-17
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Define State Activity Enumeration Type” on page 13-3
- “Base storage type for automatically created enumerations” (Simulink Coder)

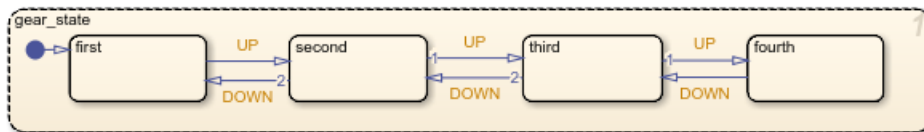
## Simplify Stateflow Charts by Incorporating Active State Output

Active state data can simplify the design of some Stateflow® charts because you do not have to maintain data that is highly correlated to the chart hierarchy. When you enable active state data, Stateflow reports state activity through an output port to Simulink® or as local data in your chart. This example shows how to simplify the design of a Stateflow chart by adding active state output data. For more information, see “Monitor State Activity Through Active State Data” on page 13-2.

In the legacy model `old_sf_car`, the Stateflow chart `shift_logic` tracks child state activity in `gear_state` by updating the value of the output data `gear`.



By incorporating active state data, the model `sf_car` avoids manual data updates reflecting chart activity. Instead, the chart outputs child state activity automatically through the active state output `gear`.



### Modify the Model

To simplify the design of the `old_sf_car` model, eliminate data that is highly correlated to the chart hierarchy and enable automatic monitoring of child state activity in `gear_state`.

#### Step 1: Eliminate Manual Tracking of State Activity

- 1 In the model `old_sf_car`, open the chart `shift_logic`.
- 2 Open the Symbols pane. In the **Modeling** tab, select **Symbols Pane**.
- 3 In each substate of `gear_state`, delete the entry action assigning a value to the output data variable `gear`.
- 4 In the Symbols pane, right-click the output variable `gear` and select **Delete**.

#### Step 2: Enable Active State Output

- 1 Open the Property Inspector. In the **Modeling** tab, select **Property Inspector**.
- 2 In the Stateflow Editor, select the state `gear_state`.
- 3 In the Property Inspector, select the **Create output for monitoring** check box and choose **Child activity**.
- 4 In the **Data name** field, enter the name `gear` of the active state data.
- 5 In the **Enum name** field, enter the name `gearType` of the enumeration data type for the active state data.

gear\_state

Properties Info

Execution order 1

▼ Monitoring

Create output for monitoring Child activity

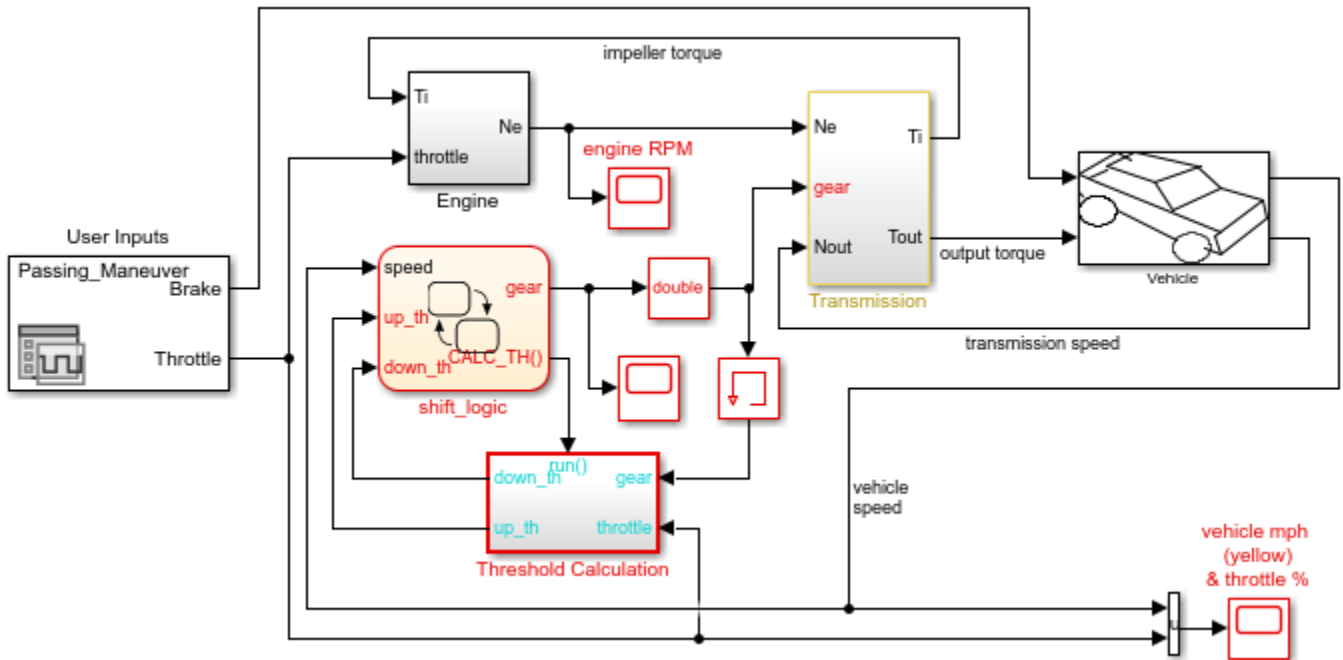
Data name gear

Enum name gearType

Define enumerated type manually

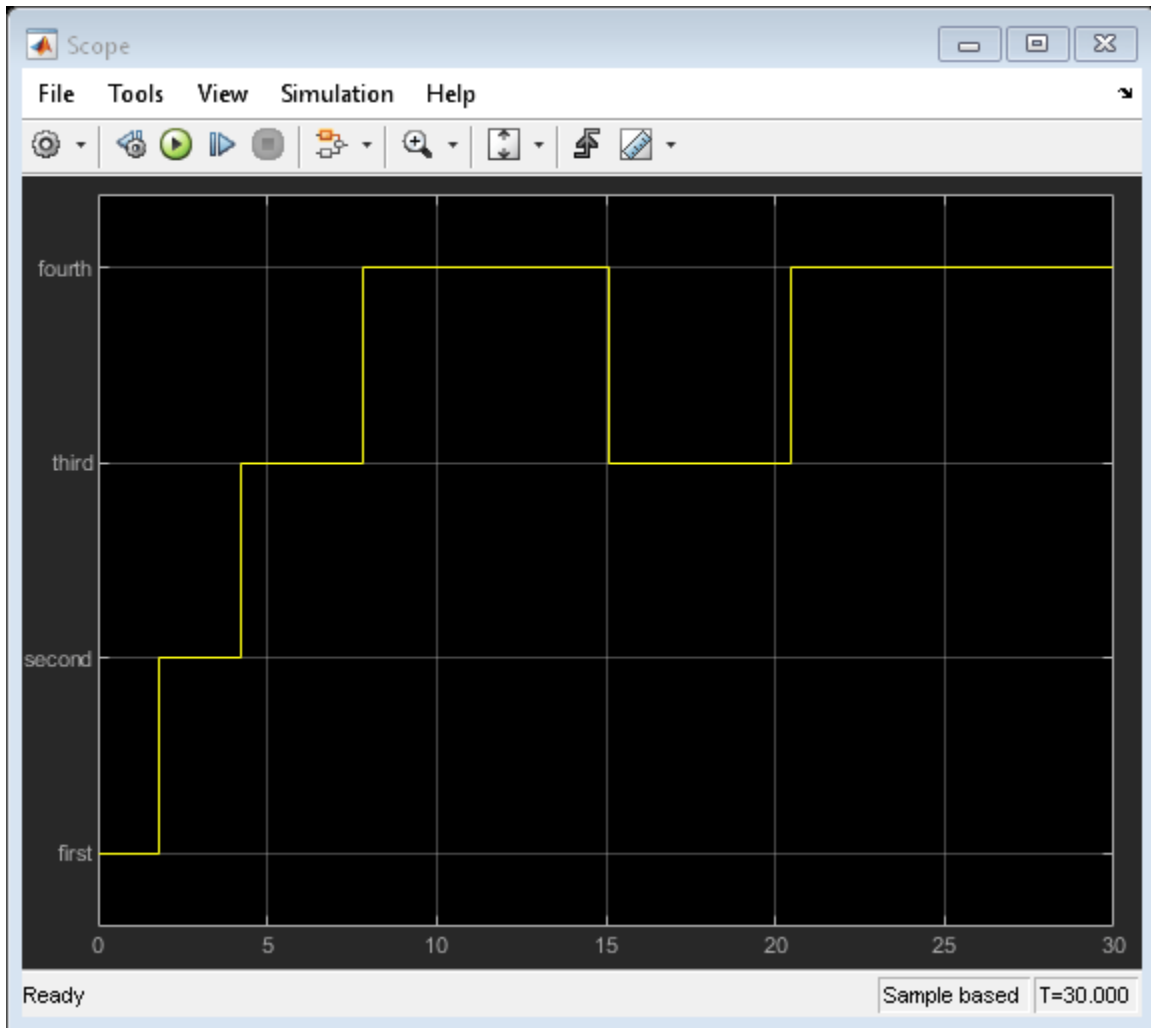
### Step 3: Connect Signal to Simulink Blocks

- 1 In the Simulink model, add a Cast To Double block. This block converts the enumerated output from the Stateflow chart to a signal of type double. For more information, see Data Type Conversion (Simulink).
- 2 Connect the output signal `gear` from the `shift_logic` chart to the Cast To Double block.
- 3 Connect the output signal from the Cast To Double block to the Transmission subsystem.
- 4 Add a Memory (Simulink) block. This block prevents an algebraic loop between the Stateflow chart and the Threshold Calculation subsystem.
- 5 Make a second connection from the output signal from the Cast To Double block to the Memory block.
- 6 Connect the output of the Memory block to the Threshold Calculation subsystem.



### View Simulation Results

The output signal `gear` is an enumerated type managed by Stateflow. You can view the active state output signal `gear` during simulation by connecting the chart to a Scope block. The names of the enumerated values match the names of the substates in `gear_state`. The additional enumerated value of `None` indicates time steps when no child is active.



## See Also

Data Type Conversion | Memory

## More About

- “Monitor State Activity Through Active State Data” on page 13-2
- “View State Activity by Using the Simulation Data Inspector” on page 13-11
- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2



## View State Activity by Using the Simulation Data Inspector

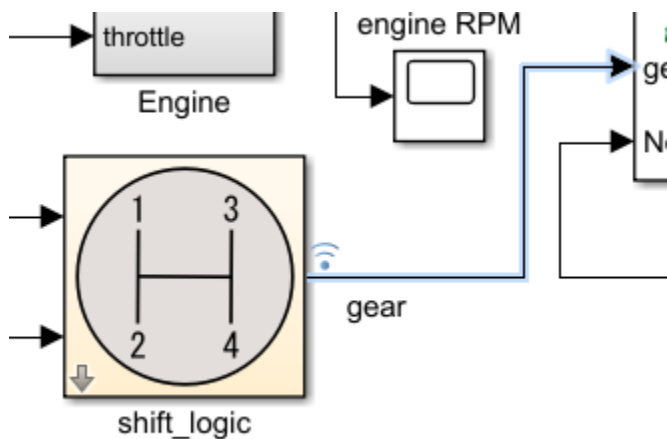
You can use the Simulation Data Inspector to log state activity and data for your Stateflow chart in a Simulink model. With the Simulation Data Inspector, you can view and compare:


- Data from your chart
- Leaf chart activity
- Child chart activity
- Child state activity
- Self state activity
- Leaf state activity

### Log to the Simulation Data Inspector from Stateflow

In this exercise, you use the Simulation Data Inspector to monitor the active state outputs for the Stateflow chart in the model `sf_car`.

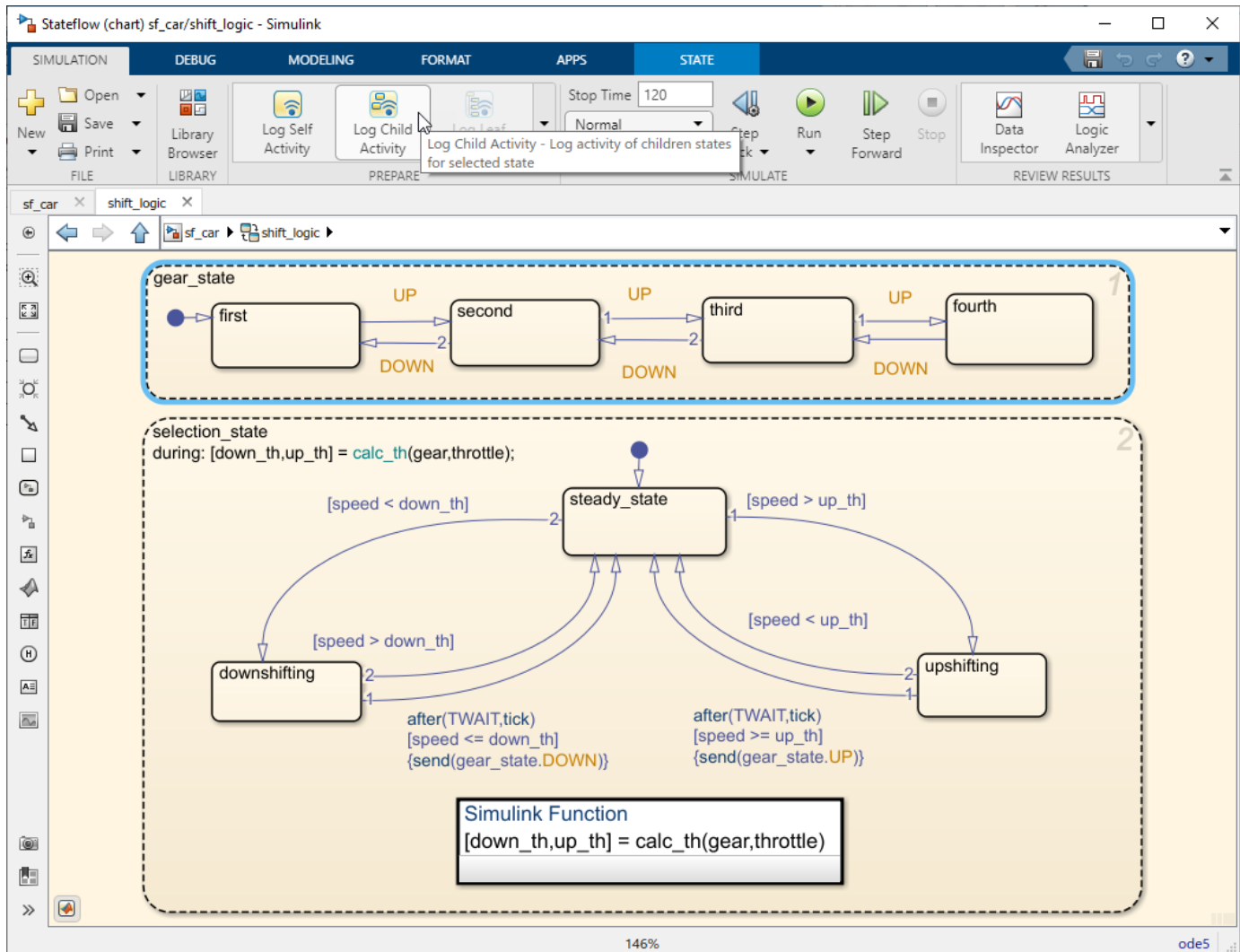
To log a signal with the Simulation Data Inspector, highlight the signal line that you want to log. Right-click the `gear` signal and choose **Log Selected Signals** from the context menu. A logging badge appears next to the `gear` signal, indicating that the data from that signal is logged when the model is run.




The logging badge  marks logged signals in the model.

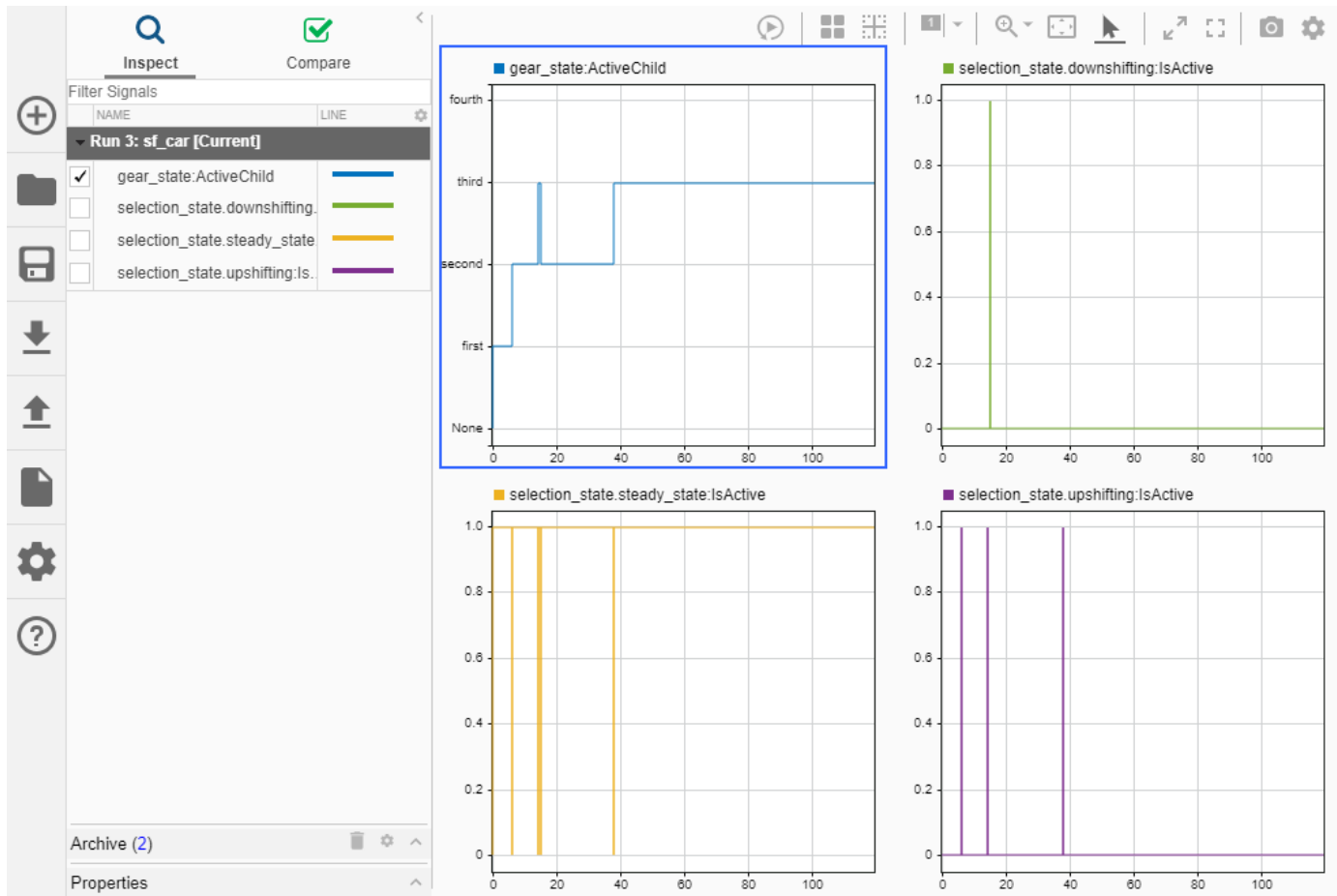
To log the active state data from `gear_state`:

- 1 Open the Stateflow chart.
- 2 To select `gear_state`, click `gear_state`.
- 3 On the Simulink Editor toolbar, in the **Simulation** tab, click **Log Child Activity**.



After running one or more simulations with signals marked for logging, click **Simulation Data**

**Inspector** button  on the Simulink editor toolbar and view your data. Multiple runs show up in the **Inspect** pane and can be viewed together. To choose which signals you want to plot, use the check boxes next to the signal names.



## See Also

### More About

- “Monitor State Activity Through Active State Data” on page 13-2
- “Simplify Stateflow Charts by Incorporating Active State Output” on page 13-7
- Simulation Data Inspector (Simulink)
- “Inspect Simulation Data” (Simulink)
- “Compare Simulation Data” (Simulink)

## View Stateflow States in the Logic Analyzer

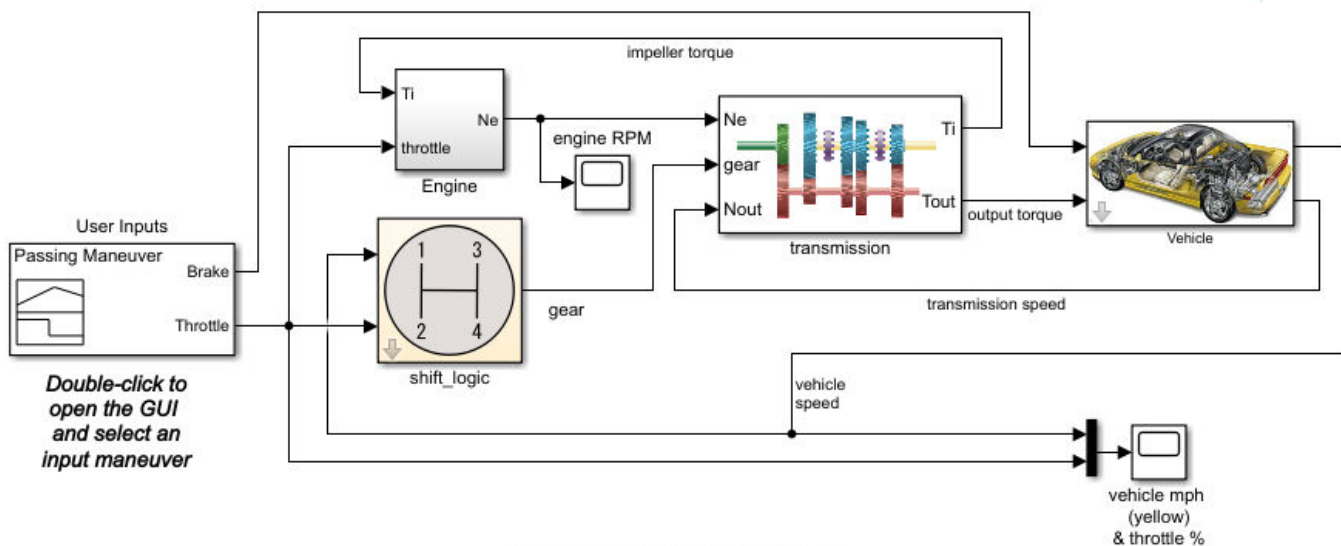
Use the **Logic Analyzer** app to visualize and measure transitions and states over time. With the **Logic Analyzer**, you can visualize:

- Leaf chart activity
- Child chart activity
- Child state activity
- Self state activity
- Leaf state activity

The **Logic Analyzer** allows you to measure the output over time and add triggers to identify the output values at specified events.

**Note** To use the **Logic Analyzer**, you must have DSP System Toolbox™ or SoC Blockset™ license.

To follow along with this tutorial, open the `sf_car` model. In this model, you can visualize the behavior of the engine, the gear state, and the vehicle speed.



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## Add Signals and States for Logging

To view a signal in the **Logic Analyzer**, you must mark the signal or state for logging.

- 1 Open the `shift_logic` chart.
- 2 Select the `gear_logic` state.
- 3 On the toolbar, in the **Simulation** tab, click **Log Child Activity**.



You will see the logging badge  in the corner of the state.

- Return to the Simulink canvas. Click on the `vehicle speed` signal, and in the signal tab, select the **Log Signals** button.

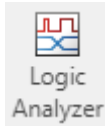


- Repeat step 4 for the `transmission speed` and `Engine RPM` signals.

You will see the logging badge above these signals.

## View Logged Output in Logic Analyzer

- In Simulink, on the **Simulation** tab, open the **Review Results** app library and select the **Logic**



**Analyzer.**

- To run the simulation, in the **Logic Analyzer** window, select the **Run** button.



- Drag the yellow cursor to different points in the output to see the different signal values. You can see the reaction of the engine RPMs as the car gears change.

**See Also**  
**Logic Analyzer**

**More About**

- “Log Simulation Output for States and Data” on page 33-43
- “View State Activity by Using the Simulation Data Inspector” on page 13-11

## Check State Activity by Using the in Operator

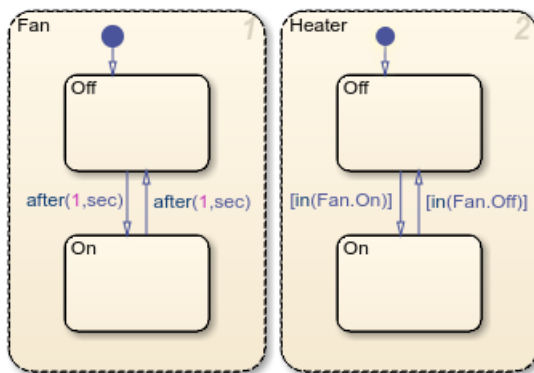
In a Stateflow chart with parallel state decomposition, substates can be active at the same time. To coordinate the behavior of different parallel states, one state can check the substate activity of another state and react accordingly. For example, one state can keep its substates synchronized with the substates of the other state.

### The in Operator

To check if a state is active in a given time step, call the `in` operator in state and transition actions. The `in` operator takes a qualified state name `state_name` and returns a Boolean output. If state `state_name` is active, `in` returns a value of 1 (true). Otherwise, `in` returns a value of 0 (false).

```
in(state_name)
```

For example, in this chart, `Fan` and `Heater` are parallel (AND) states. Each state has a pair of substates, `On` and `Off`. Every time the chart wakes up, the active substate of the state `Fan` alternates between `Fan.Off` and `Fan.On`. In the state `Heater`, the conditions on the transitions check the substate activity in `Fan` and keep the states synchronized. A change of active substate in `Fan` causes a corresponding change of active substate in `Heater`.



### Resolution of State Activity

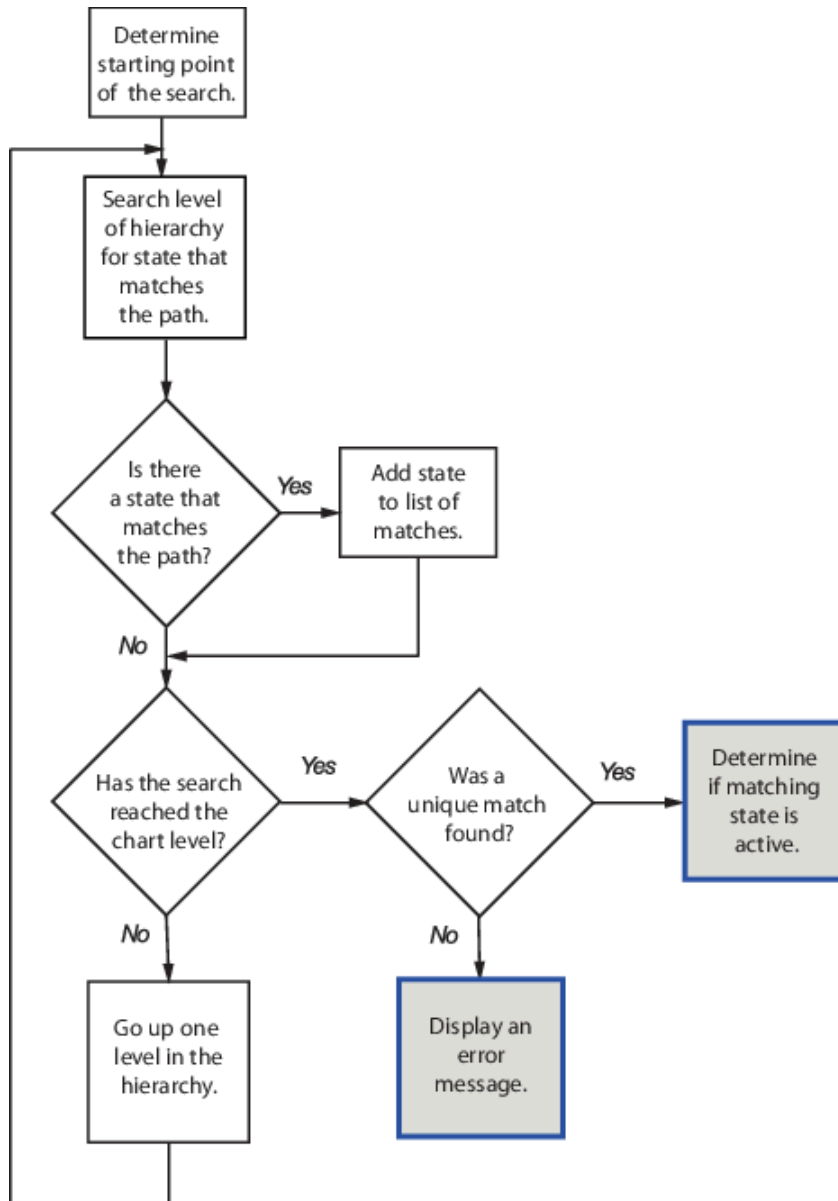
Checking state activity is a two-part process. First, the Stateflow chart resolves the qualified state name by performing a localized search of the chart hierarchy for a matching state. Then, the chart determines if the matching state is active.

The search begins at the hierarchy level where the `in` operator is called with the qualified state name:

- For a state action, the starting point is the state containing the action.
- For a transition label, the starting point is the parent of the transition source.

The resolution process searches each level of the chart hierarchy for a path to the state. If a state matches the path, the process adds that state to the list of possible matches. Then, the process continues the search one level higher in the hierarchy. The resolution process stops after it searches the chart level of the hierarchy. If a unique match exists, the chart checks if the matching state is active. Otherwise, the resolution process fails. Simulation stops with an error.

This flow chart illustrates the different stages in the process for checking state activity.



## Best Practices for Checking State Activity

To resolve the state activity, a Stateflow chart does not perform an exhaustive search for all states and does not stop after finding the first match. To improve the chances of finding a unique search result:

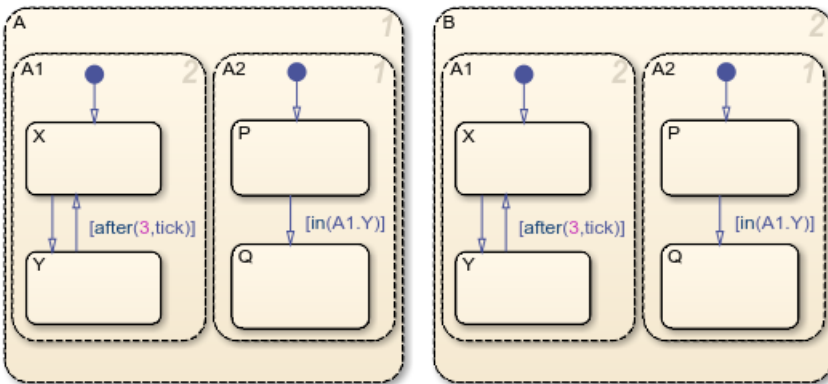
- Use specific paths in qualified data names.
- Give states unique names.
- Use states and boxes as enclosures to limit the scope of the path resolution search.



## Examples of State Activity Resolution

### Search Finds Local Copy of Substate

This chart contains two parallel states, A and B. Each state has a pair of substates, A1 and A2. A1 has substates X and Y, while A2 has substates P and Q. In A.A2 and in B.A2, the condition `in(A1.Y)` guards the transition from P to Q.



The chart resolves each qualified state name as the local copy of the substate Y:

- In the state A, the condition `in(A1.Y)` checks the activity of state A.A1.Y.
- In the state B, the condition `in(A1.Y)` checks the activity of state B.A1.Y.

For example, this table lists the different stages in the resolution process for the transition condition in state A.

Stage	Description	Result
1	Starting in state A.A2, the chart searches for the state A.A2.A1.Y.	No match found.
2	Moving up to the next level of the hierarchy (state A), the chart searches for the state A.A1.Y	Match found.
3	Moving up to the next level of the hierarchy (the chart level), the chart searches for the state A1.Y	No match found.

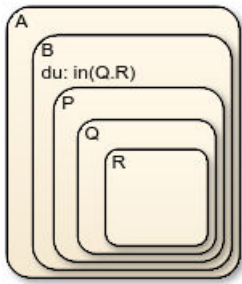
The search ends with a single match found. Because the resolution algorithm localizes the scope of the search, the `in` operator guarding the transition in A.A2 detects only the state A.A1.Y. The `in` operator guarding the transition in B.A2 detects only the state B.A1.Y.

To check the state activity of the other copy of Y, use more specific qualified state names:

- In state A, use the expression `in(B.A1.Y)`.
- In state B, use the expression `in(A.A1.Y)`.

### Search Produces No Matches

In this chart, the `during` action in state A.B contains the expression `in(Q.R)`. Stateflow cannot resolve the qualified state name Q.R.



This table lists the different stages in the resolution process.

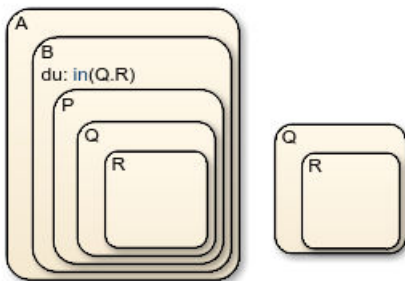
Stage	Description	Result
1	Starting in state A.B, the chart searches for the state A.B.Q.R.	No match found.
2	Moving up to the next level of the hierarchy (state A), the chart searches for the state A.Q.R.	No match found.
3	Moving up to the next level of the hierarchy (the chart level), the chart searches for the state Q.R.	No match found.

The search ends at the chart level with no match found for Q.R, resulting in an error.

To avoid this error, use a more specific qualified state name. For instance, check state activity by using the expression `in(P.Q.R)`.

**Search Finds the Wrong State**

In this chart, the during action in state A.B contains the expression `in(Q.R)`. When resolving the qualified state name Q.R, Stateflow cannot detect the substate A.B.P.Q.R.



This table lists the different stages in the resolution process.

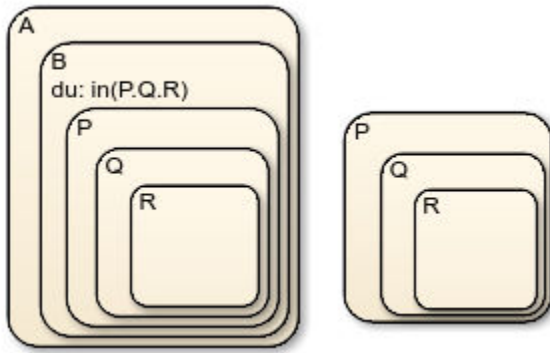
Stage	Description	Result
1	Starting in state A.B, the chart searches for the state A.B.Q.R.	No match found
2	Moving up to the next level of the hierarchy (state A), the chart searches for the state A.Q.R.	No match found.
3	Moving up to the next level of the hierarchy (the chart level), the chart searches for the state Q.R.	Match found.

The search ends with a single match found. The `in` operator detects only the substate R of the top-level state Q.

To check the state activity of A.B.P.Q.R, use a more specific qualified state name. For instance, use the expression `in(P.Q.R)`.

### Search Produces Multiple Matches

In this chart, the `during` action in state A.B contains the expression `in(P.Q.R)`. Stateflow cannot resolve the qualified state name P.Q.R.



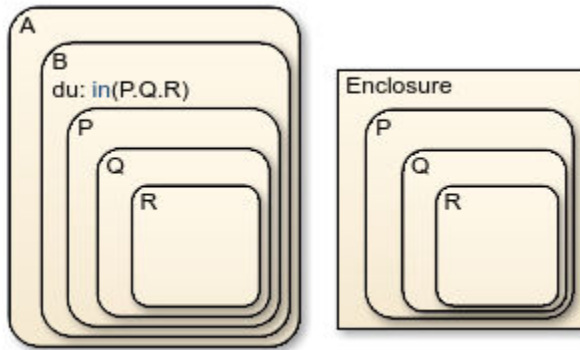
This table lists the different stages in the resolution process.

Stage	Description	Result
1	Starting in state A.B, search for the state A.B.P.Q.R.	Match found
2	Moving up to the next level of the hierarchy (state A), the chart searches for the state A.P.Q.R.	No match found.
3	Moving up to the next level of the hierarchy (the chart level), the chart searches for the state P.Q.R.	Match found.

The search ends at the chart level with two matches found for P.Q.R, resulting in an error.

To avoid this error:

- Use a more specific qualified state name. For example, to check the substate activity inside B, use the expression `in(B.P.Q.R)`.
- Rename one of the matching states.
- Enclose the top-level state P in a box or another state. Adding an enclosure prevents the search process from detecting substates in the top-level state.



### See Also

after | in

### More About

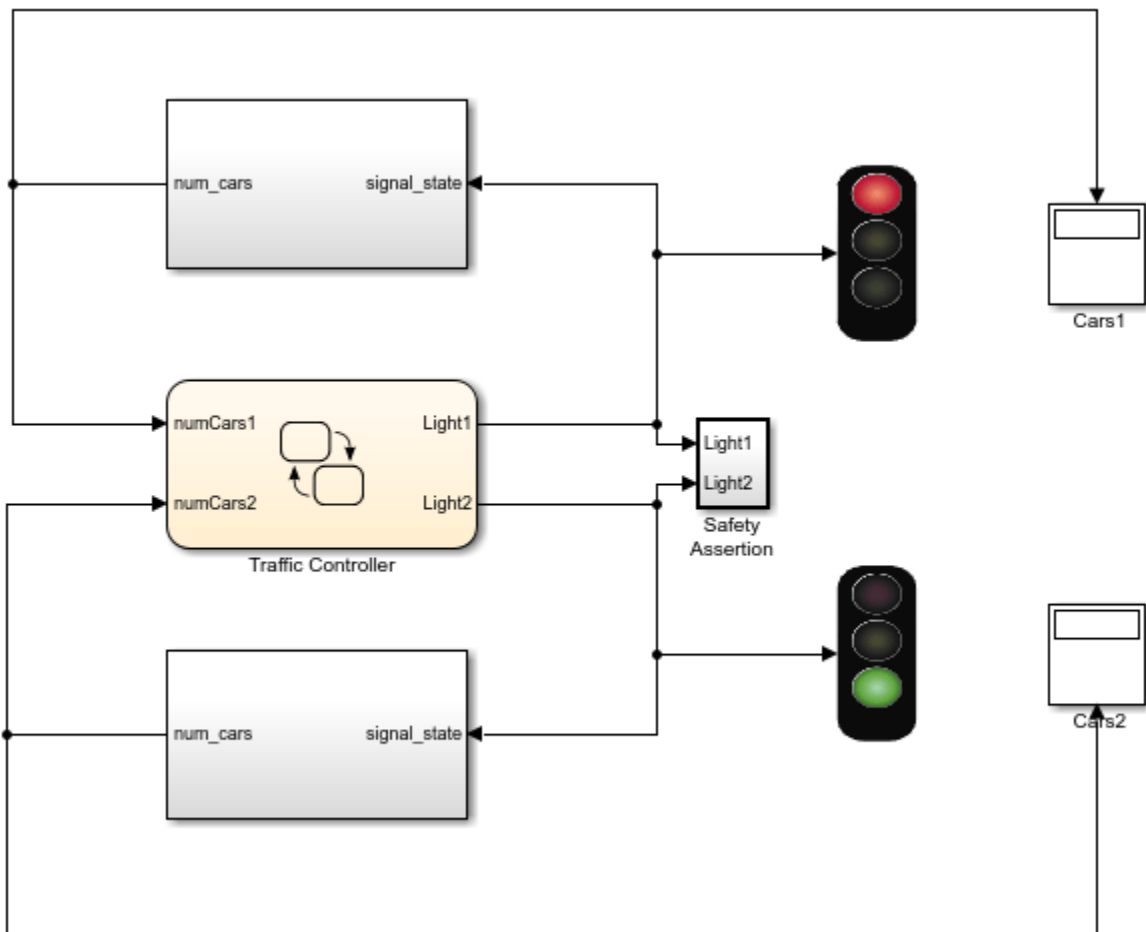
- “State Hierarchy” on page 2-17
- “Monitor State Activity Through Active State Data” on page 13-2

## Model An Intersection Of One-Way Streets

This example models an intersection of one-way roads controlled by a Stateflow® traffic light system. The Stateflow chart tracks the state of each traffic light by using active state output. The behavior of the traffic lights is controlled by parameters on the Stateflow mask.

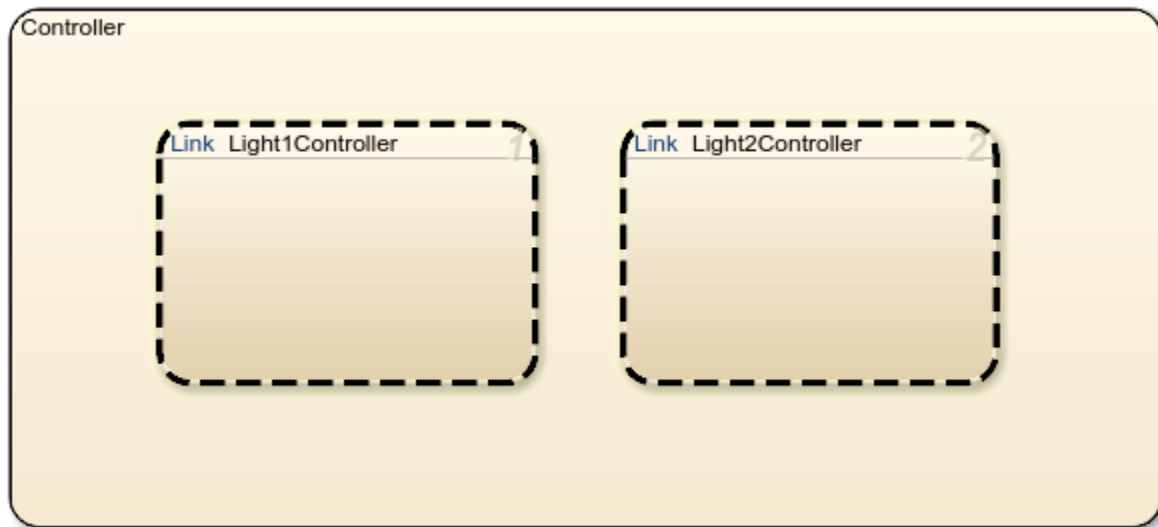
### Intersection Model

The phase of the animated traffic lights is determined by the output data from the Stateflow chart. The value of the output data corresponds to the active child of the substates `Light1Controller` and `Light2Controller`, respectively.



### Traffic Controller

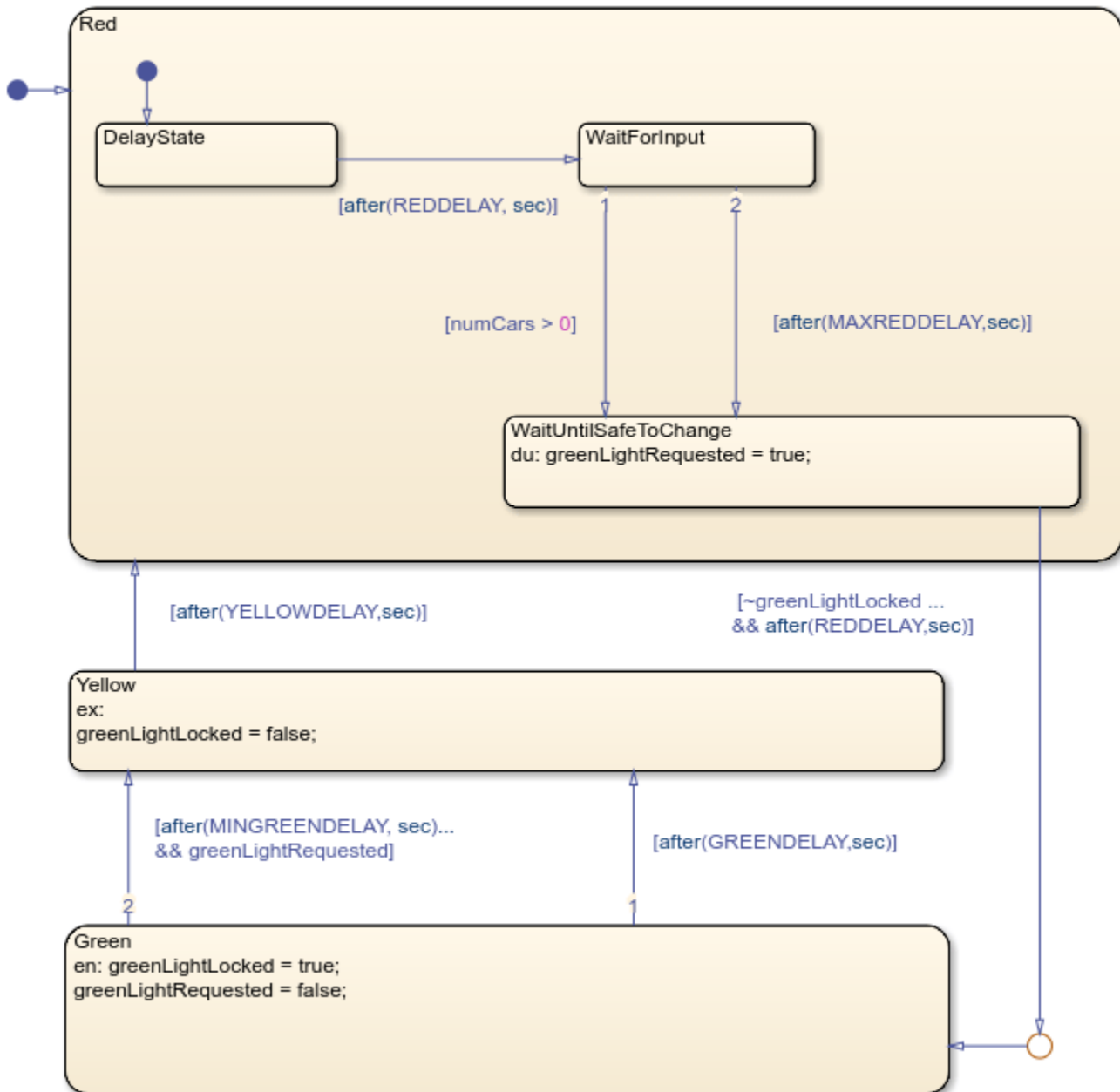
The Stateflow chart Traffic Controller manages two traffic controllers in parallel. Each controller determines the phase of the downstream traffic light based on traffic congestion at the intersection, an input from Simulink®, and parameters on the chart's mask. For more information, see “Create a Mask to Share Parameters with Simulink” on page 28-14.



### Active State Output

The child activity of both `Light1Controller` and `Light2Controller` is output to Simulink through a data of enumerated type. Stateflow manages this data automatically. For more information, see "Monitor State Activity Through Active State Data" on page 13-2.

- Open one of the Light controllers (for instance, `Light1Controller`).
- Right click and select Properties.
- Notice that the **Create output for monitoring** option is selected and set to `Child` activity.
- The field **Data name** corresponds to the name of the output data on the linked instance.
- This output is mapped to a chart level output called `Light1`.



### Simulation

Simulate the model to see the traffic light blocks animate.

### See Also

### More About

- “Monitor Chart Activity by Using Active State Data”
- “Monitor State Activity Through Active State Data” on page 13-2

- “Model a Distributed Traffic Control System by Using Messages” on page 15-20



# Define Events

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- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Set Properties for an Event” on page 14-5
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Control States in Charts Enabled by Function-Call Input Events” on page 14-11
- “Activate a Simulink Block by Sending Output Events” on page 14-14
- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Control Chart Behavior by Using Implicit Events” on page 14-26
- “Yo-Yo Control of Satellites” on page 14-29
- “Model a Security System” on page 14-31
- “Server Queueing System” on page 14-34
- “Tic-Tac-Flow: Model of a Hand-held Game” on page 14-35

## Synchronize Model Components by Broadcasting Events

An event is a Stateflow object that can trigger actions in one of these objects:

- A parallel state in a Stateflow chart
- Another Stateflow chart
- A Simulink triggered or function-call subsystem

For simulation purposes, there is no limit to the number of events in a Stateflow chart. However, for code generation, the underlying C compiler enforces a theoretical limit of  $2^{31}-1$  events.

### Types of Events

An implicit event is a built-in event that is broadcast during chart execution. These events are implicit because you do not define or trigger them explicitly. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.

An explicit event is an event that you define explicitly. Explicit events can have one of these types.

Type	Description
Input Event	Event that is broadcast to a Stateflow chart from outside the chart. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7 and “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24.
Local Event	Event that can occur anywhere in a Stateflow chart but is visible only in the parent object and its descendants. Local events are supported only in Stateflow charts in Simulink models. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.
Output Event	Event that occurs in a Stateflow chart but is broadcast to a Simulink block. Output events are supported only in Stateflow charts in Simulink models. For more information, see “Activate a Simulink Block by Sending Output Events” on page 14-14.

You can define local events at these levels of the Stateflow hierarchy.


Level of Hierarchy	Visibility
Chart	Local event is visible to the chart and all its states and substates.
Subchart	Local event is visible to the subchart and all its states and substates.
State	Local event is visible to the state and all its substates.

### Define Events in a Chart

You can add events to a Stateflow chart by using the Symbols pane, the Stateflow Editor menu, or the Model Explorer.

#### Add Events Through the Symbols Pane

- 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane**.

- 2 Click the **Create Event** icon .
- 3 In the row for the new event, under **TYPE**, click the icon and choose:
  - Input Event
  - Local Event
  - Output Event
- 4 Edit the name of the event.
- 5 For input and output events, click the **PORT** field and choose a port number.
- 6 To specify properties for the event, open the Property Inspector. In the Symbols pane, right-click the row for the event and select **Explore**. For more information, see “Set Properties for an Event” on page 14-5.

### Add Events by Using the Stateflow Editor Menu

- 1 In a Stateflow chart in a Simulink model, select the menu option corresponding to the type of the event that you want to add.

Type	Menu Option
Input Event	In the <b>Modeling</b> tab, under <b>Design Data</b> , click <b>Event Input</b> .
Output Event	In the <b>Modeling</b> tab, under <b>Design Data</b> , click <b>Event Output</b> .
Local Event	In the <b>Modeling</b> tab, under <b>Design Data</b> , click <b>Local Event</b> .

- 2 In the Event dialog box, specify data properties. For more information, see “Set Properties for an Event” on page 14-5.

### Add Events Through the Model Explorer

- 1 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
- 2 In the **Model Hierarchy** pane, select the object in the Stateflow hierarchy where you want to make the new event visible. The object that you select becomes the parent of the new event.
- 3 In the Model Explorer menu, select **Add > Event**. The new event with a default definition appears in the **Contents** pane of the Model Explorer.
- 4 In the **Event** pane, specify the properties of the event. For more information, see “Set Properties for an Event” on page 14-5.

### Access Event Information from a Stateflow Chart

You can display the properties of an input or local event, or open the destination of an output event directly from a Stateflow chart. Right-click the state or transition that contains the event of interest and select **Explore**. A context menu lists the names and scopes of all resolved symbols in the state or transition. Selecting an input or local event from the context menu displays its properties in the Model Explorer. Selecting an output event from the context menu opens the Simulink subsystem or Stateflow chart associated with the event.

## Best Practices for Using Events in Stateflow Charts

### Use the send Command to Broadcast Explicit Events in Actions

To broadcast local or output events in state or transition actions, use the `send` operator. For example, to broadcast an output event when a transition is valid, avoid using the name of the event as a condition action.

```
{output_event;}
```

Instead, call the `send` operator.

```
{send(output_event);}
```

Although both actions are valid, using the `send` operator enhances readability of a chart and ensures that explicit events are not mistaken for data.

### Avoid Using Explicit Events to Trigger Conditional Actions

Use conditions on transitions instead of events when you want to:

- Represent conditional statements, for example, `[x < 1]` or `[x == 0]`.
- Represent a change of data value, for example, `[hasChanged(x)]`.

### Avoid Using the Implicit Event enter to Check State Activity

To check state activity, use the `in` operator instead of the implicit event `enter`. For more information, see “Check State Activity by Using the `in` Operator” on page 13-17.

### Do Not Mix Edge-Triggered and Function-Call Input Events in a Chart

Mixing input events that use edge triggers and function calls results in a compile-time error.

## See Also

`enter` | `in` | `send`

## More About

- “Set Properties for an Event” on page 14-5
- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Activate a Simulink Block by Sending Output Events” on page 14-14
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Identify Data by Using Dot Notation” on page 12-39

## Set Properties for an Event

An event is a Stateflow object that can trigger actions in a parallel state, another Stateflow chart, or a Simulink triggered or function-call subsystem. For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

When you create Stateflow charts in Simulink models, you can specify event properties in either the Property Inspector or the Model Explorer.

- To use the Property Inspector:
  - 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane** and **Property Inspector**.
  - 2 In the Symbols pane, select the event.
  - 3 In the Property Inspector pane, edit the event properties.
- To use the Model Explorer:
  - 1 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
  - 2 In the **Contents** pane, select the event.
  - 3 In the **Message** pane, edit the event properties.

You can also specify event properties programmatically by using `Stateflow.Event` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Stateflow Event Properties

#### Name

Name of the event. Actions reference events by their names. Names must begin with an alphabetic character, cannot include spaces, and cannot be shared by sibling events. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

#### Scope

Scope of the event. The scope specifies where the event occurs relative to the parent object.

Scope	Description
Local	Event that can occur anywhere in a Stateflow machine but is visible only in the parent object and its descendants. For more information, see “Broadcast Local Events” on page 14-23.
Input from Simulink	Event that occurs in a Simulink block but is broadcast to a Stateflow chart. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7.
Output to Simulink	Event that occurs in a Stateflow chart but is broadcast to a Simulink block. For more information, see “Activate a Simulink Block by Sending Output Events” on page 14-14.

#### Port

Index of the port associated with the event. This property applies only to input and output events.

- For input events, port is the index of the input signal that triggers the event. For more information, see “Association of Input Events with Control Signals” on page 14-9.
- For output events, port is the index of the signal that outputs this event. For more information, see “Association of Output Events with Output Ports” on page 14-22.

### Trigger

Type of signal that triggers an input or output event. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7 and “Activate a Simulink Block by Sending Output Events” on page 14-14.

### Debugger Breakpoints

Option for setting debugger breakpoints at the start or end of an event broadcast. Available breakpoints depend on the type of the event.

Type of Event	Start of Broadcast	End of Broadcast
Local Event	Available	Available
Input Event	Available	Not available
Output Event	Not available	Not available

For more information, see “Set Breakpoints to Debug Charts” on page 33-3.

### Description

Description of the event. You can enter brief descriptions of events in the hierarchy.

### Document Link

Link to online documentation for the event. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow displays the documentation.

### See Also

### More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Broadcast Local Events” on page 14-23
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Activate a Simulink Block by Sending Output Events” on page 14-14
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Identify Data by Using Dot Notation” on page 12-39

## Activate a Stateflow Chart by Sending Input Events

An input event occurs outside a Stateflow chart but is visible only in that chart. This type of event enables other Simulink blocks, including other Stateflow charts, to notify a specific chart of events that occur outside it. To define an input event:

- 1 Add an event to the Stateflow chart, as described in “Define Events in a Chart” on page 14-2.
- 2 Set the **Scope** property for the event to **Input** from Simulink. A single trigger port appears at the top of the Stateflow block in the Simulink model.
- 3 An input event can activate a Stateflow chart through a change in a control signal (an edge trigger) or a function call from a Simulink block.
  - To specify an edge-triggered input event, set the **Trigger** property to one of these options:
    - Rising
    - Falling
    - Either
  - To specify a function-call input event, set the **Trigger** property to **Function call**.

You cannot mix edge-triggered and function-call input events in the same Stateflow chart. Mixing these input events results in a compile-time error.

For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

### Activate a Stateflow Chart by Using Edge Triggers

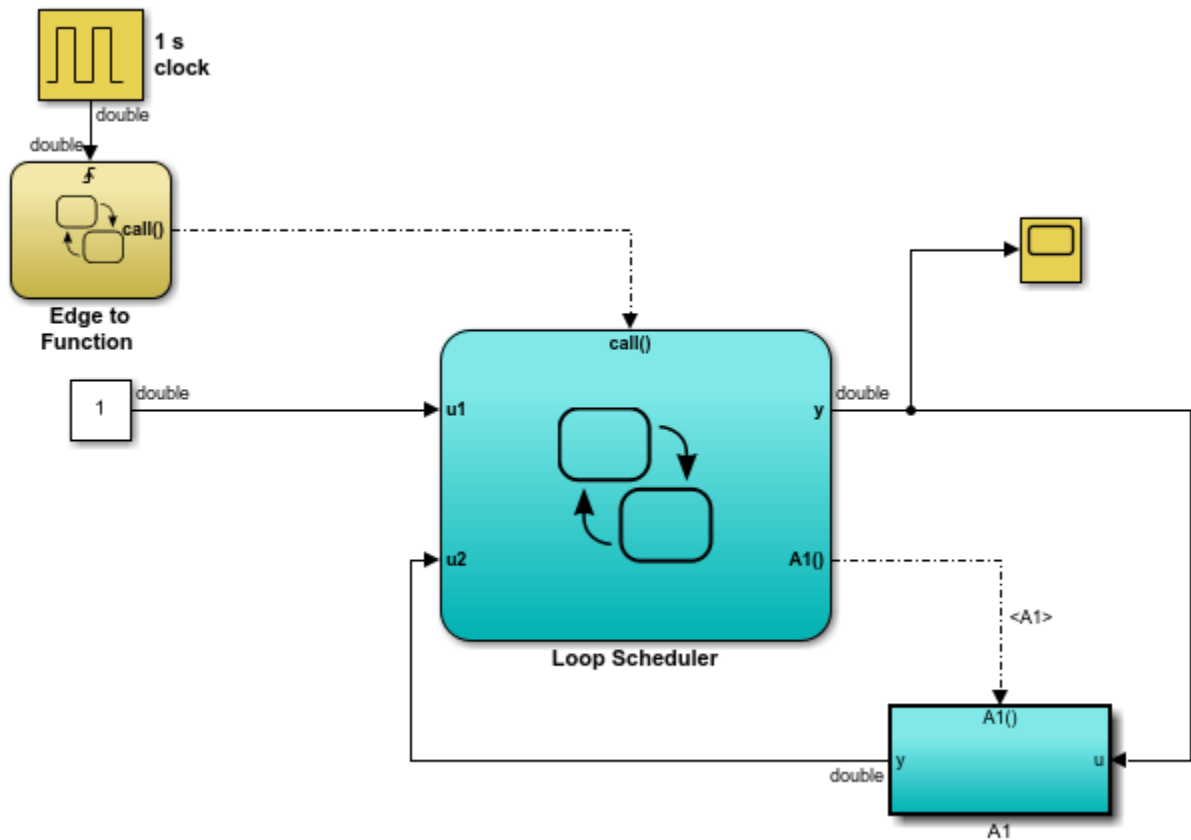
An edge-triggered input event causes a Stateflow chart to execute during the current time step of simulation. With this type of input event, a change in a control signal acts as a trigger.

Edge Trigger Type	Description
Rising	Rising edge trigger. Chart is activated when the control signal changes from either zero or a negative value to a positive value.
Falling	Falling edge trigger. Chart is activated when the control signal changes from a positive value to either zero or a negative value.
Either	Either rising or falling edge trigger. Chart is activated when the control signal crosses zero as it changes in either direction.

In all cases, the value of the control signal must cross zero to be a valid edge trigger. For example, a signal that changes from -1 to 1 is a valid rising edge trigger. A signal that changes from 1 to 2 is not a valid rising edge trigger.

#### When to Use Edge-Triggered Input Events

Use an edge-triggered input event to activate a chart when your model requires regular or periodic chart execution. For example, in this model, an edge-triggered input event activates the Edge to Function chart at regular intervals. For more information, see “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6.



### Behavior of Multiple Edge-Triggered Input Events

At any given time step, input events are checked in ascending order based on their port numbers. The chart awakens once for each valid event. For edge-triggered input events, multiple edges can occur in the same time step, waking the chart more than once in that time step. In this situation, the events wake the chart in ascending order based on their port numbers.

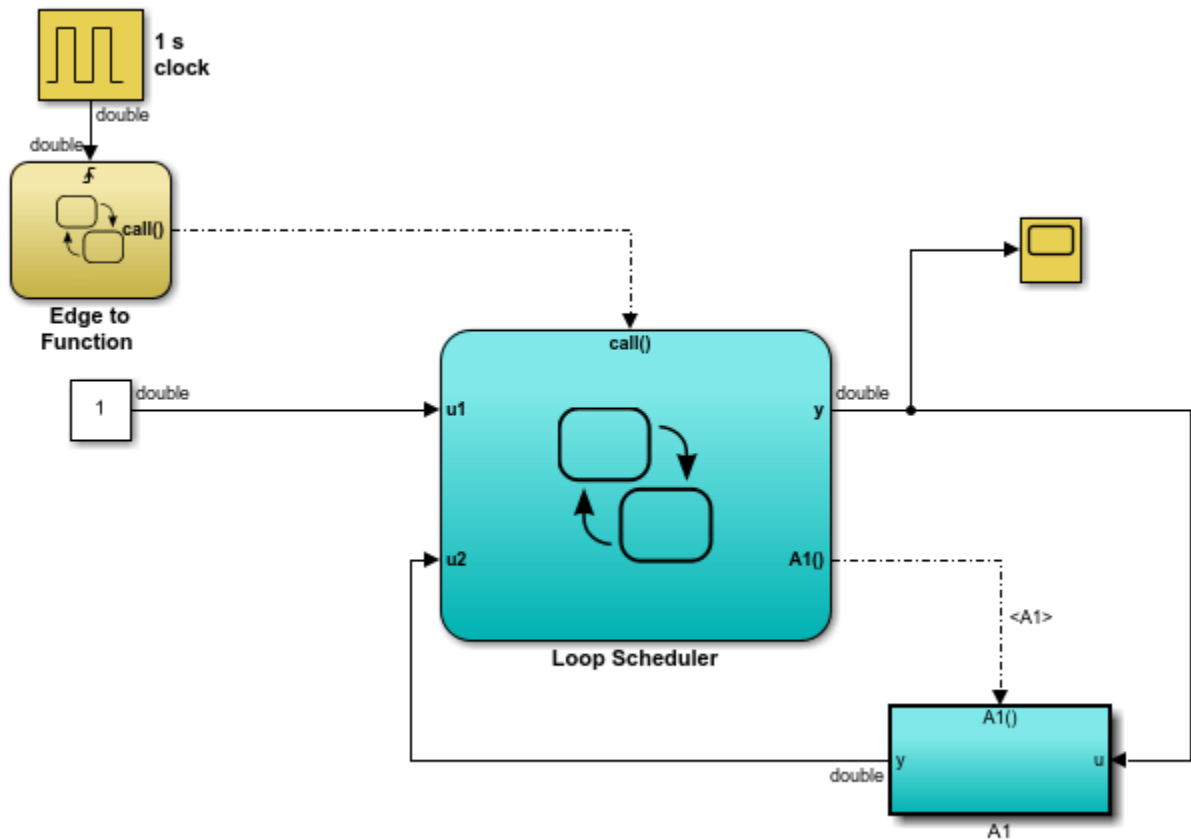
### Activate a Stateflow Chart by Using Function Calls

A function-call input event causes a Stateflow chart to execute during the current time step of simulation. With this type of input event, you must also define a function-call output event for the block that calls the Stateflow chart.

### When to Use Function-Call Input Events

Use a function-call input event to activate a chart when your model requires access to output data from the chart in the same time step as the function call. For example, in this model, a function-call input event activates the Looping Scheduler chart. For more information, see “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6.





### Behavior of Multiple Function-Call Input Events

For function-call input events, only one trigger event exists. The caller of the event explicitly calls and executes the chart. Only one function call is valid in a single time step.

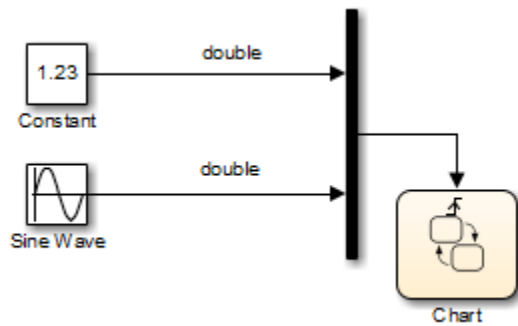
### Association of Input Events with Control Signals

When you define one or more input events in a chart, a single trigger port appears on the top side of the chart block. Multiple external Simulink blocks can trigger the input events through a vector of signals connected to the trigger port. The **Port** property of an input event specifies the index into the control signal vector that connects to the trigger port.

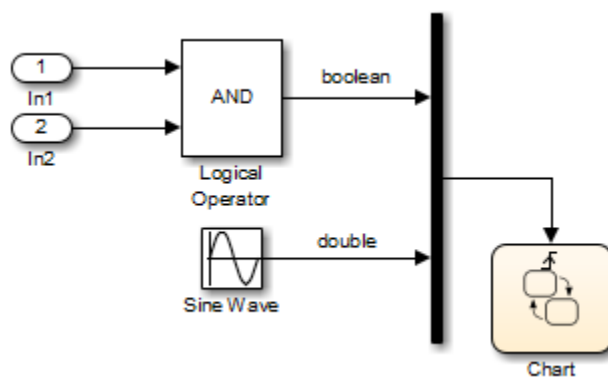
By default, **Port** values appear in the order that you add input events. You can change these assignments by modifying the **Port** property of the events. When you change the **Port** property for an input event, the **Port** values for the remaining input events automatically renumber.

### Data Types Allowed for Input Events

For multiple input events to a trigger port, all signals must have the same data type. Using signals of different data types as input events results in an error during simulation. For example, you can mux two input signals of type `double` to use as input events to a chart.



You cannot mux two input signals of different data types, such as boolean and double.



## See Also

### More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Set Properties for an Event” on page 14-5
- “Control States in Charts Enabled by Function-Call Input Events” on page 14-11
- “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14

## Control States in Charts Enabled by Function-Call Input Events

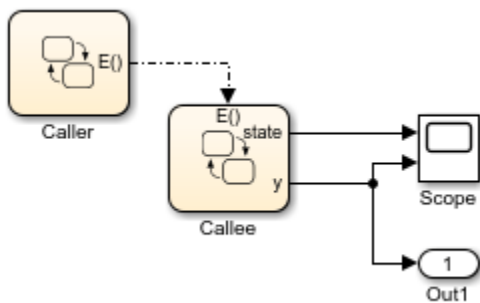
In a Simulink® model, when a Stateflow® chart is enabled by a function-call input event, you can control the state of the chart by setting the **States When Enabling** chart property. This property determines the values of states and data when the input event reenables the chart:

- Held — Maintain most recent values of the states and data.
- Reset — Revert to the initial values of the states and data.

For new charts, the default setting is Held. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7.

### Example of a Chart Enabled by a Function-Call Input Event

In this model, the Caller chart uses the event E to wake up and execute the Callee chart.



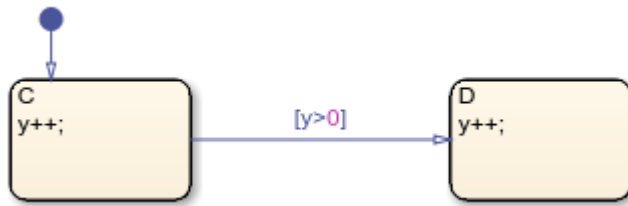
The Caller chart contains two states, A and B. When you bind the output event E in state A:

- Entering A enables the Callee chart.
- Exiting A disables the Callee chart.
- Reentering A reenables the Callee chart.

The temporal logic operator `after` changes the active state every ten time steps, so the Callee chart is repeatedly enabled and disabled.

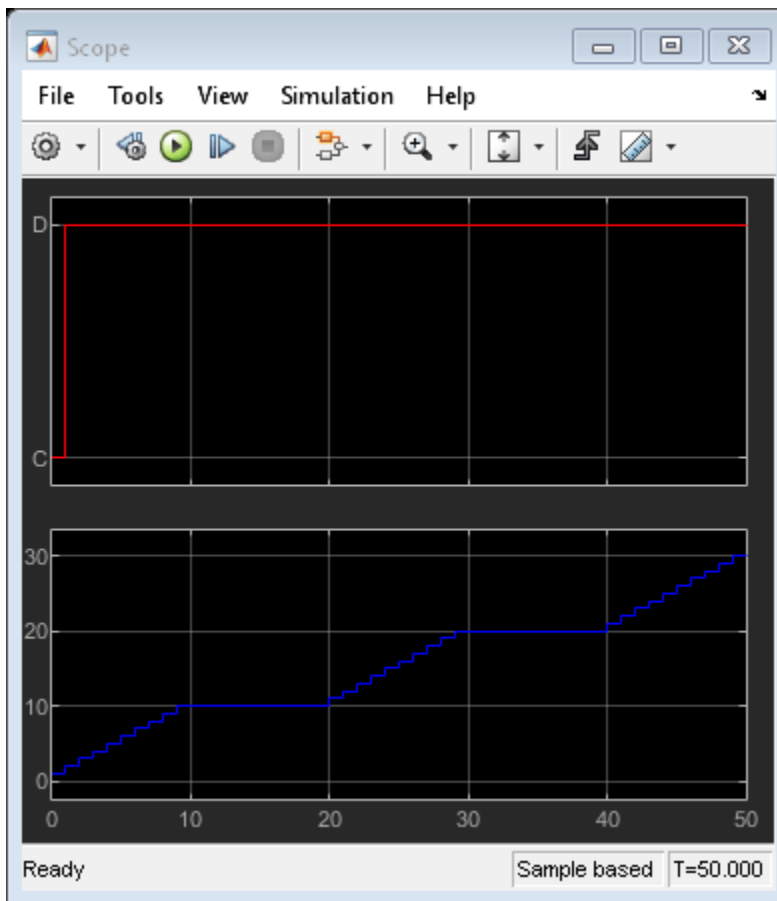


The Callee chart contains two states, C and D. Each time that the chart executes, the output data `y` increments by one. The state C is initially active. After one time step, the value of `y` is positive and the chart takes the transition to state D.



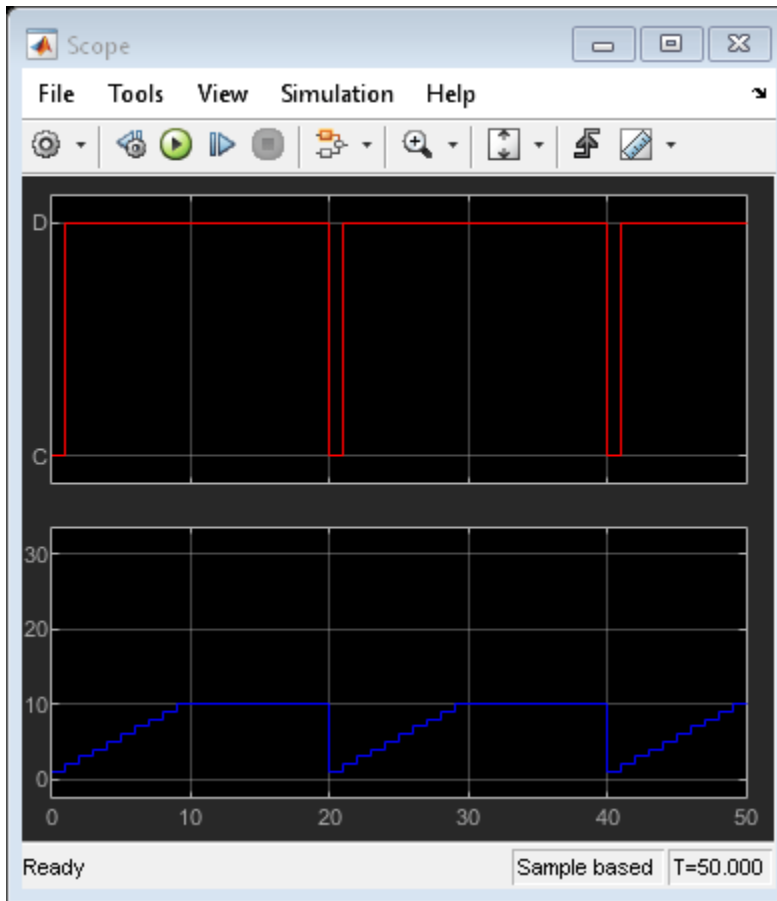
### Chart Simulation When Property Is Held

In the Callee chart, the **States When Enabling** property is set to Held. During simulation, when the function-call input event reenables the chart at times  $t = 20$  and  $t = 40$ , state D stays active and output  $y$  maintains its most recent value.



### Chart Simulation When Property is Reset

In the Callee chart, change the **States When Enabling** property to Reset. During simulation, when the function-call input event reenables the chart at times  $t = 20$  and  $t = 40$ , state C becomes active and output  $y$  reverts to its initial value of zero.



## See Also

### More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Model References” (Simulink)

## Activate a Simulink Block by Sending Output Events

An output event is an event that occurs in a Stateflow chart but is visible in Simulink blocks outside the chart. This type of event enables a chart to notify other blocks in a model about events that occur in the chart. To define an output event:

- 1 Add an event to the Stateflow chart, as described in “Define Events in a Chart” on page 14-2.
- 2 Set the **Scope** property for the event to **Output to Simulink**. For each output event that you define, an output port appears on the Stateflow block.
- 3 An output event can activate other blocks in the model through a change in a control signal (an edge trigger) or a function call to a Simulink block.
  - To specify an edge-triggered output event, set the **Trigger** property to **Either Edge**.
  - To specify a function-call output event, set the **Trigger** property to **Function call**.

For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

### Broadcast Output Events

To broadcast output events from one chart to another, use the operator `send`. The format of an output event broadcast is

```
send(event_name)
```

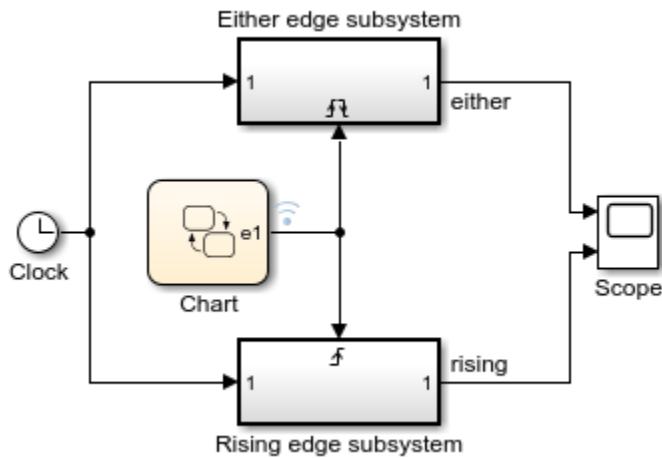
where *event\_name* is an output event.

### Activate a Simulink Block by Using Edge Triggers

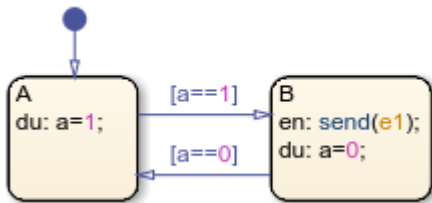
An edge-triggered output event activates a Simulink block to execute during the current time step of simulation. With this type of output event, a change in a control signal acts as a trigger. For more information, see “Using Triggered Subsystems” (Simulink).

#### When to Use Edge-Triggered Output Events

To activate a Simulink subsystem when your model requires regular or periodic subsystem execution, use an edge-triggered output event. For example, this model uses an edge-triggered output event to activate two triggered subsystems at regular intervals.

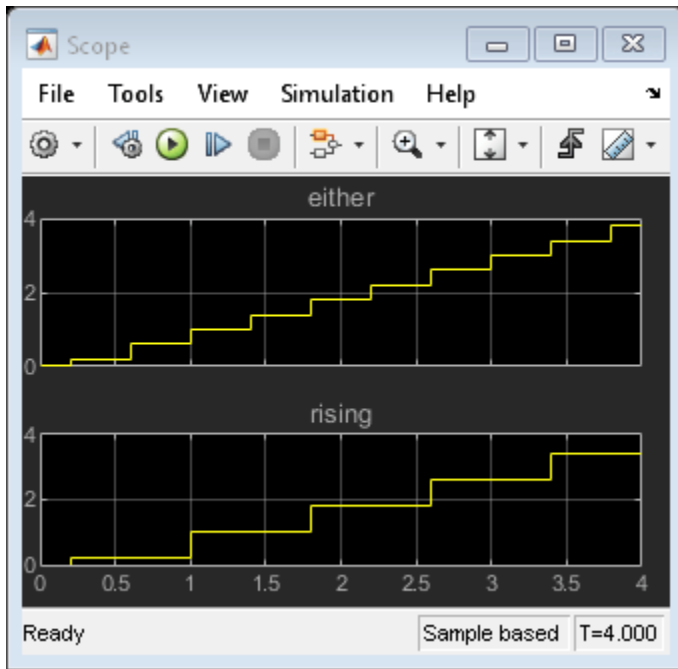


The chart contains the edge-triggered output event e1 which alternates between 0 and 1 during simulation.



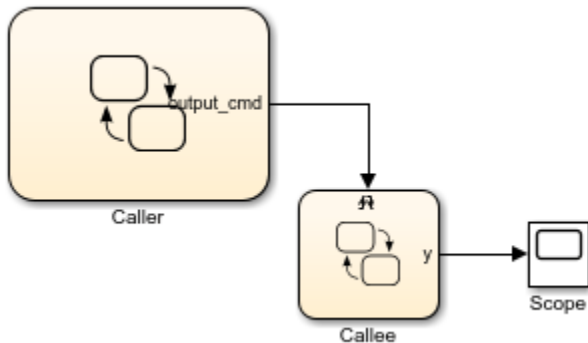
In a Stateflow chart, the **Trigger** property of an edge-triggered output event is always **Either Edge**. Simulink triggered subsystems can have a **Rising**, **Falling**, or **Either** edge trigger. The model shows the difference between triggering an **Either** edge subsystem from a **Rising** edge subsystem:

- The output event triggers the **Either** edge subsystem on every broadcast. The trigger occurs when the event signal switches from 0 to 1 or from 1 to 0.
- The output event triggers the **Rising** edge subsystem on every other broadcast. The trigger occurs only when the event signal switches from 0 to 1.

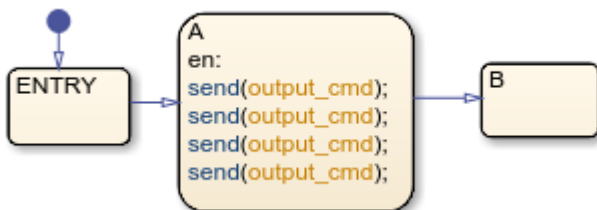


### Queuing Behavior of Multiple Edge-Triggered Output Events

A chart dispatches only one broadcast of an edge-triggered output event for each time step. When there are multiple broadcasts in a single time step, the chart dispatches one broadcast and queues up the remaining broadcasts for dispatch in successive time steps. For example, in this model, the Caller chart uses the edge-triggered output event `output_cmd` to activate the Callee chart.



The Caller chart tries to broadcast the same edge-triggered output event four times in a single time step.

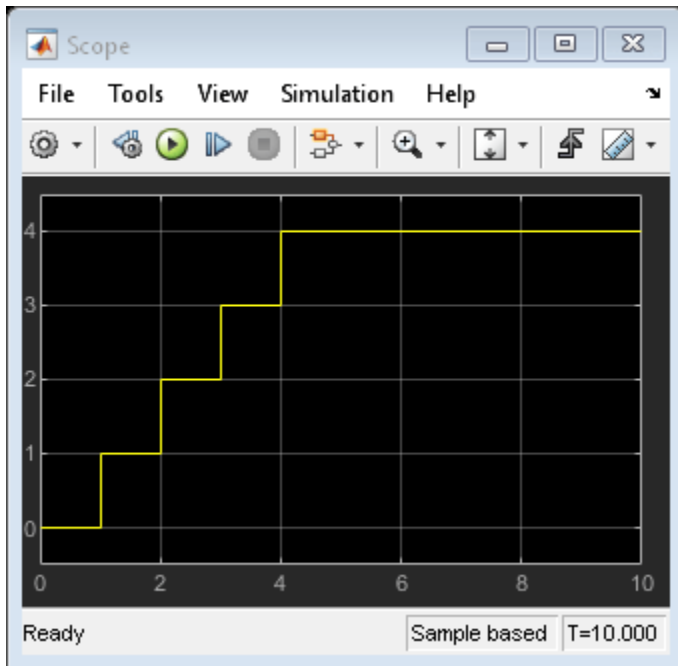




Each time the Callee chart is activated, the output data  $y$  increments by one.



When you simulate the model, at time  $t = 1$ , the Caller chart dispatches one of the four output events. The Callee chart executes once during that time step. The Caller chart queues up the other three event broadcasts for future dispatch at a time  $t = 2$ ,  $t = 3$ , and  $t = 4$ . As a result, the value of  $y$  grows in increments of one at time  $t = 1$ ,  $t = 2$ ,  $t = 3$ , and  $t = 4$ .



## Activate a Simulink Block by Using Function Calls

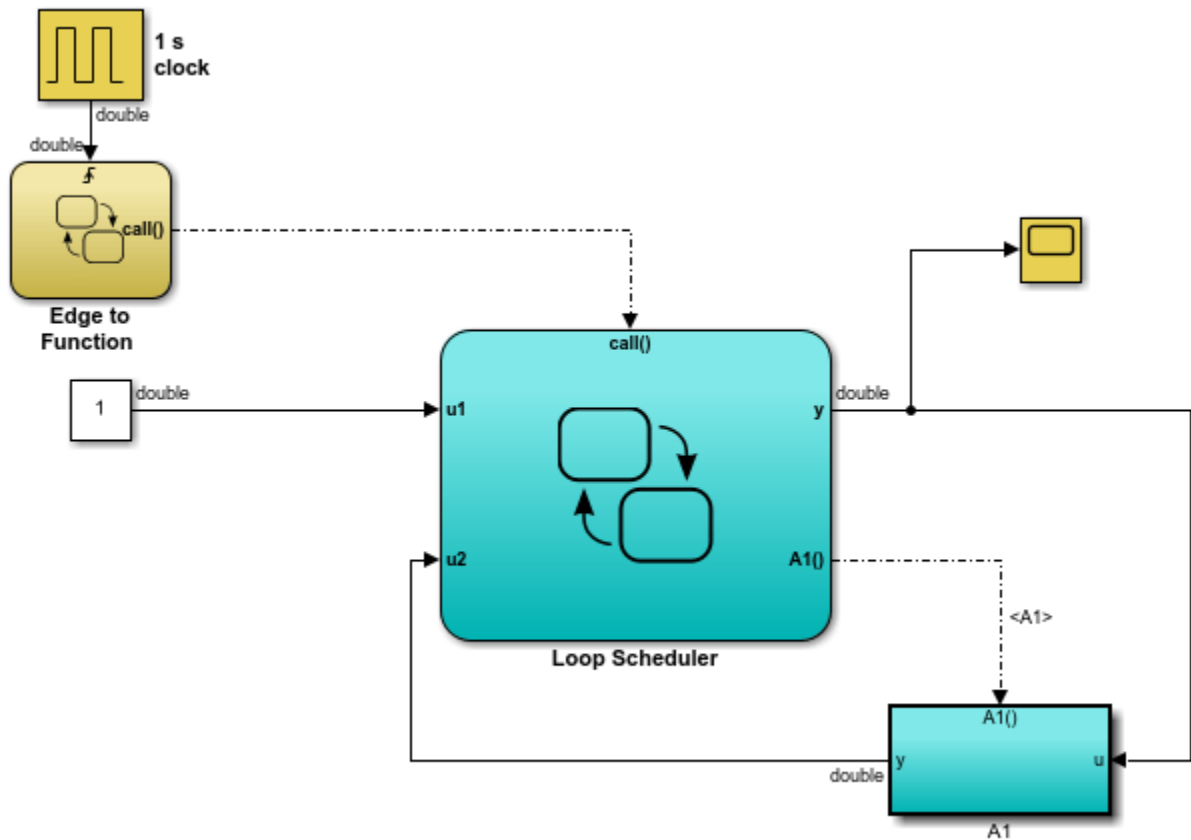
A function-call output event activates a Simulink block to execute during the current time step of simulation. This type of output event works only on blocks that you can trigger with a function call. For more information, see “Using Function-Call Subsystems” (Simulink).

### When to Use Function-Call Output Events

Use a function-call output event to activate a Simulink block when your model requires access to output data from the block in the same time step as the function call. For example, this model contains two function-call output events:

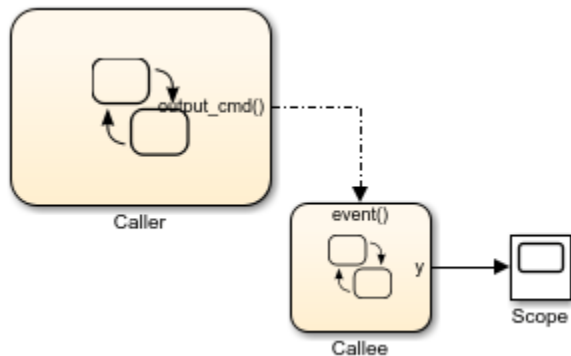
- In the Edge to Function chart, the output event `call` activates the Looping Scheduler chart.
- In the Looping Scheduler chart, the output event `A1` activates a Simulink subsystem.

For more information, see “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6.

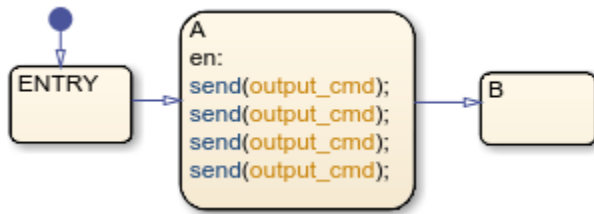


**Interleaving Behavior of Multiple Function-Call Output Events**

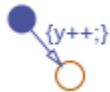
When there are multiple broadcasts of a function-call output event in a single time step, the chart dispatches all the broadcasts in that time step. Execution of function-call subsystems is interleaved with the execution of the chart, so that output from the function-call subsystem is available immediately in the chart. For example, in this model, the Caller chart uses the function-call output event `output_cmd()` to activate the Callee chart.



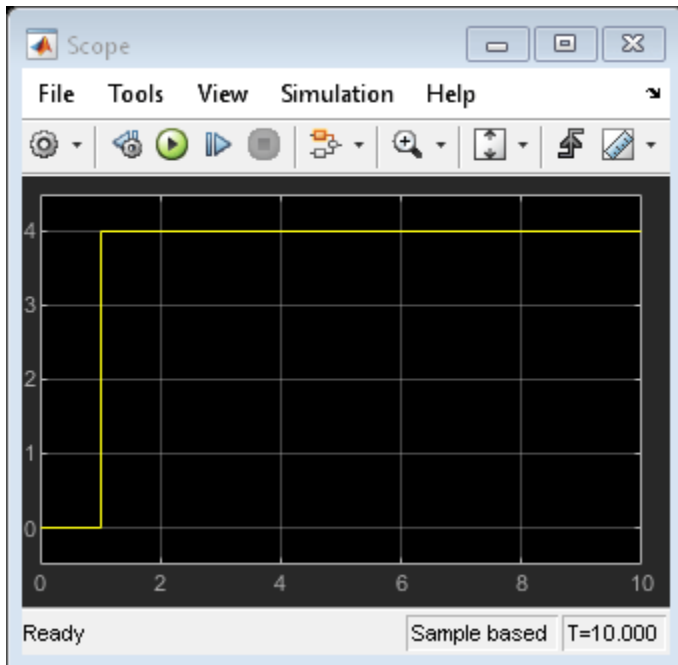
The Caller chart tries to broadcast the same function-call output event four times in a single time step.



Each time the Callee chart is activated, the output data  $y$  increments by one.



When you simulate the model, the Caller chart dispatches all four output events at time  $t = 1$ . The Callee chart executes four times during that time step. Execution of the Callee chart is interleaved with execution of the Caller chart so that output from the Callee chart is immediately available. As a result, the value of  $|y|$  increases from 0 to 4 at time  $t = 1$ .



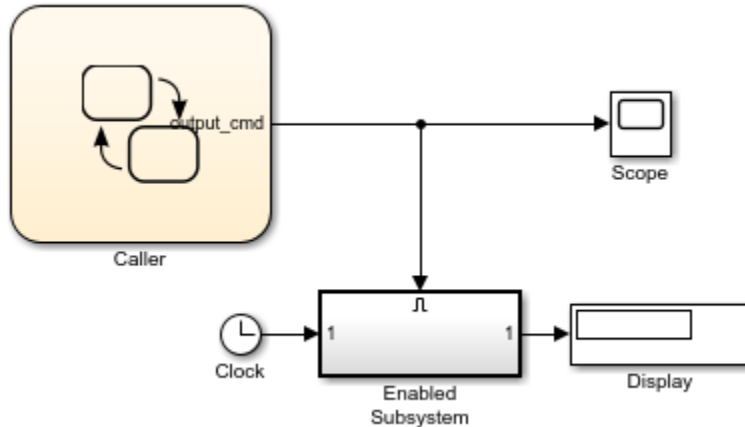
## Approximate a Function Call by Using Edge-Triggered Events

If you cannot use a function-call output event, such as for HDL code generation, you can approximate a function call by using:

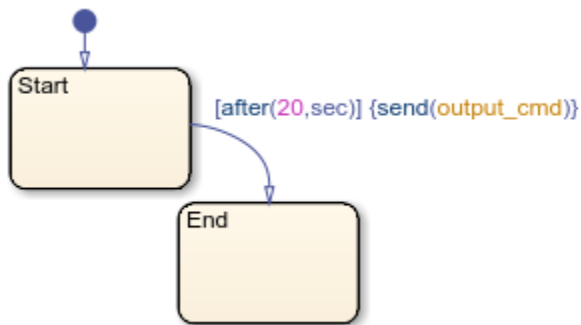
- An edge-triggered output event
- An enabled subsystem
- Two consecutive event broadcasts

The queuing behavior of consecutive edge-triggered output events enables you to approximate a function call with an enabled subsystem.

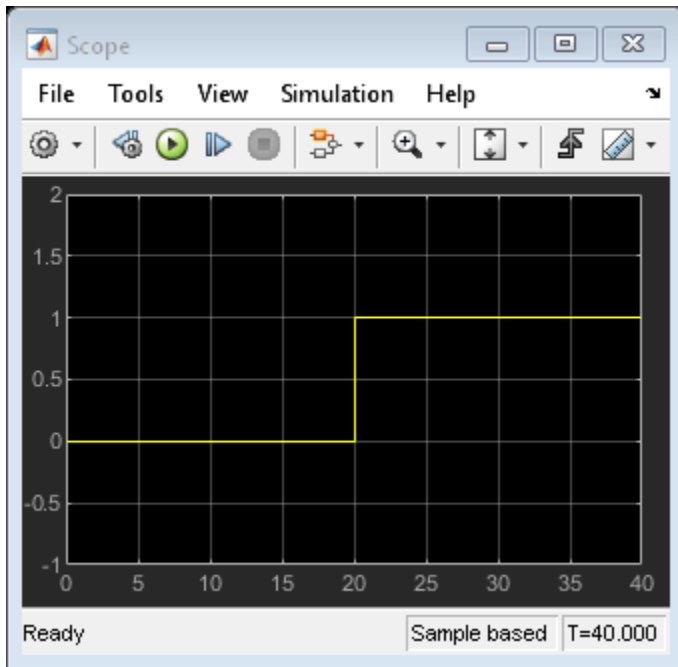
For example, in this model, the edge-triggered output event `output_cmd` activates the enabled subsystem.



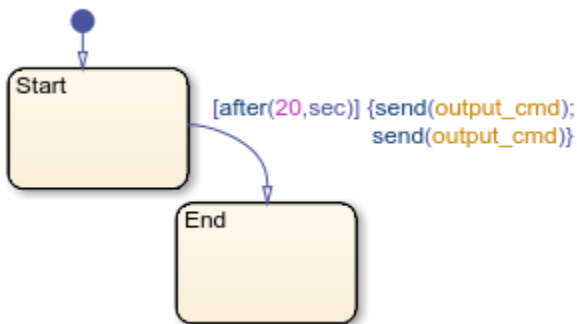
The Caller chart broadcasts the edge-triggered output event by using the `send` operator.



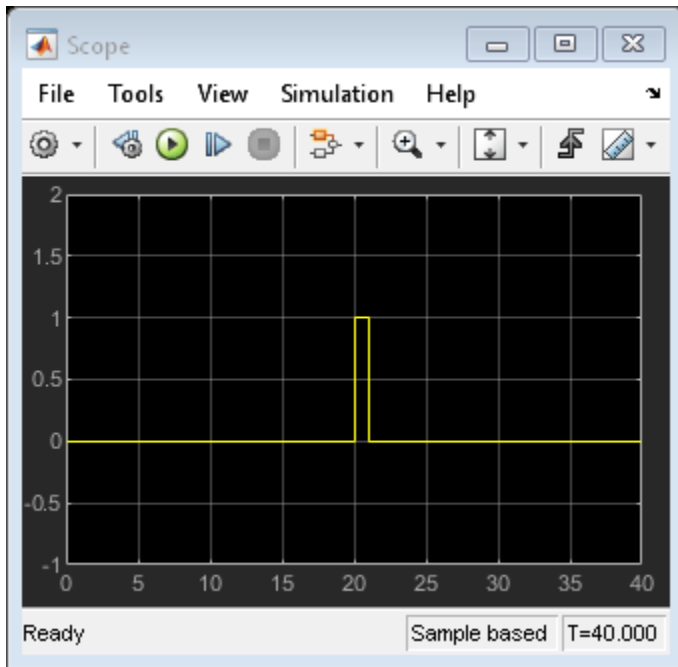
When simulation starts, the value of the trigger signal is 0. At time  $t = 20$ , the chart dispatches `output_cmd`, changing the value of the trigger signal to 1. The enabled subsystem becomes active and executes during that time step. Because no other event broadcasts occur, the enabled subsystem continues to execute at every time step until simulation ends at  $t = 40$ . The Display block shows a final value of 40.



To approximate a function call, add a second event broadcast in the same action.



When simulation starts, the value of the trigger signal is 0. At time  $t = 20$ , the chart dispatches `output_cmd`, changing the value of the trigger signal to 1. The enabled subsystem becomes active and executes during that time step. The chart queues up the second event for dispatch at the next time step. At time  $t = 21$ , the chart dispatches the second output event, which changes the value of the trigger signal back to 0. The enabled subsystem stops executing and the Display block shows a final value of 20.



Although you can approximate a function call, there is a subtle difference in execution behavior. Execution of a function-call subsystem occurs *during* execution of the chart action that provides the trigger. Execution of an enabled subsystem occurs *after* execution of the chart action is complete.

## Association of Output Events with Output Ports

When you define an output event in a chart, an output event port appears on the right side of a chart block. Output events must be scalar, but you can define multiple output events in a chart. The **Port** property of an output event specifies the position of the output port.

By default, **Port** values appear in the order in which you add output events. You can change these assignments by modifying the **Port** property of the events. When you change the **Port** property for an output event, the **Port** values for the remaining output events automatically renumber.

## See Also

send

## More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Set Properties for an Event” on page 14-5
- “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14
- “Using Triggered Subsystems” (Simulink)
- “Using Function-Call Subsystems” (Simulink)

## Broadcast Local Events to Synchronize Parallel States

A local event is an event that occurs in a Stateflow chart and is visible only in the chart. This type of event enables parallel (AND) states in the same chart to synchronize with one another, so that actions in one state trigger actions in the other state. An action in one chart cannot broadcast local events to states in another chart. To define a local event:

- 1 Add an event to the Stateflow chart, as described in “Define Events in a Chart” on page 14-2.
- 2 Set the **Scope** property for the event to **Local**.

Local events are supported only in Stateflow charts in Simulink models. For more information, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

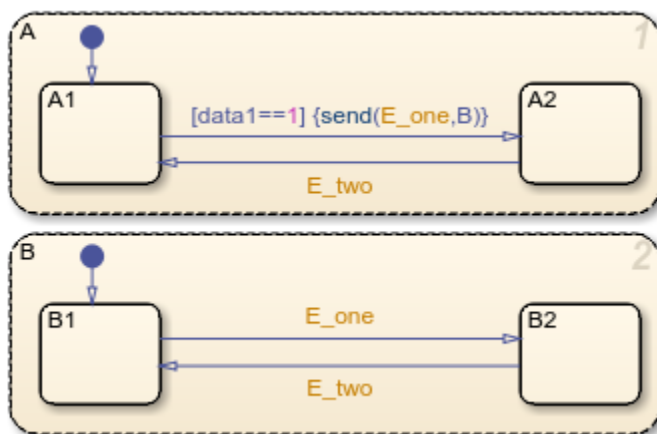
### Broadcast Local Events

A directed event broadcast sends a local event directly from one state to another by using the operator `send`:

```
send(event_name, state_name)
```

*event\_name* is a local event and *state\_name* is a receiving state. The local event is broadcast directly to the receiving state and any of its substates. The local event must be visible to both the sending state and the receiving state. The receiving state must be active during the event broadcast.

For example, this chart contains two parallel (AND) states, A and B. The local event `E_one` belongs to the chart and is visible to both states. In state A, the transition from substate A1 to substate A2 uses a directed event broadcast of the form `send(E_one, B)` to send the local event `E_one` to state B. In B, the event triggers the transition from substate B1 to substate B2. Therefore, the active substates in A and B are synchronized. For more information on the semantics of this example, see “Directed Event Broadcast Using Send” on page B-39.



The *state\_name* argument can include a full hierarchy path to the state. For example, if the state A contains the state A1, you can send an event E to state A1 with this broadcast:

```
send(E, A.A1)
```

---

**Tip** Do not include the chart name in the full hierarchy path to a state.

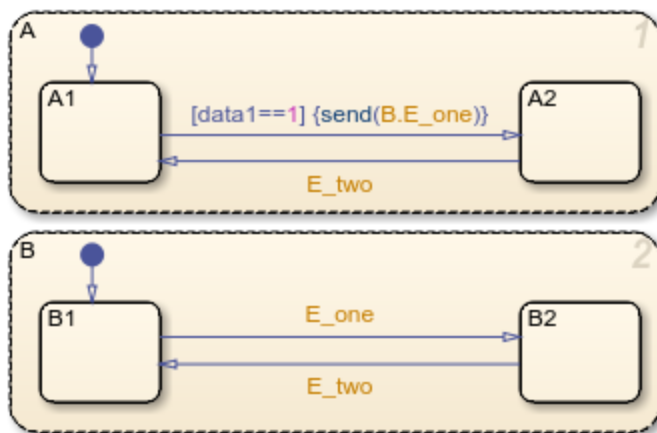
## Use Qualified Event Names in Event Broadcasts

To broadcast a local event that is not visible to the sending state, use the operator `send` with a qualified event name:

```
send(state_name.event_name)
```

*event\_name* is a local event that is owned by the receiving state *state\_name*. The local event is broadcast directly to the receiving state and any of its substates. The local event is visible to the receiving state, but not to the sending state. The receiving state must be active during the event broadcast.

For example, this chart contains two parallel (AND) states, A and B. The local event `E_one` belongs to state B and is visible only to that state. In state A, the transition from substate A1 to substate A2 uses a directed event broadcast of the form `send(B.E_one)` to send the local event `E_one` to state B. In B, the event triggers the transition from substate B1 to substate B2. Therefore, the active substates in A and B are synchronized. For more information on the semantics of this example, see “Directed Event Broadcast Using Qualified Event Name” on page B-40.



The *state\_name* argument can include a full hierarchy path to the receiving state. Do not use the chart name in the full path name of the state. For example, suppose that the state A contains the state A1, and that A1 owns the local event E. You can send event E to state A1 with this broadcast:

```
send(A.A1.E)
```

## Undirected Event Broadcasts

An undirected event broadcast sends a local event to all states in which it is visible by using the name of the event as a condition action:

```
event_name;
```

or by calling the operator `send` without specifying a receiving state:

```
send(event_name)
```

*event\_name* is a local event that is visible to the sending state.



When possible, use directed event broadcasts instead of undirected event broadcasts. Directed event broadcasts prevent unwanted recursion during simulation and improve the efficiency of generated code. For more information, see “Avoid Unwanted Recursion in a Chart” on page 33-37.

### **Diagnostic for Detecting Undirected Local Event Broadcasts**

During simulation, Stateflow charts can detect undirected local event broadcasts. To control the level of diagnostic action, open the Configuration Parameters dialog box. In the **Diagnostics > Stateflow** pane, for the **Undirected event broadcasts** diagnostic, you can select none, warning, or error. The default setting is warning. For more information, see “Undirected event broadcasts” (Simulink).

### **See Also**

send

### **More About**

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Set Properties for an Event” on page 14-5
- “Broadcast Local Events in Parallel States” on page B-39

## Control Chart Behavior by Using Implicit Events

Implicit events are built-in events that occur during chart execution when:

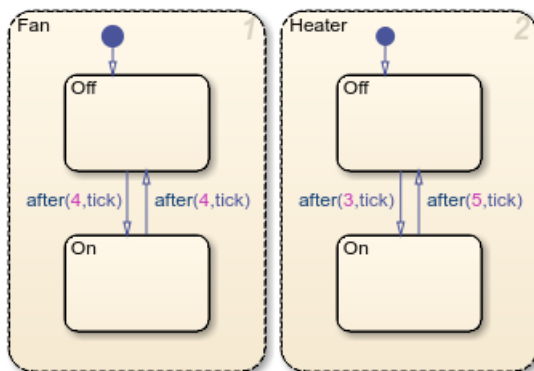
- The chart wakes up.
- The chart enters a state and the state becomes active.
- The chart exits a state and the state becomes inactive.
- The chart assigns a value to an internal data object.

These events are implicit because you do not define or trigger them explicitly. Implicit events are children of the chart in which they occur and are visible only in the parent chart.

### Implicit Events Based on Chart Execution

The keyword `tick` specifies the implicit event generated when a chart wakes up in a discrete-time simulation.

For example, in this chart, `Fan` and `Heater` are parallel (AND) states. Each state has a pair of substates, `On` and `Off`. Initially, the substates `Fan.Off` and `Heater.Off` are active. Each time the chart wakes up, it generates a `tick` event. The third `tick` triggers the transition from `Heater.Off` to `Heater.On`. Similarly, the fourth `tick` triggers the transition from `Fan.Off` to `Fan.On`. On the eighth `tick`, the chart transitions back to `Fan.Off` and `Heater.Off`.



For information about the temporal logic operator `after`, see “Control Chart Execution by Using Temporal Logic” on page 16-36.

---

**Note** The `tick` event refers to the chart containing the action being evaluated. The event cannot refer to a different chart.

---

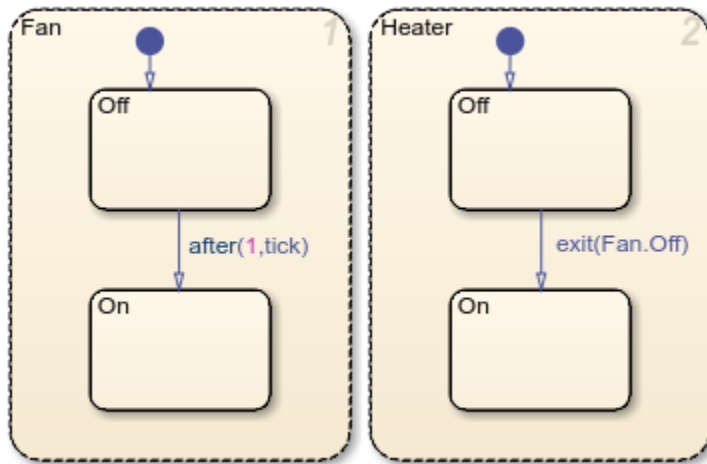
### Implicit Events Based on Data and States

In Stateflow charts in Simulink models, these operators generate implicit events when a chart sets the value of a variable or when a chart enters or exits a state.

Operator	Syntax	Description	Example
change	change( <i>data_name</i> ) chg( <i>data_name</i> )	Generates an implicit local event when the chart sets the value of the variable <i>data_name</i> . The variable <i>data_name</i> cannot be machine-parented data. This implicit event works only with data that is at the chart level or lower in the hierarchy. For machine-parented data, use change detection operators to determine when the data value changes. For more information, see “Detect Changes in Data Values” on page 16-64.	Define an implicit local event when a state or transition action writes a value to the variable Engine.rpm.  change(Engine.rpm)
enter	enter( <i>state_name</i> ) en( <i>state_name</i> )	Generates an implicit local event when the specified state <i>state_name</i> becomes active.	Define an implicit local event when the chart execution enters the state Fan.On.  enter(Fan.On)
exit	exit( <i>state_name</i> ) ex( <i>state_name</i> )	Generates an implicit local event when the specified state <i>state_name</i> becomes inactive.	Define an implicit local event when the chart execution exits the state Fan.Off.  exit(Fan.Off)

If more than one state or data object has the same name, use dot notation to qualify the name of the state. For more information, see “Identify Data by Using Dot Notation” on page 12-39.

For example, in this chart, Fan and Heater are parallel (AND) states. Each state has a pair of substates, On and Off. Initially, the substates Fan.Off and Heater.Off are active. When the chart wakes up, it generates a tick event that triggers the transition from Fan.Off to Fan.On. When the Fan.Off becomes inactive, the chart generates another implicit event that triggers the transition from Heater.Off to Heater.On. When the chart execution ends, the substates Fan.On and Heater.On are active.



---

**Note** If the same implicit event triggers multiple transitions in parallel states, the order in which the transitions execute does not necessarily match the execution order of the parallel states. To avoid unexpected behavior and ensure that the transitions execute in the order specified for the parallel states, do not use implicit events. Instead, use transition conditions that call operators such as `in` or `hasChanged`. For more information, see “Check State Activity by Using the `in` Operator” on page 13-17 and “Detect Changes in Data Values” on page 16-64.

---

### See Also

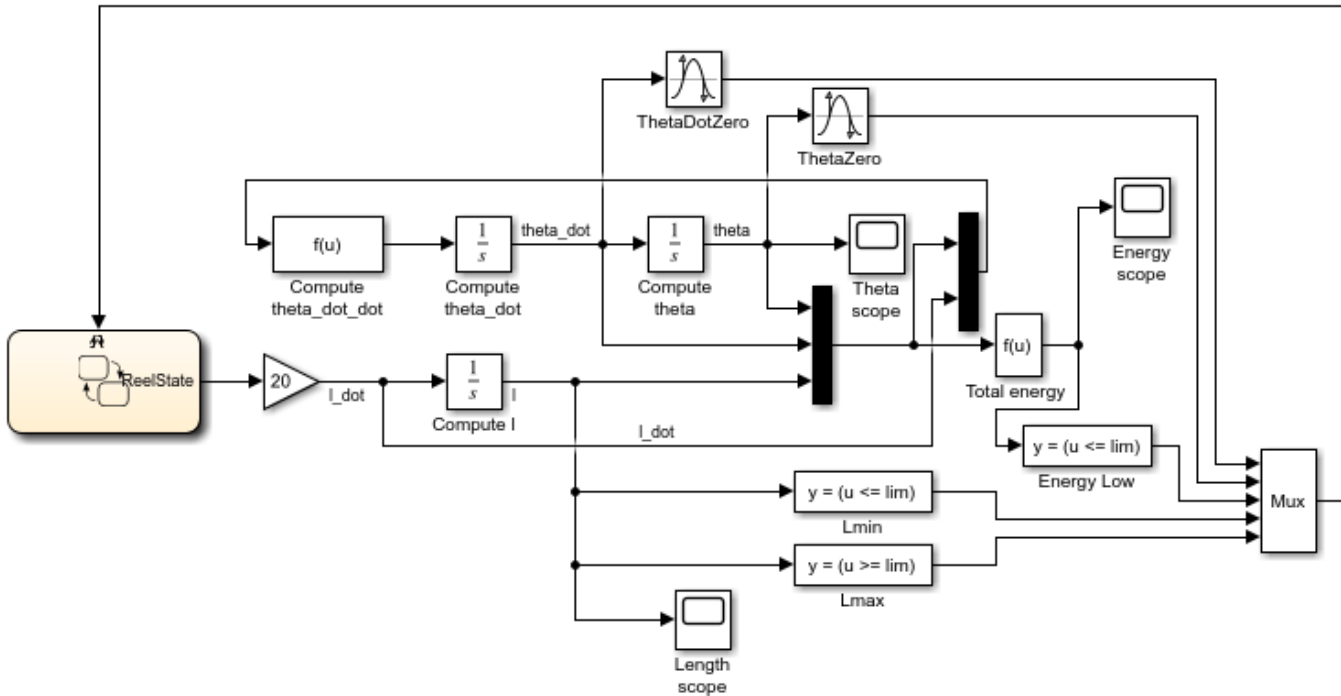
after | change | enter | exit | hasChanged | in

### More About

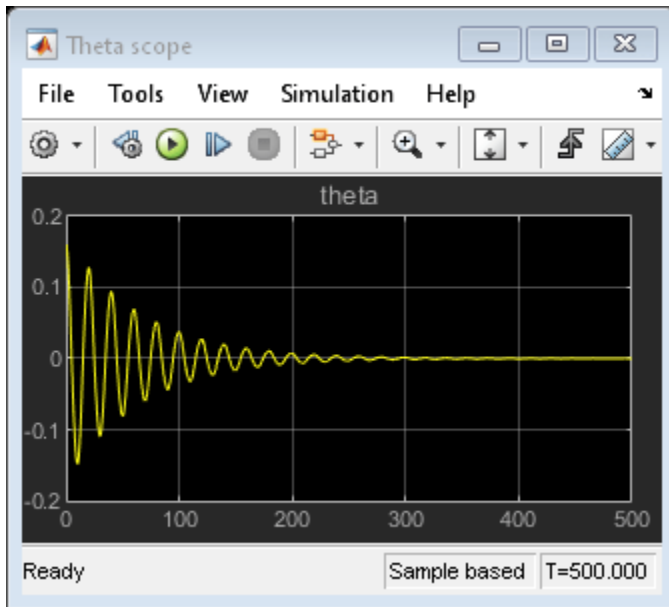
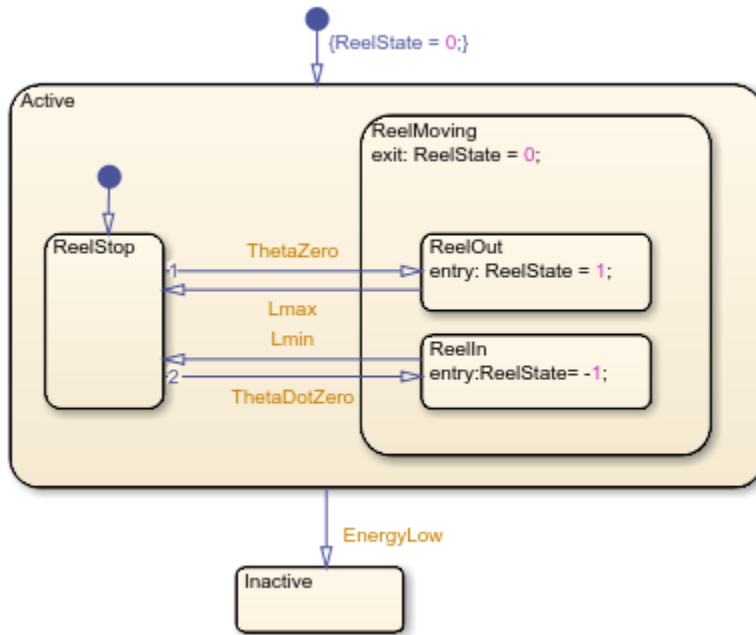
- “Use Events to Execute Charts” on page 3-53
- “Detect Changes in Data Values” on page 16-64
- “Check State Activity by Using the `in` Operator” on page 13-17
- “Control Chart Execution by Using Temporal Logic” on page 16-36

## Yo-Yo Control of Satellites

This example shows how to model the control system in a tethered satellite system. The satellite system consists of a small satellite attached by a long tether to an orbiting platform. When the tethered satellite oscillates, it behaves like a pendulum that exhibits too much libration. To stabilize the pendulum, the control system changes the length of the tether by reeling it out to its maximum length when the satellite is in the middle of its arc (which decreases its angular acceleration) and by reeling it in when the satellite has an angular velocity equal to zero.



Stateflow® is used to control when the tether is reeled in or reeled out using input events from Simulink®. When the satellite is in the middle of its swing ( $\theta = 0$ ), the state ReelOut becomes active. When the satellite has been reeled out as far as it can, the state ReelStop becomes active. When the angular velocity of the satellite reaches zero, the ReelIn state becomes active. When the tether is as short as possible, the ReelStop state becomes active once again. Finally, if the total energy of the satellite is too low, the system is deactivated by entering the Inactive state.



**Reference**

Dabney, James B. and Harman, Thomas L. *Mastering Simulink*, 2003.

**See Also**

**More About**

- “Synchronize Model Components by Broadcasting Events” on page 14-2

## Model a Security System

This example shows how to model a home alarm system that has multiple intrusion-detection sensors. When the system detects an intrusion, it gives you a short amount of time to disable the alarm. If you do not disable the alarm within the allotted time, the system calls the police.

This model shows how to use:

- Local event broadcasts to coordinate between parallel states.
- Output events to drive external blocks.
- Input events to simulate periodic triggering of a system.

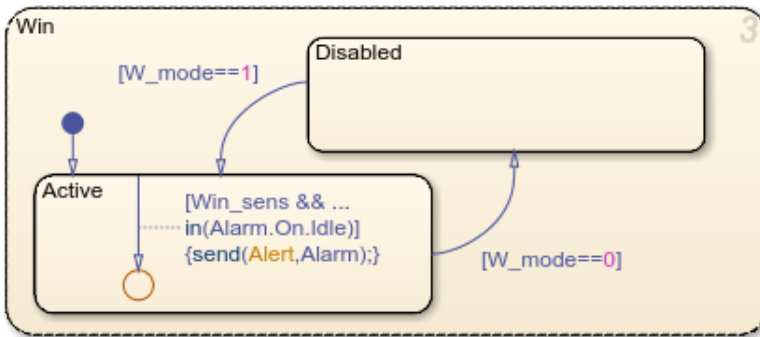
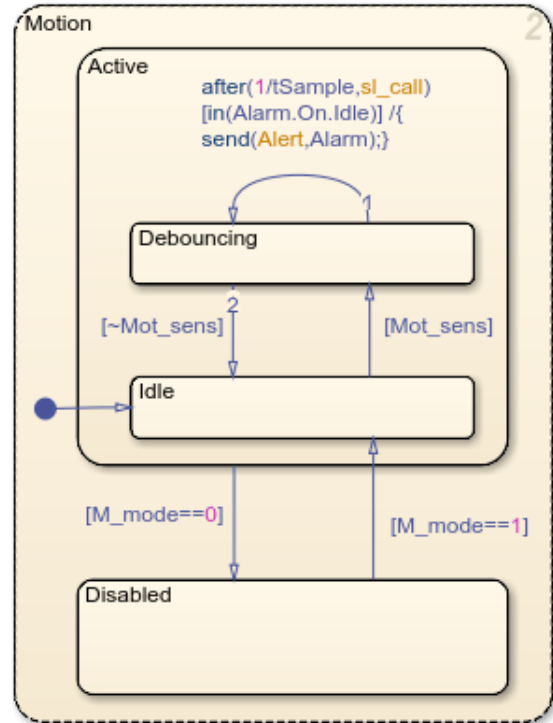
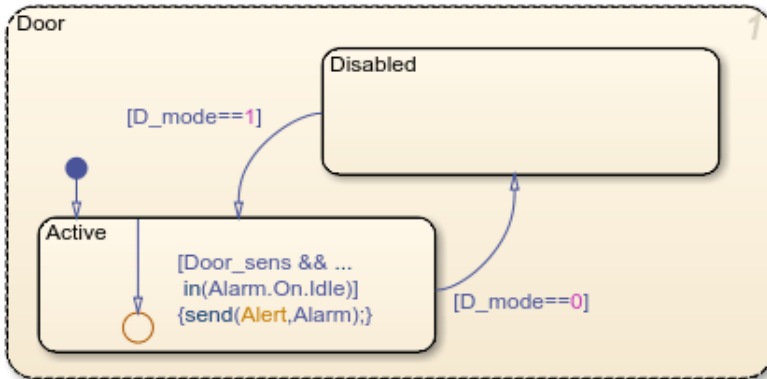
The chart models the logic of the security system. It consists of four parallel states: one for each type of anti-intrusion sensor (window, door, and motion detector), and a fourth state that controls the alarm. In each time step, the parallel states are evaluated in sequence as indicated by the numbers in the top right corners of the states.

Inputs to the system include a signal that controls whether the alarm is enabled and, for each sensor, an on/off control and an intrusion signal. The chart outputs signals to sound an alert and to call the police.

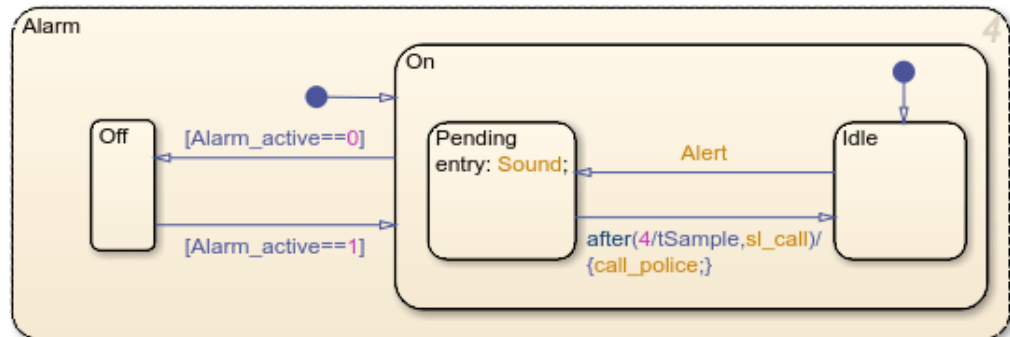
For additional implementation details, see the chart annotations.

The Door and Win states model anti-intrusion sensors at a window and a door. When these sensors are active, the corresponding states check the value of D\_mode and W\_mode. If one of these variables is true, the states broadcast a local event to the Alarm state.

Input from the motion sensor can be sporadic, so a debouncing state is used. The debouncing state remains active while Mot\_sens is true. After a delay period, the debouncing state broadcasts a local event to the Alert state.



When an Alert event is broadcast to the Alarm state, the Pending state becomes activate for a delay period. If the alarm is not disabled during the delay period, the police are contacted by the output event call\_police.



**See Also**

**More About**

- “Synchronize Parallel States by Broadcasting Events”
- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Activate a Simulink Block by Sending Output Events” on page 14-14

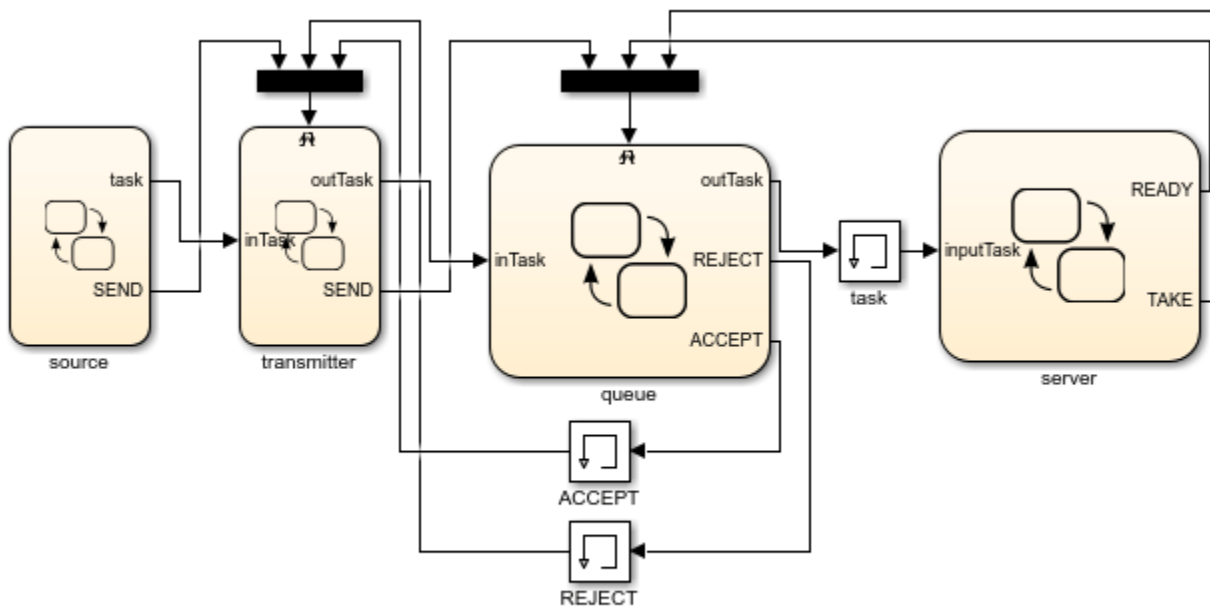


- “Activate a Stateflow Chart by Sending Input Events” on page 14-7

## Server Queuing System

This example shows the simulation of a queuing system for a server processing tasks. There are four Stateflow® charts involved in the process:

- 1 The Source produces tasks that are weighted 1 to 5. Tasks take an amount of time proportional to their weight.
- 2 The Transmitter takes a signal from the source and sends it to the Queue. It shows the weight of the task on the left of the display in blue. It waits for either an ACCEPT or REJECT notification from the Queue. It releases the task to the Queue upon an ACCEPT. It marks the task as dropped (red) upon a REJECT.
- 3 The Queue receives tasks from the Transmitter. If there is room in the Queue, it queues the task for the Server. If there is no room, the Queue overflows, and it rejects the task. The tasks in the Queue are shown in the black boxes in the display.
- 4 The Server polls the Queue for tasks. If the Queue has a task waiting, the Server takes the task and processes it. The task that is processing is shown in black on the right of the display. The Server remains busy for the amount of time the task takes, and then goes back to polling the Queue.



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### See Also

### More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Export Stateflow Functions for Reuse” on page 8-23

## Tic-Tac-Flow: Model of a Hand-held Game

This model shows a variation of the classic tic-tac-toe game with an interesting twist. Only the last three moves of each player count. Thus the user needs to also account for the order in which the opponent has played the last few moves. This adds a nontrivial twist to the gameplay.

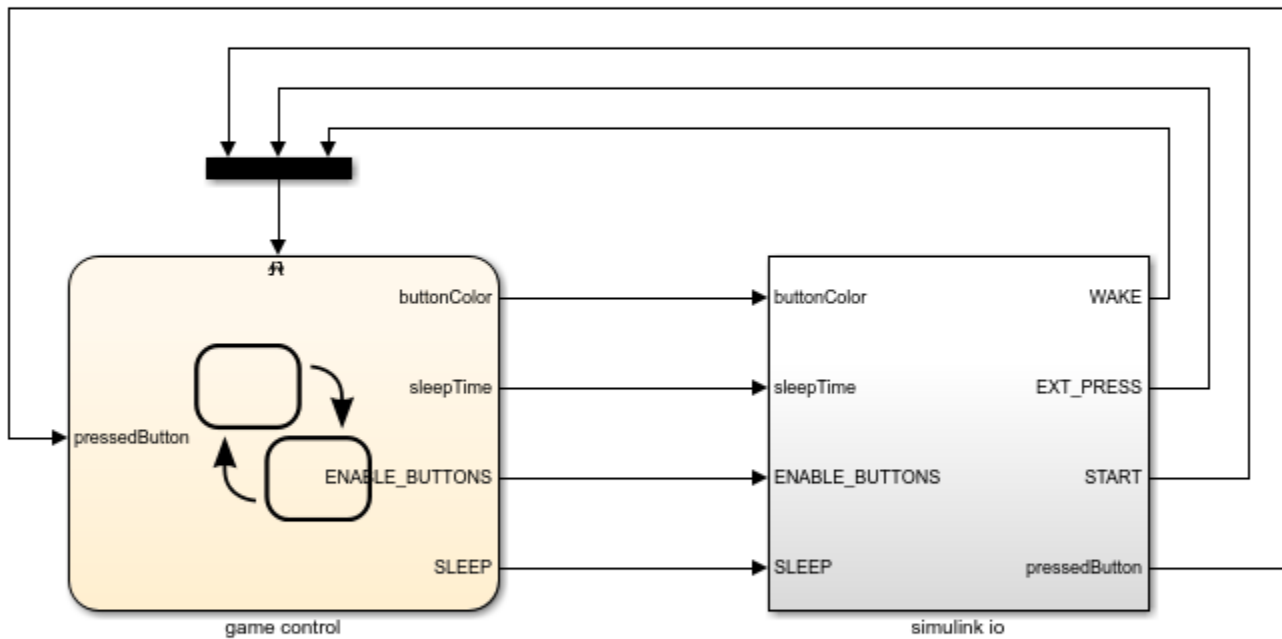
The model shows several Stateflow® charts interacting with each other. It exhibits how heavily event-based logic can be captured naturally in Stateflow. It also describes Stateflow semantics such as parallel substates, graphical functions and MATLAB® handle graphics from Stateflow. The model is divided into several subsystems which naturally separate the game control from the I/O. This allows for the Stateflow code generated from the game control chart to be reused in a hardware component.

## Tic Tac Flow Model of a Hand-Held Game

Click **Play** or **Simulation > Run** to play "Tic Tac Flow"

This example illustrates how a microcontroller-based product can be modeled and implemented using Stateflow.

The model is partitioned to separate the hardware-independent portion (in this case, the game logic) from the hardware-specific portion (the user interface). By using Handle Graphics to build a high-level simulation of the user interface, the product concept can be tested and refined via simulation early in the design cycle before any hardware is designed or constructed. For the final product implementation, the hardware-independent portion is implemented automatically by Stateflow, while the hardware-specific portion is replaced by actual hardware and low-level driver software.



### Game Logic By Stateflow

This Stateflow diagram implements the rules of the game.

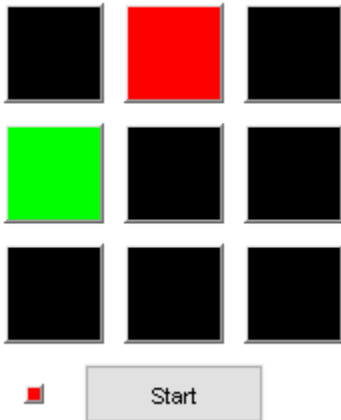
In the final product, the software for this part of the game is generated automatically by Stateflow without modifying the diagram.

### Simulation of Hardware I/O

This subsystem uses MATLAB, Handle Graphics, Simulink, and Stateflow to simulate the user interface of a hand-held game.

In the final product, this subsystem is replaced by electronic hardware and low-level driver software.

The UI is implemented as a MATLAB figure which interacts with the Stateflow simulation. The button callback functions drive the inputs to the Stateflow chart.



## See Also

### More About

- “State Decomposition” on page 2-19
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Graphics Objects”



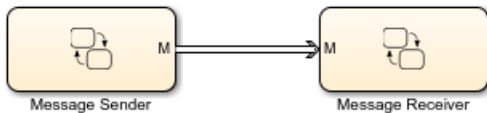
# Messages

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- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Set Properties for a Message” on page 15-5
- “Control Message Activity in Stateflow Charts” on page 15-9
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14
- “Model a Distributed Traffic Control System by Using Messages” on page 15-20
- “Use the Sequence Viewer to Visualize Messages, Events, and Entities” on page 15-24

## Communicate with Stateflow Charts by Sending Messages

To communicate within and between Stateflow charts in a Simulink model, use messages. A message is a Stateflow object that communicates data locally or between charts. From a sender chart, you can send or forward a message containing data. In the receiving chart, a queue receives the message and holds it until the chart can evaluate it.



Messages combine some of the functionality of data and events. Like data, messages can transmit numeric and textual information. Like events, messages can trigger transition and state actions. However:

- Messages do not trigger charts to wake up. Instead, messages are queued until the chart wakes up. When the chart wakes up, it can respond to the messages in the queue.
- Messages are not lost if the receiver chart cannot respond immediately.


For more information, see “View Differences Between Stateflow Messages, Events, and Data” on page 15-14.

When a chart transition or state action evaluates a message, the chart determines if the queue contains any messages. If it does, the chart removes the message from the queue. The message remains valid until the end of the time step or until the chart forwards or discards it. While the message is valid, other transitions or actions can access the message data and the chart does not remove another message from the queue. The chart destroys all valid messages at the end of the current time step.

### Define Messages in a Chart

You can add messages to a Stateflow chart by using the Symbols pane, the Stateflow Editor menu, or the Model Explorer.

#### Add Messages Through the Symbols Pane

- 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane**.
- 2 Click the **Create Message** icon .
- 3 In the row for the new message, under **TYPE**, click the icon and choose:
  - Input Message
  - Local Message
  - Output Message
- 4 Edit the name of the message.
- 5 For input and output messages, click the **PORT** field and choose a port number.
- 6 To specify properties for the message, open the Property Inspector. In the Symbols pane, right-click the row for the message and select **Explore**. For more information, see “Set Properties for a Message” on page 15-5.



## Add Messages by Using the Stateflow Editor Menu

- 1 In the Stateflow Editor, select the option corresponding to the scope of the message that you want to add.

Scope	Option
Input	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Message Input</b> .
Output	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Message Output</b> .
Local	In the <b>Modeling</b> tab, under <b>Design Data</b> , select <b>Message</b> .

- 2 In the Message dialog box, specify data properties. For more information, see “Set Properties for a Message” on page 15-5.

## Add Messages Through the Model Explorer

- 1 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
- 2 In the **Model Hierarchy** pane, select the object in the Stateflow hierarchy where you want to make the new message visible. The object that you select becomes the parent of the new message.
- 3 In the Model Explorer menu, select **Add > Message**. The new message with a default definition appears in the **Contents** pane of the Model Explorer.
- 4 In the **Message** pane, specify the properties of the message. For more information, see “Set Properties for a Message” on page 15-5.

## Lifetime of a Stateflow Message

A Stateflow message has a finite lifetime. The lifetime begins when you send a message to a receiving queue with the `send` operator. The message remains in the queue until a transition or state on action evaluates it or the chart receives it by using the `receive` operator.

A message becomes valid when a chart evaluates or receives it. The message remains valid until:

- The end of the current time step, when the chart destroys any remaining valid messages.
- The chart forwards the message to another queue by using the `forward` operator. The message continues its lifetime in the new queue.
- The chart discards the message by using the `discard`.

While a message is valid, other transitions and actions can evaluate the message and access its data. To check if a message is valid, use the `isvalid` operator.

To view the interchange of messages during simulation, add a Sequence Viewer block to your Simulink model. The Sequence Viewer block displays:

- Sent messages
- Received messages
- Forwarded messages
- Dropped messages
- Destroyed messages
- Discarded messages

For more information, see “Use the Sequence Viewer to Visualize Messages, Events, and Entities” on page 15-24.

## **Limitations for Messages**

You cannot use messages in:

- Moore charts
- Atomic subcharts
- Breakpoint condition expressions

In charts that use C as the action language, messages do not support multiword fixed-point data.

## **See Also**

Queue | Sequence Viewer | discard | forward | isvalid | receive | send

## **More About**

- “Set Properties for a Message” on page 15-5
- “Control Message Activity in Stateflow Charts” on page 15-9
- “Send Messages with String Data” on page 24-10
- “Use the Sequence Viewer to Visualize Messages, Events, and Entities” on page 15-24

## Set Properties for a Message

A message is a Stateflow object that communicates data locally or between charts in a Simulink model. For more information, see “Communicate with Stateflow Charts by Sending Messages” on page 15-2.

When you create Stateflow charts in Simulink models, you can specify message properties in either the Property Inspector or the Model Explorer.

- To use the Property Inspector:
  - 1 In the **Modeling** tab, under **Design Data**, select **Symbols Pane** and **Property Inspector**.
  - 2 In the Symbols pane, select the message.
  - 3 In the Property Inspector pane, edit the message properties.
- To use the Model Explorer:
  - 1 In the **Modeling** tab, under **Design Data**, select **Model Explorer**.
  - 2 In the **Contents** pane, select the message.
  - 3 In the **Message** pane, edit the message properties.

You can also specify message properties programmatically by using `Stateflow.Message` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Stateflow Message Properties

#### Name

Name of the message. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

#### Scope

Scope of the message. The scope specifies where the message occurs relative to the parent object.

Scope	Description
Input	Message that is received from another block in the Simulink model. Each input message can use an internal receiving queue that is maintained by the Stateflow chart or an external receiving queue that is managed by a Queue block.
Output	Message that is sent through an output port to another block in the Simulink model.
Local	Message that is local to the Stateflow chart. The Stateflow chart maintains an internal receiving queue for each local message. When you send a local message, it is visible by state and transition actions in the same chart. You cannot send a local message outside the chart.

#### Port

Index of the port associated with the message. This property applies only to input and output messages.

**Size**

Size of the message data field. For more information, see “Specify Size of Stateflow Data” on page 12-33.

**Complexity**

Specifies whether the message data field accepts complex values.


Complexity Setting	Description
Off	Data field does not accept complex values.
On	Data field accepts complex values.
Inherited	Data field inherits the complexity setting from a Simulink block.

The default value is Off. For more information, see “Complex Data in Stateflow Charts” on page 27-2.

**Type**

Type of the message data field. To specify the data type:

- From the **Type** drop-down list, select a built-in type.
- In the **Type** field, enter an expression that evaluates to a data type.

Additionally, in the Model Explorer, you can open the Data Type Assistant by clicking the **Show data type assistant** button . Specify a data **Mode**, and then specify the data type based on that mode. For more information, see “Specify Type of Stateflow Data” on page 12-27.

---

**Note** In charts that use C as the action language, messages do not support multiword fixed-point data.

---

**Initial Value**

Initial value of the message data. Enter an expression or parameter defined in the Stateflow hierarchy, MATLAB base workspace, or Simulink masked subsystem. This property applies only to local and output messages.

If you do not specify a value, the default value for numeric data is 0. For enumerated data, the default value typically is the first one listed in the `enumeration` section of the definition. You can specify a different default enumerated value in the `methods` section of the definition. For more information, see “Define Enumerated Data Types” on page 23-5.

**Priority**

Priority for the message. If two distinct messages occur at the same time, this property determines which message is processed first. A smaller numeric value indicates a higher priority. This property is visible only for local and output messages in discrete-event charts. For more information, see “Create Custom Queuing Systems Using Discrete-Event Stateflow Charts” (SimEvents).

### Add to Watch Window

Enables watching the message queue and data field in the Stateflow Breakpoints and Watch window. For more information, see “View Data in the Breakpoints and Watch Window” on page 33-11.

## Message Queue Properties

These properties define the behavior of receiving queues and apply only to input and local messages.

### Use Internal Queue

Specifies that the Stateflow chart maintains an internal receiving queue for the input message. By default, this property is enabled. When you disable this property, you can connect the message input port to:

- A Queue block that manages an external queue in your Simulink model
- A root-level Inport block that enables messages to cross the model boundary

For more information on external message queues, see “Messages” (Simulink).

### Queue Capacity

Specifies the maximum number of messages held in an internal receiving queue. If a chart sends a message when the queue is full, a queue overflow occurs. To avoid dropped messages, set the queue capacity high enough that incoming messages do not cause the queue to overflow. The maximum queue capacity is  $2^{16}-1$ .

### Queue Overflow Diagnostic

Specifies the level of diagnostic action when the number of incoming messages exceeds the queue capacity. The default option is Error.

Diagnostic Setting	Description
Error	When the queue overflows, the simulation stops with an error.
Warning	When the queue overflows, the queue drops the last message and simulation continues with a warning.
None	When the queue overflows, the queue drops the last message and simulation continues without issuing a warning.

### Queue Type

Specifies the order in which messages are removed from the receiving queue. The default option is FIFO.

Queue Type Setting	Description
FIFO	First in, first out
LIFO	Last in, first out

<b>Queue Type Setting</b>	<b>Description</b>
Priority	Remove messages according to the value in the data field. Choosing this setting exposes the <b>Priority order</b> field, which has these options: <ul style="list-style-type: none"><li data-bbox="555 386 1425 449">• <b>Ascending</b> – The messages are removed in ascending order of the message data value.</li><li data-bbox="555 457 1458 520">• <b>Descending</b> – The messages are removed in descending order of the message data value.</li></ul>

## See Also

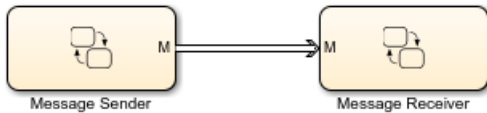
Queue

## More About

- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Guidelines for Naming Stateflow Objects” on page 2-5
- “Specify Size of Stateflow Data” on page 12-33
- “Specify Type of Stateflow Data” on page 12-27
- “Complex Data in Stateflow Charts” on page 27-2

## Control Message Activity in Stateflow Charts

A message is a Stateflow object that communicates data locally or between charts in a Simulink model. From a sender chart, you can send or forward a message. In the receiving chart, a queue receives the message and holds it until the chart can evaluate it.



Using Stateflow operators, you can access message data, and send, receive, discard, or forward a message. You can also determine whether a message is valid and find the number of messages in a queue. For more information, see “Communicate with Stateflow Charts by Sending Messages” on page 15-2.

### Access Message Data

Stateflow messages have a data field. To read or write to the message data field of a valid message, use dot notation syntax:

```
message_name.data
```

If you send a message without first assigning a value to the message data, the default value for numeric data is 0. For enumerated data, the default is the first value listed in the `enumeration` section of the definition, unless you specify otherwise in the `methods` section of the definition.

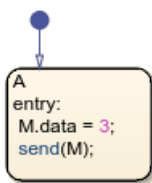
You cannot access message data for messages that are still in the queue or that have already been discarded.

### Send a Message

To send an output or local message, use the send operator:

```
send(message_name)
```

For example, in this chart, the entry action in state A sends a message M with a data value of 3. If the message scope is `Local`, then the message goes in the local receiving queue. If the message scope is `Output`, then the chart sends the message through the output port to another block in the Simulink model.



In a single time step, you can send multiple messages through an output port or to a local receiving queue.

If a chart sends a message that exceeds the capacity of the receiving queue, a queue overflow occurs. The result of the queue overflow depends on the type of receiving queue.

- When an overflow occurs in an internal queue, the Stateflow chart drops the new message. You can control the level of diagnostic action by setting the **Queue Overflow Diagnostic** property for the message. See “Queue Overflow Diagnostic” on page 15-7.
- When an overflow occurs in an external queue, the Queue block either drops the new message or overwrites the oldest message in the queue, depending on the configuration of the block. See “Overwrite the oldest element if queue is full” (Simulink). An overflow in an external queue always results in a warning.

## Guard Transitions and Actions

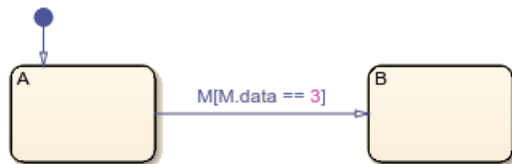
Messages can guard transitions or state actions of type `on`. During a time step, when the guarding message is evaluated for the first time, the chart removes the message from the queue and makes the message valid. While the message is valid, other transitions or actions can access the message data but they do not remove another message from the queue.

### Guard a Transition with a Message

In this chart, a message `M` guards the transition from state `A` to state `B`. The transition occurs when both of these conditions are true:

- A message is present in the queue.
- The data value of the message is equal to 3.

If a message is not present or if the data value is not equal to 3, then the transition does not occur. If a message is present, it is removed from the queue regardless of whether the transition occurs.

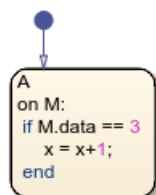


### Guard a State on Action with a Message

In this chart, a message `M` guards the `on` action in state `A`. When state `A` becomes active, it increments the value of `x` if both of these conditions are true:

- A message is present in the queue.
- The data value of the message is equal to 3.

If a message is not present or if the data value is not equal to 3, then the value of `x` does not change. If a message is present, it is removed from the queue regardless of whether `x` is modified.





## Receive a Message

To extract an input or local message from its receiving queue, use the `receive` operator:

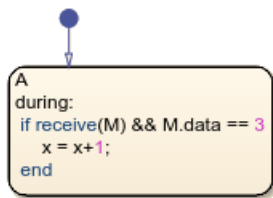
```
receive(message_name)
```

If a valid message `M` exists, `receive(M)` returns `true`. If a valid message does not exist but there is a message in the queue, then the chart removes the message from the queue and `receive(M)` returns `true`. If a valid message does not exist and there are no messages in the queue, `receive(M)` returns `false`.

For example, in this chart, the `during` action in state `A` checks the queue for message `M` and increments the value of `x` if both of these conditions are true:

- A message is present in the queue.
- The data value of the message is equal to 3.

If a message is not present or if the data value is not equal to 3, then the value of `x` does not change. If a message is present, the chart removes it from the queue regardless of the data value.



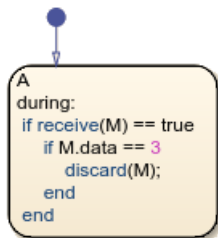
## Discard a Message

To discard a valid input or local message, use the `discard` operator:

```
discard(message_name)
```

After a chart discards a message, it can remove another message from the queue in the same time step. A chart cannot access the data of a discarded message.

For example, in this chart, the `during` action in state `A` checks the queue for message `M`. If a message is present, the chart removes it from the queue. If the message has a data value equal to 3, the chart discards the message.



## Forward a Message

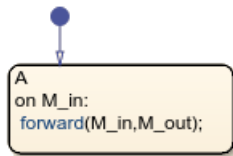
To forward a valid input or local message to a local queue or an output port, use the `forward` operator:

```
forward(message_in_name,message_out_name)
```

After a chart forwards a message, it can remove another message from the queue in the same time step.

### Forward an Input Message

In this chart, state A checks the input queue for message `M_in`. If a message is present, the chart removes the message from the queue and forwards it to the output port `M_out`. After the chart forwards the message, the message is no longer valid in state A.



### Forward a Local Message

In this chart, the transition between state A and state B checks the local queue for message `M_local`. If a message is present, the transition removes the message from the `M_local` message queue and forwards it to the output port `M_out`.



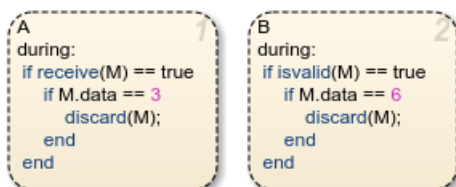
## Determine if a Message Is Valid

To check if an input or local message is valid, use the `isvalid` operator:

```
isvalid(message_name)
```

A message is valid if the chart has removed it from the receiving queue and has not forwarded or discarded it.

For example, this chart first executes state A, as described in “Discard a Message” on page 15-11. When the chart executes state B, the `during` action checks that the message `M` is valid. If the message is valid and has a data value equal to 6, the chart discards the message.

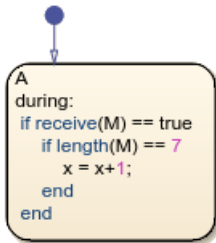


## Determine the Length of the Queue

To check the number of messages in an internal receiving queue of an input or local message, use the `length` operator:

```
length(message_name)
```

For example, in this chart, the `during` action in state A checks the queue for message M. If a message is present, the chart removes it from the queue. If exactly seven messages remain in the queue, the chart increments the value of `x`.



The `length` operator is not supported for input messages that use external receiving queues managed by a Queue block.

## See Also

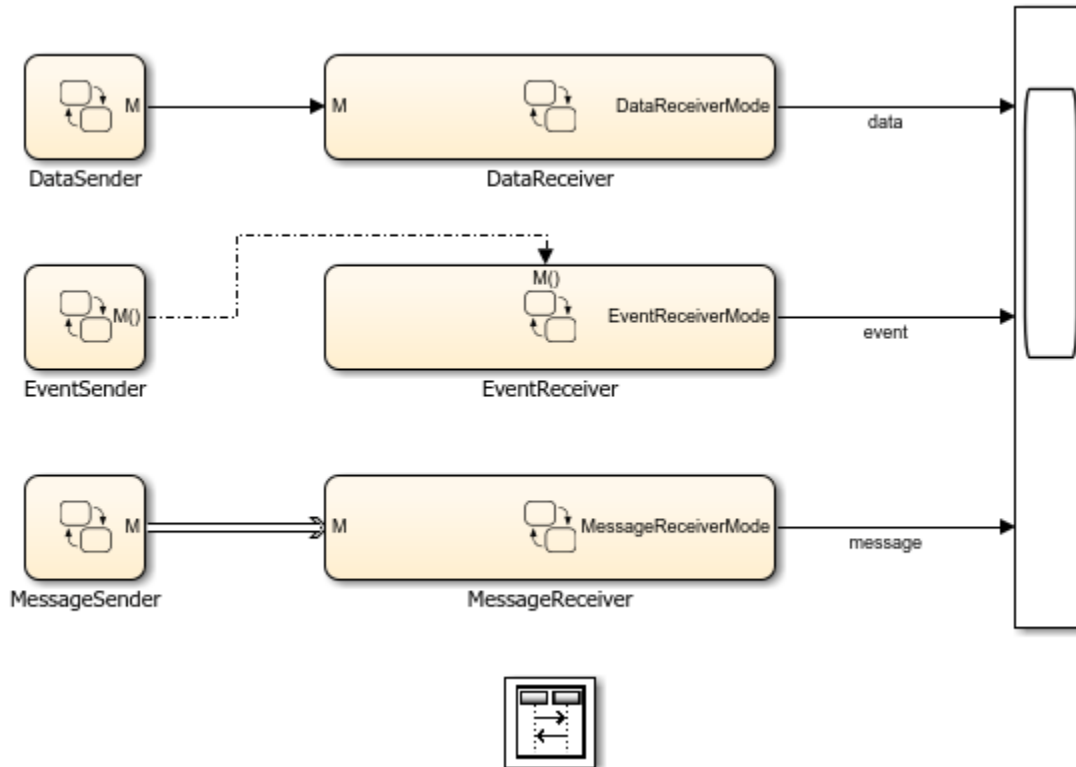
Queue | discard | forward | isvalid | length | receive | send

## More About

- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Set Properties for a Message” on page 15-5
- “Use the Sequence Viewer to Visualize Messages, Events, and Entities” on page 15-24
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14

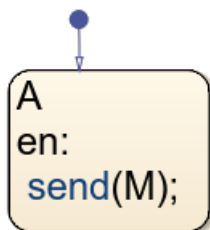
## View Differences Between Stateflow Messages, Events, and Data

This example compares the behavior of messages, events, and data in Stateflow®.



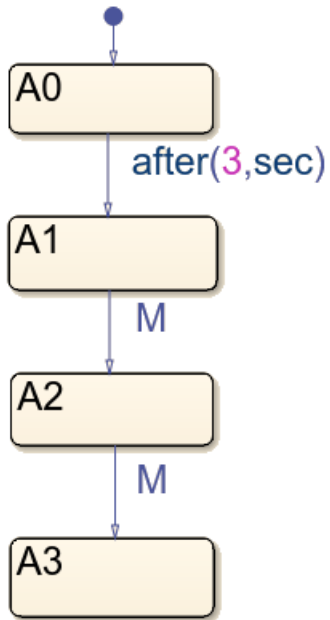
### Sender Charts

This model has three sender charts: **DataSender**, **EventSender**, and **MessageSender**. Each sender chart has one state. In the entry action of the state, the charts assign a value to data, send a function-call event, or send a message.



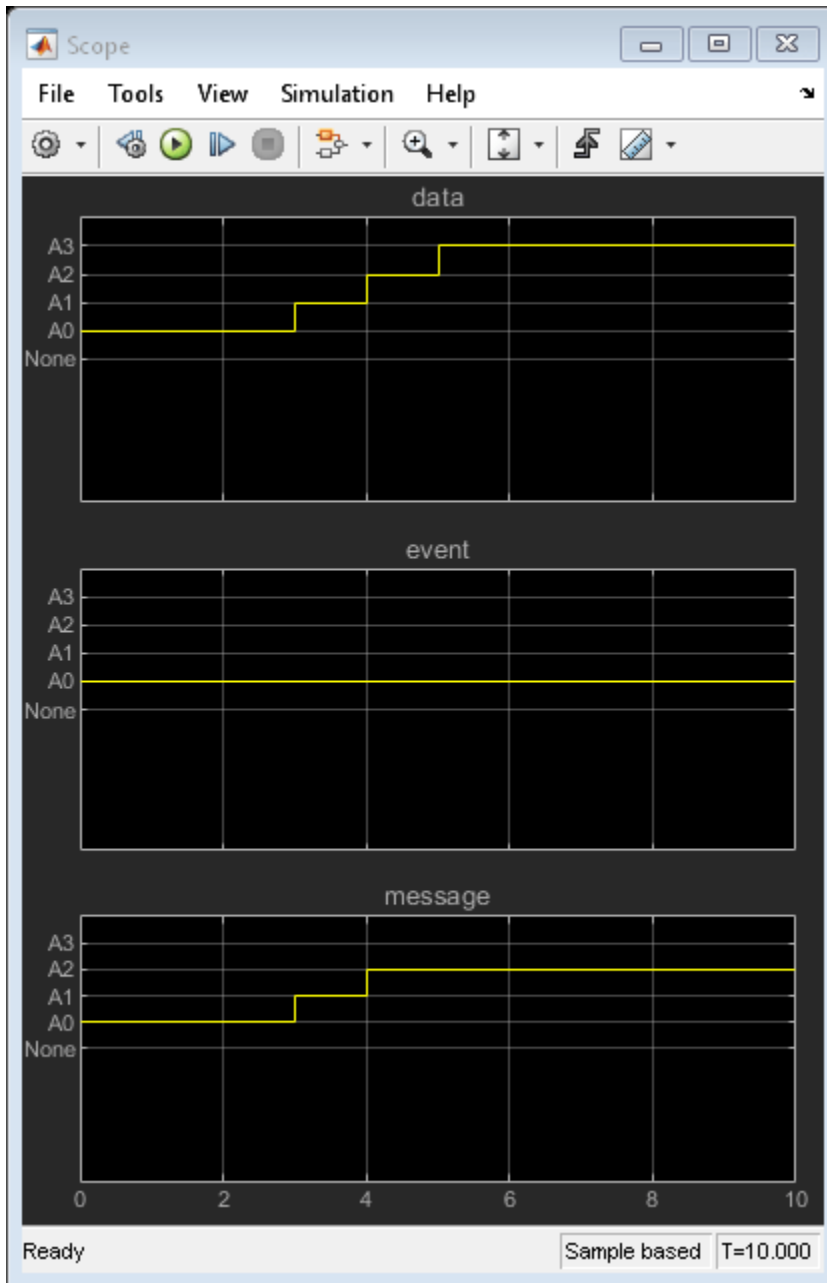
### Receiver Charts

For each of the sender charts, there is a corresponding receiver chart. Each receiver chart has a state diagram with states **A0**, **A1**, **A2**, and **A3**. The implicit event `after(3, sec)` triggers the transition from **A0** to **A1**. The data, event, or message from the corresponding sender chart guards the transitions between **A1**, **A2**, and **A3**.



### Scope Output

Each receiver chart has active state output enabled and connected to a scope. The scope shows which states are active in each time step. This output highlights the difference in behavior between output data, events, and messages.

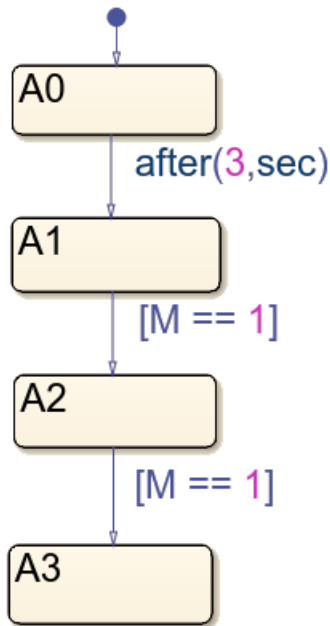


### Behavior of Data

The DataSender chart assigns a value of 1 to the output data M, which connects as an input to the DataReceiver chart.

The DataReceiver chart executes once at every time step. At the start of simulation, state A0 is active. At time  $t=3$ , the transition from A0 to A1 occurs. At time  $t=4$ , the chart tests whether M equals 1. This condition is true, so the chart transitions from A1 to A2. At time  $t=5$ , M still equals 1, so the chart transitions from A2 to A3. On the scope, you see that DataReceiver changes states three times.

After data is assigned a value, it holds its value throughout the simulation. Therefore, each time that the DataReceiver evaluates the condition `[M == 1]`, it transitions to a new state.

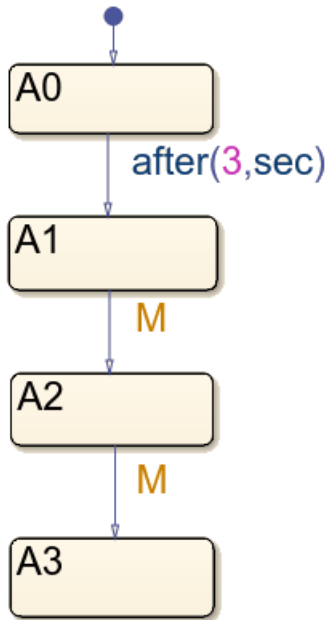


### Behavior of Event

The EventSender chart uses the command `send(M)` to send a function-call output event to wake up the EventReceiver chart.

The EventReceiver chart executes only when the input event `M` wakes up the chart. At the start of simulation, state `A0` is active. The transition from `A0` to `A1` is based on absolute-time temporal logic and is not valid at time `t=0`. `A0` remains active and the chart goes back to sleep. Because EventSender sends the event `M` only once, EventReceiver does not wake up again. On the scope, you see that EventReceiver never transitions out of `A0`.

Events do not remain valid across time steps, so the receiving chart has only one chance to respond to the event. When EventSender sends the event, EventReceiver is not ready to respond to it. The opportunity for EventReceiver to transition in response to the event is lost.



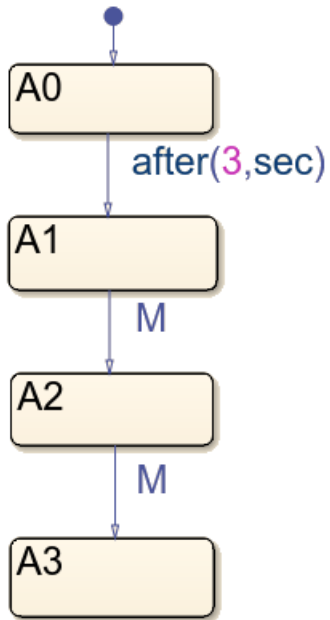
### Behavior of Message

The `MessageSender` chart uses the syntax `send(M)` to send a message through the output message port. The message goes into the input message queue of the `MessageReceiver` chart. The message waits in the queue until `MessageReceiver` evaluates it.

The `MessageReceiver` chart executes once at every time step. At the start of simulation, state `A0` is active. At time  $t=3$ , the transition from `A0` to `A1` occurs. At time  $t=4$ , the chart determines that `M` is present in the queue, so it takes the transition to `A2`. At the end of the time step, the chart removes `M` from the queue. At time  $t=5$ , there is no message present in the queue, so the chart does not transition to `A3`. `A2` remains the active state. On the scope, you see that `MessageReceiver` changes state only two times.

Unlike events, messages are queued. The receiving chart can choose to respond to a message anytime after it was sent. Unlike data, the message does not remain valid indefinitely. The message is destroyed at the end of the time step.





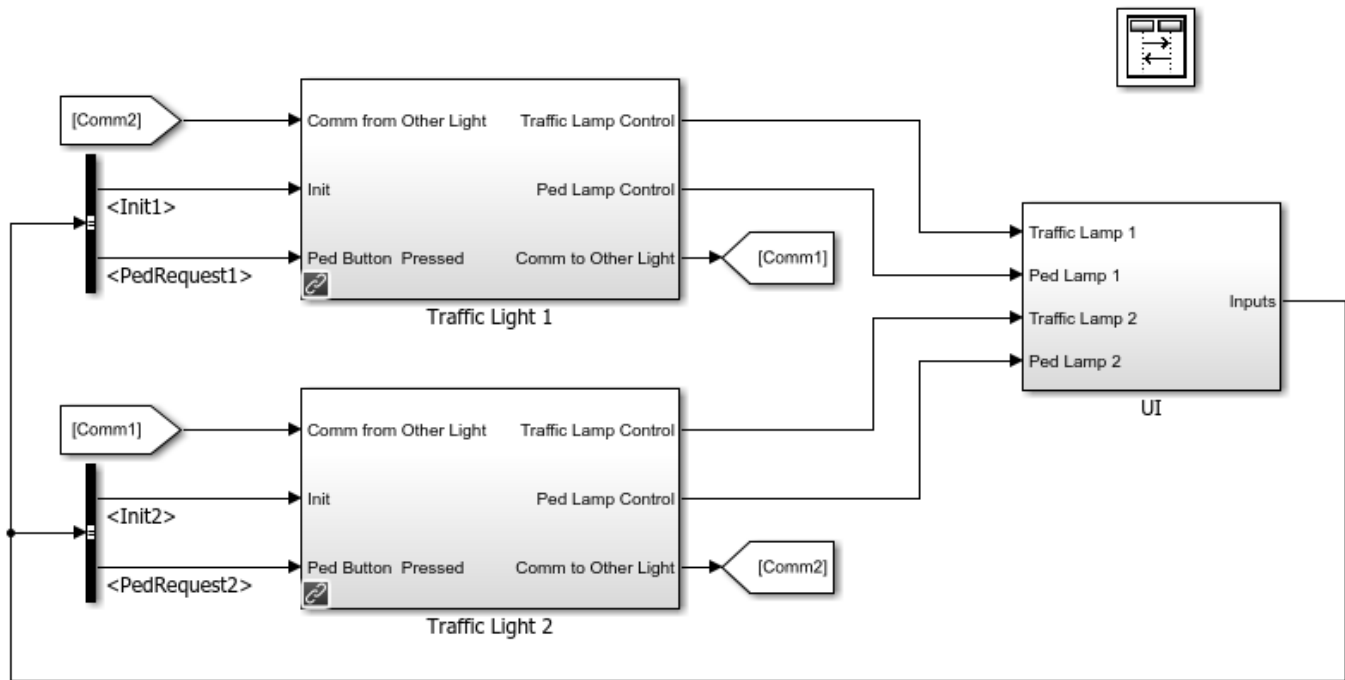
## See Also

### More About

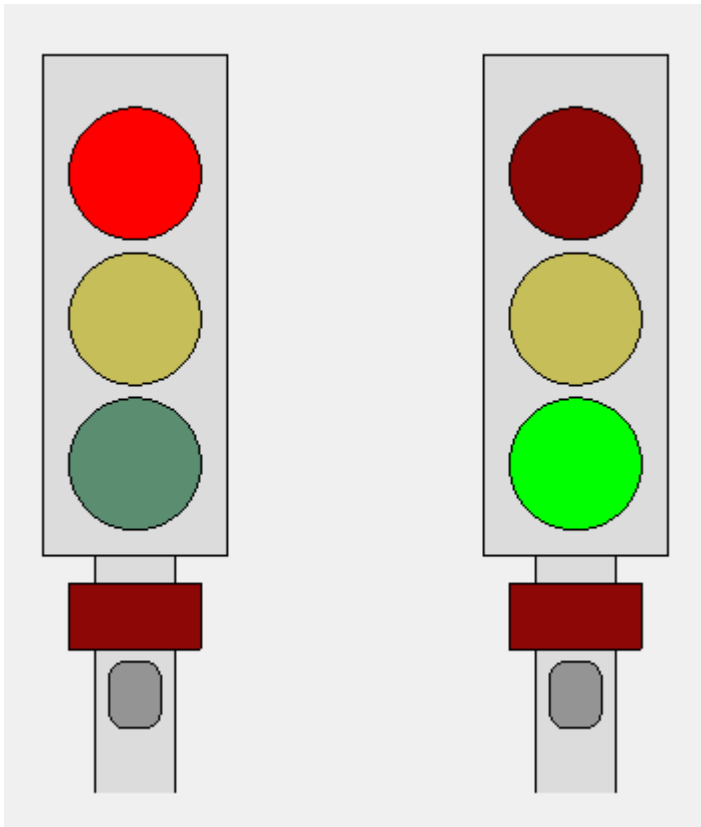
- “Share Data with Simulink and the MATLAB Workspace” on page 12-19
- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Communicate with Stateflow Charts by Sending Messages” on page 15-2

## Model a Distributed Traffic Control System by Using Messages

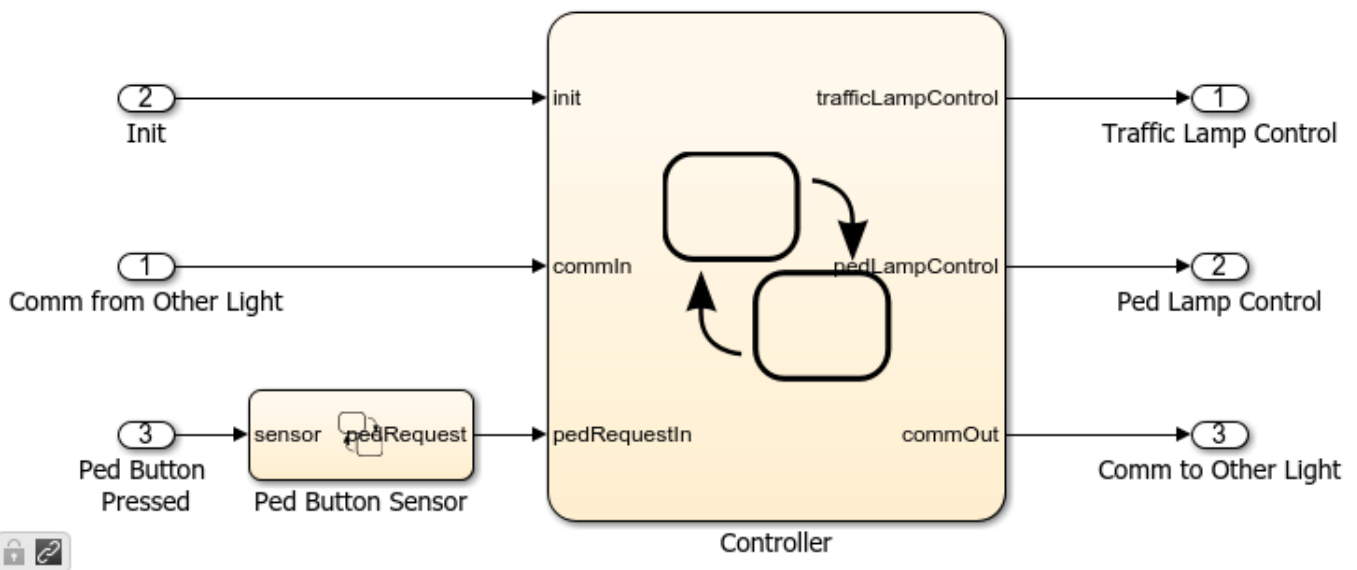
This example shows how to model a distributed control system for an intersection of one-way roads. To coordinate the state of the traffic lights, the two charts communicate with each other by using messages. The design of the two charts is identical.



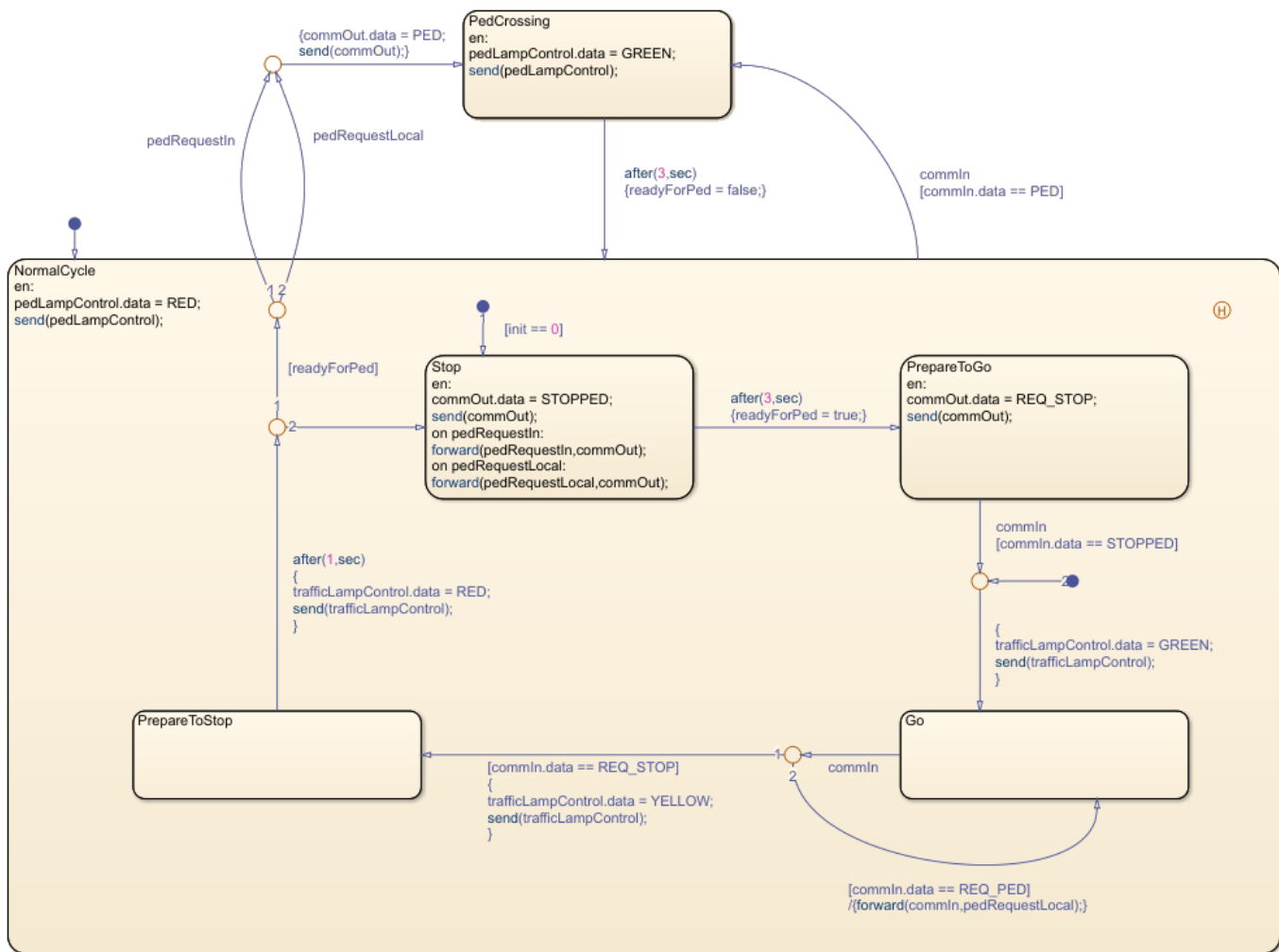
You can interact with the traffic signals through a MATLAB® UI. To request a pedestrian crossing, click one of the dark gray request buttons at the bottom of the traffic signal.



The controller for each road is implemented by the traffic light controller subsystems Traffic Light 1 and Traffic Light 2.



In each subsystem, the Controller chart describes the main logic of the traffic controller through the various states of the traffic signal.



This model takes advantage of these semantic features of messages:

- Messages are not discarded if they are not acted upon immediately. For example, in this model, pedestrian requests are queued up until the controller can react to a request when the traffic light turns red.
- You can set up message loops between different components. These loops do not result in algebraic loops in your model.
- Normally, input messages are destroyed at the end of the time step in which they are evaluated. However, you can preserve these input messages for use at a later time by temporarily forwarding them to a local "holding" queue. For example, when the Controller chart exits the Go state, it uses the local queue `pedRequestLocal` to store pedestrian requests made on the other road. The chart checks for those requests later, when it exits the PrepareToStop state.

To change the speed of the simulation, in the **Simulation** tab, select **Run > Simulation Pacing**. In the Simulation Pacing Options dialog box, adjust the slider setting. For more information, see “Simulation Pacing” (Simulink).

## See Also

### More About

- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Use the Sequence Viewer to Visualize Messages, Events, and Entities” on page 15-24
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14
- “Simulation Pacing” (Simulink)

## Use the Sequence Viewer to Visualize Messages, Events, and Entities

To see the interchange of messages and events between the blocks from the Simulink Messages & Events library, Stateflow charts in Simulink models, and SimEvents blocks, you can:

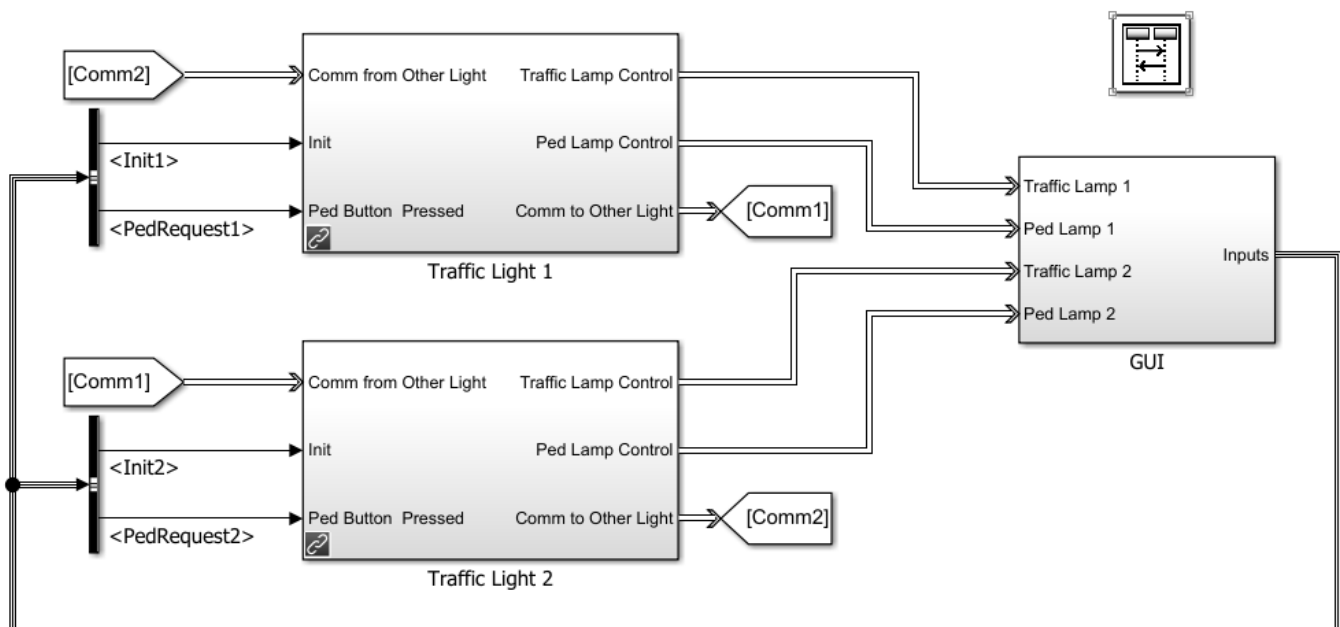
- Use the Sequence Viewer (Simulink) tool from the Simulink toolstrip.
- Add a Sequence Viewer block to your Simulink model.

The Sequence Viewer allows you to visualize message transition events and the data that the messages carry. In the Sequence Viewer, you can view event data related to Stateflow chart execution and the exchange of messages between Stateflow charts. The Sequence Viewer window shows messages as they are created, sent, forwarded, received, and destroyed at different times during model execution. The Sequence Viewer window also displays state activity, transitions, and function calls to Stateflow graphical functions, Simulink functions, and MATLAB functions.

With the Sequence Viewer, you can also visualize the movement of entities between blocks when simulating SimEvents models. All SimEvents blocks that can store entities appear as lifelines in the Sequence Viewer window. Entities moving between these blocks appear as lines with arrows. You can view calls to Simulink Function blocks and to MATLAB Function blocks.

You can add a Sequence Viewer block to the top level of a model or any subsystem. If you place a Sequence Viewer block in a subsystem that does not have messages, events, or state activity, the Sequence Viewer window informs you that there is nothing to display.

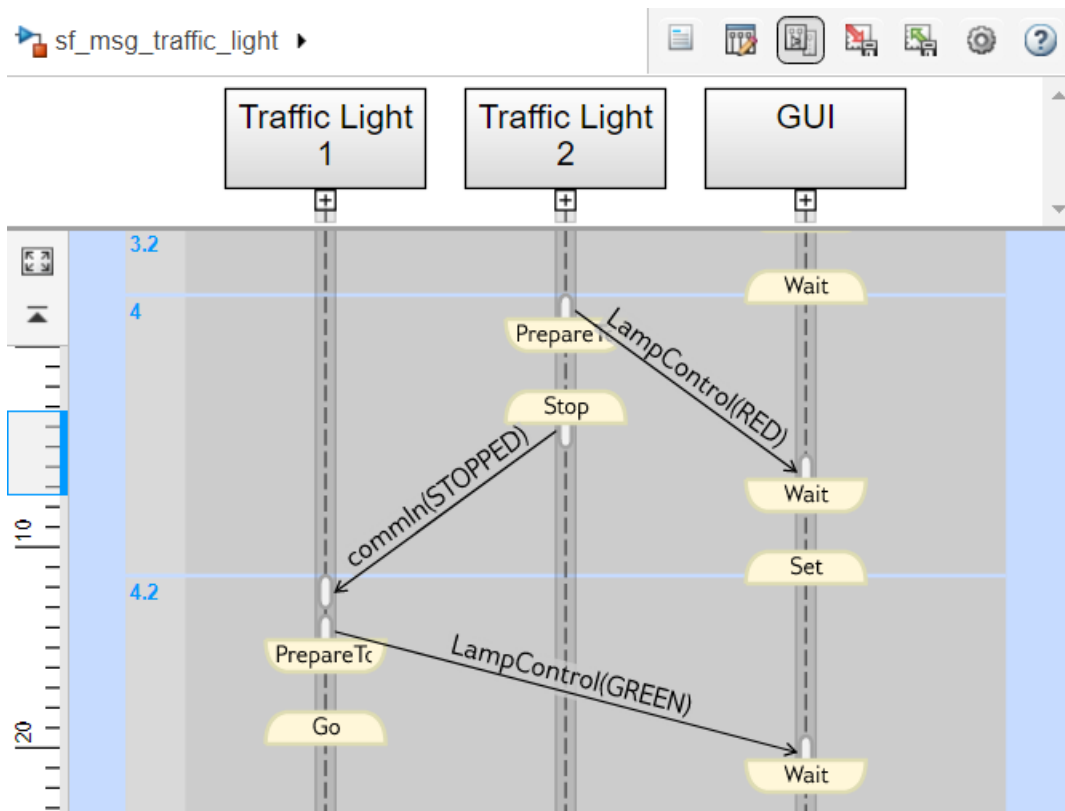
For instance, suppose that you simulate the Stateflow example `sf_msg_traffic_light`.



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This model has three Simulink subsystems: Traffic Light 1, Traffic Light 2, and GUI. The Stateflow charts in these subsystems exchange data by sending messages. As messages pass through the








system, you can view them in the Sequence Viewer window. The Sequence Viewer window represents each block in the model as a vertical lifeline with simulation time progressing downward.



## Components of the Sequence Viewer Window

### Navigation Toolbar

At the top of the Sequence Viewer window, a navigation toolbar displays the model hierarchy path. Using the toolbar buttons, you can:

-  Show or hide the Property Inspector.
-  Select an automatic or manual layout.
-  Show or hide inactive lifelines.
-  Save Sequence Viewer settings.
-  Restore Sequence Viewer settings.
-  Configure Sequence Viewer parameters.
-  Access the Sequence Viewer documentation.

### Property Inspector

In the Property Inspector, you can choose filters to show or hide:

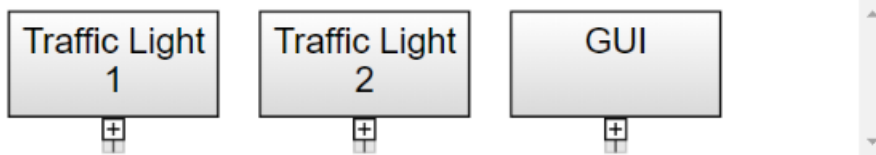
- Events
- Messages
- Function Calls
- State Changes and Transitions

**Header Pane**

The header pane below the Sequence Viewer toolbar shows lifeline headers containing the names of the corresponding blocks in a model.

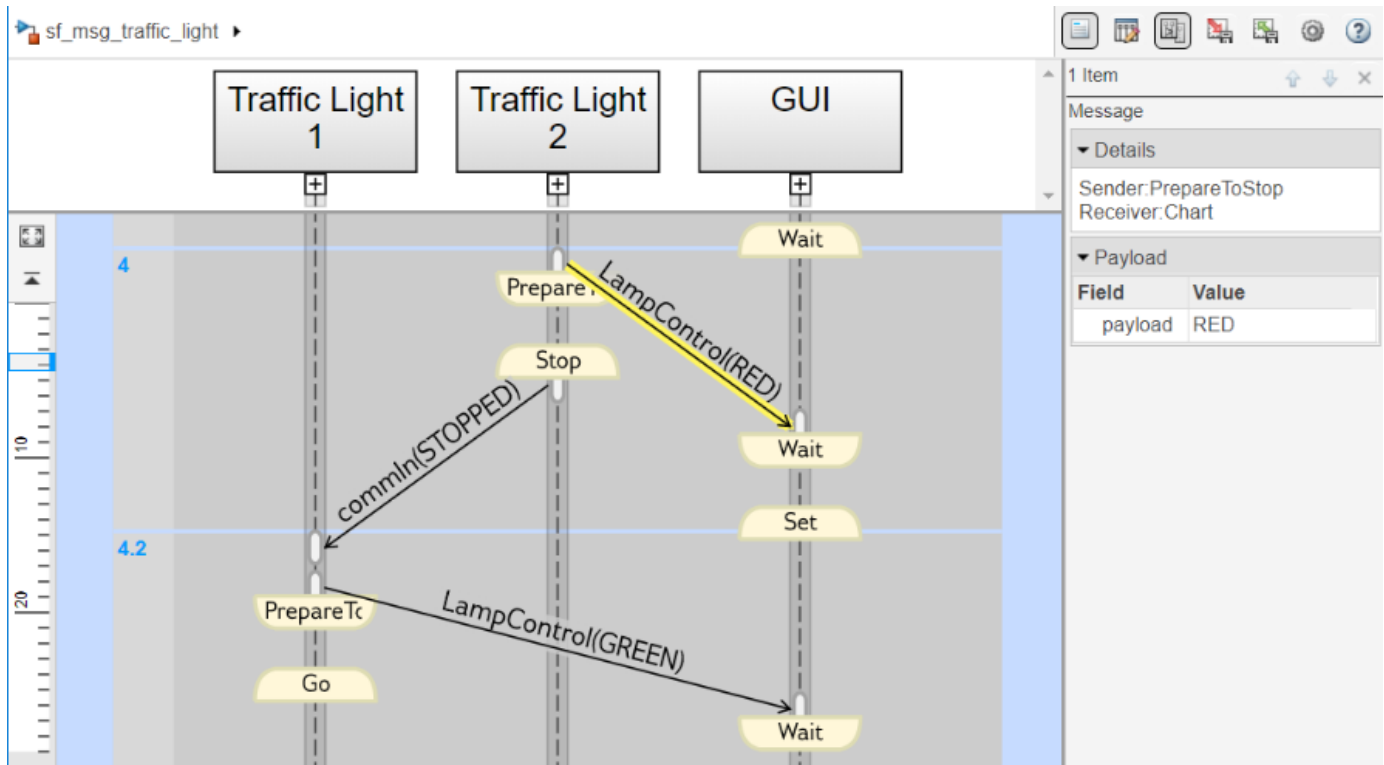
- Gray rectangular headers correspond to subsystems.
- White rectangular headers correspond to masked subsystems.
- Yellow headers with rounded corners correspond to Stateflow charts.

To open a block in the model, click the name in the corresponding lifeline header. To show or hide a lifeline, double-click the corresponding header. To resize a lifeline header, click and drag its right-hand side. To fit all lifeline headers in the Sequence Viewer window, press the space bar.

**Message Pane**

Below the header pane is the message pane. The message pane displays messages, events, and function calls between lifelines as arrows from the sender to the receiver. To display sender, receiver, and payload information in the Property Inspector, click the arrow corresponding to the message, event, or function call.






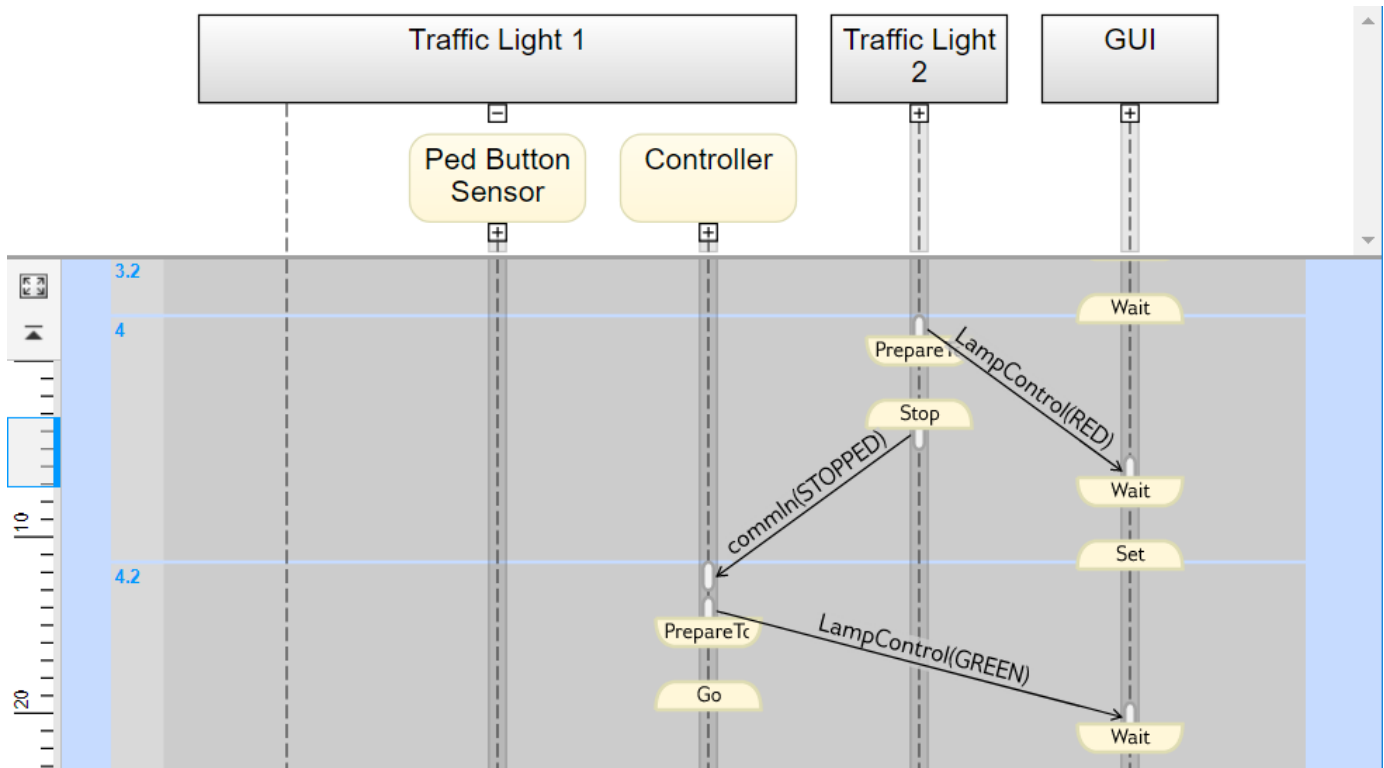
## Navigate the Lifeline Hierarchy

In the Sequence Viewer window, the hierarchy of lifelines corresponds to the model hierarchy. When you pause or stop the model, you can expand or contract lifelines and change the root of focus for the viewer.

### Expand a Parent Lifeline

In the message pane, a thick, gray lifeline indicates that you can expand the lifeline to see its children. To show the children of a lifeline, click the expander icon  below the header or double-click the parent lifeline.

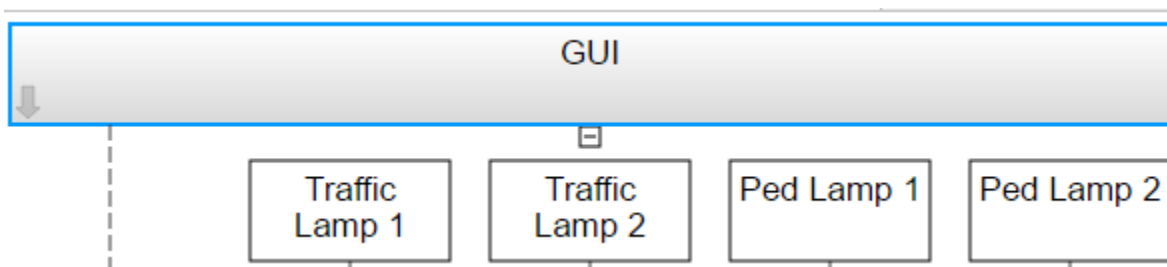
For example, expanding the lifeline for the Traffic Light 1 block reveals two new lifelines corresponding to the Stateflow charts Ped Button Sensor and Controller.



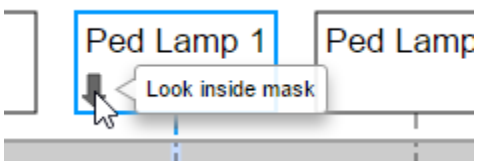
### Expand a Masked Subsystem Lifeline

The Sequence Viewer window displays masked subsystems as white blocks. To show the children of a masked subsystem, point over the bottom left corner of the lifeline header and click the arrow.

For example, the GUI subsystem contains four masked subsystems: Traffic Lamp 1, Traffic Lamp 2, Ped Lamp 1, and Ped Lamp 2.

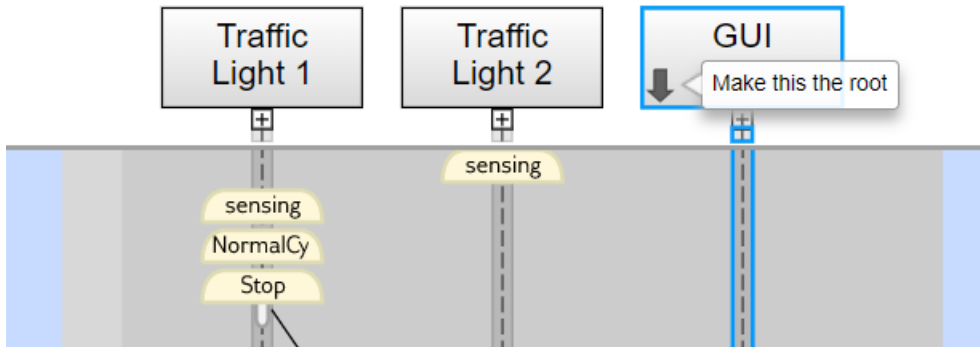


You can display the child lifelines in these masked subsystems by clicking the arrow in the parent lifeline header.

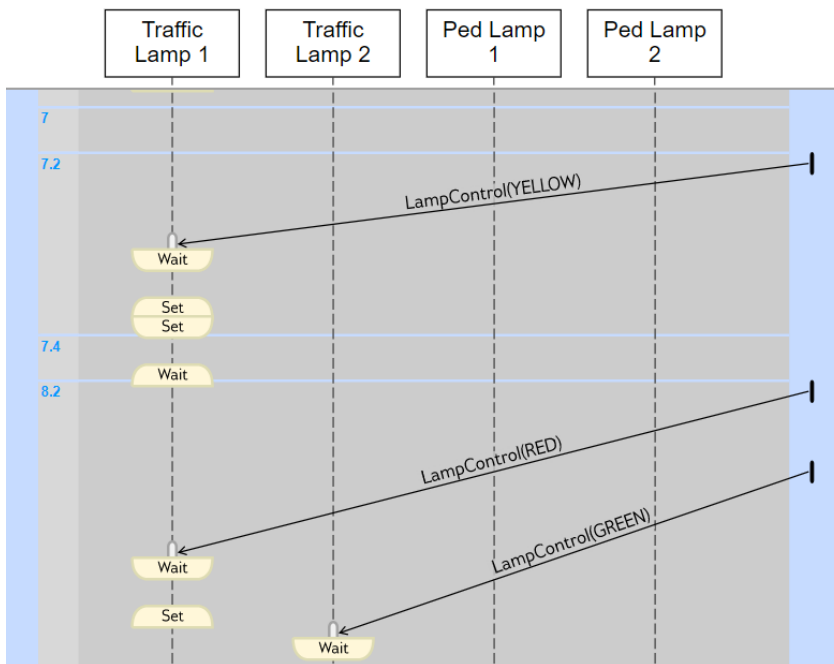


## Change Root of Focus

To make a lifeline the root of focus for the viewer, point over the bottom left corner of the lifeline header and click the arrow. Alternatively, you can use the navigation toolbar at the top of the Sequence Viewer window to move the current root up and down the lifeline hierarchy. To move the current root up one level, press the **Esc** key.



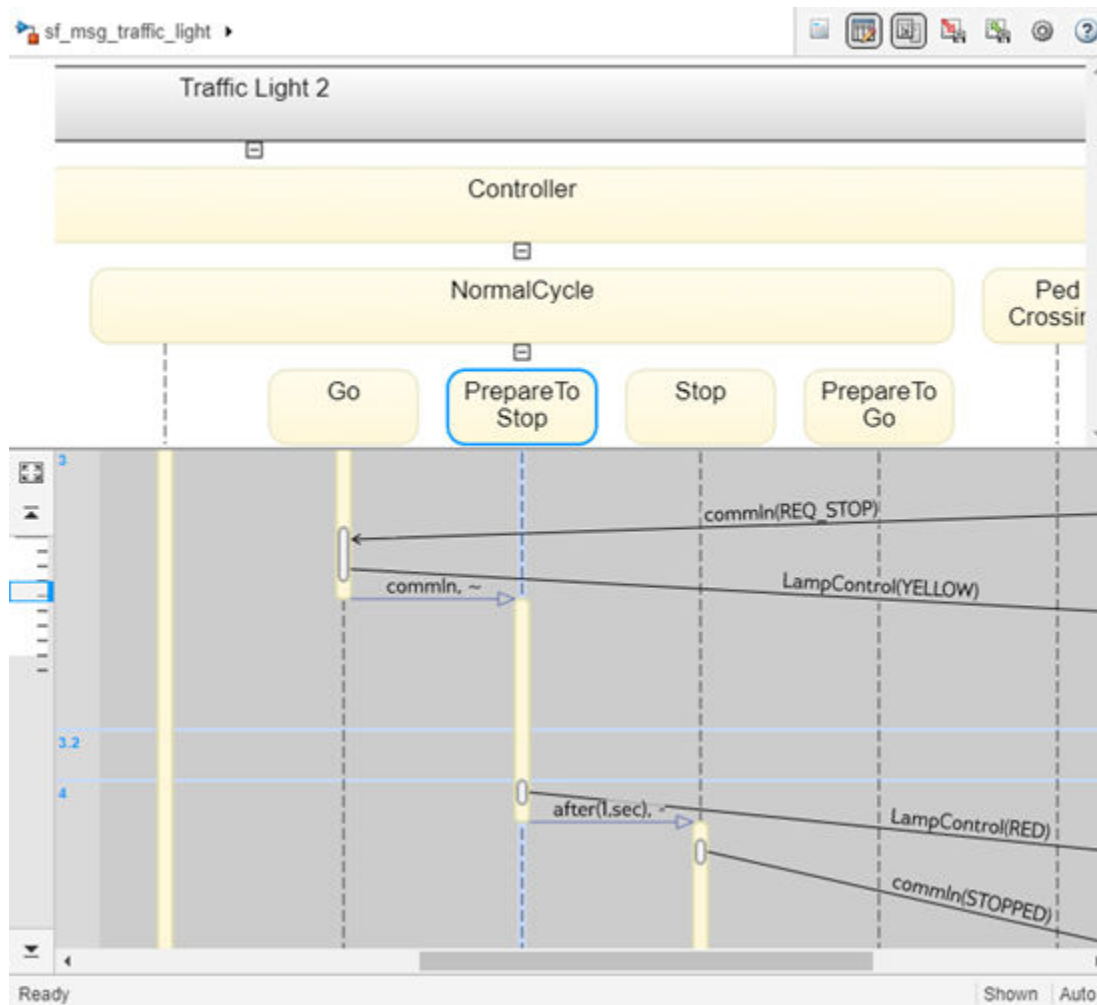
The Sequence Viewer window displays the current root lifeline path and shows its child lifelines. Any external events and messages are displayed as entering or exiting through vertical slots in the diagram gutter. When you point to a slot in the diagram gutter, a tooltip displays the name of the sending or receiving block.



## View State Activity and Transitions

To see state activity and transitions in the Sequence Viewer window, expand the state hierarchy until you have reached the lowest child state. Vertical yellow bars show which state is active. Blue horizontal arrows denote the transitions between states.

In this example, you can see a transition from Go to PrepareToStop followed, after 1 second, by a transition to Stop.



To display the start state, end state, and full transition label in the Property Inspector, click the arrow corresponding to the transition.

To display information about the interactions that occur while a state is active, click the yellow bar corresponding to the state. In the Property Inspector, use the **Search Up** and **Search Down** buttons to move through the transitions, messages, events, and function calls that take place while the state is active.

## View Function Calls

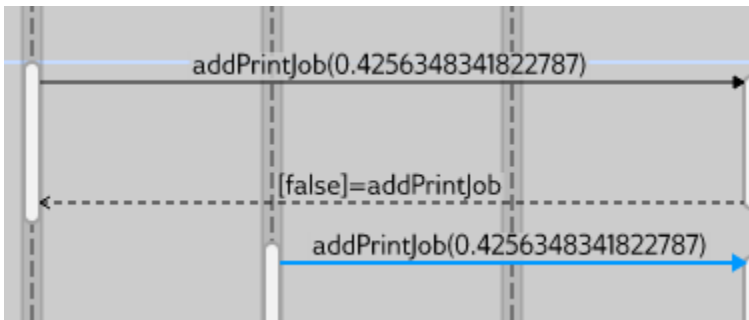
The Sequence Viewer displays function calls and replies. This table lists the type of support for each type of function call.

Function Call Type	Support
Calls to Simulink Function blocks	Fully supported

Function Call Type	Support
Calls to Stateflow graphical or Stateflow MATLAB functions	<ul style="list-style-type: none"> <li>• Scoped — Select the <b>Export chart level functions</b> chart option. Use the <i>chartName.functionName</i> dot notation.</li> <li>• Global — Select the <b>Treat exported functions as globally visible</b> chart option. You do not need the dot notation.</li> </ul>
Calls to function-call subsystems	Not displayed in the Sequence Viewer window

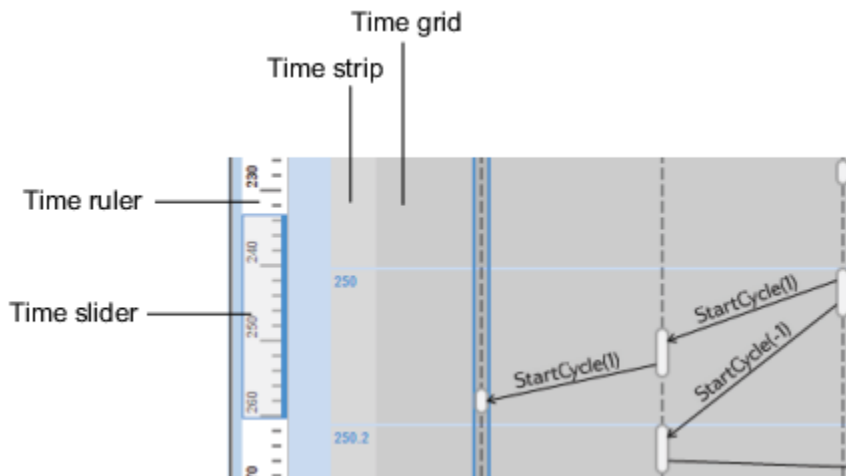
The Sequence Viewer window displays function calls as solid arrows labeled with the format *function\_name(argument\_list)*. Replies to function calls are displayed as dashed arrows labeled with the format *[argument\_list]=function\_name*.


For example, in the model `slexPrinterExample`, a subsystem calls the Simulink Function block `addPrinterJob`. The function block replies with an output value of `false`.



## Simulation Time in the Sequence Viewer Window



The Sequence Viewer window shows events vertically, ordered in time. Multiple events in Simulink can happen at the same time. Conversely, there can be long periods of time during simulation with no events. As a consequence, the Sequence Viewer window shows time by using a combination of linear and nonlinear displays. The time ruler shows linear simulation time. The time grid shows time in a nonlinear fashion. Each time grid row, bordered by two blue lines, contains events that occur at the same simulation time. The time strip provides the times of the events in that grid row.



To show events in a specific simulation time range, use the scroll wheel or drag the time slider up and down the time ruler. To navigate to the beginning or end of the simulation, click the **Go to first event** or **Go to last event** buttons. To see the entire simulation duration on the time ruler, click the **Fit to view** button .

When using a variable step solver, you can adjust the precision of the time ruler. In the Model Explorer, on the **Main** tab of the Sequence Viewer Block Parameters pane, adjust the value of the **Time Precision for Variable Step** field.

## Redisplay of Information in the Sequence Viewer Window

The Sequence Viewer saves the order and states of lifelines between simulation runs. When you close and reopen the Sequence Viewer window, it preserves the last open lifeline state. To save a particular viewer state, click the **Save Settings** button  in the toolbar. Saving the model then saves that state information across sessions. To load the saved settings, click the **Restore Settings** button .

You can modify the **Time Precision for Variable Step** and **History** parameters only between simulations. You can access the buttons in the toolbar before simulation or when the simulation is paused. During a simulation, the buttons in the toolbar are disabled.

## See Also

Sequence Viewer

## More About

- “Synchronize Model Components by Broadcasting Events” on page 14-2
- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Model a Distributed Traffic Control System by Using Messages” on page 15-20

# Use Actions in Charts

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- “Eliminate Redundant Code by Combining State Actions” on page 16-2
- “Supported Operations for Chart Data” on page 16-5
- “Supported Symbols in Actions” on page 16-12
- “Call C Library Functions in C Charts” on page 16-15
- “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20
- “Control Function-Call Subsystems by Using bind Actions” on page 16-29
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Model Bang-Bang Temperature Control System” on page 16-52
- “Control Oscillations by Using the duration Operator” on page 16-56
- “Implement an Automatic Transmission Gear System by Using the duration Operator” on page 16-59
- “Count Events by Using the temporalCount Operator” on page 16-62
- “Detect Changes in Data Values” on page 16-64
- “Design a Game by Using Stateflow” on page 16-71
- “Modeling an Automatic Transmission Controller” on page 16-75

## Eliminate Redundant Code by Combining State Actions

You can combine entry, during, and exit actions that execute the same tasks in a state.

By combining state actions that execute the same tasks, you eliminate redundant code. For example:

Separate Actions	Equivalent Combined Actions
<pre>entry:   y = 0;   y=y+1; during: y=y+1;</pre>	<pre>entry: y = 0; entry, during: y=y+1;</pre>
<pre>en:   fcn1();   fcn2(); du: fcn1(); ex: fcn1();</pre>	<pre>en, du, ex: fcn1(); en: fcn2();</pre>

Combining state actions this way produces the same chart execution behavior (semantics) and generates the same code as the equivalent separate actions.

### How to Combine State Actions

Combine a set of entry, during, and/or exit actions that perform the same task as a comma-separated list in a state. Here is the syntax:

```
entry, during, exit: task1; task2;...taskN;
```

You can also use the equivalent abbreviations:

```
en, du, ex: task1; task2;...taskN;
```

### Valid Combinations

You can use any combination of the three actions. For example, the following combinations are valid:

- en, du:
- en, ex:
- du, ex:
- en, du, ex:

You can combine actions in any order in the comma-separated list. For example, en, du: gives the same result as du, en:.

### Invalid Combinations

You cannot combine two or more actions of the same type. For example, the following combinations are invalid:

- en, en:
- ex, en, ex:
- du, du, ex:



If you combine multiple actions of the same type, you receive a warning that the chart executes the action only once.

## Order of Execution of Combined Actions

States execute combined actions in the same order as they execute separate actions:

- 1 Entry actions first, from top to bottom in the order they appear in the state
- 2 During actions second, from top to bottom
- 3 Exit actions last, from top to bottom

The order in which you combine actions does not affect state execution behavior. For example:

This state...	Executes actions in this order...
<div style="border: 1px solid black; border-radius: 10px; padding: 10px; background-color: #f0f0f0;"> <p>A</p> <pre>en: y = 0; en, du: y = y + 1;</pre> </div>	<ol style="list-style-type: none"> <li>1 en: y = 0;</li> <li>2 en: y=y+1;</li> <li>3 du: y=y+1;</li> </ol>
<div style="border: 1px solid black; border-radius: 10px; padding: 10px; background-color: #f0f0f0;"> <p>B</p> <pre>en, du: y = y + 1; en: y = 0;</pre> </div>	<ol style="list-style-type: none"> <li>1 en: y=y+1;</li> <li>2 en: y = 0;</li> <li>3 du: y=y+1;</li> </ol>
<div style="border: 1px solid black; border-radius: 10px; padding: 10px; background-color: #f0f0f0;"> <p>C</p> <pre>du, en: y = y + 1; en: y = 0;</pre> </div>	<ol style="list-style-type: none"> <li>1 en: y=y+1;</li> <li>2 en: y = 0;</li> <li>3 du: y=y+1;</li> </ol>
<div style="border: 1px solid black; border-radius: 10px; padding: 10px; background-color: #f0f0f0;"> <p>D</p> <pre>du, en: y = y + 1; en, ex: y = 10;</pre> </div>	<ol style="list-style-type: none"> <li>1 en: y=y+1;</li> <li>2 en: y = 10;</li> <li>3 du: y=y+1;</li> <li>4 ex: y = 10;</li> </ol>

## Rules for Combining State Actions

- Do not combine multiple actions of the same type.
- Do not create data, events, or messages that have the same name as the action keywords: `entry`, `en`, `during`, `du`, `exit`, `ex`.



## **See Also**

### **More About**

- “States” on page 2-8

## Supported Operations for Chart Data

Stateflow charts in Simulink models have an action language property that defines the operations that you can use in state and transition actions. The language properties are:

-  MATLAB as the action language.
-  C as the action language.

For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Binary Operations

This table summarizes the interpretation of all binary operations in Stateflow charts according to their order of precedence (0 = highest, 10 = lowest). Binary operations are left associative so that, in any expression, operators with the same precedence are evaluated from left to right. The order of evaluation for other operations is unspecified. For example, in this assignment

$$A = f() > g();$$

the order of evaluation of  $f()$  and  $g()$  is unspecified. For more predictable results, it is good coding practice to split expressions that depend on the order of evaluation into multiple statements.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a \wedge b$	0	Power.	Power. This operation is equivalent to the C library function <code>pow</code> . Operands are first cast to floating-point numbers. For more information, see “Call C Library Functions” on page 16-15.  Enable this operation by clearing the <b>Enable C-bit operations</b> chart property. For more information, see “Enable C-bit operations” on page 28-4.
$a * b$	1	Multiplication.	Multiplication.
$a / b$	1	Division.	Division.
$a \% b$	1	Not supported. Use the <code>rem</code> or <code>mod</code> function.	Remainder. Noninteger operands are first cast to integers.
$a + b$	2	Addition.	Addition.
$a - b$	2	Subtraction.	Subtraction.
$a \gg b$	3	Not supported. Use the <code>bitshift</code> function.	Shift <code>a</code> to the right by <code>b</code> bits. For more information, see “Bitwise Operations” on page 16-9.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a \ll b$	3	Not supported. Use the <code>bitshift</code> function.	Shift $a$ to the left by $b$ bits. For more information, see “Bitwise Operations” on page 16-9.
$a > b$	4	Comparison, greater than.	Comparison, greater than.
$a < b$	4	Comparison, less than.	Comparison, less than.
$a \geq b$	4	Comparison, greater than or equal to.	Comparison, greater than or equal to.
$a \leq b$	4	Comparison, less than or equal to.	Comparison, less than or equal to.
$a == b$	5	Comparison, equal to.	Comparison, equal to.
$a ~= b$	5	Comparison, not equal to.	Comparison, not equal to.
$a != b$	5	Not supported. Use the operation $a ~= b$ .	Comparison, not equal to.
$a <> b$	5	Not supported. Use the operation $a ~= b$ .	Comparison, not equal to.
$a \& b$	6	Logical AND. For bitwise AND, use the <code>bitand</code> function.	<ul style="list-style-type: none"> <li>Bitwise AND (default). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property.</li> <li>Logical AND. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property.</li> </ul> <p>For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.</p>
$a \wedge b$	7	Not supported. For bitwise XOR, use the <code>bitxor</code> function.	Bitwise XOR (default). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property. For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.
$a   b$	8	Logical OR. For bitwise OR, use the <code>bitor</code> function.	<ul style="list-style-type: none"> <li>Bitwise OR (default). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property.</li> <li>Logical OR. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property.</li> </ul> <p>For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.</p>
$a \&\& b$	9	Logical AND.	Logical AND.
$a    b$	10	Logical OR.	Logical OR.

## Unary Operations and Actions

This table summarizes the interpretation of all unary operations and actions in Stateflow charts. Unary operations:

- Have higher precedence than the binary operators.
- Are right associative so that, in any expression, they are evaluated from right to left.

Operation	MATLAB as the Action Language	C as the Action Language
$\sim a$	Logical NOT. For bitwise NOT, use the <code>bitcmp</code> function.	<ul style="list-style-type: none"> <li>• Bitwise NOT (default). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property.</li> <li>• Logical NOT. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property.</li> </ul> <p>For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.</p>
$!a$	Not supported. Use the operation $\sim a$ .	Logical NOT.
$-a$	Negative.	Negative.
$a++$	Not supported. Use the expression $a = a + 1$ .	Increment. Equivalent to $a = a + 1$ .
$a--$	Not supported. Use the expression $a = a - 1$ .	Decrement. Equivalent to $a = a - 1$ .

## Assignment Operations

This table summarizes the interpretation of assignment operations in Stateflow charts.

Operation	MATLAB as the Action Language	C as the Action Language
$a = b$	Simple assignment.	Simple assignment.
$a := b$	Not supported. Use type cast operations to override fixed-point promotion rules. See “Type Cast Operations” on page 16-8.	Assignment of fixed-point numbers. See “Override Fixed-Point Promotion in C Charts” on page 26-15.
$a += b$	Not supported. Use the expression $a = a + b$ .	Equivalent to $a = a + b$ .
$a -= b$	Not supported. Use the expression $a = a - b$ .	Equivalent to $a = a - b$ .
$a *= b$	Not supported. Use the expression $a = a * b$ .	Equivalent to $a = a * b$ .
$a /= b$	Not supported. Use the expression $a = a / b$ .	Equivalent to $a = a / b$ .

Operation	MATLAB as the Action Language	C as the Action Language
$a \&= b$	Not supported. Use the expression <code>a = bitand(a,b)</code> .	Equivalent to <code>a = a&amp;b</code> (bitwise AND). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property. For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.
$a \^= b$	Not supported. Use the expression <code>a = bitxor(a,b)</code> .	Equivalent to <code>a = a^b</code> (bitwise XOR). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property. For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.
$a  = b$	Not supported. Use the expression <code>a = bitor(a,b)</code> .	Equivalent to <code>a = a b</code> (bitwise OR). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property. For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.

## Type Cast Operations

To convert a value of one type to a value of another type, use type cast operations. You can cast data to an explicit type or to the type of another variable.

### Cast to Explicit Data Type

To cast a numeric expression to an explicit data type, use a MATLAB type conversion function of the form:

```
<type_fun>(expression)
```

<type\_fun> is a type conversion function that can be `double`, `single`, `int32`, `int16`, `int8`, `uint32`, `uint16`, `uint8`, or `fi`. <type\_fun> can also be `boolean`, `int64`, or `uint64`. For example, this statement casts the expression `x+3` to a 16-bit unsigned integer and assigns its value to the data `y`:

```
y = uint16(x+3)
```

Alternatively, in charts that use MATLAB as the action language, you can use the `cast` function with a type keyword <type\_key>:

```
cast(expression,<type_key>)
```

Type keywords include `'double'`, `'single'`, `'int32'`, `'int16'`, `'int8'`, `'uint32'`, `'uint16'`, and `'uint8'`. For instance, as in the preceding example, this statement casts the expression `x+3` to a 16-bit unsigned integer and assigns it to `y`:

```
y = cast(x+3,'uint16')
```

## Cast Type Based on Other Data

To make type casting easier, you can convert the type of a numeric expression based on the types of other data.

In charts that use MATLAB as the action language, call the `cast` function with the keyword `'like'`. For example, this statement converts the value of `x+3` to the same type as that of data `z` and assigns it to `y`:

```
y = cast(x+3, 'like', z)
```

In this case, the data `z` can have any acceptable Stateflow type.

In charts that use C as the action language, the `type` operator returns the type of an existing Stateflow data. Use this return value in place of an explicit type in a `cast` operation. For example, this statement converts the value of `x+3` to the same type as that of data `z` and assigns it to `y`:

```
cast(x+3, type(z))
```

## Bitwise Operations

This table summarizes the interpretation of all bitwise operations in Stateflow charts that use C as the action language.

Operation	Description
<code>a &amp; b</code>	Bitwise AND.
<code>a   b</code>	Bitwise OR.
<code>a ^ b</code>	Bitwise XOR.
<code>~a</code>	Bitwise NOT.
<code>a &gt;&gt; b</code>	Shift <code>a</code> to the right by <code>b</code> bits.
<code>a &lt;&lt; b</code>	Shift <code>a</code> to the left by <code>b</code> bits.

Except for the bit shift operations `a >> b` and `a << b`, you must enable all bitwise operations by selecting the **Enable C-bit operations** chart property. See “Enable C-bit operations” on page 28-4.

Bitwise operations work on integers at the binary level. Noninteger operands are first cast to integers. Integer operands follow C promotion rules to determine the intermediate value of the result. This intermediate value is then cast to the type that you specify for the result of the operation.

---

**Note** Bitwise operations are not supported in charts that use MATLAB as the action language. Instead, use the functions `bitand`, `bitor`, `bitxor`, `bitnot`, or `bitshift`.

---

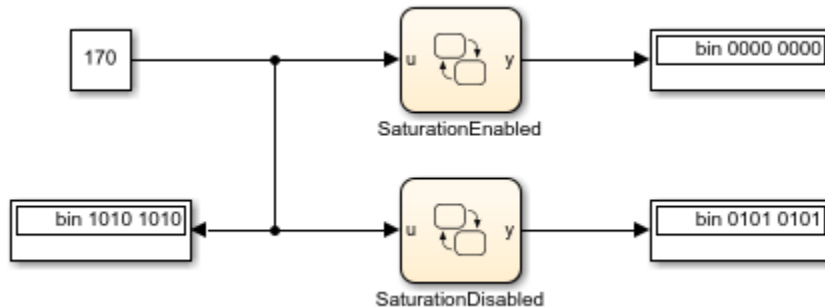
### Bitwise Operations and Integer Overflows

The implicit cast used to assign the intermediate value of a bitwise operation can result in an overflow. To preserve the rightmost bits of the result and avoid unexpected behavior, disable the chart property **Saturate on Integer Overflows**.

For example, both charts in this model compute the bitwise operation `y = ~u`. The charts compute the intermediate value for this operation by using the target integer size of 32 bits, so the 24 leftmost

bits in this value are all ones. When the charts assign the intermediate value to `y`, the cast to `uint8` causes an integer overflow. The output from each chart depends on how the chart handles integer overflows.

- If **Saturate on Integer Overflow** is enabled, the chart saturates the result of the bitwise operation and outputs a value of zero.
- If **Saturate on Integer Overflow** is disabled, the chart wraps the result of the bitwise operation and outputs its eight rightmost bits.



For more information, see “Saturate on integer overflow” on page 28-5.

## Pointer and Address Operations

This table summarizes the interpretation of pointer and address operations in Stateflow charts that use C as the action language.

Operation	Description
<code>&amp;a</code>	Address operation. Use with custom code and Stateflow variables.
<code>*a</code>	Pointer operation. Use only with custom code variables.

For example, the model `sf_bus_demo` contains a custom C function that takes pointers as arguments. When the chart calls the custom code function, it uses the `&` operation to pass the Stateflow data by address. For more information, see “Integrate Custom Structures in Stateflow Charts” on page 29-11.

Pointer and address operations are not supported in charts that use MATLAB as the action language.

## Replace Operations with Application Implementations

If you have Embedded Coder or Simulink Coder, you can configure the code generator to apply a code replacement library (CRL) during code generation. The code generator changes the code that it generates for operations to meet application requirements. With Embedded Coder, you can develop and apply custom code replacement libraries.

Operation entries of the code replacement library can specify integral or fixed-point operand and result patterns. You can use operation entries for these operations:

- Addition +



- Subtraction -
- Multiplication \*
- Division /

For example, in this expression, you can replace the addition operator + with a target-specific implementation if `u1`, `u2`, and `y` have types that permit a match with an addition entry in the code replacement library:

```
y = u1+u2
```

C chart semantics limit operator entry matching because the chart uses the target integer size as its intermediate type in arithmetic expressions. For example, this arithmetic expression computes the intermediate addition into a target integer:

```
y = (u1 + u2) % 3
```

If the target integer size is 32 bits, then you cannot replace this expression with an addition operator from the code replacement library and produce a signed 16-bit result without a loss of precision.

For more information about using code replacement libraries that MathWorks® provides, see “What Is Code Replacement?” (Simulink Coder) and “Code Replacement Libraries” (Simulink Coder). For information about developing custom code replacement libraries, see “What Is Code Replacement Customization?” (Embedded Coder) and “Code You Can Replace From Simulink Models” (Embedded Coder).

## See Also

### More About

- “Differences Between MATLAB and C as Action Language Syntax” on page 17-5
- “Specify Properties for Stateflow Charts” on page 28-2
- “Supported Operations for Fixed-Point Data” on page 26-12

## Supported Symbols in Actions

### Boolean Symbols, true and false

Use the symbols `true` and `false` to represent Boolean constants. You can use these symbols as scalars in expressions. Examples include:

```
cooling_fan = true;
heating_fan = false;
```

---

**Tip** These symbols are case-sensitive. Therefore, `TRUE` and `FALSE` are not Boolean symbols.

---

Do not use `true` and `false` in the following cases. Otherwise, error messages appear.

- Left-hand side of assignment statements
  - `true++;`
  - `false += 3;`
  - `[true, false] = my_function(x);`
- Argument of the change implicit event (see “Control Chart Behavior by Using Implicit Events” on page 14-26)
  - `change(true);`
  - `chg(false);`
- Indexing into a vector or matrix (see “Supported Operations for Vectors and Matrices” on page 21-4)
  - `x = true[1];`
  - `y = false[1][1];`

---

**Note** If you define `true` and `false` as Stateflow data objects, your custom definitions of `true` and `false` override the built-in Boolean constants.

---

### Comment Symbols, %, //, /\*

Use the symbols `%`, `//`, and `/*` to represent comments as shown in these examples:

```
% MATLAB comment line
// C++ comment line
/* C comment line */
```

You can also include comments in generated code for an embedded target (see “Model Configuration Parameters: Comments” (Simulink Coder). C chart comments in generated code use multibyte character code. Therefore, you can have code comments with characters for non-English alphabets, such as Japanese Kanji characters.

## Hexadecimal Notation Symbols, 0xFF

C charts support C style hexadecimal notation, for example, 0xFF. You can use hexadecimal values wherever you can use decimal values.

## Infinity Symbol, inf

Use the MATLAB symbol `inf` to represent infinity in C charts. Calculations like  $n/0$ , where  $n$  is any nonzero real value, result in `inf`.

---

**Note** If you define `inf` as a Stateflow data object, your custom definition of `inf` overrides the built-in value.

---

## Line Continuation Symbol, ...

Use the characters `...` at the end of a line to indicate that the expression continues on the next line. For example, you can use the line continuation symbol in a state action:

```
entry: total1 = 0, total2 = 0, ...
      total3 = 0;
```

## Literal Code Symbol, \$

Use `$` characters to mark actions that you want the Stateflow parser to ignore but you want to appear in the generated code. For example, the parser does not process any text between these `$` characters:

```
$
ptr -> field = 1.0;
$
```

---

**Note** Avoid frequent use of literal symbols.

---

## MATLAB Display Symbol, ;

Omitting the semicolon after an expression displays the results of the expression in the Diagnostic Viewer. If you use a semicolon, the results do not appear.

## Single-Precision Floating-Point Number Symbol, F

Use a trailing `F` to specify single-precision floating-point numbers in C charts. For example, you can use the action statement `x = 4.56F`; to specify a single-precision constant with the value 4.56. If a trailing `F` does not appear with a number, double precision applies.

## Time Symbol, t

Use the letter `t` to represent absolute time that the chart inherits from a Simulink signal in simulation targets. For example, the condition `[t - On_time > Duration]` specifies that the condition is true if the difference between the simulation time `t` and `On_time` is greater than the value of `Duration`.

The letter **t** has no meaning for nonsimulation targets, since **t** depends on the specific application and target hardware.



---

**Note** If you define **t** as a Stateflow data object, your custom definition of **t** overrides the built-in value.

---

## Call C Library Functions in C Charts

Stateflow charts in Simulink models have an action language property that defines the syntax for state and transition actions. An icon in the lower-left corner of the chart canvas indicates the action language for the chart.

-  MATLAB as the action language.
-  C as the action language.

### Call C Library Functions

You can call this subset of the C Math Library functions:

<code>abs**</code>	<code>acos**</code>	<code>asin**</code>	<code>atan**</code>	<code>atan2**</code>	<code>ceil**</code>
<code>cos**</code>	<code>cosh**</code>	<code>exp**</code>	<code>fabs</code>	<code>floor**</code>	<code>fmod**</code>
<code>labs</code>	<code>ldexp**</code>	<code>log**</code>	<code>log10**</code>	<code>pow**</code>	<code>rand</code>
<code>sin**</code>	<code>sinh**</code>	<code>sqrt**</code>	<code>tan**</code>	<code>tanh**</code>	

\* The Stateflow `abs` function goes beyond that of its standard C counterpart with its own built-in functionality. For more information, see “Call the `abs` Function” on page 16-15.

\*\* You can also replace calls to the C Math Library with application-specific implementations for this subset of functions. For more information, see “Replacement of Math Library Functions with Application Implementations” on page 16-16.

When you call these functions, double precision applies unless all the input arguments are explicitly single precision. When a type mismatch occurs, a cast of the input arguments to the expected type replace the original arguments. For example, if you call the `sin` function with an integer argument, a cast of the input argument to a floating-point number of type `double` replaces the original argument.

---

**Note** Because the input arguments to the C library functions are first cast to floating-point numbers, function calls with arguments of type `int64` or `uint64` can result in loss of precision.

---

If you call other C library functions not listed above, include the appropriate `#include...` statement in the **Simulation Target** pane of the Configuration Parameters.

### Call the `abs` Function

Interpretation of the Stateflow `abs` function goes beyond the standard C version to include integer and floating-point arguments of all types as follows:

- If `x` is an integer of type `int32` or `int64`, the standard C function `abs` applies to `x`, or `abs(x)`.
- If `x` is an integer of type `int16` or `int8`, the standard C `abs` function applies to a cast of `x` as an integer of type `int32`, or `abs((int32)x)`.
- If `x` is a floating-point number of type `double`, the standard C function `fabs` applies to `x`, or `fabs(x)`.

- If  $x$  is a floating-point number of type `single`, the standard C function `fabs` applies to a cast of  $x$  as a `double`, or `fabs((double)x)`.
- If  $x$  is a fixed-point number, the standard C function `fabs` applies to a cast of the fixed-point number as a `double`, or `fabs((double) Vx)`, where  $V_x$  is the real-world value of  $x$ .

If you want to use the `abs` function in the strict sense of standard C, cast its argument or return values to integer types. See “Type Cast Operations” on page 16-8.

---

**Note** If you declare  $x$  in custom code, the standard C `abs` function applies in all cases. For instructions on inserting custom code into charts, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

---

## Call min and max Functions

You can call `min` and `max` by emitting the following macros automatically at the top of generated code.

```
#define min(x1,x2) ((x1) > (x2) ? (x2):(x1))
#define max(x1,x2) ((x1) > (x2) ? (x1):(x2))
```

To allow compatibility with user graphical functions named `min()` or `max()`, generated code uses a mangled name of the following form: `<prefix>_min`. However, if you export `min()` or `max()` graphical functions to other charts in your model, the name of these functions can no longer be emitted with mangled names in generated code and conflict occurs. To avoid this conflict, rename the `min()` and `max()` graphical functions.

## Replacement of Math Library Functions with Application Implementations

You can configure the code generator to change the code that it generates for math library functions such that the code meets application requirements. To do this you configure the code generator to apply a code replacement library (CRL) during code generation. If you have an Embedded Coder license, you can develop and apply custom code replacement libraries.

For more information about replacing code, using code replacement libraries that MathWorks provides, see “What Is Code Replacement?” (Simulink Coder) and “Code Replacement Libraries” (Simulink Coder). For information about developing custom code replacement libraries, see “What Is Code Replacement Customization?” (Embedded Coder) and “Code You Can Replace From Simulink Models” (Embedded Coder).

## Call Custom C Code Functions

You can specify custom code functions for use in C charts for simulation and C code generation.

- “Specify Custom C Functions for Simulation” on page 16-17
- “Specify Custom C Functions for Code Generation” on page 16-17
- “Guidelines for Calling Custom C Functions in Your Chart” on page 16-17
- “Guidelines for Writing Custom C Functions That Access Input Vectors” on page 16-17
- “Function Call in Transition Action” on page 16-18

- “Function Call in State Action” on page 16-18
- “Pass Arguments by Reference” on page 16-19

### Specify Custom C Functions for Simulation

To specify custom C functions for simulation:

- 1 Open the Model Configuration Parameters dialog box.
- 2 Select **Simulation Target**.
- 3 Specify your custom C files, as described in “Access Custom C Code in Nonlibrary Charts” on page 31-4.

### Specify Custom C Functions for Code Generation

To specify custom C functions for code generation:

- 1 Open the Model Configuration Parameters dialog box.
- 2 Select **Code Generation > Custom Code**.
- 3 Specify your custom C files, as described in “Integrate External Code for All Charts” (Simulink Coder).

### Guidelines for Calling Custom C Functions in Your Chart

- Define a function by its name, any arguments in parentheses, and an optional semicolon.
- Pass parameters to user-written functions using single quotation marks. For example, `func('string')`.
- An action can nest function calls.
- An action can invoke functions that return a scalar value (of type `double` in the case of MATLAB functions and of any type in the case of C user-written functions).

### Guidelines for Writing Custom C Functions That Access Input Vectors

- Use the `sizeof` function to determine the length of an input vector.

For example, your custom function can include a for-loop that uses `sizeof` as follows:

```
for(i=0; i < sizeof(input); i++) {
    .....
}
```

- If your custom function uses the value of the input vector length multiple times, include an input to your function that specifies the input vector length.

For example, you can use `input_length` as the second input to a `sum` function as follows:

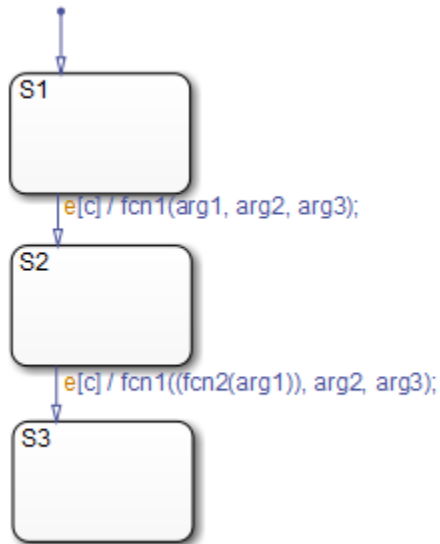
```
int sum(double *input, double input_length)
```

Your `sum` function can include a for-loop that iterates over all elements of the input vector:

```
for(i=0; i < input_length; i++) {
    .....
}
```

### Function Call in Transition Action

Example formats of function calls using transition action notation appear in the following chart.



A function call to `fcn1` occurs with `arg1`, `arg2`, and `arg3` if the following are true:

- `S1` is active.
- Event `e` occurs.
- Condition `c` is true.
- The transition destination `S2` is valid.

The transition action in the transition from `S2` to `S3` shows a function call nested within another function call.

### Function Call in State Action

Example formats of function calls using state action notation appear in the following chart.

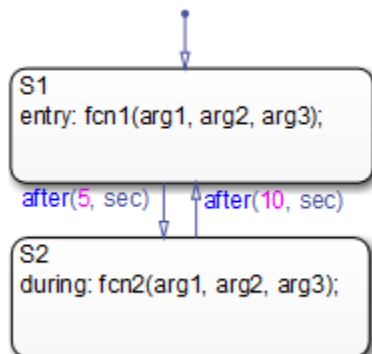


Chart execution occurs as follows:

- 1 When the default transition into `S1` occurs, `S1` becomes active.



- 2 The entry action, a function call to `fcn1` with the specified arguments, executes.
- 3 After 5 seconds of simulation time, S1 becomes inactive and S2 becomes active.
- 4 The during action, a function call to `fcn2` with the specified arguments, executes.
- 5 After 10 seconds of simulation time, S2 becomes inactive and S1 becomes active again.
- 6 Steps 2 through 5 repeat until the simulation ends.

### Pass Arguments by Reference

A Stateflow action can pass arguments to a user-written function by reference rather than by value. In particular, an action can pass a pointer to a value rather than the value itself. For example, an action could contain the following call:

```
f(&x);
```

where `f` is a custom-code C function that expects a pointer to `x` as an argument.

If `x` is the name of a data item defined in the Stateflow hierarchy, the following rules apply:

- Do not use pointers to pass data items input from a Simulink model.

If you need to pass an input item by reference, for example, an array, assign the item to a local data item and pass the local item by reference.

- If `x` is a Simulink output data item having a data type other than `double`, the chart property **Use Strong Data Typing with Simulink I/O** must be on (see “Specify Properties for Stateflow Charts” on page 28-2).
- If the data type of `x` is `boolean`, you must turn off the coder option **Use bitsets for storing state configuration**.
- If `x` is an array with its first index property set to 0 (see “Set Data Properties” on page 12-5), then you must call the function as follows.

```
f(&(x[0]));
```

This passes a pointer to the first element of `x` to the function.



- If `x` is an array with its first index property set to a nonzero number (for example, 1), the function must be called in the following way:

```
f(&(x[1]));
```

This passes a pointer to the first element of `x` to the function.

## Access MATLAB Functions and Workspace Data in C Charts

Stateflow charts in Simulink models have an action language property that defines the syntax for state and transition actions. An icon in the lower-left corner of the chart canvas indicates the action language for the chart.

-  MATLAB as the action language.
-  C as the action language.

In charts that use C as the action language, you can call built-in MATLAB functions and access MATLAB workspace variables by using the `m1` namespace operator or the `m1` function.

---

**Caution** Because MATLAB functions are not available in a target environment, do not use the `m1` namespace operator and the `m1` function if you plan to build a code generation target.

---

### m1 Namespace Operator

For C charts, the `m1` namespace operator uses standard dot ( `.` ) notation to reference MATLAB variables and functions. For example, the statement `a = m1.x` returns the value of the MATLAB workspace variable `x` to the Stateflow data `a`.

For functions, the syntax is as follows:

```
[return_val1, return_val2, ...] = m1.matfunc(arg1, arg2, ...)
```

For example, the statement `[a, b, c] = m1.matfunc(x, y)` passes the return values from the MATLAB function `matfunc` to the Stateflow data `a`, `b`, and `c`.

If the MATLAB function you call does not require arguments, you must still include the parentheses. If you omit the parentheses, Stateflow software interprets the function name as a workspace variable, which, when not found, generates a run-time error during simulation.

### Examples

In these examples, `x`, `y`, and `z` are workspace variables and `d1` and `d2` are Stateflow data:

- `a = m1.sin(m1.x)`

In this example, the MATLAB function `sin` evaluates the sine of `x`, which is then assigned to Stateflow data variable `a`. However, because `x` is a workspace variable, you must use the namespace operator to access it. Hence, `m1.x` is used instead of just `x`.

- `a = m1.sin(d1)`

In this example, the MATLAB function `sin` evaluates the sine of `d1`, which is assigned to Stateflow data variable `a`. Because `d1` is Stateflow data, you can access it directly.

- `m1.x = d1*d2/m1.y`

The result of the expression is assigned to `x`. If `x` does not exist prior to simulation, it is automatically created in the MATLAB workspace.

- `ml.v[5][6][7] = ml.matfunc(ml.x[1][3], ml.y[3], d1, d2, 'string')`

The workspace variables `x` and `y` are arrays. `x[1][3]` is the (1,3) element of the two-dimensional array variable `x`. `y[3]` is the third element of the one-dimensional array variable `y`. The last argument, `'string'`, is a character vector.

The return from the call to `matfunc` is assigned to element (5,6,7) of the workspace array, `v`. If `v` does not exist prior to simulation, it is automatically created in the MATLAB workspace.

## ml Function

For C charts, you can use the `ml` function to specify calls to MATLAB functions. The format for the `ml` function call uses this notation:

```
ml(evalString, arg1, arg2,...);
```

`evalString` is an expression that is evaluated in the MATLAB workspace. It contains a MATLAB command (or a set of commands, each separated by a semicolon) to execute along with format specifiers (`%g`, `%f`, `%d`, etc.) that provide formatted substitution of the other arguments (`arg1`, `arg2`, etc.) into `evalString`.

The format specifiers used in `ml` functions are the same as those used in the C functions `printf` and `sprintf`. The `ml` function call is equivalent to calling the MATLAB `eval` function with the `ml` namespace operator if the arguments `arg1`, `arg2`, ... are restricted to scalars or literals in the following command:

```
ml.eval(ml.sprintf(evalString, arg1, arg2,...))
```

Format specifiers used in the `ml` function must either match the data types of the arguments or the arguments must be of types that can be promoted to the type represented by the format specifier.

Stateflow software assumes scalar return values from `ml` namespace operator and `ml` function calls when they are used as arguments in this context. See “How Charts Infer the Return Size for `ml` Expressions” on page 16-25.

## Examples

In these examples, `x` is a MATLAB workspace variable, and `d1` and `d2` are Stateflow data:

- `a = ml('sin(x)')`

In this example, the `ml` function calls the MATLAB function `sin` to evaluate the sine of `x` in the MATLAB workspace. The result is then assigned to Stateflow data variable `a`. Because `x` is a workspace variable, and `sin(x)` is evaluated in the MATLAB workspace, you enter it directly in the `evalString` argument (`'sin(x)'`).

- `a = ml('sin(%f)', d1)`

In this example, the MATLAB function `sin` evaluates the sine of `d1` in the MATLAB workspace and assigns the result to Stateflow data variable `a`. Because `d1` is Stateflow data, its value is inserted in the `evalString` argument (`'sin(%f)'`) using the format expression `%f`. This means that if `d1 = 1.5`, the expression evaluated in the MATLAB workspace is `sin(1.5)`.

- `a = ml('matfunc(%g, 'abcdefg', x, %f)', d1, d2)`

In this example, the expression `'matfunc(%g, 'abcdefg', x, %f)'` is the `evalString` shown in the preceding format statement. Stateflow data `d1` and `d2` are inserted into that

expression with the format specifiers %g and %f, respectively. ' 'abcdefg' ' is a literal enclosed with two single pairs of quotation marks because it is part of the evaluation expression, which is already enclosed in single quotation marks.

- `sfmat_44 = ml('rand(4)')`

In this example, a square 4-by-4 matrix of random numbers between 0 and 1 is returned and assigned to the Stateflow data `sf_mat44`. Stateflow data `sf_mat44` must be defined as a 4-by-4 array before simulation. If its size is different, a size mismatch error is generated during run-time.

## ml Expressions

For C charts, you can mix `ml` namespace operator and `ml` function expressions along with Stateflow data in larger expressions. The following example squares the sine and cosine of an angle in workspace variable `X` and adds them:

```
ml.power(ml.sin(ml.X),2) + ml('power(cos(X),2)')
```

The first operand uses the `ml` namespace operator to call the `sin` function. Its argument is `ml.X`, since `X` is in the MATLAB workspace. The second operand uses the `ml` function. Because `X` is in the workspace, it appears in the *evalString* expression as `X`. The squaring of each operand is performed with the MATLAB `power` function, which takes two arguments: the value to square, and the power value, 2.

Expressions using the `ml` namespace operator and the `ml` function can be used as arguments for `ml` namespace operator and `ml` function expressions. The following example nests `ml` expressions at three different levels:

```
a = ml.power(ml.sin(ml.X + ml('cos(Y)')),2)
```

In composing your `ml` expressions, follow the levels of precedence set out in “Binary Operations” on page 16-5. Use parentheses around power expressions with the `^` operator when you use them in conjunction with other arithmetic operators.

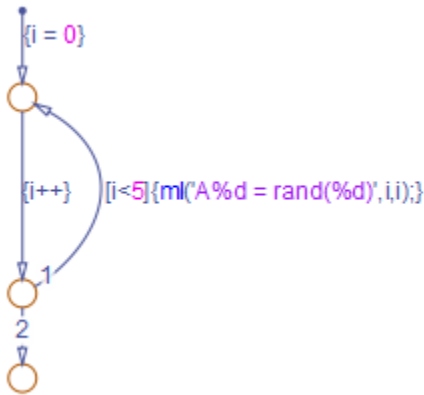
Stateflow software checks expressions for data size mismatches in your actions when you update or simulate the model. Because the return values for `ml` expressions are not known until run time, Stateflow software must infer the size of their return values. See “How Charts Infer the Return Size for `ml` Expressions” on page 16-25.

## Which ml Should I Use?

In most cases, the notation of the `ml` namespace operator is more straightforward. However, using the `ml` function call does offer a few advantages:

- Use the `ml` function to dynamically construct workspace variables.

The following flow chart creates four new MATLAB matrices:



The for loop creates four new matrix variables in the MATLAB workspace. The default transition initializes the Stateflow counter *i* to 0, while the transition segment between the top two junctions increments it by 1. If *i* is less than 5, the transition segment back to the top junction evaluates the `ml` function call `ml('A%d = rand(%d)', i, i)` for the current value of *i*. When *i* is greater than or equal to 5, the transition segment between the bottom two junctions occurs and execution stops.

The transition executes the following MATLAB commands, which create a workspace scalar (*A1*) and three matrices (*A2*, *A3*, *A4*):

```
A1 = rand(1)
A2 = rand(2)
A3 = rand(3)
A4 = rand(4)
```

- Use the `ml` function with full MATLAB notation.

You cannot use full MATLAB notation with the `ml` namespace operator, as the following example shows:

```
ml.A = ml.magic(4)
B = ml('A + A''')
```

This example sets the workspace variable *A* to a magic 4-by-4 matrix using the `ml` namespace operator. Stateflow data *B* is then set to the addition of *A* and its transpose matrix, *A'*, which produces a symmetric matrix. Because the `ml` namespace operator cannot evaluate the expression *A'*, the `ml` function is used instead. However, you can call the MATLAB function `transpose` with the `ml` namespace operator in the following equivalent expression:

```
B = ml.A + ml.transpose(ml.A)
```

As another example, you cannot use arguments with cell arrays or subscript expressions involving colons with the `ml` namespace operator. However, these can be included in an `ml` function call.

## ml Data Type

Stateflow data of type `ml` is typed internally with the MATLAB type `mxAarray` for C charts. You can assign (store) any type of data available in the Stateflow hierarchy to a data of type `ml`. These types include any data type defined in the Stateflow hierarchy or returned from the MATLAB workspace with the `ml` namespace operator or `ml` function.

## Rules for Using ml Data Type

These rules apply to Stateflow data of type `ml`:

- You can initialize `ml` data from the MATLAB workspace just like other data in the Stateflow hierarchy (see “Initialize Data from the MATLAB Base Workspace” on page 12-19).
- Any numerical scalar or array of `ml` data in the Stateflow hierarchy can participate in any kind of unary operation and any kind of binary operation with any other data in the hierarchy.

If `ml` data participates in any numerical operation with other data, the size of the `ml` data must be inferred from the context in which it is used, just as return data from the `ml` namespace operator and `ml` function are. See “How Charts Infer the Return Size for `ml` Expressions” on page 16-25.

- You cannot define `ml` data with the scope **Constant**.

This option is disabled in the Data properties dialog box and in the Model Explorer for Stateflow data of type `ml`.

- You can use `ml` data to build a simulation target but not to build an embeddable code generation target.
- If data of type `ml` contains an array, you can access the elements of the array via indexing with these rules:
  - a You can index only arrays with numerical elements.
  - b You can index numerical arrays only by their dimension.

In other words, you can access only one-dimensional arrays by a single index value. You cannot access a multidimensional array with a single index value.

- c The first index value for each dimension of an array is 1, and not 0, as in C language arrays.

In the examples that follow, `mldata` is a Stateflow data of type `ml`, `ws_num_array` is a 2-by-2 MATLAB workspace array with numerical values, and `ws_str_array` is a 2-by-2 MATLAB workspace array with character vector values.

```
mldata = ml.ws_num_array; /* OK */
n21 = mldata[2][1]; /* OK for numerical data of type ml */
n21 = mldata[3]; /* NOT OK for 2-by-2 array data */
mldata = ml.ws_str_array; /* OK */
s21 = mldata[2][1]; /* NOT OK for character vector data of type ml*/
```

- `ml` data cannot have a scope outside a C chart; that is, you cannot define the scope of `ml` data as **Input from Simulink** or **Output to Simulink**.

## Place Holder for Workspace Data

Both the `ml` namespace operator and the `ml` function can access data directly in the MATLAB workspace and return it to a C chart. However, maintaining data in the MATLAB workspace can present Stateflow users with conflicts with other data already resident in the workspace. Consequently, with the `ml` data type, you can maintain `ml` data in a chart and use it for MATLAB computations in C charts.

As an example, in the following statements, `mldata1` and `mldata2` are Stateflow data of type `ml`:

```
mldata1 = ml.rand(3);
mldata2 = ml.transpose(mldata1);
```

In the first line of this example, `mldata1` receives the return value of the MATLAB function `rand`, which, in this case, returns a 3-by-3 array of random numbers. Note that `mldata1` is not specified as an array or sized in any way. It can receive any MATLAB workspace data or the return of any MATLAB function because it is defined as a Stateflow data of type `m1`.

In the second line of the example, `mldata2`, also of Stateflow data type `m1`, receives the transpose matrix of the matrix in `mldata1`. It is assigned the return value of the MATLAB function `transpose` in which `mldata1` is the argument.

Note the differences in notation if the preceding example were to use MATLAB workspace data (`wsdata1` and `wsdata2`) instead of Stateflow `m1` data to hold the generated matrices:

```
m1.wsdata1 = m1.rand(3);
m1.wsdata2 = m1.transpose(m1.wsdata1);
```

In this case, each workspace data must be accessed through the `m1` namespace operator.

## How Charts Infer the Return Size for m1 Expressions

In C charts, Stateflow expressions using the `m1` namespace operator and the `m1` function evaluate in the MATLAB workspace at run time. The actual size of the data returned from the following expression types is known only at run time:

- MATLAB workspace data or functions using the `m1` namespace operator or the `m1` function call

For example, the size of the return values from the expressions `m1.var`, `m1.func()`, or `m1(evalString, arg1, arg2, ...)`, where `var` is a MATLAB workspace variable and `func` is a MATLAB function, cannot be known until run-time.

- Stateflow data of type `m1`
- Graphical functions that return Stateflow data of type `m1`

When these expressions appear in actions, Stateflow code generation creates temporary data to hold intermediate returns for evaluation of the full expression of which they are a part. Because the size of these return values is unknown until run time, Stateflow software must employ context rules to infer the sizes for creation of the temporary data.

During run time, if the actual returned value from one of these commands differs from the inferred size of the temporary variable that stores it, a size mismatch error appears. To prevent run-time errors, use the following guidelines to write actions with MATLAB commands or `m1` data:

Guideline	Example
Return sizes of MATLAB commands or data in an expression must match return sizes of peer expressions.	In the expression <code>m1.func() * (x + m1.y)</code> , if <code>x</code> is a 3-by-2 matrix, then <code>m1.func()</code> and <code>m1.y</code> are also assumed to evaluate to 3-by-2 matrices. If either returns a value of different size (other than a scalar), an error results during run-time.

Guideline	Example				
<p>Expressions that return a scalar never produce an error.</p> <p>You can combine matrices and scalars in larger expressions because MATLAB commands use scalar expansion.</p>	<p>In the expression <math>m1.x + y</math>, if <math>y</math> is a 3-by-2 matrix and <math>m1.x</math> returns a scalar, the resulting value is the result of adding the scalar value of <math>m1.x</math> to every member of <math>y</math> to produce a matrix with the size of <math>y</math>, that is, a 3-by-2 matrix.</p> <p>The same rule applies to subtraction (-), multiplication (*), division (/), and any other binary operations.</p>				
<p>MATLAB commands or Stateflow data of type <math>m1</math> can be members of these independent levels of expression, for which resolution of return size is necessary:</p>	<table border="1"> <tr> <td data-bbox="565 615 902 909"> <p>Arguments</p> <p>The expression for each function argument is a larger expression for which the return size of MATLAB commands or Stateflow data of type <math>m1</math> must be determined.</p> </td> <td data-bbox="902 615 1477 909"> <p>In the expression <math>z + func(x + m1.y)</math>, the size of <math>m1.y</math> is independent of the size of <math>z</math>, because <math>m1.y</math> is used at the function argument level. However, the return size for <math>func(x + m1.y)</math> must match the size of <math>z</math>, because they are both at the same expression level.</p> </td> </tr> <tr> <td data-bbox="565 909 902 1136"> <p>Array indices</p> <p>The expression for an array index is an independent level of expression that must be scalar in size.</p> </td> <td data-bbox="902 909 1477 1136"> <p>In the expression <math>x + array[y]</math>, the size of <math>y</math> is independent of the size of <math>x</math> because <math>y</math> and <math>x</math> are at different levels of expression. Also, <math>y</math> must be a scalar.</p> </td> </tr> </table>	<p>Arguments</p> <p>The expression for each function argument is a larger expression for which the return size of MATLAB commands or Stateflow data of type <math>m1</math> must be determined.</p>	<p>In the expression <math>z + func(x + m1.y)</math>, the size of <math>m1.y</math> is independent of the size of <math>z</math>, because <math>m1.y</math> is used at the function argument level. However, the return size for <math>func(x + m1.y)</math> must match the size of <math>z</math>, because they are both at the same expression level.</p>	<p>Array indices</p> <p>The expression for an array index is an independent level of expression that must be scalar in size.</p>	<p>In the expression <math>x + array[y]</math>, the size of <math>y</math> is independent of the size of <math>x</math> because <math>y</math> and <math>x</math> are at different levels of expression. Also, <math>y</math> must be a scalar.</p>
<p>Arguments</p> <p>The expression for each function argument is a larger expression for which the return size of MATLAB commands or Stateflow data of type <math>m1</math> must be determined.</p>	<p>In the expression <math>z + func(x + m1.y)</math>, the size of <math>m1.y</math> is independent of the size of <math>z</math>, because <math>m1.y</math> is used at the function argument level. However, the return size for <math>func(x + m1.y)</math> must match the size of <math>z</math>, because they are both at the same expression level.</p>				
<p>Array indices</p> <p>The expression for an array index is an independent level of expression that must be scalar in size.</p>	<p>In the expression <math>x + array[y]</math>, the size of <math>y</math> is independent of the size of <math>x</math> because <math>y</math> and <math>x</math> are at different levels of expression. Also, <math>y</math> must be a scalar.</p>				
<p>The return size for an indexed array element access must be a scalar.</p>	<p>The expression <math>x[1][1]</math>, where <math>x</math> is a 3-by-2 array, must evaluate to a scalar.</p>				
<p>MATLAB command or data elements used in an expression for the input argument of a MATLAB function called through the <math>m1</math> namespace operator are resolved for size. This resolution uses the rule for peer expressions (preceding rule 1) for the expression itself, because no size definition prototype is available.</p>	<p>In the function call <math>m1.func(x + m1.y)</math>, if <math>x</math> is a 3-by-2 array, <math>m1.y</math> must return a 3-by-2 array or a scalar.</p>				
<p>MATLAB command or data elements used for the input argument for a graphical function in an expression are resolved for size by the function prototype.</p>	<p>If the graphical function <math>gfunc</math> has the prototype <math>gfunc(arg1)</math>, where <math>arg1</math> is a 2-by-3 Stateflow data array, the calling expression, <math>gfunc(m1.y + x)</math>, requires that both <math>m1.y</math> and <math>x</math> evaluate to 2-by-3 arrays (or scalars) during run-time.</p>				
<p><math>m1</math> function calls can take only scalar or character vector literal arguments. Any MATLAB command or data that specifies an argument for the <math>m1</math> function must return a scalar value.</p>	<p>In the expression <math>a = m1('sin(x)')</math>, the <math>m1</math> function calls the MATLAB function <code>sin</code> to evaluate the sine of <math>x</math> in the MATLAB workspace. Stateflow data variable <math>a</math> stores that result.</p>				



Guideline	Example
<p>In an assignment, the size of the right-hand expression must match the size of the left-hand expression, with one exception. If the left-hand expression is a single MATLAB variable, such as <code>m1.x</code>, or Stateflow data of type <code>m1</code>, the right-hand expression determines the sizes of both expressions.</p>	<p>In the expression <code>s = m1.func(x)</code>, where <code>x</code> is a 3-by-2 matrix and <code>s</code> is scalar Stateflow data, <code>m1.func(x)</code> must return a scalar to match the left-hand expression, <code>s</code>. However, in the expression <code>m1.y = x + s</code>, where <code>x</code> is a 3-by-2 data array and <code>s</code> is scalar, the left-hand expression, workspace variable <code>y</code>, is assigned the size of a 3-by-2 array to match the size of the right-hand expression, <code>x+s</code>, a 3-by-2 array.</p>
<p>In an assignment, Stateflow column vectors on the left-hand side are compatible with MATLAB row or column vectors of the same size on the right-hand side.</p> <p>A matrix you define with a row dimension of 1 is considered a row vector. A matrix you define with one dimension or with a column dimension of 1 is considered a column vector.</p>	<p>In the expression <code>s = m1.func()</code>, where <code>m1.func()</code> returns a 1-by-3 matrix, if <code>s</code> is a vector of size 3, the assignment is valid.</p>
<p>If you cannot resolve the return size of MATLAB command or data elements in a larger expression by any of the preceding rules, they are assumed to return scalar values.</p>	<p>In the expression <code>m1.x = m1.y + m1.z</code>, none of the preceding rules can be used to infer a common size among <code>m1.x</code>, <code>m1.y</code>, and <code>m1.z</code>. In this case, both <code>m1.y</code> and <code>m1.z</code> are assumed to return scalar values. Even if <code>m1.y</code> and <code>m1.z</code> return matching sizes at run-time, if they return nonscalar values, a size mismatch error results.</p>
<p>The preceding rules for resolving the size of member MATLAB commands or Stateflow data of type <code>m1</code> in a larger expression apply only to cases in which numeric values are expected for that member. For nonnumeric returns, a run-time error results.</p>	<p>The expression <code>x + m1.str</code>, where <code>m1.str</code> is a character vector workspace variable, produces a run-time error stating that <code>m1.str</code> is not a numeric type.</p>
<p><b>Note</b> Member MATLAB commands or data of type <code>m1</code> in a larger expression are limited to numeric values (scalar or array) only if they participate in numeric expressions.</p>	

Special cases exist, in which no size checking occurs to resolve the size of MATLAB command or data expressions that are part of larger expressions. Use of the following expressions does not require enforcement of size checking at run-time:

- `m1.var`
- `m1.func()`
- `m1(evalString, arg1, arg2, ...)`
- Stateflow data of type `m1`
- Graphical function returning a Stateflow data of type `m1`

In these cases, assignment of a return to the left-hand side of an assignment statement or a function argument occurs without checking for a size mismatch between the two:

- An assignment in which the left-hand side is a MATLAB workspace variable

For example, in the expression `m1.x = m1.y`, `m1.y` is a MATLAB workspace variable of any size and type (structure, cell array, character vector, and so on).

- An assignment in which the left-hand side is a data of type `m1`

For example, in the expression `m_x = m1.func()`, `m_x` is a Stateflow data of type `m1`.

- Input arguments of a MATLAB function

For example, in the expression `m1.func(m_x, m1.x, gfunc())`, `m_x` is a Stateflow data of type `m1`, `m1.x` is a MATLAB workspace variable of any size and type, and `gfunc()` is a Stateflow graphical function that returns a Stateflow data of type `m1`. Although size checking does not occur for the input type, if the passed-in data is not of the expected type, an error results from the function call `m1.func()`.

- Arguments for a graphical function that are specified as Stateflow data of type `m1` in its prototype statement

---

**Note** If you replace the inputs in the preceding cases with non-MATLAB numeric Stateflow data, conversion to an `m1` type occurs.

---

## Control Function-Call Subsystems by Using bind Actions

You can bind specified data and events to a state by using `bind` actions. Events bound to a state can be broadcast only by the actions in that state or its children. You can also bind a function-call event to a state to enable or disable the function-call subsystem that the event triggers. The function-call subsystem enables when the state with the bound event is entered and disables when that state is exited. Execution of the function-call subsystem is fully bound to the activity of the state that calls it.

### Bind a Function-Call Subsystem to a State

By default, a function-call subsystem is controlled by the chart in which the associated function call output event is defined. This association means that the function-call subsystem is enabled when the chart wakes up and remains active until the chart goes to sleep. To achieve a finer level of control, you can bind a function-call subsystem to a state within the chart hierarchy by using a `bind` action (see “bind Actions” on page 2-14).

You can bind function-call output events to a state. When you create this type of binding, the function-call subsystem that is called by the event is also bound to the state. In this situation, the function-call subsystem is enabled when the state is entered and disabled when the state is exited.

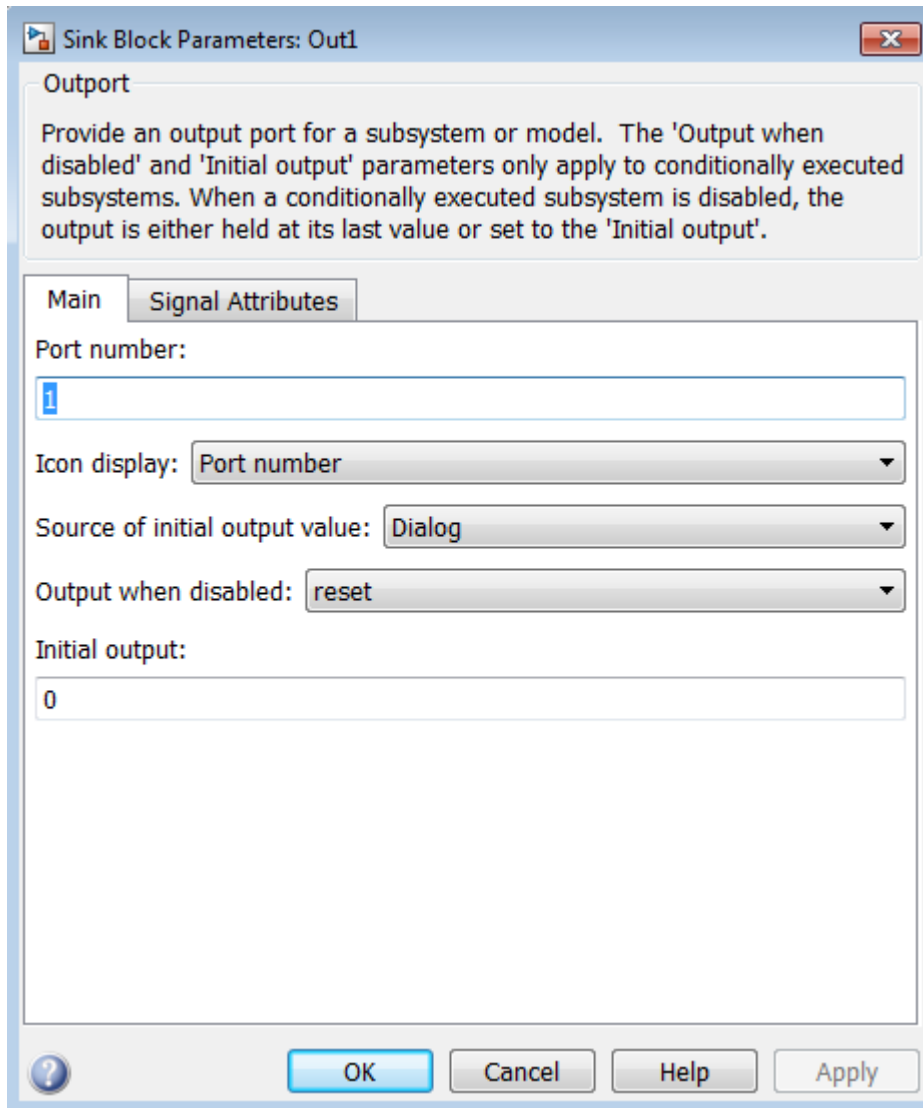
When you bind a function-call subsystem to a state, you can fine-tune the behavior of the subsystem when it is enabled and disabled, as described in the following sections:

- “Handle Outputs When the Subsystem is Disabled” on page 16-29
- “Control Behavior of States When the Subsystem is Enabled” on page 16-30

### Handle Outputs When the Subsystem is Disabled

Although function-call subsystems do not execute while disabled, their output signals are available to other blocks in the model. If a function-call subsystem is bound to a state, you can hold its outputs at their values from the previous time step or reset the outputs to their initial values when the subsystem is disabled. Follow these steps:

- 1 Double-click the output block of the subsystem to open the Block Parameters dialog box.



- 2 Select an option for **Output when disabled**:

Select:	To:
held	Maintain most recent output value
reset	Reset output to its initial value

- 3 Click **OK** to record the settings.

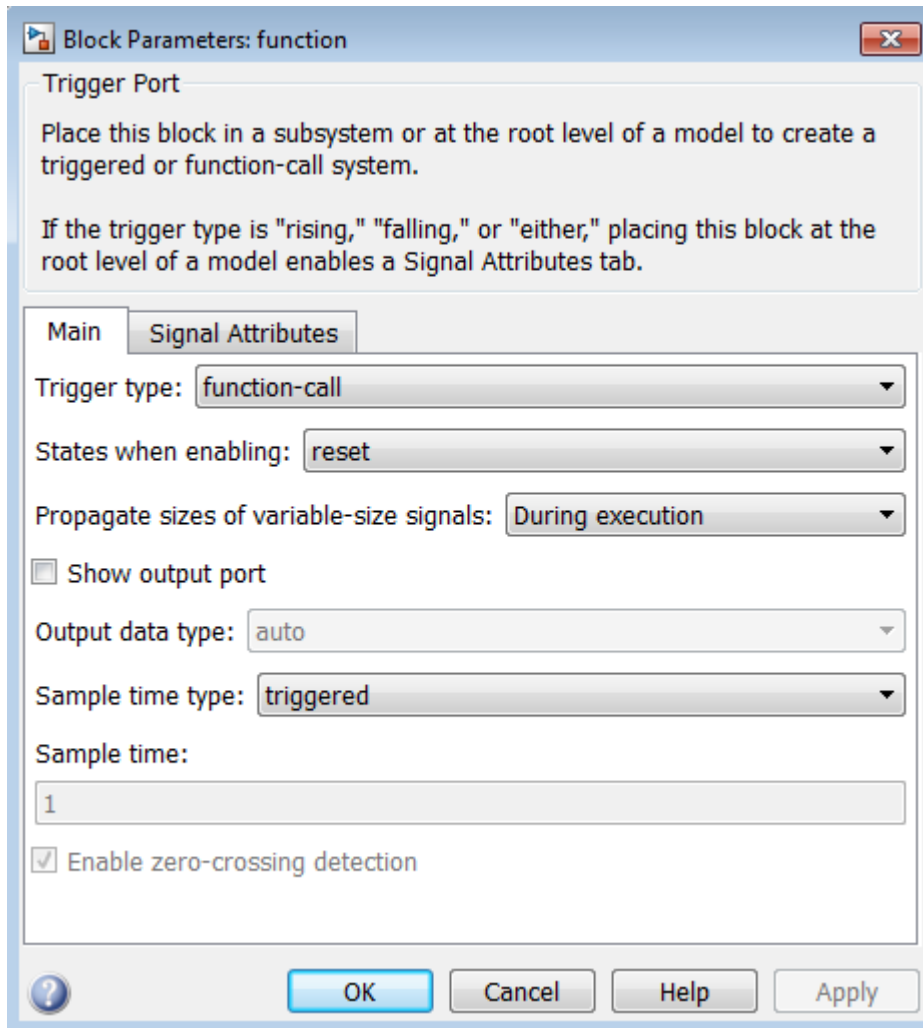
**Note** Setting **Output when disabled** is meaningful only when the function-call subsystem is bound to a state, as described in “Bind a Function-Call Subsystem to a State” on page 16-29.

### Control Behavior of States When the Subsystem is Enabled

If a function-call subsystem is bound to a state, you can hold the subsystem state variables at their values from the previous time step or reset the state variables to their initial conditions when the

subsystem executes. In this way, the binding state gains full control of state variables for the function-call subsystem. Follow these steps:

- 1 Double-click the trigger port of the subsystem to open the Block Parameters dialog box.



- 2 Select an option for **States when enabling**:

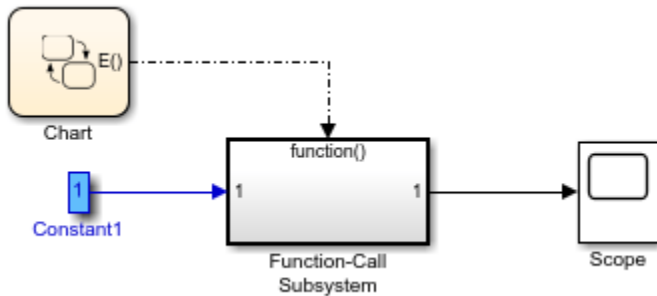
Select:	To:
held	Maintain most recent values of the states of the subsystem that contains the trigger port
reset	Revert to the initial conditions of the states of the subsystem that contains this trigger port
inherit	Inherit this setting from the function-call initiator's parent subsystem. If the parent of the initiator is the model root, the inherited setting is held. If the trigger has multiple initiators, the parents of all initiators must have the same setting: either all held or all reset.

- 3 Click **OK** to record the settings.

**Note** Setting **States when enabling** is meaningful only when the function-call subsystem is bound to a state, as described in “Bind a Function-Call Subsystem to a State” on page 16-29.

## Bind a Function-Call Subsystem to a State

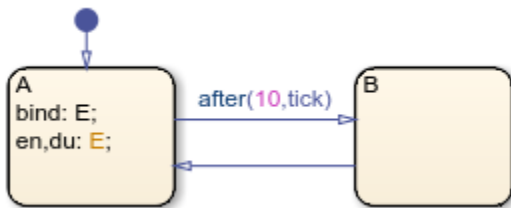
This model triggers a function-call subsystem with a trigger event E that binds to a state of a chart. In the **Solver** pane of the Model Configuration Parameters dialog box, the model specifies a fixed-step solver with a fixed-step size of 1.



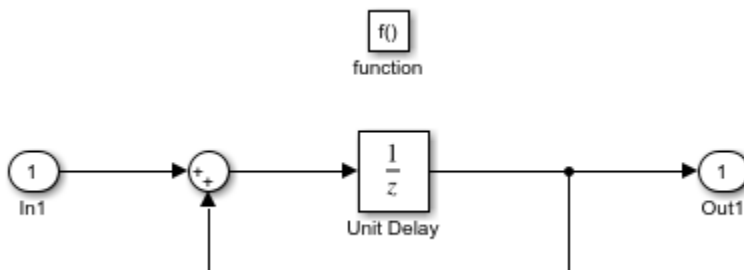
The chart contains two states. Event E binds to state A with the action

```
bind:E
```

Event E is defined for the chart with a scope of `Output` to Simulink and a trigger type of `function-call`.



The function-call subsystem contains a trigger port block, an input port, an output port, and a simple block diagram. The block diagram increments a counter by 1 at each time step, using a Unit Delay block.



The Block Parameters dialog box for the trigger port contains these settings:

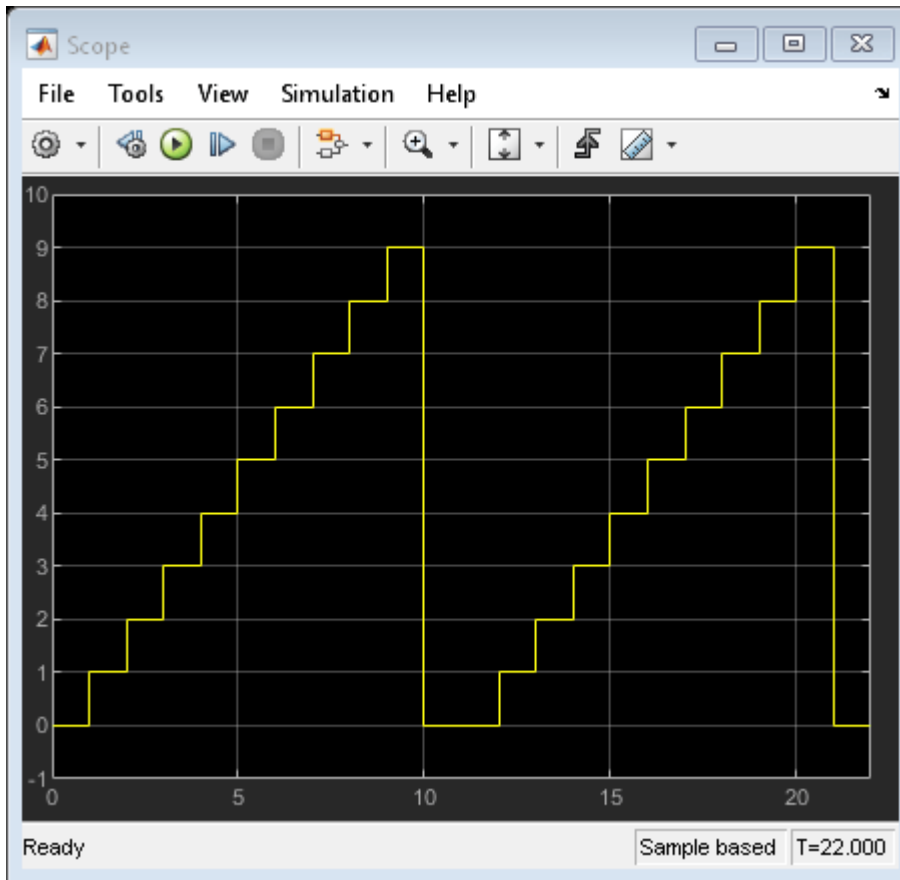
- **Trigger type:** function-call.
- **States when enabling:** reset. This setting resets the state values for the function-call subsystem to zero when it is enabled.
- **Sample time type:** triggered. This setting sets the function-call subsystem to execute only when it is triggered by a calling event while it is enabled.

Setting **Sample time type** to **periodic** enables the **Sample time** field below it, which defaults to 1. These settings force the function-call subsystem to execute for each time step specified in the **Sample time** field while it is enabled. To accomplish this, the state that binds the calling event for the function-call subsystem must send an event for the time step coinciding with the specified sampling rate in the **Sample time** field. States can send events with entry or during actions at the simulation sample rate.

- For fixed-step sampling, the **Sample time** value must be an integer multiple of the fixed-step size.
- For variable-step sampling, the **Sample time** value has no limitations.

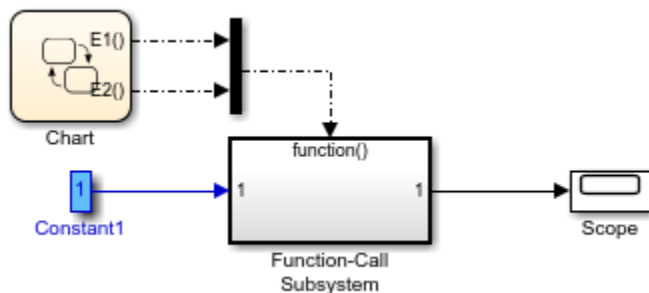
To see how a state controls a bound function-call subsystem, begin simulating the model.

- At time  $t = 0$ , the default transition to state A occurs. State A executes its bind and entry actions. The binding action binds event E to state A, enabling the function-call subsystem and resetting its state variables to 0. The entry action triggers the function-call subsystem and executes its block diagram. The block diagram increments a counter by 1 using a Unit Delay block. The Unit Delay block outputs a value of 0 and holds the new value of 1 until the next call to the subsystem.
- At time  $t = 1$ , the next update event from the model tests state A for an outgoing transition. The transition to state B does not occur because the temporal operator `after(10, tick)` allows the transition to be taken only after ten update events are received. State A remains active and its during action triggers the function-call subsystem. The Unit Delay block outputs its held value of 1. The subsystem also increments its counter to produce the value of 2, which the Unit Delay block holds until the next triggered execution.
- The next eight update events increment the subsystem output by one at each time step.
- At time  $t = 10$ , the transition from state A to state B occurs. Because the binding to state A is no longer active, the function-call subsystem is disabled, and its output drops back to 0.
- At time  $t = 11$ , the transition from state B to state A occurs. Again, the binding action enables the function-call subsystem. Subsequent update events increment the subsystem output by one at each time step until the next transition to state B occurs at time  $t = 21$ .



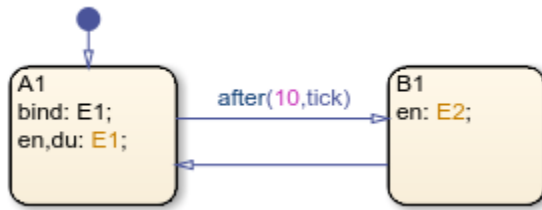
## Avoid Muxed Trigger Events with Binding

Binding events gives control of a function-call subsystem to a single state in a chart. This control does not work when you allow other events to trigger the function-call subsystem through a mux. For example, this model defines two function-call events to trigger a function-call subsystem using a Mux block.

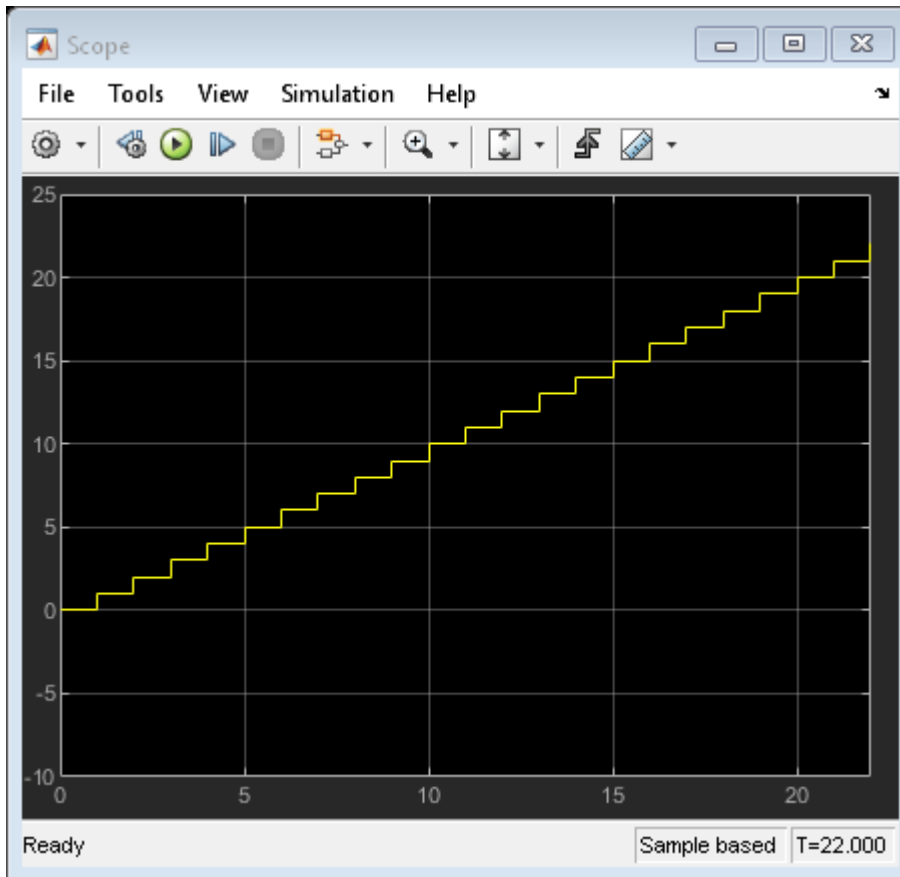


In the chart, E1 binds to state A, but E2 does not. State B sends the triggering event E2 in its entry action.





When you simulate this model, the output does not reset when the transition from state A to state B occurs.



Binding is not recommended when you provide multiple trigger events to a function-call subsystem through a mux. Muxed trigger events can interfere with event binding and cause undefined behavior.

## Control Chart Execution by Using Temporal Logic

Temporal logic controls the execution of a chart in terms of time. In state actions and transitions, you can use two types of temporal logic:

- Event-based temporal logic tracks recurring events. You can use any explicit or implicit event as a base event.
- Absolute-time temporal logic tracks the elapsed time since a state became active. The timing for absolute-time temporal logic operators depends on the type of Stateflow chart:
  - Charts in a Simulink model define absolute-time temporal logic in terms of simulation time.
  - Standalone charts in MATLAB define absolute-time temporal logic in terms of wall-clock time, which is limited to 1 millisecond precision.

### Temporal Logic Operators

To define the behavior of a Stateflow chart based on temporal logic, use the operators listed in this table. These operators can appear in:

- State on actions
- Actions on transition paths that originate from a state

Each temporal logic operator has an associated state, which is the state in which the action appears or from which the transition path originates. The Stateflow chart resets the counter used by each operator every time that the associated state reactivates.

Operator	Syntax	Description	Example
after	<code>after(n,E)</code> n is a positive integer or an expression that evaluates to a positive integer value.  E is the base event for the operator.	Returns <code>true</code> if the event E has occurred at least n times since the associated state became active. Otherwise, the operator returns <code>false</code> .	Display a status message when the chart processes a broadcast of the event E, starting on the third broadcast of E after the state became active.  <pre>on after(3,E):     disp('ON');</pre> Transition out of the associated state when the chart processes a broadcast of the event E, starting on the fifth broadcast of E after the state became active.  <code>after(5,E)</code>

Operator	Syntax	Description	Example
	<p><code>after(n,tick)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p>	<p>Returns <code>true</code> if the chart has woken up at least <code>n</code> times since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>The implicit event <code>tick</code> is not supported when a Stateflow chart in a Simulink model has input events. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.</p>	<p>Transition out of the associated state when the chart wakes up for at least the seventh time since the state became active, but only if the variable <code>temp</code> is greater than 98.6.</p> <pre>after(7,tick)[temp &gt; 98.6]</pre>
	<p><code>after(n,sec)</code></p> <p><code>after(n,msec)</code></p> <p><code>after(n,usec)</code></p> <p><code>n</code> is a positive real number or an expression that evaluates to a positive real value.</p>	<p>Returns <code>true</code> if at least <code>n</code> units of time have elapsed since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>In charts in a Simulink model, specify time in seconds (<code>sec</code>), milliseconds (<code>msec</code>), or microseconds (<code>usec</code>).</p> <p>In standalone charts in MATLAB, specify time in seconds (<code>sec</code>). The operator creates a MATLAB <code>timer</code> object that generates an implicit event to wake up the chart. MATLAB <code>timer</code> objects are limited to 1 millisecond precision. For more information, see “Events in Standalone Charts” on page 3-55.</p>	<p>Set the <code>temp</code> variable to <code>LOW</code> every time that the chart wakes up, starting when the associated state is active for at least 12.3 seconds.</p> <pre>on after(12.3,sec):     temp = LOW;</pre>
<code>at</code>	<p><code>at(n,E)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p> <p><code>E</code> is the base event for the operator.</p>	<p>Returns <code>true</code> if the event <code>E</code> has occurred exactly <code>n</code> times since the associated state became active. Otherwise, the operator returns <code>false</code>.</p>	<p>Display a status message when the chart processes the third broadcast of the event <code>E</code> after the state became active.</p> <pre>on at(3,E):     disp('ON');</pre> <p>Transition out of the associated state when the chart processes the fifth broadcast of the event <code>E</code> after the state became active.</p> <pre>at(5,E)</pre>

Operator	Syntax	Description	Example
	<p><code>at(n,tick)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p>	<p>Returns <code>true</code> if the chart has woken up exactly <code>n</code> times since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>The implicit event <code>tick</code> is not supported when a Stateflow chart in a Simulink model has input events. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.</p>	<p>Transition out of the associated state when the chart wakes up for the seventh time since the state became active, but only if the variable <code>temp</code> is greater than 98.6.</p> <pre>at(7,tick)[temp &gt; 98.6]</pre>
	<p><code>at(n,sec)</code></p> <p><code>n</code> is a positive real number or an expression that evaluates to a positive real value.</p>	<p>Returns <code>true</code> if exactly <code>n</code> seconds have elapsed since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>Using <code>at</code> as an absolute-time temporal logic operator is supported only in standalone charts in MATLAB. The operator creates a MATLAB <code>timer</code> object that generates an implicit event to wake up the chart. MATLAB <code>timer</code> objects are limited to 1 millisecond precision. For more information, see “Events in Standalone Charts” on page 3-55.</p>	<p>Set the <code>temp</code> variable to <code>HIGH</code> if the state has been active for exactly 12.3 seconds.</p> <pre>on at(12.3,sec):     temp = HIGH;</pre>
before	<p><code>before(n,E)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p> <p><code>E</code> is the base event for the operator.</p>	<p>Returns <code>true</code> if the event <code>E</code> has occurred fewer than <code>n</code> times since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>The temporal logic operator <code>before</code> is supported only in Stateflow charts in Simulink models.</p>	<p>Display a status message when the chart processes the first and second broadcasts of the event <code>E</code> after the state became active.</p> <pre>on before(3,E):     disp('ON');</pre> <p>Transition out of the associated state when the chart processes a broadcast of the event <code>E</code>, but only if the state has been active for fewer than five broadcasts of <code>E</code>.</p> <pre>before(5,E)</pre>

Operator	Syntax	Description	Example
	<p><code>before(n, tick)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p>	<p>Returns <code>true</code> if the chart has woken up fewer than <code>n</code> times since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>The implicit event <code>tick</code> is not supported when a Stateflow chart in a Simulink model has input events. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.</p> <p>The temporal logic operator <code>before</code> is supported only in Stateflow charts in Simulink models.</p>	<p>Transition out of the associated state when the chart wakes up, but only if the variable <code>temp</code> is greater than 98.6 and the chart has woken up fewer than seven times since the state became active.</p> <pre>before(7, tick) [temp &gt; 98.6]</pre>
	<p><code>before(n, sec)</code></p> <p><code>before(n, msec)</code></p> <p><code>before(n, usec)</code></p> <p><code>n</code> is a positive real number or an expression that evaluates to a positive real value.</p>	<p>Returns <code>true</code> if fewer than <code>n</code> units of time have elapsed since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>Specify time in seconds (<code>sec</code>), milliseconds (<code>msec</code>), or microseconds (<code>usec</code>).</p> <p>The temporal logic operator <code>before</code> is supported only in Stateflow charts in Simulink models.</p>	<p>Set the <code>temp</code> variable to <code>MED</code> every time that the chart wakes up, but only if the associated state has been active for fewer 12.3 seconds.</p> <pre>on before(12.3, sec):     temp = MED;</pre>
every	<p><code>every(n, E)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p> <p><code>E</code> is the base event for the operator.</p>	<p>Returns <code>true</code> at every <math>n^{\text{th}}</math> occurrence of the event <code>E</code> since the associated state became active. Otherwise, the operator returns <code>false</code>.</p>	<p>Display a status message when the chart processes every third broadcast of the event <code>E</code> after the state became active.</p> <pre>on every(3, E):     disp('ON');</pre> <p>Transition out of the associated state when the chart processes every fifth broadcast of the event <code>E</code> after the state became active.</p> <pre>every(5, E)</pre>

Operator	Syntax	Description	Example
	<p><code>every(n,tick)</code></p> <p><code>n</code> is a positive integer or an expression that evaluates to a positive integer value.</p>	<p>Returns <code>true</code> at every <math>n^{\text{th}}</math> time that the chart wakes up since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>The implicit event <code>tick</code> is not supported when a Stateflow chart in a Simulink model has input events. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.</p>	<p>Transition out of the associated state every seventh <code>tick</code> event since the state became active, but only if the variable <code>temp</code> is greater than 98.6.</p> <pre>every(7,tick)[temp &gt; 98.6]</pre>
	<p><code>every(n,sec)</code></p> <p><code>n</code> is a positive real number or an expression that evaluates to a positive real value.</p>	<p>Returns <code>true</code> every <code>n</code> seconds since the associated state became active. Otherwise, the operator returns <code>false</code>.</p> <p>Using <code>every</code> as an absolute-time temporal logic operator is supported only in standalone charts in MATLAB. The operator creates a MATLAB <code>timer</code> object that generates an implicit event to wake up the chart. MATLAB <code>timer</code> objects are limited to 1 millisecond precision. For more information, see “Events in Standalone Charts” on page 3-55.</p>	<p>Increment the <code>temp</code> variable by 5 every 12.3 seconds that the state is active.</p> <pre>on every(12.3,sec):     temp = temp+5;</pre>
temporal Count	<p><code>temporalCount(E)</code></p> <p><code>E</code> is the base event for the operator.</p>	<p>Returns the number of occurrences of the event <code>E</code> since the associated state became active.</p> <p>Using <code>temporalCount</code> as an event-based temporal logic operator is supported only in Stateflow charts in Simulink models.</p>	<p>Access successive elements of the array <code>M</code> each time that the chart processes a broadcast of the event <code>E</code>.</p> <pre>on E:     y = M(temporalCount(E));</pre>
	<p><code>temporalCount(tick)</code></p>	<p>Returns the number of times that the chart has woken up since the associated state became active.</p> <p>The implicit event <code>tick</code> is not supported when a Stateflow chart in a Simulink model has input events.</p> <p>Using <code>temporalCount</code> as an event-based temporal logic operator is supported only in Stateflow charts in Simulink models.</p>	<p>Store the value of the input data <code>u</code> in successive elements of the array <code>M</code>.</p> <pre>en,du:     M(temporalCount(tick)+1) = u;</pre>

Operator	Syntax	Description	Example
	temporalCount(sec) temporalCount(msec) temporalCount(usec)	Returns the length of time that has elapsed since the associated state became active.  Specify time in seconds (sec), milliseconds (msec), or microseconds (usec).	Store the number of milliseconds since the state became active.  en,du: y = temporalCount(msec);
elapsed	elapsed(sec)	Returns the length of time that has elapsed since the associated state became active.  Equivalent to temporalCount(sec).	Store the number of seconds since the state became active.  en,du: y = elapsed(sec);
	et	An alternative way to execute elapsed(sec).	When the chart processes a broadcast of the event E, transition out of the associated state and display the elapsed time since the state became active.  E{disp(et);}
count	count(C)  C is an expression that evaluates to true or false.	Returns the number of times that the chart has woken up since the conditional expression C became true and the associated state became active.  The Stateflow chart resets the value of the count operator if the conditional expression C becomes false or if the associated state becomes inactive.  In charts in a Simulink model, the value of count may depend on the step size. Changing the solver or step size for the model affects the results produced by the count operator.	Transition out of the associated state when the variable x has been greater than or equal to 2 for longer than five chart executions.  [count(x>=2) > 5]
			Store the number of chart executions since the variable x became greater than 5.  en,du: y = count(x>5);
duration	duration(C) duration(C,sec) duration(C,msec) duration(C,usec)	Returns the length of time that has elapsed since the conditional expression C became true and the associated state became active.  Specify time in seconds (sec), milliseconds (msec), or microseconds (usec). The default unit is seconds.  The Stateflow chart resets the value of the duration operator if the	Transition out of the state when the variable x has been greater than or equal to 0 for longer than 0.1 seconds.  [duration(x>=0) > 0.1]
			• C is an expression that evaluates to true or false.

Operator	Syntax	Description	Example
		conditional expression C becomes false or if the associated state becomes inactive.  The temporal logic operator <b>duration</b> is not supported in standalone charts in MATLAB.	Store the number of milliseconds since the variable x became greater than 5 and the state became active.  en,du: y = duration(x>5,msec);

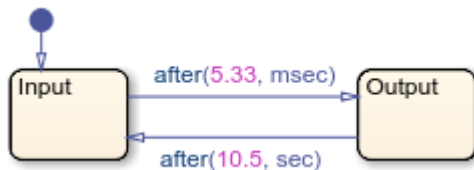
You can use quotation marks to enclose the keywords 'tick', 'sec', 'msec', and 'usec'. For example, `after(5, 'tick')` is equivalent to `after(5, tick)`.

**Note** The temporal logic operators `after`, `at`, `before`, and `every` compare the threshold `n` to an internal counter of integer type. If `n` is a fixed-point number defined by either a slope that is not an integer power of two or a nonzero bias, then the comparison can yield unexpected results due to rounding. For more information, see “Relational Operations for Fixed-Point Data” on page 26-19.

## Examples of Temporal Logic

### Define Time Delays

This example shows how to define two absolute time delays in a continuous-time chart.



The execution of the chart follows these steps:

- 1 When the chart awakens, the state `Input` activates first.
- 2 After 5.33 milliseconds of simulation time, the transition from `Input` to `Output` occurs.
- 3 The state `Input` becomes inactive and the state `Output` becomes active.
- 4 After 10.5 seconds of simulation time, the transition from `Output` to `Input` occurs.
- 5 The state `Output` becomes inactive and the state `Input` becomes active.

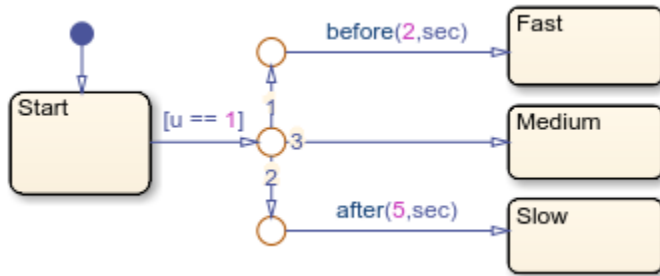
Steps 2 through 5 are repeated until the simulation ends.

If a chart has a discrete sample time, any action in the chart occurs at integer multiples of this sample time. For example, suppose that you change the configuration parameters so that the Simulink® solver uses a fixed step of size 0.1 seconds. Then the first transition from state `Input` to state `Output` occurs at  $t = 0.1$  seconds. This behavior applies because the solver does not wake the chart at exactly  $t = 5.33$  milliseconds. Instead, the solver wakes the chart at integer multiples of 0.1 seconds, such as  $t = 0.0$  and 0.1 seconds.

### Detect Elapsed Time

In this example, a Step (Simulink) block provides a unit step input to a Stateflow chart.





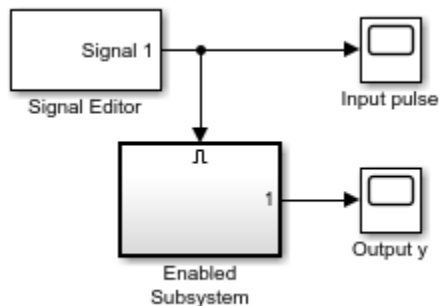
The chart determines when the input  $u$  equals 1:

- If the input equals 1 before  $t = 2$  seconds, a transition occurs from **Start** to **Fast**.
- If the input equals 1 between  $t = 2$  and  $t = 5$  seconds, a transition occurs from **Start** to **Medium**.
- If the input equals 1 after  $t = 5$  seconds, a transition occurs from **Start** to **Slow**.

### Use Absolute-Time Temporal Logic in an Enabled Subsystem

You can use absolute-time temporal logic in a chart that resides in a conditionally executed subsystem. When the subsystem is disabled, the chart becomes inactive and the temporal logic operator pauses while the chart is asleep. The operator does not continue to count simulation time until the subsystem is reenabled and the chart is awake.

This model has an enabled subsystem with the **States when enabling** parameter set to held.

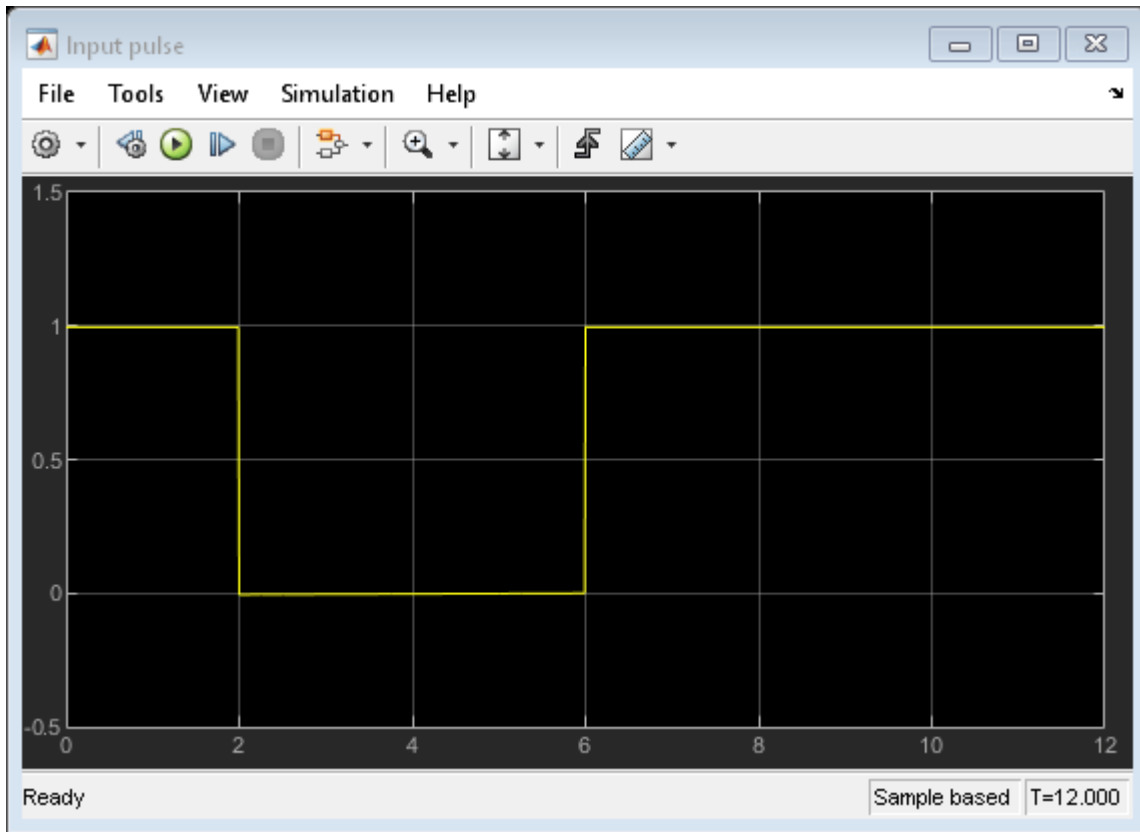


The subsystem contains a chart that uses the **after** operator to trigger a transition.

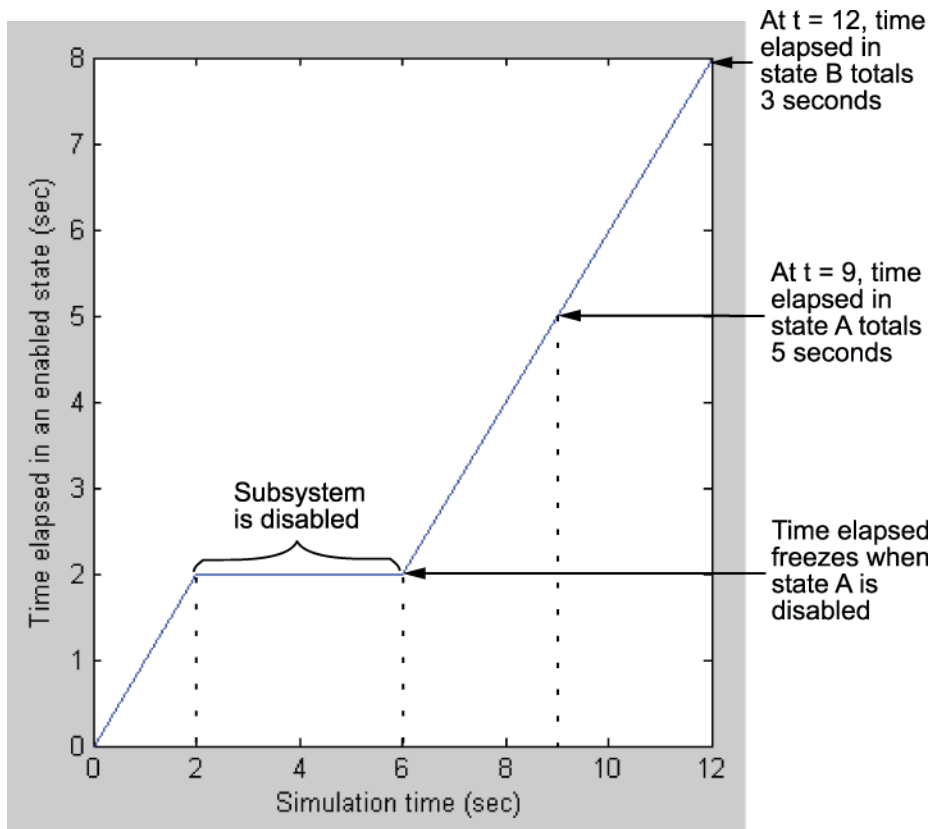


The Signal Editor (Simulink) block provides an input signal with these characteristics:

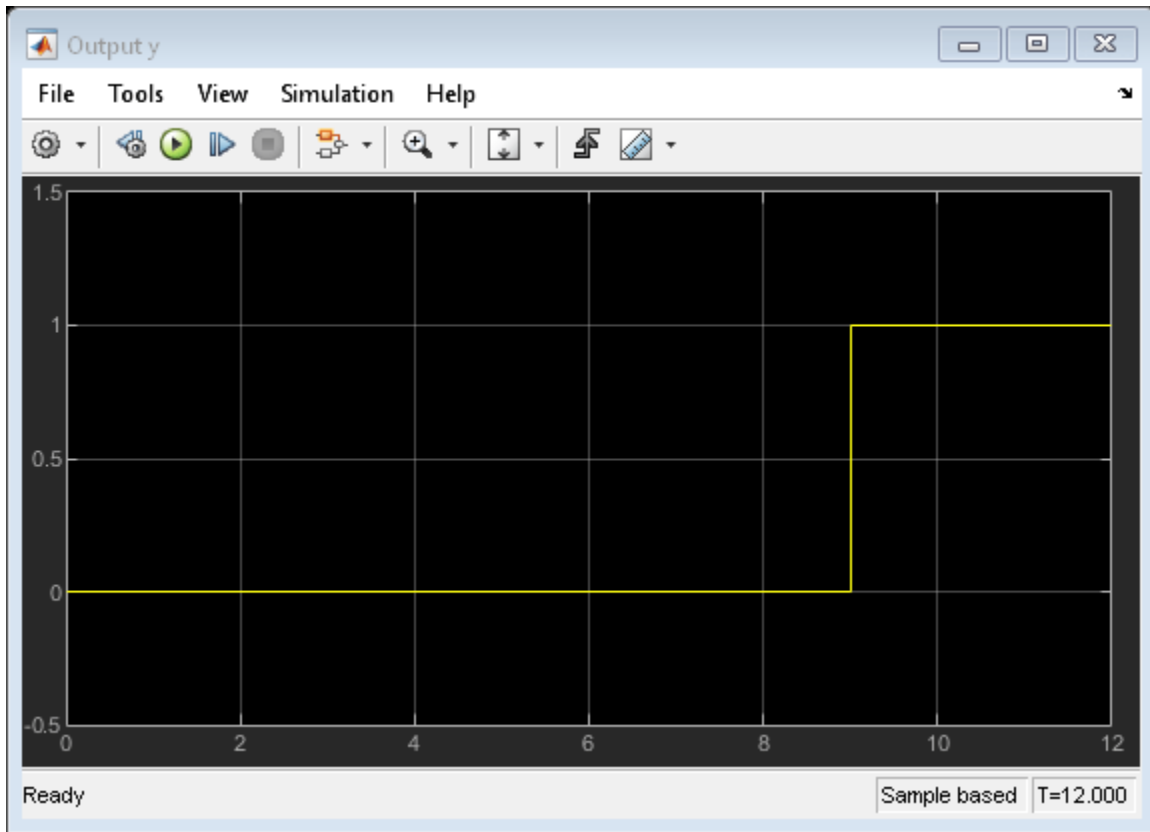
- The signal enables the subsystem at  $t = 0$ .
- The signal disables the subsystem at  $t = 2$ .
- The signal reenables the subsystem at  $t = 6$ .



This graph shows the total time elapsed in the chart. When the input signal enables the subsystem at time  $t = 0$ , state A becomes active. While the system is enabled, the elapsed time increases. When the subsystem is disabled at  $t = 2$ , the chart goes to sleep and the elapsed time stops increasing. For  $2 < t < 6$ , the elapsed time stays frozen at 2 seconds because the system is disabled. When the chart wakes up at  $t = 6$ , elapsed time starts to increase again.



The transition from state A to state B depends on the elapsed time while state A is active, not on the simulation time. Therefore, the transition occurs at  $t = 9$ , when the elapsed time in state A equals 5 seconds. When the transition occurs, the output value  $y$  changes from 0 to 1.



This model behavior applies only to subsystems where you set the Enable block parameter **States when enabling** to held. If you set the parameter to reset, the chart reinitializes completely when the subsystem is reenabled. Default transitions execute and any temporal logic counters reset to 0.

## Notation for Event-Based Temporal Logic in Transitions

In Stateflow charts in Simulink models, the operators *after*, *at*, and *before* support two distinct notations to express event-based temporal logic in a transition.

- Trigger notation defines a transition that depends only on the base event for the temporal logic operator. Trigger notation follows this syntax:

$$\text{temporalLogicOperator}(n,E)[C]$$

where:

- *temporalLogicOperator* is a Boolean temporal logic operator.
- *n* is the occurrence count of the operator.
- *E* is the base event of the operator.
- *C* is an optional condition expression.

When you use trigger notation, the transition can occur only when the chart processes a broadcast of the base event *E*.

- Conditional notation defines a transition that depends on base and nonbase events. Conditional notation follows this syntax:

$F[\text{temporalLogicOperator}(n,E) \ \&\& \ C]$

where:

- *temporalLogicOperator* is a Boolean temporal logic operator.
- *n* is the occurrence count of the operator.
- *E* is the base event of the operator.
- *F* is an optional nonbase event.
- *C* is an optional condition expression.

When you use conditional notation with a nonbase event *F*, the transition can occur only when the chart processes a broadcast of *F*. If you omit the nonbase event, the transition can occur when the chart is processing any explicit or implicit event.

Conditional notation for temporal logic operators is not supported in standalone charts in MATLAB.

For example, this transition label uses trigger notation to indicate a transition out of the associated state when the chart processes a broadcast of the base event *E*, starting on the fifth broadcast of *E* after the state became active.

`after(5,E)`

In contrast, this transition label uses conditional notation to indicate a transition out of the associated state when the state has been active for at least five broadcasts of the base event *E*, even if the chart is not processing a broadcast of *E*.

`[after(5,E)]`

---

**Note** The operator `every` supports trigger and conditional notations. However, both notations are equivalent for this operator. The transition labels `every(5,E)` and `[every(5,E)]` indicate a transition out of the associated state when the chart processes the  $k^{\text{th}}$  broadcast of the base event *E* after the state became active, where *k* is a multiple of five.

---

## Best Practices for Temporal Logic

### Do Not Use Temporal Logic on Transition Paths Without A Source State

The value of a temporal logic operator depends on when its associated state became active. To ensure that every temporal logic operator has a unique associated state, only use these operators in:

- State on actions
- Actions on transition paths that originate from a state

Do not use temporal logic operators on default transitions or on transitions in graphical functions because these transitions do not originate from a state.

### Use Absolute-time Temporal Logic Instead of tick in Charts in Simulink Models

In charts in a Simulink model, the value of delay expressions that use absolute-time temporal logic are semantically independent of the sample time of the model. In contrast, delay expressions that use temporal logic based on the implicit event `tick` depend on the step size used by the Simulink solver.

Additionally, absolute-time temporal logic is supported in charts that have input events. The implicit event tick is not supported when a Stateflow chart in a Simulink model has input events.

### Do Not Use `at` for Absolute-Time Temporal Logic in Charts in Simulink Models

In charts in a Simulink model, using `at` as an absolute-time temporal logic operator is not supported. Instead, use the `after` operator. For example, suppose that you want to define a time delay using the expression `at(5.33, sec)`.

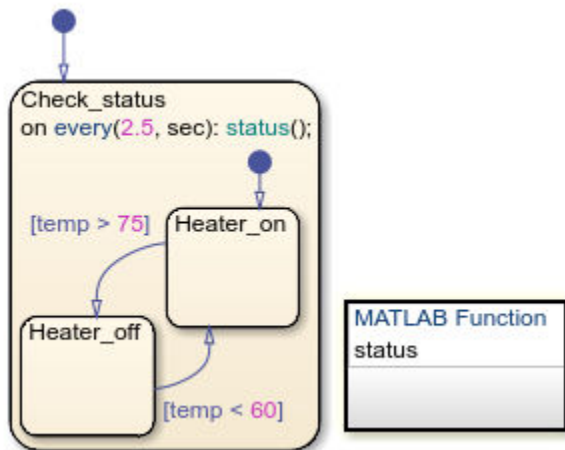


To prevent a run-time error, change the transition label to `after(5.33, sec)`.

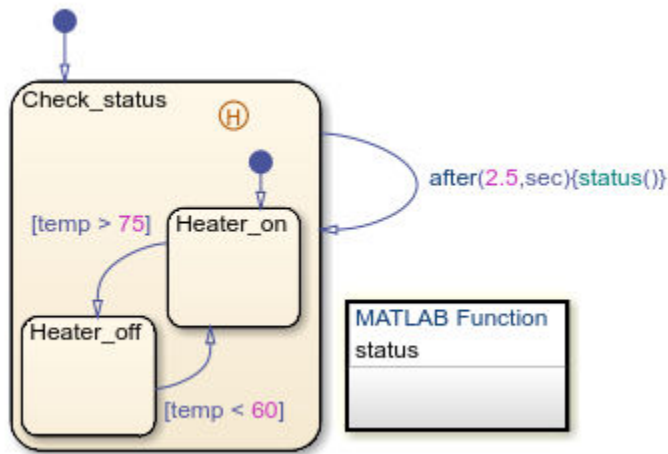


### Do Not Use `every` for Absolute-Time Temporal Logic in Charts in Simulink Models

In charts in a Simulink model, using `every` as an absolute-time temporal logic operator is not supported. Instead, use an outer self-loop transition with the `after` operator. For example, suppose that you want to print a status message for an active state every 2.5 seconds during chart execution.



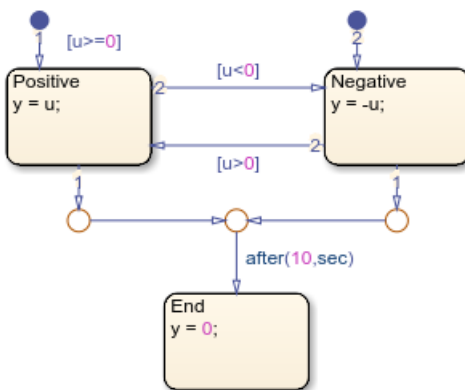
To prevent a run-time error, replace the state action with an outer self-loop transition.



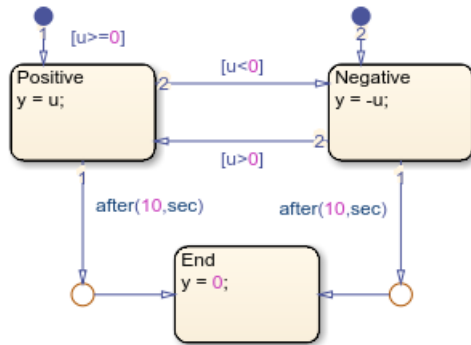
Add a history junction in the state so the chart remembers the state settings prior to each self-loop transition. See “Record State Activity by Using History Junctions” on page 8-2.

### Do Not Use Temporal Logic in Transition Paths with Multiple Sources in Standalone Charts in MATLAB

Standalone charts in MATLAB do not support the use of temporal logic operators on transition paths that have more than one source state. For example, this standalone chart produces a run-time error because the temporal logic expression `after(10,sec)` triggers a transition path that has more than one source state.



To resolve the issue, use temporal logic expressions on separate transition paths, each with a single source state.

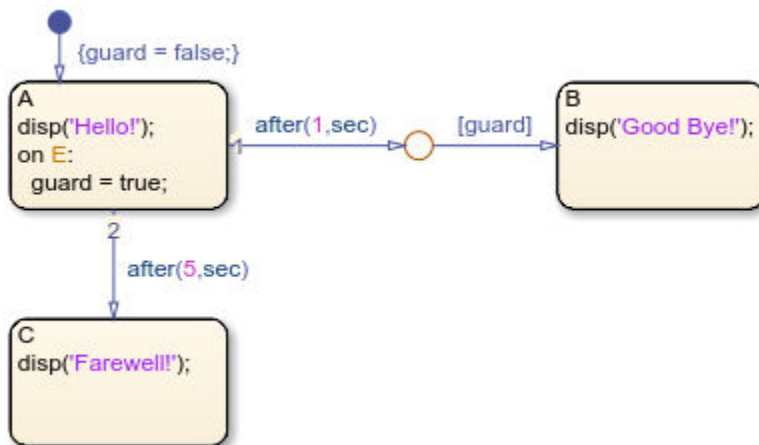


### Avoid Mixing Absolute-time Temporal Logic and Conditions in Transition Paths of Standalone Charts in MATLAB

In standalone charts in MATLAB, the operators `after`, `at`, and `every` create MATLAB timer objects that generate implicit events to wake up the chart. Combining these operators with conditions on the same transition path can result in unintended behavior:

- If a condition on the transition path is false when the timer wakes up the chart, the chart performs the during and on actions of the active state.
- The chart does not reset the timer object associated with the operators `after` and `at`. If the condition on the transition path becomes true at a later time, the transition does not take place until another explicit or implicit event wakes up the chart.

For example, in this chart, the transition path from state A to state B combines the absolute-time temporal logic trigger `after(1, sec)` and the condition `[guard]`. The transition from state A to state C has the absolute-time temporal logic trigger `after(5, sec)`. Each transition is associated with a timer object that generates an implicit event. Initially, the local variable `guard` is false.



When you execute the chart, state A becomes active. The chart performs the entry action and displays the message 'Hello!'. After 1 second, the timer associated with the transition from A to B wakes up the chart. Because the transition is not valid, the chart executes the during action in state A and displays the message 'Hello!' a second time.

Suppose that, after 2 seconds, the chart receives the input event E. The chart executes the on action in state A and changes the value of `guard` to true. Because the chart does not reset the timer



associated with the operator `after`, the transition from A to B does not take place until another event wakes up the chart.

After 5 seconds, the `timer` associated with the transition from A to C wakes up the chart. Because the transition from A to B is valid and has a higher execution order, the chart does not take the transition to state C or display the message 'Farewell!'. Instead, state B becomes active and the chart displays the message 'Good bye!'.

### **Use Charts with Discrete Sample Times for More Efficient Code Generation**

The code generated for discrete charts that are not inside a triggered or enabled subsystem uses integer counters to track time instead of the time provided by Simulink. This behavior allows for more efficient code generation in terms of overhead and memory, and enables this code for use in software-in-the-loop (SIL) and processor-in-the-loop (PIL) simulation modes. For more information, see “SIL and PIL Simulations” (Embedded Coder).

### **See Also**

Signal Editor | Step | after | at | before | count | duration | elapsed | every | temporalCount | timer

### **More About**

- “Control Oscillations by Using the duration Operator” on page 16-56
- “Implement an Automatic Transmission Gear System by Using the duration Operator” on page 16-59
- “Count Events by Using the temporalCount Operator” on page 16-62
- “Events in Standalone Charts” on page 3-55
- “Record State Activity by Using History Junctions” on page 8-2

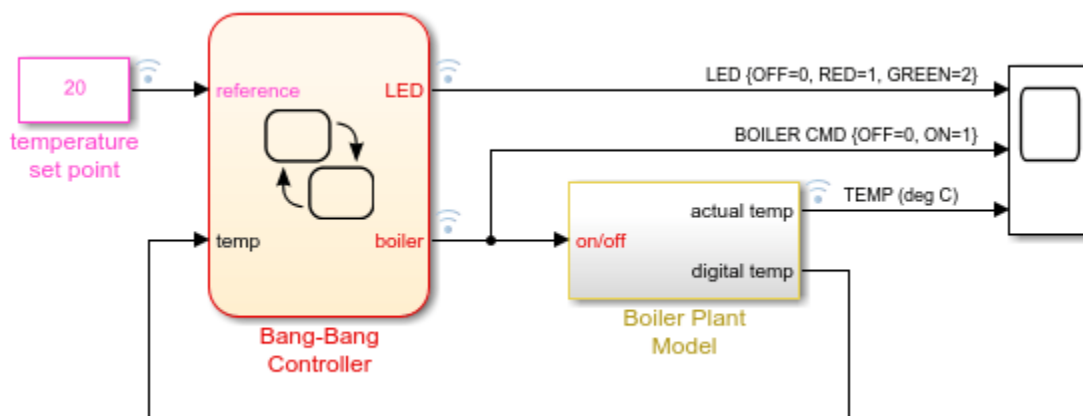
## Model Bang-Bang Temperature Control System

This example shows how to model a bang-bang control system that regulates the temperature of a boiler. The model has two components:

- Boiler Plant Model is a Simulink® subsystem the models the boiler dynamics.
- Bang-Bang Controller is a Stateflow® chart that implements the bang-bang control logic.

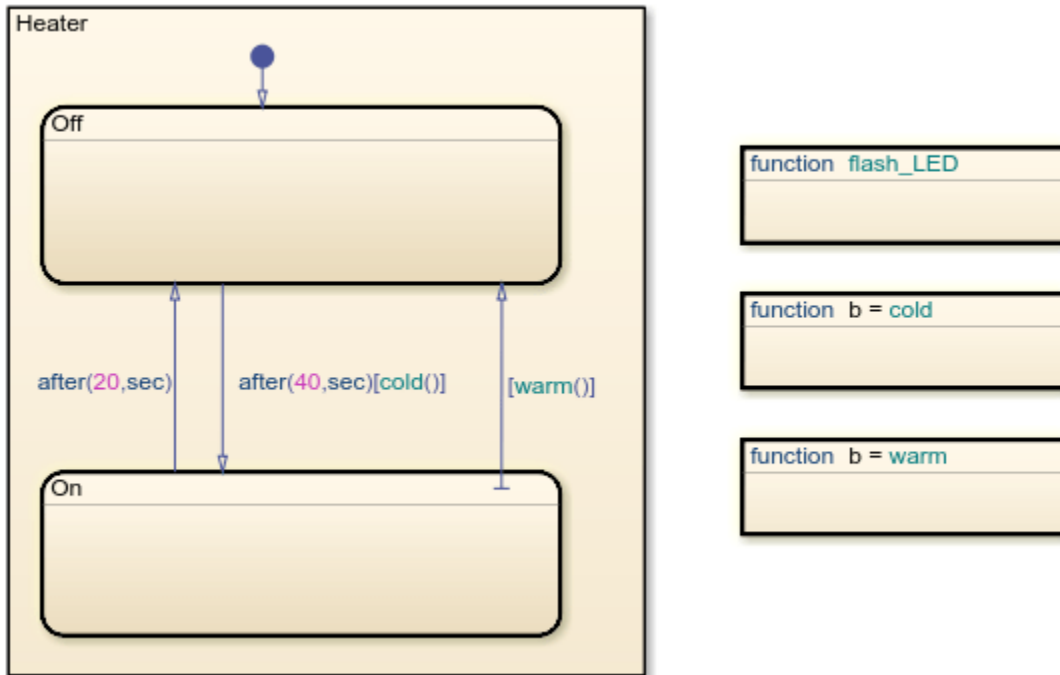
The chart uses:

- temporal logic to implement the timing of the bang-bang cycle
- 8-bit fixed-point data to represent the temperature of the boiler



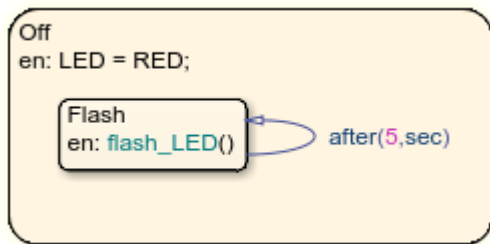
### Implement Control Logic by Using after Operator

The Bang-Bang Controller determines when the boiler turns on or off. Initially, the boiler is off. After 40 seconds, if the boiler is cold, the boiler turns on. After 20 seconds, the boiler turns off and the bang-bang control cycle repeats.



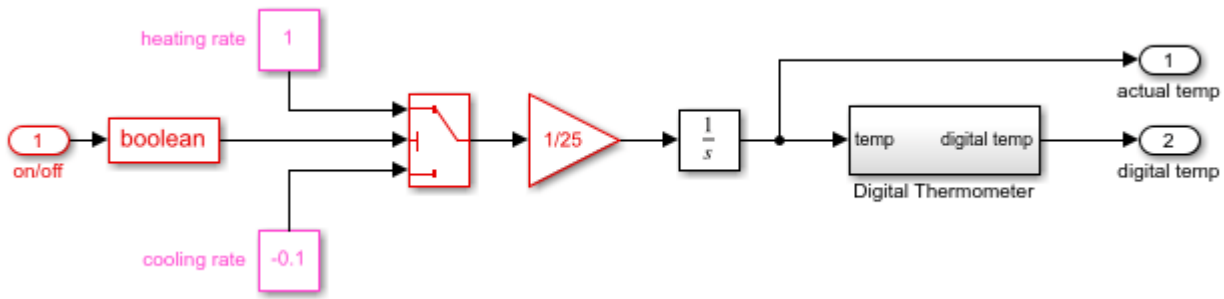
To control the transitions between the **On** and **Off** states, the chart calls the absolute-time temporal logic operator `after`. For example, the transition label `after(20,sec)` triggers the transition from **On** to **Off** after the **On** state is active for 20 seconds. The label `after(40,sec)[cold()]` causes the transition from **Off** to **On** to occur if the function `cold` returns `true` after the **Off** state is active for 40 seconds.

The **Off** state also uses temporal logic to control a status LED. Because Stateflow charts in Simulink models do not support the operator `every` for absolute time temporal logic, the state implements the operation of the LED by using a substate **Flash** with a self-loop transition. The transition label `after(5,sec)` triggers the entry action of the substate and causes the LED to flash every 5 seconds.

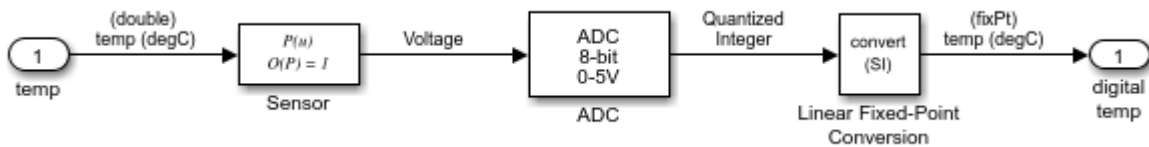


**Process Floating-Point Data on an 8-Bit Processor**

The Boiler Plant Model subsystem simulates the temperature reaction of the boiler during periods of heating or cooling.

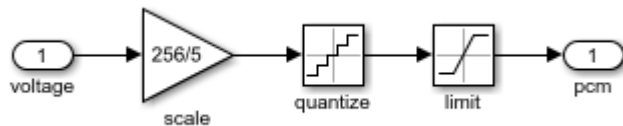


Depending on the output of the Bang-Bang Controller chart, the subsystem adds or subtracts a temperature increment (+1 for heating or -0.1 for cooling) to the previous boiler temperature and passes the result to the Digital Thermometer subsystem.



The Digital Thermometer subsystem converts the resulting temperature into an 8-bit fixed-point representation. The conversion occurs in three steps.

- The Sensor block converts input boiler temperature  $T_{actual}$  to an intermediate analog voltage output  $V_{sensor} = 0.05 \cdot T_{actual} + 0.75$ .
- The Analog-to-Digital Converter (ADC) subsystem digitizes the analog voltage from the sensor block by multiplying the voltage by  $\frac{256}{5}$ , rounding to the integer floor, and then limiting the result to a maximum of 255 (the largest unsigned 8-bit integer value). The subsystem outputs a quantized integer  $Q = \lfloor \frac{256}{5} \cdot V_{sensor} \rfloor = \lfloor \frac{256 \times 0.05}{5} \cdot T_{actual} + \frac{256 \times 0.75}{5} \rfloor$ .

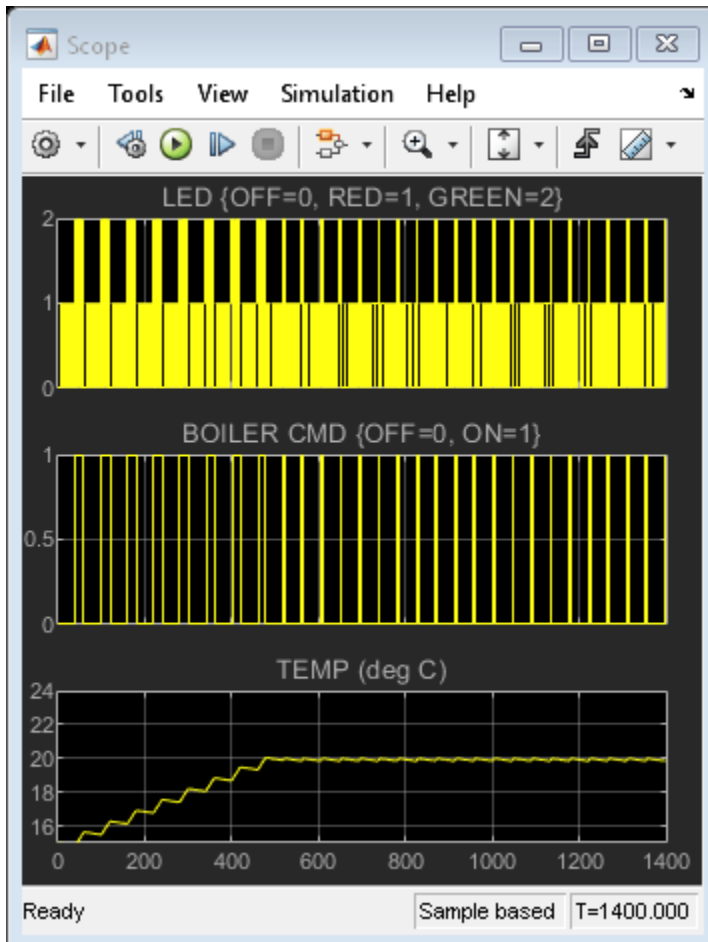


- The Linear Fixed-Point Conversion block inverts the combined transfer function of the Sensor and ADC blocks to encode the boiler temperature as a fixed-point number with a slope of  $S = \frac{5}{256 \times 0.05} = 0.390625$  and a bias of  $B = -\frac{0.75}{0.05} = -15$ . These fixed-point parameters convert the 8-bit quantized integer  $Q$  into a digital coded temperature  $T_{digital} = SQ + B = \frac{5}{256 \times 0.05} \cdot \lfloor \frac{256 \times 0.05}{5} \cdot T_{actual} + \frac{256 \times 0.75}{5} \rfloor - \frac{0.75}{0.05} \approx T_{actual}$ .

The Bang-Bang Controller chart receives this digital coded temperature and interprets it as the unsigned 8-bit fixed-point data temp. The chart processes this temperature data in an 8-bit environment without any explicit conversions.

## Examine Simulation Results

After simulation, the Simulink scope shows that the boiler reaches a temperature of 20 degrees Celsius after approximately 450 seconds (7.5 minutes). The bang-bang control logic effectively maintains that temperature for the rest of the simulation.



## See Also

Data Type Conversion | after | every

## More About

- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Fixed-Point Data in Stateflow Charts” on page 26-2
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16

## Control Oscillations by Using the duration Operator

The following example focuses on the gear logic of a car as it shifts from first gear to fourth gear.

When modeling the gear changes of this system, it is important to control the oscillation that occur. The model `sf_car` uses parallel state debouncer logic that controls which gear state is active. For more information about how debouncers work in Stateflow, see “Reduce Transient Signals by Using Debouncing Logic” on page 30-12.

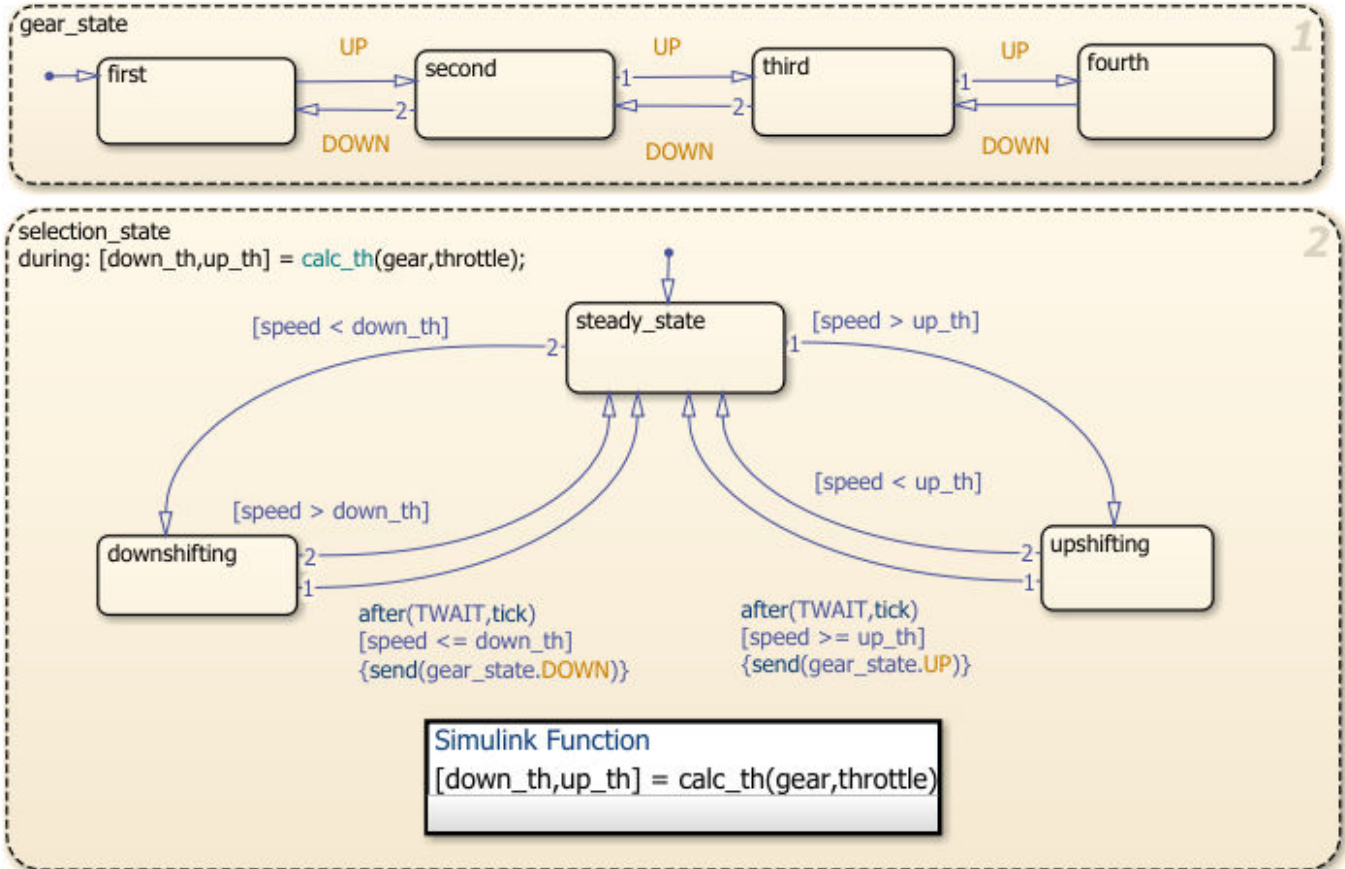
You can simplify the debouncer logic by using the `duration` operator. You can see this simplification in the model `sf_car_using_duration`. The `duration` operator evaluates a condition expression and outputs the length of time that the expression has been `true`. When that length of time crosses a known time threshold, the state transitions to a higher or lower gear.

By removing the parallel state logic and using the `duration` operator, you can control oscillations with simpler Stateflow logic. The `duration` operator is supported only in Stateflow charts in a Simulink model.

### Control Oscillation with Parallel State Logic

Open the model `sf_car`. While `shift_logic` is highlighted, in the **State Chart** tab, click **Look Under Mask**.

The Stateflow chart `shift_logic` controls which gear the car is in, given the speed of the car and how much throttle is being applied. Within `shift_logic` there are two parallel states: `gear_state` and `selection_state`. `gear_state` contains four exclusive states for each gear. `selection_state` determines whether the car is downshifting, upshifting, or remaining in its current gear.

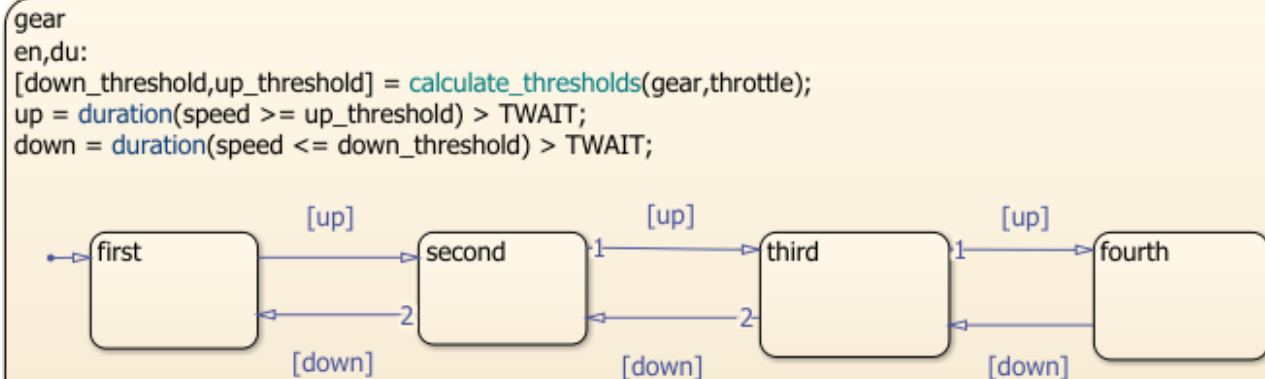


In this Stateflow chart, for the car to move from first gear to second gear, the event UP must be sent from selection\_state to gear\_state. The event is sent when the speed crosses the threshold and remains higher than the threshold for the length of time determined by TWAIT. When the event UP is sent, gear\_state transitions from first to second.

## Control Oscillation with the duration Operator

Open the model sf\_car\_using\_duration. While Gear\_Logic is highlighted, in the **State Chart** tab, click **Look Under Mask**.

Within Gear\_Logic there are four exclusive states for each gear. The local variables up and down guard the transitions between each state.



```

Simulink Function
[down_th,up_th] = calculate_thresholds(gear,throttle)

```

In this Stateflow chart, for the car to move from first gear to second gear, the condition `up` must be true. The condition `up` is defined as true if the length of time that the speed is greater than or equal to the threshold is greater than the length of time that is specified by `TWAIT`. The condition `down` is defined as true if the length of time that the speed is less than or equal to the threshold is greater than the length of time that is specified by `TWAIT`. The operator `duration` keeps track of the length of time that the speed has been above or below the threshold. When the `up` condition is met, the active state transitions from `first` to `second`.

By replacing the parallel state debouncer logic with the `duration` operator, you can create a simpler Stateflow chart to model the gear shifting.

## See Also

`duration`

## Related Examples

- “Reduce Transient Signals by Using Debouncing Logic” on page 30-12
- “Control Chart Execution by Using Temporal Logic” on page 16-36



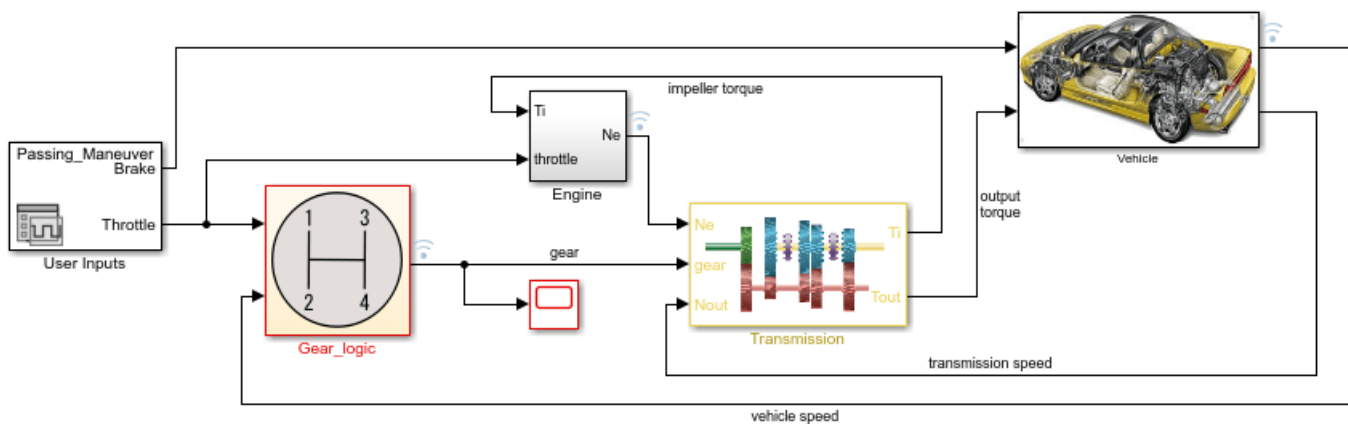
## Implement an Automatic Transmission Gear System by Using the duration Operator

This example models an automotive transmission system by using the Stateflow® temporal logic operator `duration` to automatically shift gears based on the vehicle's throttle requirements and speed. For more information, see “Control Chart Execution by Using Temporal Logic” on page 16-36.

### Model Description

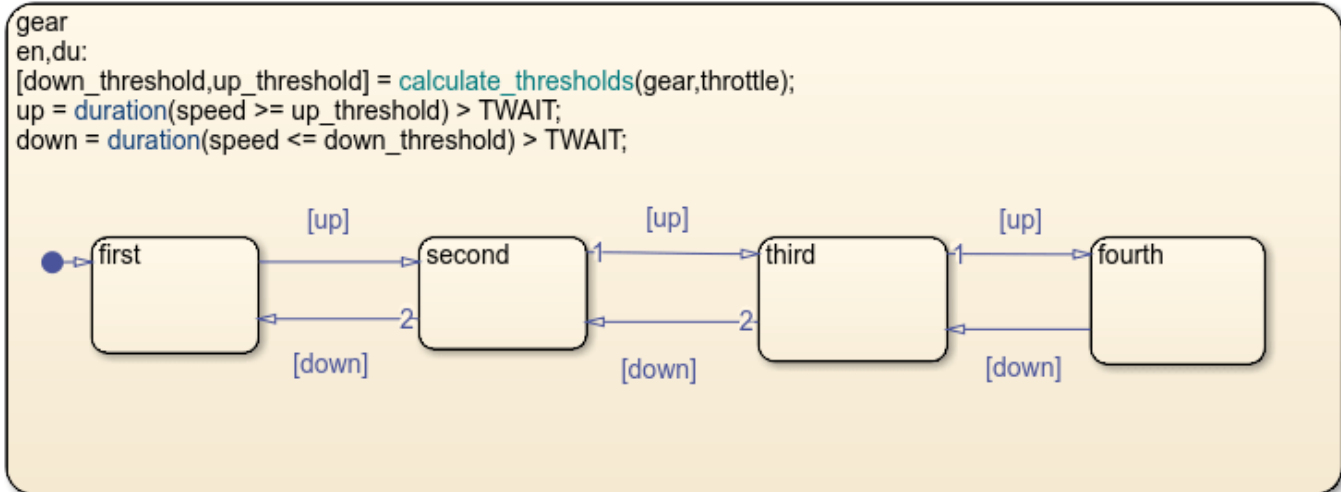
There are five major blocks in this model.

- User Inputs: Provides two inputs to the model, brake and throttle.
- Engine: Calculates engine RPM based on impeller torque value and throttle.
- Gear\_logic: Calculates next gear based on current gear, throttle, and current vehicle speed.
- Transmission: Calculates impeller and output torque based on RPM, gear and transmission speed.
- Vehicle: Calculates vehicle and transmission speed based on output torque and brake.



### Chart Description

The Stateflow chart models the shifting of gears based on throttle and speed of the vehicle. The `down_threshold` and `up_threshold` outputs represent minimum and maximum speed values that throttle and current gear are able to handle. The Simulink function `calculate_thresholds` calculates these two values using `throttle` and `gear` as inputs. If the actual speed is higher than `up_threshold` for longer than `TWAIT`, then the chart transitions to higher gear. Conversely, if the actual speed is lower than `down_threshold` for longer than `TWAIT`, then the chart transitions to a lower gear. At each time step, the chart calls the `duration` operator to find the amount of time for which speed is higher than `up_threshold`. If this time exceeds `TWAIT` then boolean variable `up` is set which in turn transitions chart from current gear to a higher gear. Conversely the chart transitions to a lower gear based on the value of `down_threshold`.



```

Simulink Function
[down_th,up_th] = calculate_thresholds(gear,throttle)

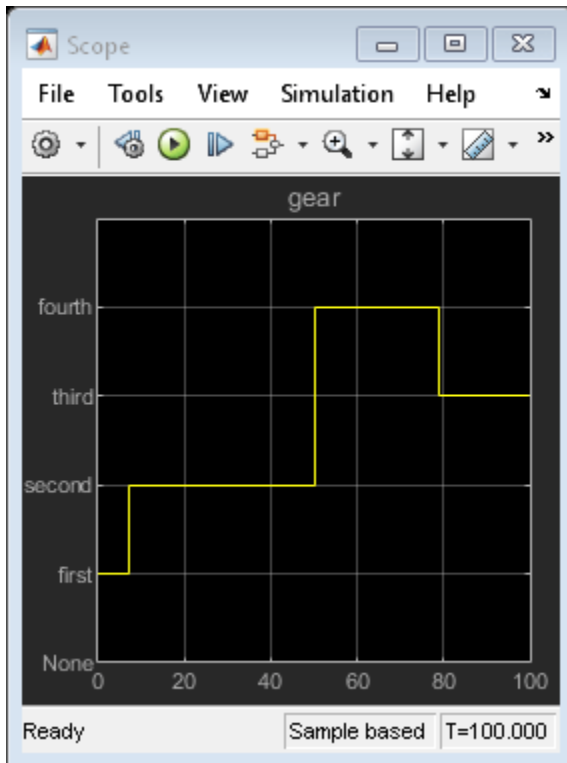
```

### Active State Data

Active State Data is the enumerated data that represents the current active state during simulation. In this chart, the output data `gear` maintains the current active state which in turn represents the current gear. This data automatically updates when a transition is taken. The data is used by downstream blocks as well as by the Simulink® function `calculate_thresholds`. For more information, see “Monitor State Activity Through Active State Data” on page 13-2.

### Simulation

To visualize these changes, simulate the model and open the scope.



## See Also

duration

## More About

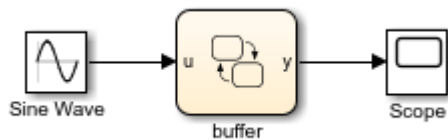
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Control Oscillations by Using the duration Operator” on page 16-56
- “Monitor State Activity Through Active State Data” on page 13-2
- “Simplify Stateflow Charts by Incorporating Active State Output” on page 13-7

## Count Events by Using the temporalCount Operator

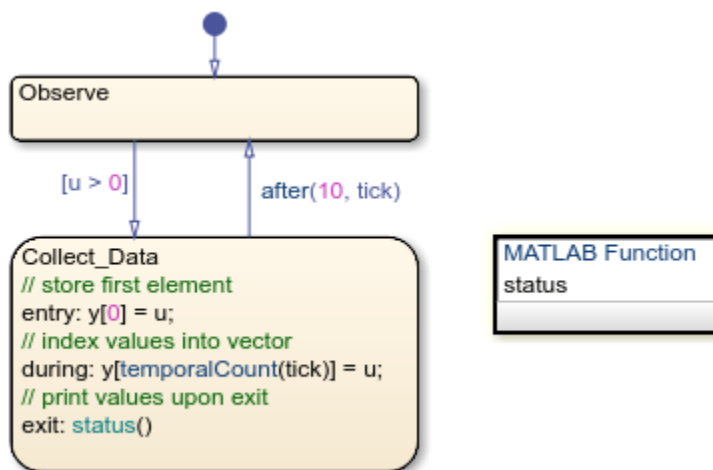
This example shows how to use the `temporalCount` operator to count occurrences of explicit and implicit events. For more information, see “Control Chart Execution by Using Temporal Logic” on page 16-36.

### Collect and Store Input Data in a Vector

The Stateflow chart in this model collects and stores input data in a vector during simulation.



The chart contains two states and one MATLAB® function.



### Simulate the Model

The execution of the chart consists of three stages.

#### Stage 1: Observation of Input Data

The chart wakes up and remains in the `Observe` state until the input data `u` is positive. Then, the transition to the state `Collect_Data` occurs.

#### Stage 2: Storage of Input Data

When the state `Collect_Data` becomes active, the value of the input data `u` is assigned to the first element of the vector `y`. While this state is active, each subsequent value of `u` is assigned to successive elements of `y` by using the `temporalCount` operator.

#### Stage 3: Display of Data Stored in the Vector

After the chart wakes up ten times, the data collection process ends. The chart calls the function `status` to display the vector data in the Diagnostic Viewer. Then, the chart takes the transition back to the state `Observe`.

## See Also

`temporalCount`

## More About

- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Control Chart Behavior by Using Implicit Events” on page 14-26
- “Vectors and Matrices in Stateflow Charts” on page 21-2

## Detect Changes in Data Values

Stateflow charts can detect changes in the values of data and expressions between time steps. You can use change detection operators to determine when a variable changes to or from a value.

To generate an implicit local event when the chart sets the value of a variable, use the change operator. For more information, see “Control Chart Behavior by Using Implicit Events” on page 14-26.

### Change Detection Operators

To detect changes in Stateflow data, use the operators listed in this table.

Operator	Syntax	Description	Example
hasChanged	<code>tf = hasChanged(data_name)</code>	Returns 1 (true) if the value of <code>data_name</code> at the beginning of the current time step is different from the value of <code>data_name</code> at the beginning of the previous time step. Otherwise, the operator returns 0 (false).	<p>Transition out of state if any element of the matrix <code>M</code> has changed value since the last time step or input event.</p> <pre>[hasChanged(M)]</pre> <p>Transition out of state if the element in row 1 and column 3 of the matrix <code>M</code> has changed value since the last time step or input event.</p> <p>In charts that use MATLAB as the action language, use:</p> <pre>[hasChanged(M(1,3))]</pre> <p>In charts that use C as the action language, use:</p> <pre>[hasChanged(M[0][2])]</pre>
hasChangedFrom	<code>tf = hasChangedFrom(data_name, value)</code>	Returns 1 (true) if the value of <code>data_name</code> was equal to the specified <code>value</code> at the beginning of the previous time step and is a different value at the beginning of the current time step. Otherwise, the operator returns 0 (false).	<p>Transition out of state if the previous value of the structure <code>struct</code> was equal to <code>structValue</code> and any field of <code>struct</code> has changed value since the last time step or input event.</p> <pre>[hasChangedFrom(struct, structValue)]</pre>
hasChangedTo	<code>tf = hasChangedTo(data_name, value)</code>	Returns 1 (true) if the value of <code>data_name</code> was not equal to the specified <code>value</code> at the beginning of the previous time step and is equal to <code>value</code> at the beginning of the current time step. Otherwise, the operator returns 0 (false).	<p>Transition out of state if the structure field <code>struct.field</code> has changed to the value 5 since the last time step or input event.</p> <pre>[hasChangedTo(struct.field,5)]</pre>

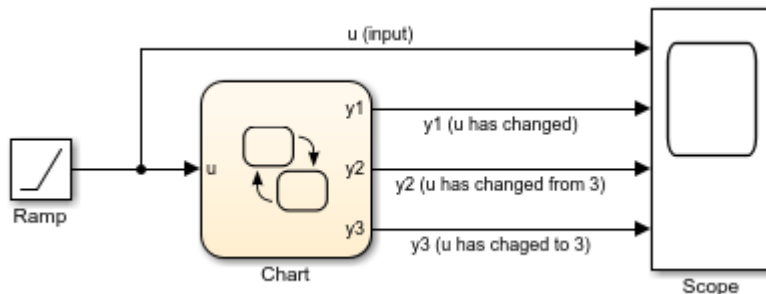
---

**Note** If multiple input events occur in the same time step, these operators can detect changes in data value between input events.

---

### Example of Chart with Change Detection

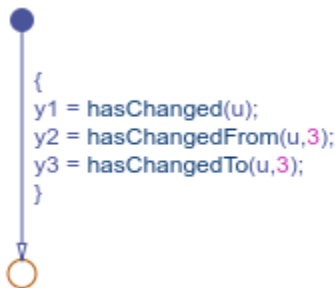
This model shows how the operators `hasChanged`, `hasChangedFrom`, and `hasChangedTo` detect specific changes in an input signal. In this example, a Ramp (Simulink) block sends a discrete, increasing time signal to a chart.



The model uses a fixed-step solver with a step size of 1. The signal increments by 1 every time step. The chart analyzes the input signal  $u$  for these changes:

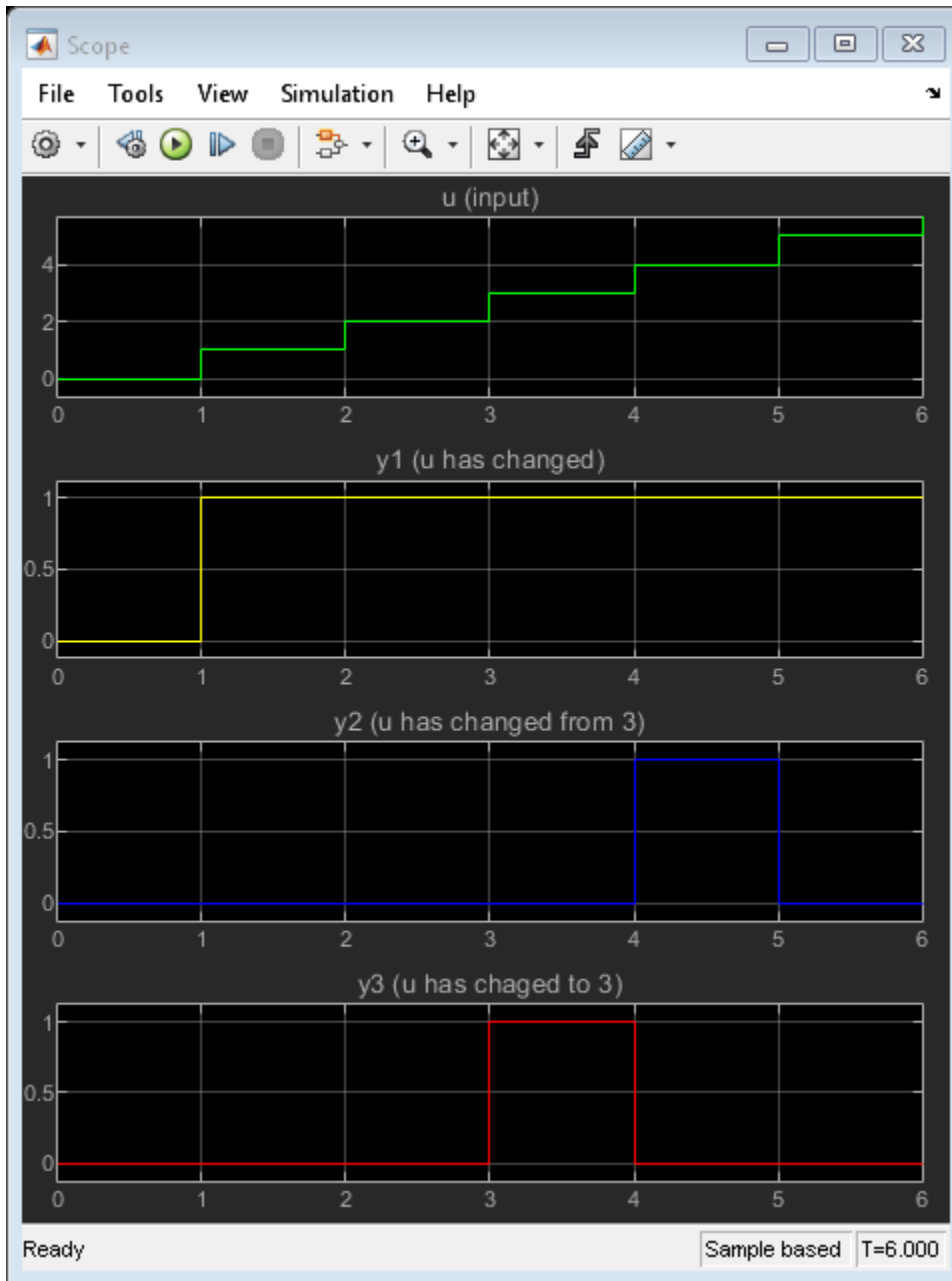
- Any change from the previous time step
- A change to the value 3
- A change from the value 3

To check the signal, the chart calls three change detection operators in a transition action. The chart outputs the return values as  $y1$ ,  $y2$ , and  $y3$ .



During simulation, the Scope (Simulink) block shows the input and output signals for the chart.

- The value of  $u$  increases by 1 every time step.
- The value of  $y1$  changes from 0 to 1 at time  $t = 1$ . The value of  $y1$  remains 1 because  $u$  continues to change at each subsequent time step.
- The value of  $y2$  changes from 0 to 1 at time  $t = 4$  when the value of  $u$  changes from 3 to 4. The value of  $y2$  returns to 0 after one time step.
- The value of  $y3$  changes from 0 to 1 at time  $t = 3$  when the value of  $u$  changes from 2 to 3. The value of  $y3$  returns to 0 after one time step.



### Limitations of Change Detection

The type of Stateflow chart determines the scope of the data supported for change detection:

- Standalone Stateflow charts in MATLAB: Local only
- In Simulink models, charts that use MATLAB as the action language: Input only
- In Simulink models, charts that use C as the action language: Input, Output, Local, or Data Store Memory

The argument `data_name` can be:



- A scalar variable.
- A matrix or an element of a matrix.
  - If `data_name` is a matrix, the operator returns `true` when it detects a change in any element of `data_name`.
  - Index elements of a matrix by using numbers or expressions that evaluate to a constant integer. See “Supported Operations for Vectors and Matrices” on page 21-4.
- A structure or a field in a structure.
  - If `data_name` is a structure, the change detection operator returns `true` when it detects a change in any field of `data_name`.
  - Index fields in a structure by using dot notation. See “Index and Assign Values to Stateflow Structures” on page 29-7.
- Any valid combination of structure fields or matrix elements.

The argument `data_name` cannot be a nontrivial expression or a custom code variable.

---

**Note** Standalone charts in MATLAB do not support change detection on an element of a matrix or a field in a structure.

---

For the `hasChangedFrom` and `hasChangedTo` operators, the argument `value` can be any expression that resolves to a value that is comparable with `data_name`.

- If `data_name` is a scalar, then `value` must resolve to a scalar value.
- If `data_name` is a matrix, then `value` must resolve to a matrix value with the same dimensions as `data_name`.

Alternatively, in a chart that uses C as the action language, `value` can resolve to a scalar value. The chart uses scalar expansion to compare `data_name` to a matrix whose elements are all equal to the value specified by `value`. See “Assign Values to All Elements of a Matrix” on page 21-6.

- If `data_name` is a structure, then `value` must resolve to a structure value whose field specification matches `data_name` exactly.

When you use change detection operators in charts while row-major array layout is enabled, code generation produces an error. Before generating code in charts that use change detection operators, enable column-major array layout. See “Select Array Layout for Matrices in Generated Code” on page 32-5.

## Implementation of Change Detection

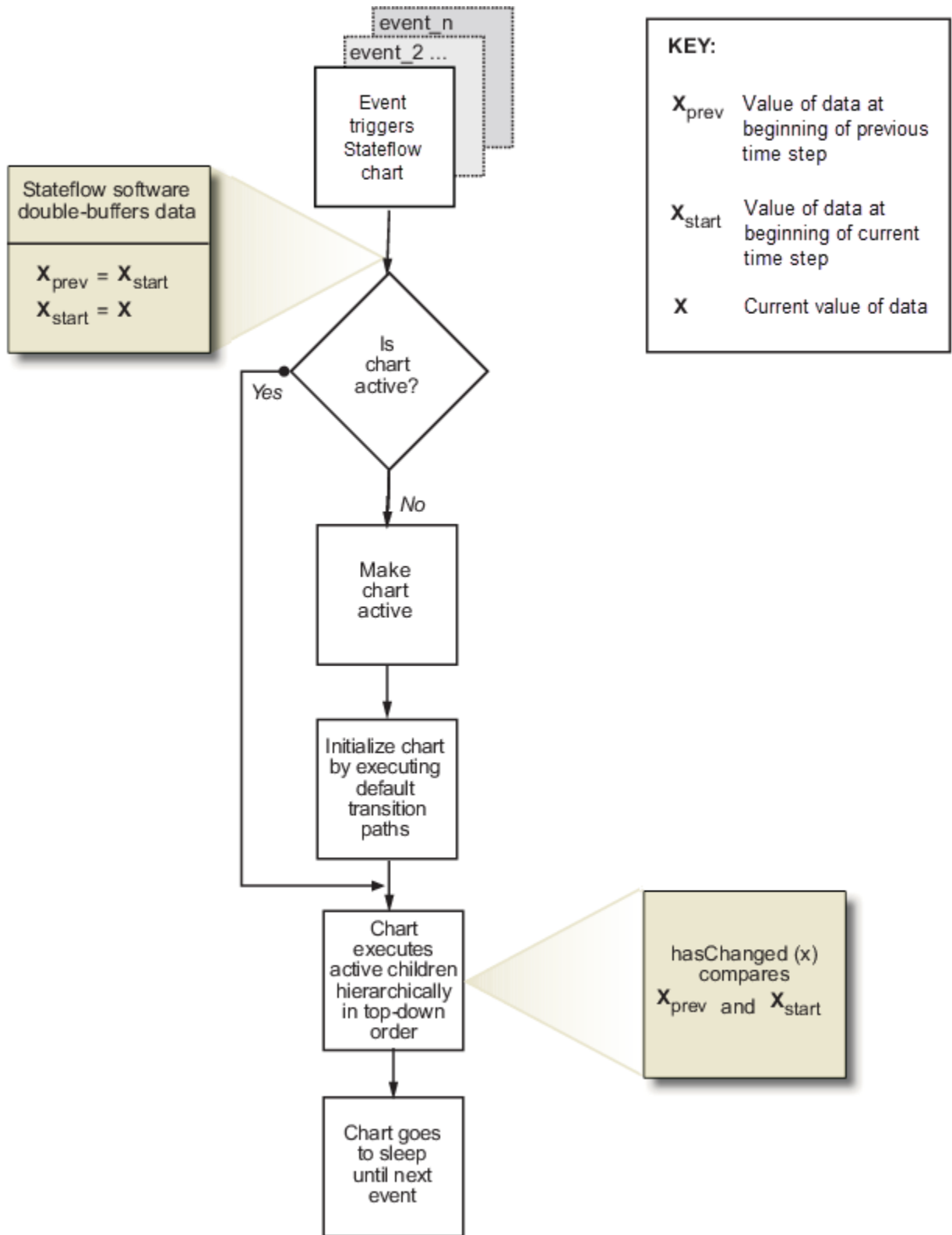
A chart detects changes in chart data by evaluating values at time step boundaries. The chart compares the value at the beginning of the previous execution step with the value at the beginning of the current execution step.

For example, when you invoke the `hasChanged` operator with an argument of `x`, the Stateflow chart double-buffers the values of `x` in local variables.

Local Buffer	Description
<code>x_prev</code>	Value of data <code>x</code> at the beginning of the last time step

Local Buffer	Description
x_start	Value of data x at the beginning of the current time step

To detect changes, the chart double-buffers data values *after* an event triggers the chart but *before* the chart begins execution. If the values of  $x_{prev}$  and  $x_{start}$  match, the change detection operator returns `false` (to indicate that no change occurred); otherwise, it returns `true` (to indicate a change). This diagram places these tasks in the context of the chart life cycle.



### **Transient Value Changes in Local Data**

The change detection operators attempt to filter out transient changes in local chart variables by evaluating their values only at time boundaries. The chart evaluates the specified local variable only once at the end of the execution step. The return value of the change detection operators remains constant even if the value of the local variable fluctuates within a given time step. For example, suppose that in the current time step, the local variable `temp` changes from its value at the previous time step but then reverts to the original value. The operator `hasChanged(temp)` returns `false` for the next time step, indicating that no change occurred.

### **Detect Value Changes Between Input Events or Super Step Iterations**

When multiple input events occur in the same time step, or when you enable super step semantics, the chart updates the `xprev` and `xstart` buffers every time it executes. The chart detects changes in value between input events and super step iterations, even if the changes occur more than once in a given time step. For more information, see “Use Events to Execute Charts” on page 3-53 and “Super Step Semantics” on page 3-45.

### **See Also**

`change` | `hasChanged` | `hasChangedFrom` | `hasChangedTo`

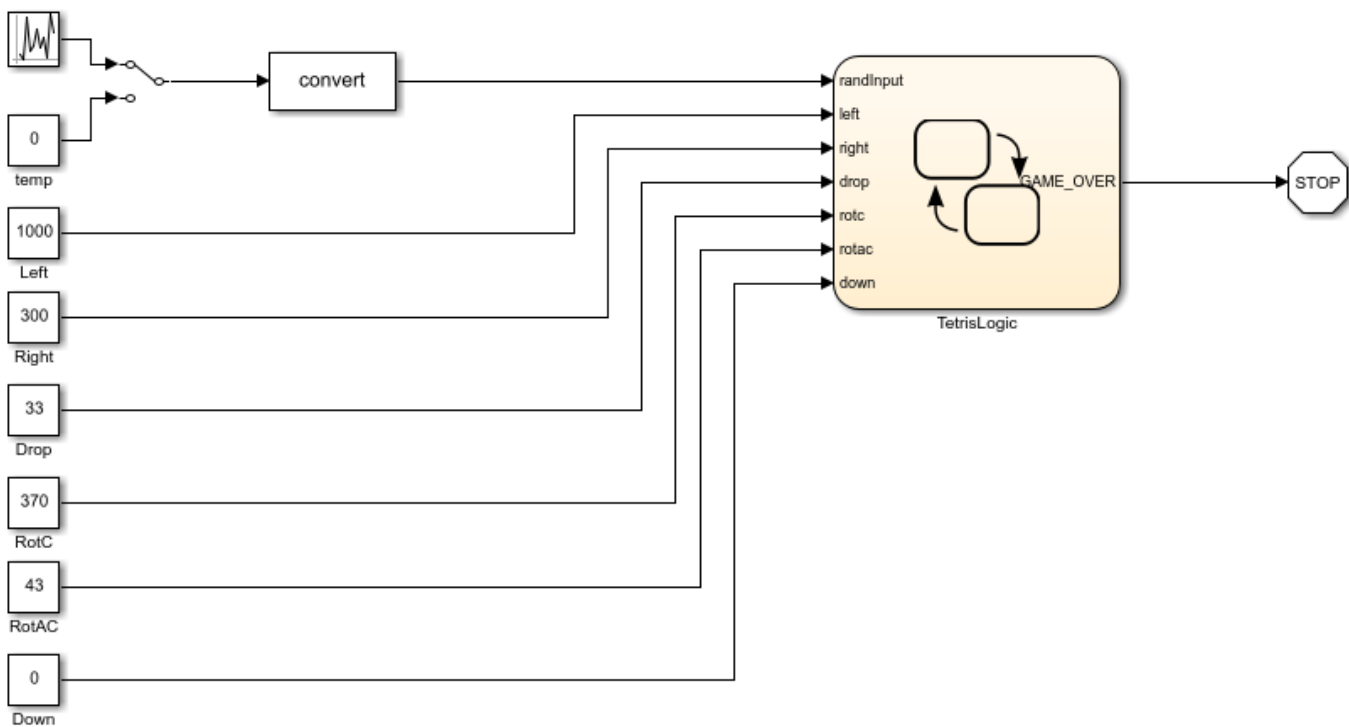
### **More About**

- “Design a Game by Using Stateflow” on page 16-71
- “Control Chart Behavior by Using Implicit Events” on page 14-26
- “Use Events to Execute Charts” on page 3-53
- “Super Step Semantics” on page 3-45

## Design a Game by Using Stateflow

This example shows how to implement the game of Tetris by using a Stateflow® chart. This model is a redesigned version of the classic Stateflow demo `sf_tetris`. The new design incorporates these programming paradigms:

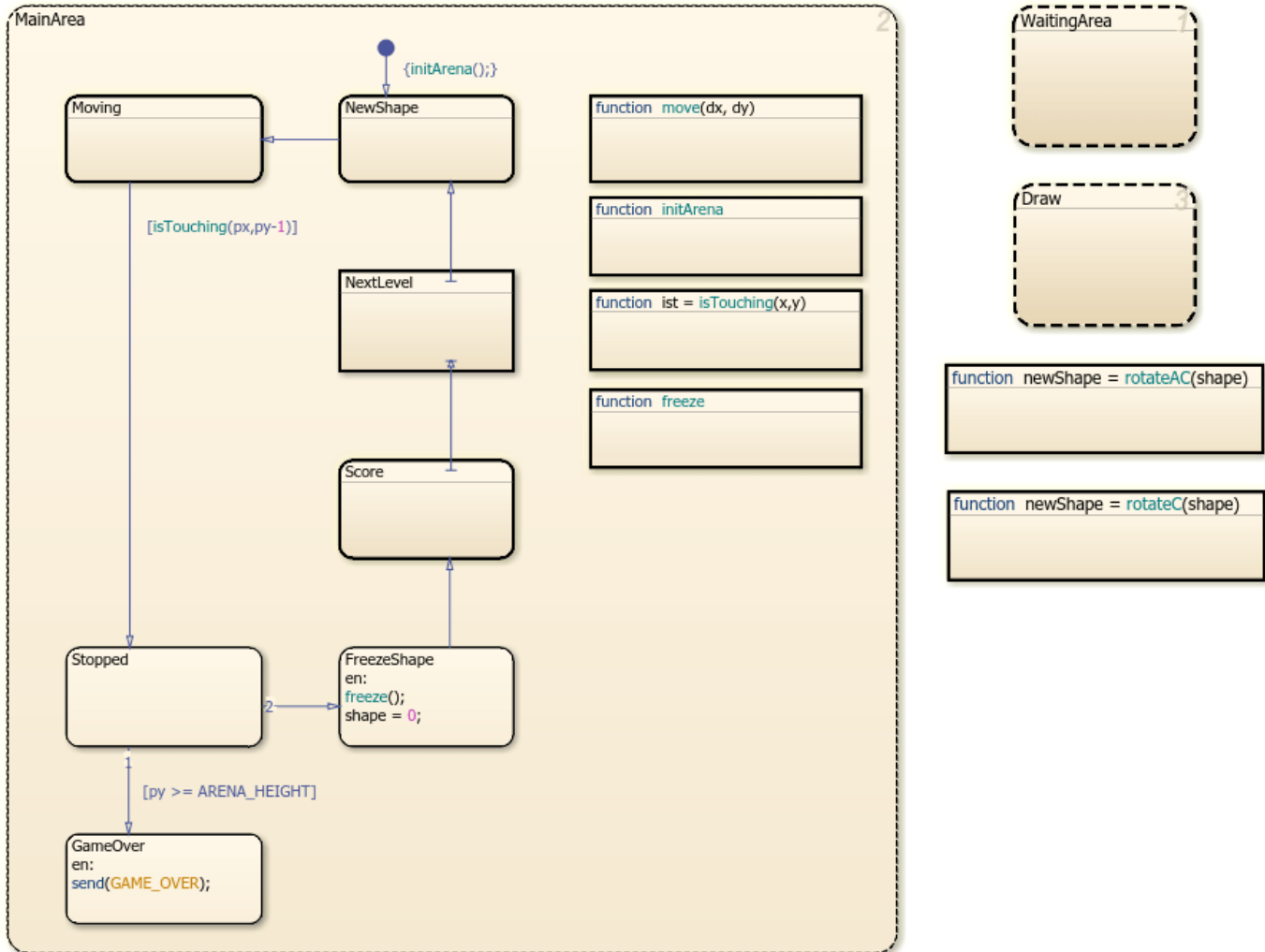
- Parallel decomposition to separate pre- and post-processing tasks from the main game control logic.
- State hierarchy and subcharts to provide semantic abstractions that simplify the design of the chart.
- Change detection operators to query for input from the keyboard.



### Separate Subcomponents by Using Parallel Decomposition

The chart `TetrisLogic` implements the logic behind the game. The chart consists of three parallel states, which execute in this order:

- `WaitingArea` performs preprocessing tasks such as randomly generating the next *tetronimo* (a shape consisting of four squares). During simulation, the smaller square on the right of the game UI displays this tetronimo.
- `MainArea` implements the main control logic for the game. To represent the playing arena, this state uses a 21-by-12 array `arena`. At each simulation step, the chart updates the array based on the state of the game and the input from the player.
- `Draw` performs post-processing tasks such as calling the MATLAB® script `sf_tetris_gui`. This script displays the arena as an image and captures keystrokes from the player.



### Simplify Chart Design by Using Hierarchy and Subcharts

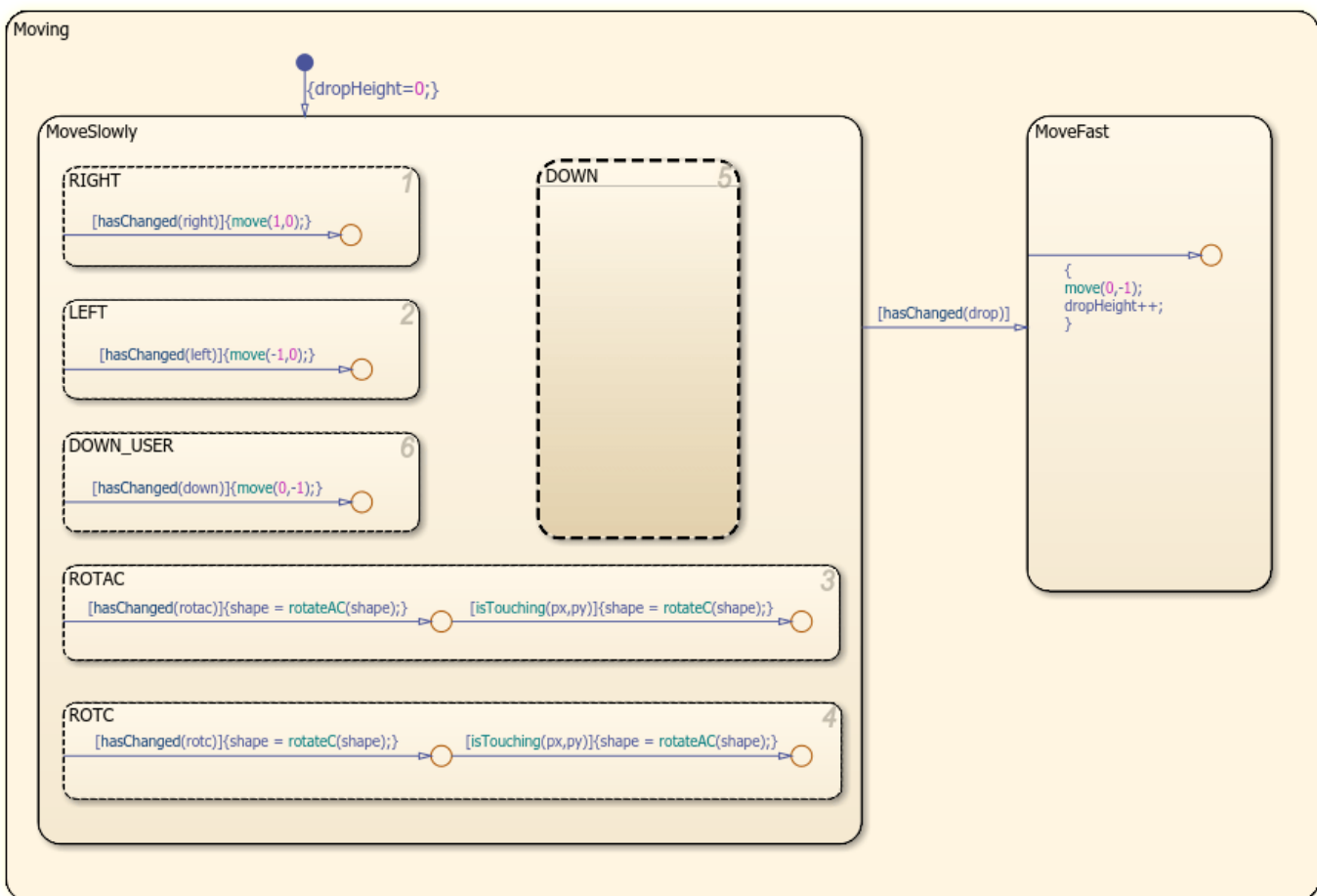
By using state hierarchy and subcharts, you can graphically abstract the game logic, present a high-level overview of the flow of the game, and hide the inner complexity of each stage of the game. For example, each substate of the parallel state `MainArea` represents a separate stage in the flow of the game.

- The game starts by generating a new tetronimo (substate `NewShape`).
- The tetronimo moves down or sideways, depending on the input from the player (substate `Moving`).
- When the tetronimo touches the bottom of the arena or an earlier tetronimo below it, the tetronimo stops moving (substate `Stopped`).
- If the tetronimo stops at too high a point on the arena, the game ends (substate `GameOver`). Otherwise, the chart freezes the tetronimo (substate `FreezeShape`), adjusts the score (substate `Score`), advances to the next level if necessary (substate `NextLevel`), and proceeds to the next tetronimo (substate `NewShape`).

## Capture Keyboard Input Through Change Detection

The Moving subchart moves the tetronimo based on the input from the player. By default, the substate MoveSlowly is active. The tetronimo moves slowly down the playing arena while the parallel substates in MoveSlowly monitor the input from the keyboard. If the player presses the space bar, the substate MoveFast becomes active. The tetronimo drops quickly to the bottom of the arena.

To gather input from the keyboard, the subchart uses the change detection operator `hasChanged`. Every time that the player presses a key, `sf_tetris_gui` increments an input to the chart, which makes the corresponding `hasChanged` operator return a value of `true`. Because MoveSlowly has a parallel decomposition, the chart can process multiple keystrokes each time step.



## Key Mappings

To interact with the game UI, use these keys:

- Move left: **Left arrow** or **J**
- Move right: **Right arrow** or **L**
- Rotate clockwise: **Up arrow** or **I**
- Rotate counterclockwise: **Down arrow** or **K**

- Drop to bottom: **Space bar**
- To pause and resume play: **P**
- To quit: **Q**



Press P to Pause/Play  
Press Q to Quit



Score 0  
Level: 1  
Lines: 0

## See Also

hasChanged

## More About

- “State Decomposition” on page 2-19
- “State Hierarchy” on page 2-17
- “Encapsulate Modal Logic by Using Subcharts” on page 8-10
- “Detect Changes in Data Values” on page 16-64

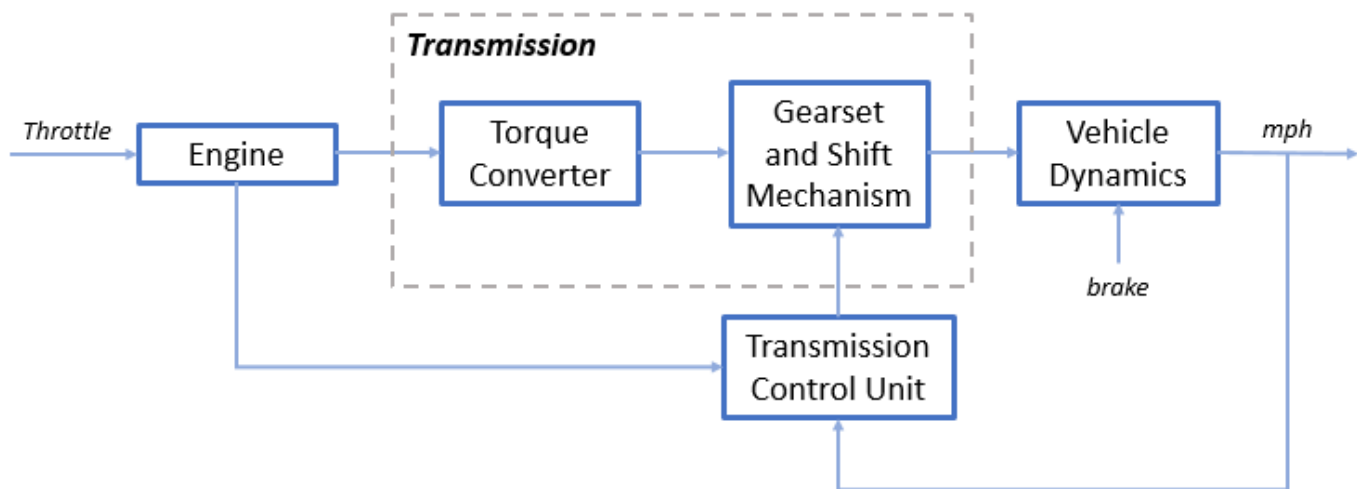


## Modeling an Automatic Transmission Controller

This example shows how to model an automotive drivetrain with Simulink®. Stateflow® enhances the Simulink model with its representation of the transmission control logic. Simulink provides a powerful environment for the modeling and simulation of dynamic systems and processes. In many systems, though, supervisory functions like changing modes or invoking new gain schedules must respond to events that may occur and conditions that develop over time. As a result, the environment requires a language capable of managing these multiple modes and developing conditions. In the following example, Stateflow shows its strength in this capacity by performing the function of gear selection in an automatic transmission. This function is combined with the drivetrain dynamics in a natural and intuitive manner by incorporating a Stateflow block in the Simulink block diagram.

### Analysis and Physics

The figure below shows the power flow in a typical automotive drivetrain. Nonlinear ordinary differential equations model the engine, four-speed automatic transmission, and vehicle. The model discussed in this example directly implements the blocks from this figure as modular Simulink subsystems. On the other hand, the logic and decisions made in the Transmission Control Unit (TCU) do not lend themselves to well-formulated equations. TCU is better suited for a Stateflow representation. Stateflow monitors the events which correspond to important relationships within the system and takes the appropriate action as they occur.



The throttle opening is one of the inputs to the engine. The engine is connected to the impeller of the torque converter which couples it to the transmission (see Equation 1).

### Equation 1

$$I_{ei} \dot{N}_e = T_e - T_i$$

$N_e$  = engine speed (RPM)

$I_{ei}$  = moment of inertia of the engine and the impeller

$T_e, T_i$  = engine and impeller torque

The input-output characteristics of the torque converter can be expressed as functions of the engine speed and the turbine speed. In this example, the direction of power flow is always assumed to be from the impeller to the turbine (see Equation 2).

**Equation 2**

$$T_i = \frac{N_e^2}{K^2}$$

$$K = f_2 \frac{N_{in}}{N_e} = \text{K-factor (capacity)}$$

$N_{in}$  = speed of turbine (torque converter output) = transmission input speed (RPM)

$$R_{TQ} = f_3 \frac{N_{in}}{N_e} = \text{torque ratio}$$

The transmission model is implemented via static gear ratios, assuming small shift times (see Equation 3).

**Equation 3**

$$R_{TR} = f_4(\text{gear}) = \text{transmission ratio}$$

$$T_{out} = R_{TR} T_{in}$$

$$N_{in} = R_{TR} N_{out}$$

$T_{in}, T_{out}$  = transmission input and output torques

$N_{in}, N_{out}$  = transmission input and output speed (RPM)

The final drive, inertia, and a dynamically varying load constitute the vehicle dynamics (see Equation 4).

**Equation 4**

$$I_v \dot{N}_w = R_{fd}(T_{out} - T_{load})$$

$I_v$  = vehicle inertia

$N_w$  = wheel speed (RPM)

$R_{fd}$  = final drive ratio

$$T_{load} = f_5(N_w) = \text{load torque}$$

The load torque includes both the road load and brake torque. The road load is the sum of frictional and aerodynamic losses (see Equation 5).

**Equation 5**

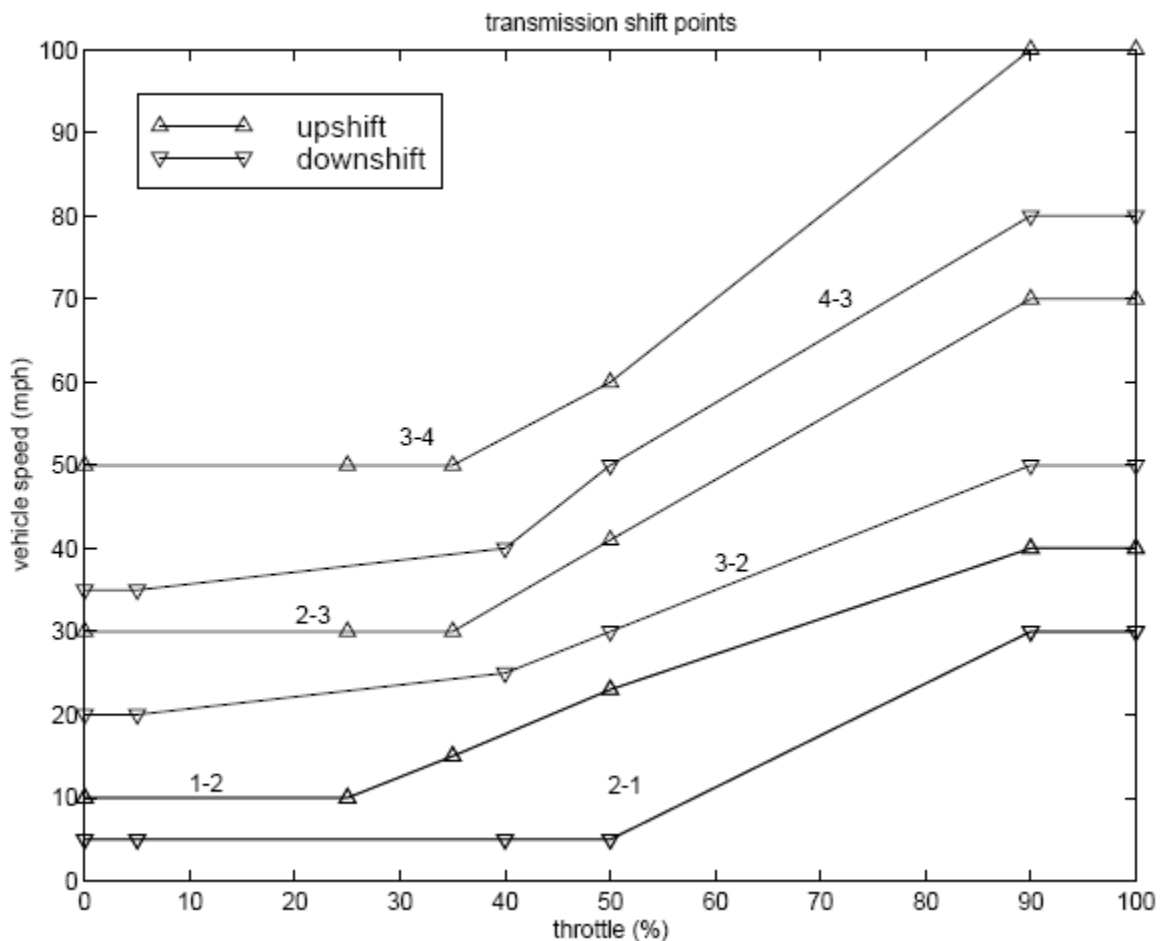
$$T_{load} = \text{sgn}(mph)(R_{load0} + R_{load2}mph^2 + T_{brake})$$

$R_{load0}, R_{load2}$  = friction and aerodynamic drag coefficients

$T_{load}, T_{brake}$  = load and brake torques

$mph$  = vehicle linear velocity

The model programs the shift points for the transmission according to the schedule shown in the figure below. For a given throttle in a given gear, there is a unique vehicle speed at which an upshift takes place. The simulation operates similarly for a downshift.



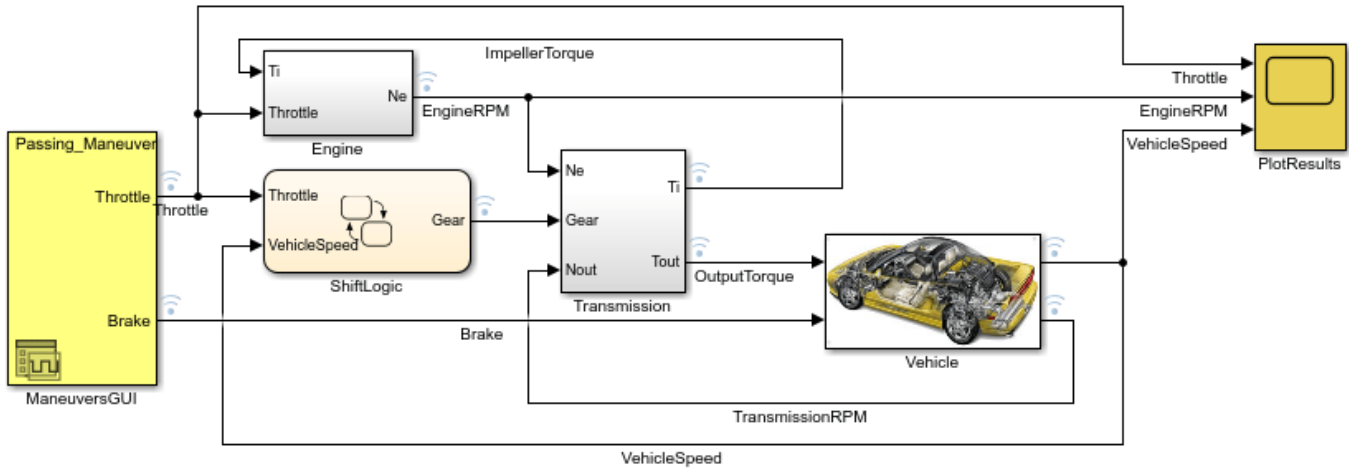
## Modeling

When you open the model, the Initial conditions are set in the Model Workspace.

The top-level diagram of the model is shown in the figure below. To run the simulation, on the Simulation tab, click **Run**. Note that the model logs relevant data to MATLAB Workspace in a data structure called `sldemo_autotrans_output`. Logged signals have a blue indicator. After you run the simulation, you can view the components of the data structure by typing `sldemo_autotrans_output` in MATLAB Command Window. Also note that the units appear on the subsystem icons and signal lines.



### Modeling an Automatic Transmission Controller



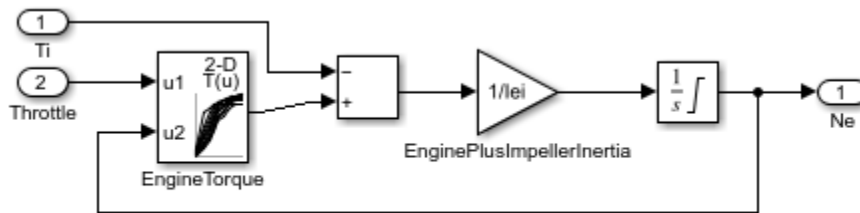
Double-click on ManeuversGUI and select a maneuver

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### Modeling

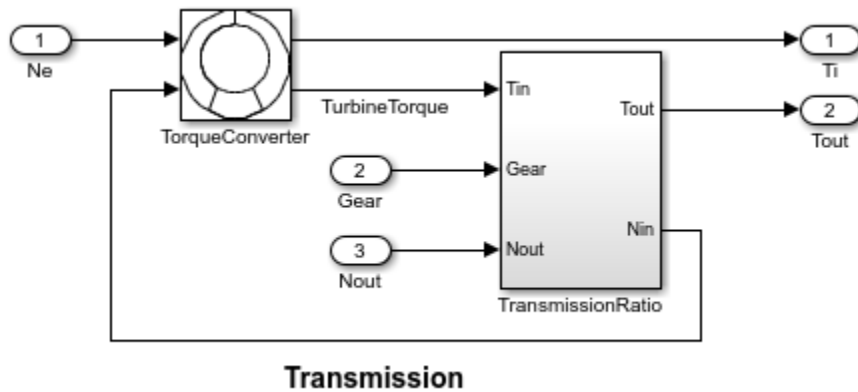
The Simulink model shown above is composed of modules which represent the engine, transmission, and the vehicle, with an additional shift logic block to control the transmission ratio. User inputs to the model are in the form of throttle (given in percent) and brake torque (given in ft-lb). The user inputs throttle and brake torques using the ManeuversGUI interface.

The Engine subsystem consists of a two-dimensional table that interpolates engine torque versus throttle and engine speed. The figure below shows the composite Engine subsystem. Double click on this subsystem in the model to view its structure.

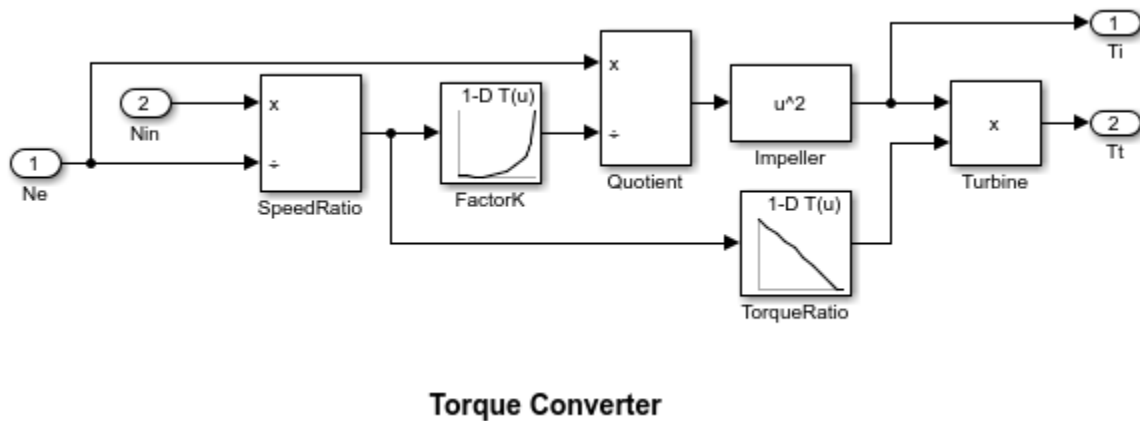


### Engine

The TorqueConverter and the TransmissionRatio blocks make up the Transmission subsystem, as shown in the figure below. Double click on the Transmission subsystem in the model window to view its components.



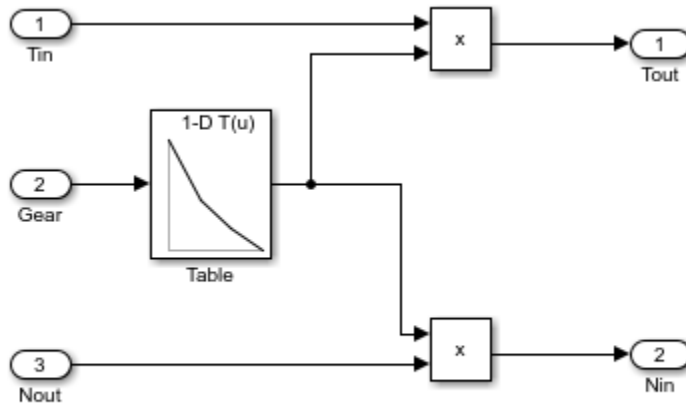
The TorqueConverter is a masked subsystem, which implements Equation 2. To open this subsystem, right click on it and select **Mask > Look Under Mask** from the drop-down menu. The mask requires a vector of speed ratios (  $N_{in}/N_e$  ) and vectors of K-factor (f2) and torque ratio (f3). This figure shows the implementation of the TorqueConverter subsystem.



The transmission ratio block determines the ratio shown in Table 1 and computes the transmission output torque and input speed, as indicated in Equation 3. The figure that follows shows the block diagram for the subsystem that realizes this ratio in torque and speed.

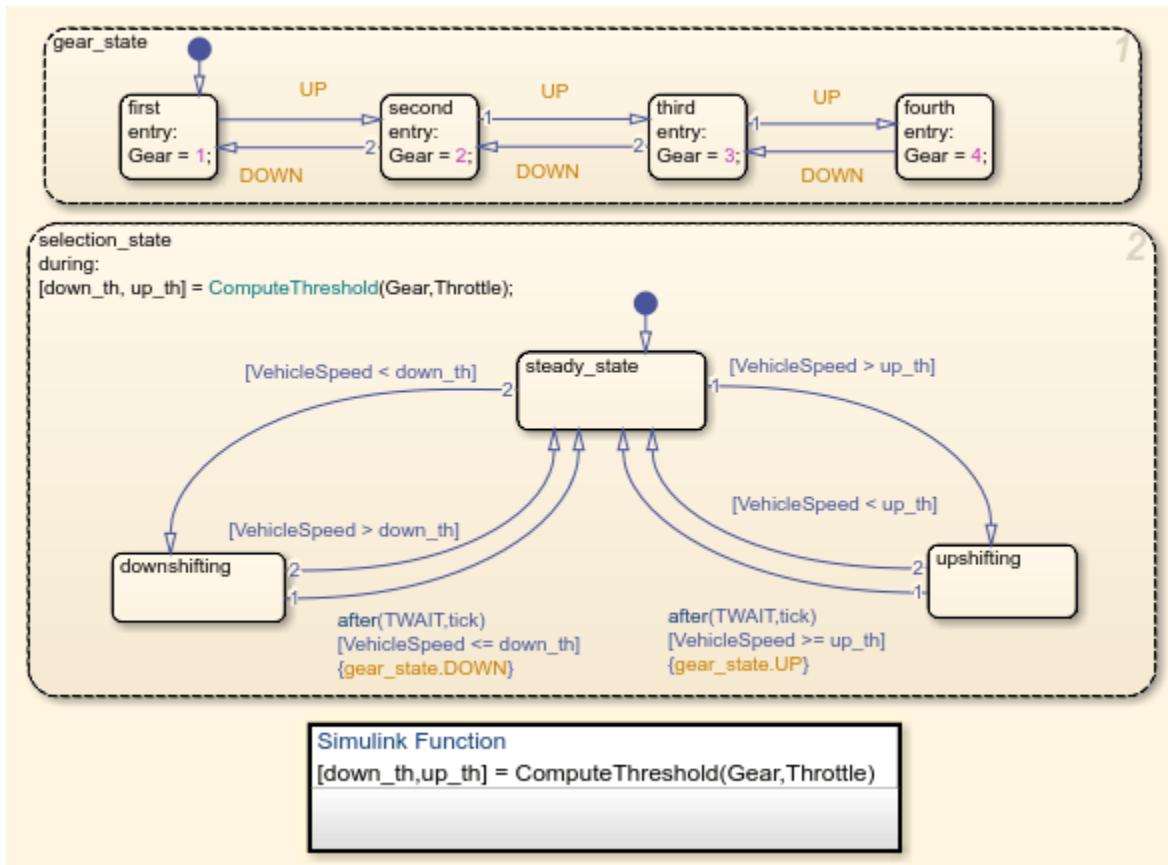
**Table 1:** Transmission gear ratios

gear	Rtr = $N_{in}/N_e$
1	2.393
2	1.450
3	1.000
4	0.677



**Transmission Gear Ratio**

The Stateflow block labeled ShiftLogic implements gear selection for the transmission. Double click on ShiftLogic in the model window to open the Stateflow diagram. The Model Explorer is utilized to define the inputs as throttle and vehicle speed and the output as the desired gear number. Two dashed AND states keep track of the gear state and the state of the gear selection process. The overall chart is executed as a discrete-time system, sampled every 40 milliseconds. The Stateflow diagram shown below illustrates the functionality of the block.

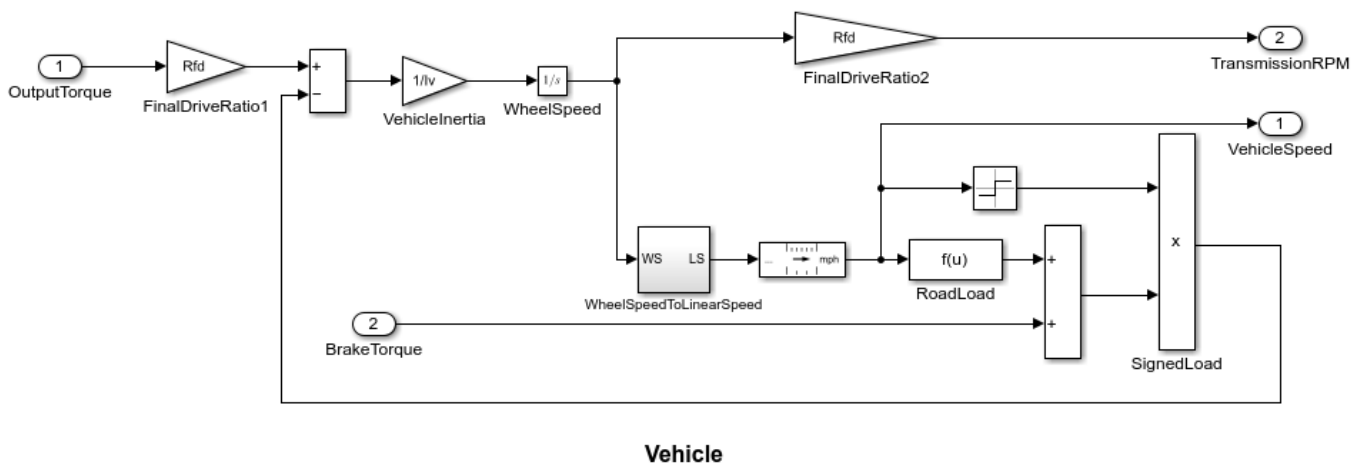


The shift logic behavior can be observed during simulation by enabling animation in the Stateflow debugger. The `selection_state` (always active) begins by performing the computations indicated in its `during` function. The model computes the upshift and downshift speed thresholds as a function of the instantaneous values of gear and throttle. While in `steady_state`, the model compares these values to the present vehicle speed to determine if a shift is required. If so, it enters one of the confirm states (`upshifting` or `downshifting`), which records the time of entry.

If the vehicle speed no longer satisfies the shift condition, while in the confirm state, the model ignores the shift and it transitions back to `steady_state`. This prevents extraneous shifts due to noise conditions. If the shift condition remains valid for a duration of `TWAIT` ticks, the model transitions through the lower junction and, depending on the current gear, it broadcasts one of the shift events. Subsequently, the model again activates `steady_state` after a transition through one of the central junctions. The shift event, which is broadcast to the `gear_selection` state, activates a transition to the appropriate new gear.

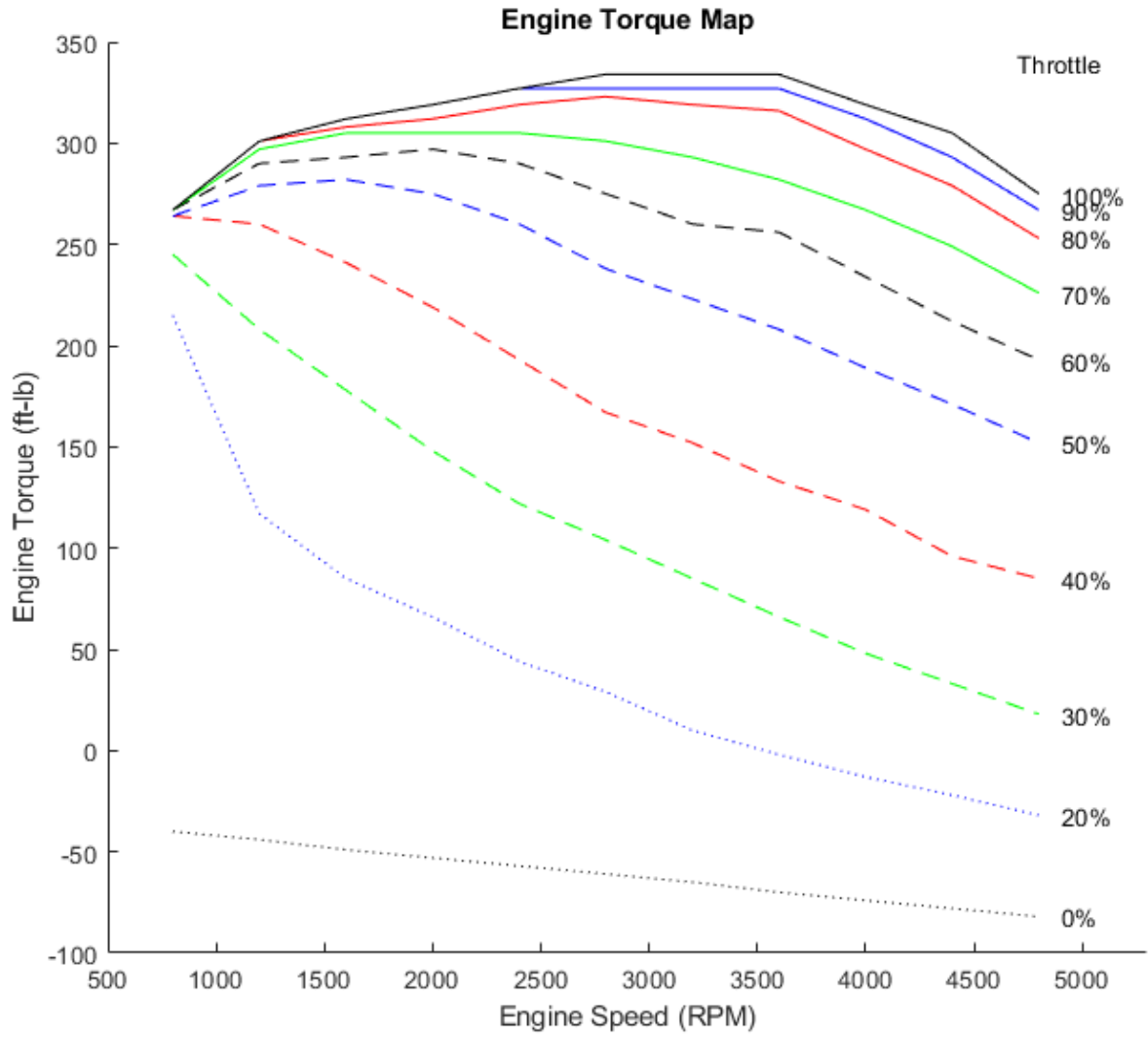
For example, if the vehicle is moving along in second gear with 25% throttle, the state `second` is active within `gear_state`, and `steady_state` is active in the `selection_state`. The `during` function of the latter, finds that an upshift should take place when the vehicle exceeds 30 mph. At the moment this becomes true, the model enters the `upshifting` state. While in this state, if the vehicle speed remains above 30 mph for `TWAIT` ticks, the model satisfies the transition condition leading down to the lower right junction. This also satisfies the condition `[gear == 2]` on the transition leading from here to `steady_state`, so the model now takes the overall transition from `upshifting` to `steady_state` and broadcasts the event `UP` as a transition action. Consequently, the transition from second to third is taken in `gear_state` which completes the shift logic.

The Vehicle subsystem uses the net torque to compute the acceleration and integrate it to compute the vehicle speed, per Equation 4 and Equation 5. The Vehicle subsystem is masked. To see the structure of the Vehicle block, right click on it and select **Mask > Look Under Mask** from the drop-down menu. The parameters entered in the mask menu are the final drive ratio, the polynomial coefficients for drag friction and aerodynamic drag, the wheel radius, vehicle inertia, and initial transmission output speed.



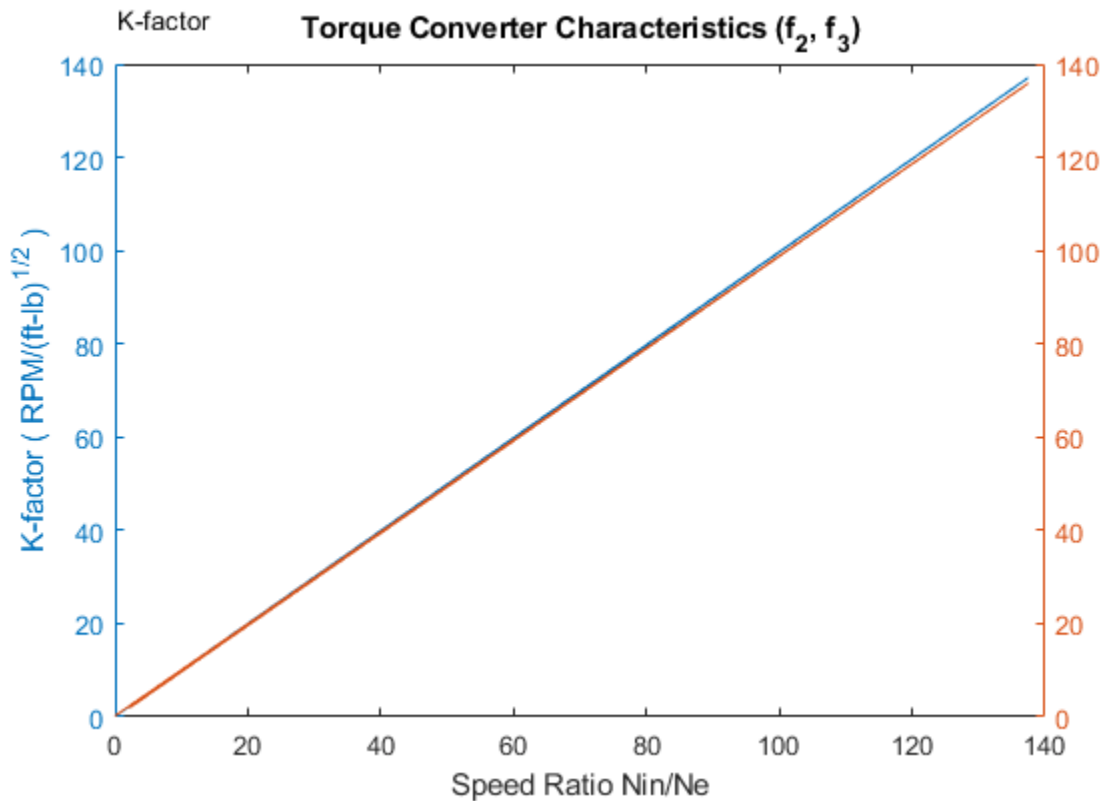
## Results

The engine torque map, and torque converter characteristics used in the simulations are shown below.



Get the FactorK (second row) and the TorqueRatio (third row) vs SpeedRatio(first row)



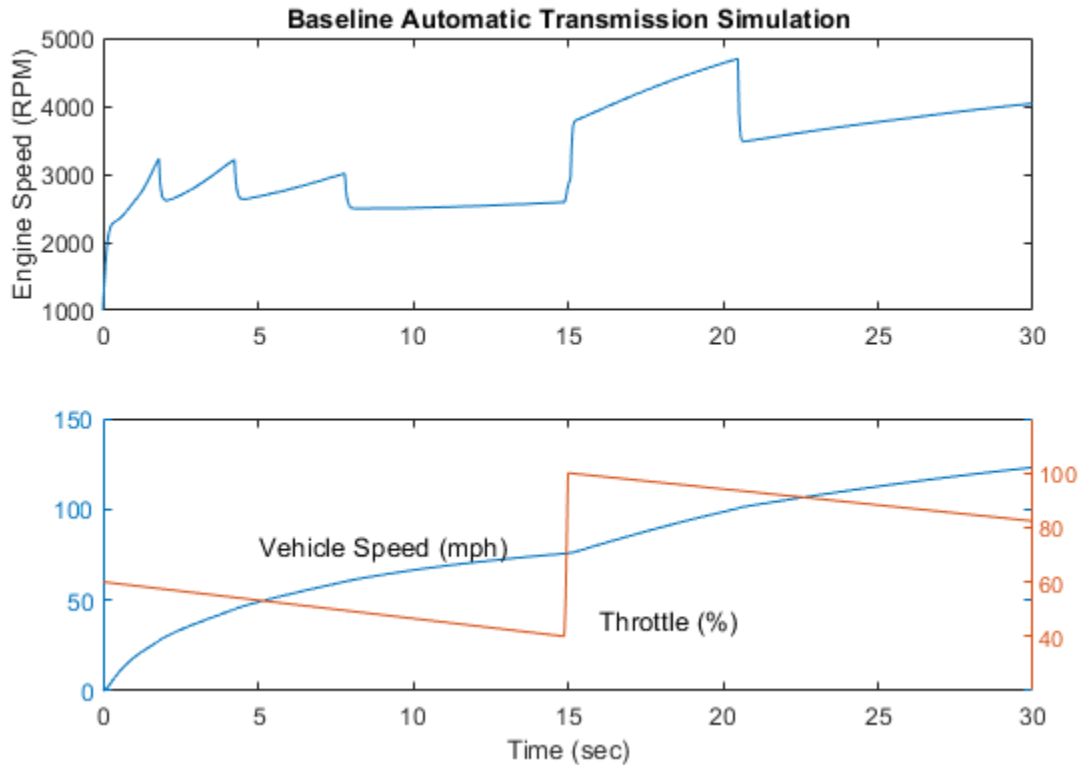


The first simulation (passing maneuver) uses the throttle schedule given in Table 2 (this data is interpolated linearly).

**Table 2:** Throttle schedule for first simulation (passing maneuver)

Time (sec)	Throttle (%)
0	60
14.9	40
15	100
100	0
200	0

The first column corresponds to time; the second column corresponds to throttle opening in percent. In this case no brake is applied (brake torque is zero). The vehicle speed starts at zero and the engine at 1000 RPM. The following figure shows the plot for the baseline results, using the default parameters. As the driver steps to 60% throttle at  $t=0$ , the engine immediately responds by more than doubling its speed. This brings about a low speed ratio across the torque converter and, hence, a large torque ratio. The vehicle accelerates quickly (no tire slip is modeled) and both the engine and the vehicle gain speed until about  $t = 2$  sec, at which time a 1-2 upshift occurs. The engine speed characteristically drops abruptly, then resumes its acceleration. The 2-3 and 3-4 upshifts take place at about four and eight seconds, respectively. Notice that the vehicle speed remains much smoother due to its large inertia.



At  $t=15\text{sec}$ , the driver steps the throttle to 100% as might be typical of a passing maneuver. The transmission downshifts to third gear and the engine jumps from about 2600 RPM to about 3700 RPM. The engine torque thus increases somewhat, as well as the mechanical advantage of the transmission. With continued heavy throttle, the vehicle accelerates to about 100 mph and then shifts into overdrive at about  $t = 21 \text{ sec}$ . The vehicle cruises along in fourth gear for the remainder of the simulation. Double click on the ManeuversGUI block and use the graphical interface to vary the throttle and brake history.

### Closing the Model

Close the model, clear generated data.

### Conclusions

You can enhance this basic system in a modular manner, for example, by replacing the engine or transmission with a more complex model. You can build large systems within this structure via step-wise refinement. The seamless integration of Stateflow control logic with Simulink signal processing enables the construction of a model that is efficient and visually intuitive.

### See Also

### More About

- "Unit Specification in Simulink Models" (Simulink)
- "Powertrain Blockset"



# MATLAB Syntax Support for States and Transitions

---

- “Modify the Action Language for a Chart” on page 17-2
- “Differences Between MATLAB and C as Action Language Syntax” on page 17-5
- “Model an Assembly Line Feeder” on page 17-9

## Modify the Action Language for a Chart

Stateflow charts in Simulink models have an action language property that defines the syntax for state and transition actions. An icon in the lower-left corner of the chart canvas indicates the action language for the chart.

-  MATLAB as the action language.
-  C as the action language.

You can change the action language of a chart in the **Action Language** box of the Chart properties dialog box. For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Change the Default Action Language

MATLAB is the default action language syntax for new Stateflow charts. To create a chart that uses C as the action language, enter:

```
sfnew -C
```

To change the default action language of new charts, use these commands.

Command	Result
<code>sfpref('ActionLanguage', 'MATLAB')</code>	All new charts created have MATLAB as the action language, unless otherwise specified in <code>sfnew</code> .
<code>sfpref('ActionLanguage', 'C')</code>	All new charts created have C as the action language, unless otherwise specified in <code>sfnew</code> .

For more information, see `sfpref`.

### Auto Correction When Using MATLAB as the Action Language

Stateflow charts that use MATLAB as the action language automatically correct common C constructs to MATLAB syntax:

- Increment and decrement operations such as `a++` and `a--`. For example, `a++` is changed to `a = a + 1`.
- Assignment operations such as `a += b`, `a -= b`, `a *= b`, and `a /= b`. For example, `a += b` is changed to `a = a + b`.
- Evaluation operations such as `a != b` and `!a`. For example, `a != b` is changed to `a ~= b`.
- Comment markers `//` and `/* */` are changed to `%`.

To disable this preference, you can use the `sfpref` function and the following command:

```
sfpref('EnableLabelAutoCorrectionForMAL', 0)
```

For more information, see `sfpref`.

## C to MATLAB Syntax Conversion

For nonempty charts, after you change the action language property from C to MATLAB, a notification appears at the top of the chart. The notification provides the option to convert some of the C syntax to MATLAB syntax. In the notification, click the link to have Stateflow convert syntax in the chart. C syntax constructs that are converted include:

- Zero-based indexing.
- Increment and decrement operations such as `a++` and `a--`. For example, `a++` is changed to `a = a + 1`.
- Assignment operations such as `a += b`, `a -= b`, `a *= b`, and `a /= b`. For example, `a += b` is changed to `a = a + b`.
- Binary operations such as `a %% b`, `a >> b`, and `a << b`. For example, `a %% b` is changed to `rem(a, b)`.
- Bitwise operations such as `a ^ b`, `a & b`, and `a | b`. For example, if the chart property **Enable C-bit operations** is selected, then `a ^ b` is changed to `bitxor(a, b)`.
- C style comment markers. For example, `//` and `/* */` are changed to `%`.

If the chart contains C constructs that cannot be converted to MATLAB, Stateflow shows a message in a dialog box. Click on the warnings link to display the warnings in the Diagnostic Viewer. Choose whether or not to continue with the conversion of supported syntax. C constructs not converted to MATLAB include:

- Explicit type casts with `cast` and `type`
- Operators such as `&`, `*` and `:=`
- Custom data
- Access to workspace variables using `ml` operator
- Functions not supported in code generation
- Hexadecimal and single precision notation
- Context-sensitive constants

## Rules for Using MATLAB as the Action Language

### Use unique names for data in a chart

Using the same name for data at different levels of the chart hierarchy causes a compile-time error.

### Use unique names for functions in a chart

Using the same name for functions at different levels of the chart hierarchy causes a compile-time error.

### Include a type prefix for identifiers of enumerated values

The identifier `TrafficColors.Red` is valid, but `Red` is not.

### Use the MATLAB format for comments

Use `%` to specify comments in states and transitions for consistency with MATLAB. For example, the following comment is valid:

`%` This is a valid comment in the style of MATLAB

C style comments, such as `//` and `/* */`, are auto-corrected to use `%`.

### **Use one-based indexing for vectors and matrices**

One-based indexing is consistent with MATLAB syntax.

### **Use parentheses instead of brackets to index into vectors and matrices**

This statement is valid:

```
a(2,5) = 0;
```

This statement is not valid:

```
a[2][5] = 0;
```

### **Do not use control flow logic in condition actions and transition actions**

If you try to use control flow logic in condition actions or transition actions, you get an error. Use of an `if`, `switch`, `for`, or `while` statement does not work.

### **Do not use transition actions in graphical functions**

Transition labels in graphical functions do not support transition actions.

### **Enclose transition actions with braces**

The following transition label contains a valid transition action:

```
E [x > 0] / {x = x+1;}
```

The following transition label:

```
E [x > 0] / x = x+1;
```

is incorrect, but is auto-corrected to the valid syntax.

### **Do not declare global or persistent variables in state actions**

The keywords `global` and `persistent` are not supported in state actions.

### **To generate code from your model, use MATLAB language features supported for code generation**



Otherwise, use `coder.extrinsic` to call unsupported functions, which gives the functionality that you want for simulation, but not in the generated code. For a list of supported features and functions, see “Language, Function, and Object Support” (Simulink).

### **Assign an initial value to local and output data**

When using MATLAB as the action language, data read without an initial value causes an error.

## Differences Between MATLAB and C as Action Language Syntax

Stateflow charts in Simulink models have an action language property that defines the syntax for state and transition actions. An icon in the lower-left corner of the chart canvas indicates the action language for the chart.

-  MATLAB as the action language.
-  C as the action language.

MATLAB is the default action language syntax for new Stateflow charts. To create a chart that uses C as the action language, enter:

```
sfnew -c
```

### Compare Functionality of Action Languages

This table lists the most significant differences in functionality between the two action languages.

Functionality	MATLAB as the Action Language	C as the Action Language
Vector and matrix indexing	One-based indexing delimited by parentheses and commas. For example, <code>A(4,5)</code> . See “Supported Operations for Vectors and Matrices” on page 21-4.	Zero-based indexing delimited by square brackets. For example, <code>A[3][4]</code> . See “Supported Operations for Vectors and Matrices” on page 21-4.
C constructs: <ul style="list-style-type: none"> <li>• Increment and decrement operations <code>a++</code> and <code>a--</code></li> <li>• Assignment operations <code>a += b</code>, <code>a -= b</code>, <code>a *= b</code>, and <code>a /= b</code></li> <li>• Evaluation operations <code>a != b</code> and <code>!a</code></li> <li>• Binary operations <code>a %% b</code>, <code>a &gt;&gt; b</code>, <code>a &lt;&lt; b</code>, <code>a &amp; b</code>, and <code>a   b</code></li> <li>• Comment markers <code>//</code> and <code>/* */</code></li> </ul>	Auto-correction to MATLAB syntax. For example, <code>a++</code> is corrected to <code>a = a+1</code> . See “Auto Correction When Using MATLAB as the Action Language” on page 17-2.	Supported. See “Supported Operations for Chart Data” on page 16-5.
Conditional and loop control statements in state actions	Supported. For example, you can use <code>if</code> , <code>for</code> , and <code>while</code> statements in state actions. See “Loops and Conditional Statements”.	Not supported. For conditional and loop patterns, use graphical functions instead. See “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18.

Functionality	MATLAB as the Action Language	C as the Action Language
Format of transition actions	Auto-correction encloses transition actions with braces {}. See "Transition Actions" on page 2-24.	Not required to enclose transition actions with braces {}. See "Transition Actions" on page 2-24.
Ordering of parallel states	Explicit ordering only. See "Execution Order for Parallel States" on page 3-60.	Explicit or implicit ordering. See "Execution Order for Parallel States" on page 3-60.
Variable-size data	Access and modify variable-size input, output, and local data in state and transition actions.	Access and modify variable-size input and output data by using: <ul style="list-style-type: none"> <li>• MATLAB functions</li> <li>• Simulink functions</li> <li>• Truth tables that use MATLAB as the action language</li> </ul> All computations with variable-size data must occur inside these functions, and not directly in states or transitions. For more information, see "Guidelines for Using Variable-Size Data" on page 22-3.
Fixed-point constructs: <ul style="list-style-type: none"> <li>• Special assignment operator :=</li> <li>• Context-sensitive constants such as 4.3C</li> </ul>	Not supported.	Supported. See "Override Fixed-Point Promotion in C Charts" on page 26-15 and "Fixed-Point Context-Sensitive Constants" on page 26-4.
Complex data	Use complex number notation <code>a + bi</code> or the <code>complex</code> operator. See "Supported Operations for Complex Data" on page 27-4.	Use the <code>complex</code> operator. Complex number notation is not supported. See "Supported Operations for Complex Data" on page 27-4.
Data type propagation	Follows MATLAB typing rules. For example, adding data of type <code>double</code> to data of type <code>int32</code> results in data of type <code>int32</code> .	Follows C typing rules. For example, adding data of type <code>double</code> to data of type <code>int32</code> results in data of type <code>double</code> .



Functionality	MATLAB as the Action Language	C as the Action Language
Explicit type cast operations	Use one of these casting forms: <ul style="list-style-type: none"> <li>• MATLAB type conversion function. For example, <code>single(x)</code>.</li> <li>• <code>cast</code> function with a type keyword. For example, <code>cast(x, 'int8')</code>.</li> <li>• <code>cast</code> function with the 'like' keyword. For example, <code>cast(x, 'like', z)</code>.</li> </ul> The type operator is not supported. See "Type Cast Operations" on page 16-8.	Use one of these casting forms: <ul style="list-style-type: none"> <li>• MATLAB type conversion function. For example, <code>uint16(x)</code>.</li> <li>• <code>cast</code> function with the type operator. For example, <code>cast(x, type(z))</code>.</li> </ul> Type keywords for the <code>cast</code> function are not supported. See "Type Cast Operations" on page 16-8.
Scalar expansion	Not supported.	Supported. See "Assign Values to All Elements of a Matrix" on page 21-6.
String data	Not supported.	Supported. See "Manage Textual Information by Using Strings" on page 24-2.
Specification of data properties: <ul style="list-style-type: none"> <li>• First index</li> <li>• Save final value to base workspace</li> <li>• Units</li> </ul>	Not supported.	Supported. For more information, see: <ul style="list-style-type: none"> <li>• "First Index" on page 12-8</li> <li>• "Save Final Value to Base Workspace" on page 12-17</li> <li>• "Units" on page 12-17</li> </ul>
Scope of data in graphical, truth table, and MATLAB functions	Constant, Parameter, Input, Output	Local, Constant, Parameter, Input, Output, Temporary
Dot notation for specifying states, local data, message, and local events inside MATLAB functions	Supported. See "Identify Data by Using Dot Notation" on page 12-39.	Not supported.

Functionality	MATLAB as the Action Language	C as the Action Language
Custom code functions and variables	<p>Behavior depends on the <b>Import Custom Code</b> configuration parameter.</p> <ul style="list-style-type: none"> <li>When <b>Import Custom Code</b> is on, both custom code functions and variables are supported in states and transitions (default).</li> <li>When <b>Import Custom Code</b> is off, only custom code functions are supported. Use the <code>coder.ceval</code> function.</li> </ul> <p>See “Custom Code” and “Import custom code” (Simulink).</p>	Custom code functions and variables are supported in states and transitions.
Row-major array layout in generated code	Not supported.	Supported. See “Row-Major Array Layout” on page 32-6.
Multidimensional array layout in generated code	Not supported.	Supported for local data. See “Multidimensional Array Layout” on page 32-7.
Structure parameters	Tunable and nontunable parameters are supported.	Only tunable parameters are supported.
Use of global <code>fimath</code> object	Supported.	Not supported.

## See Also

`sfnew`

## More About

- “Modify the Action Language for a Chart” on page 17-2
- “Supported Operations for Chart Data” on page 16-5
- “Supported Operations for Vectors and Matrices” on page 21-4
- “Supported Operations for Complex Data” on page 27-4
- “Supported Operations for Fixed-Point Data” on page 26-12
- “Execution Order for Parallel States” on page 3-60

# Model an Assembly Line Feeder

## Typical Approaches to Chart Programming

There are two general approaches to programming a Stateflow chart in a Simulink model:

- Identify the operating modes of your system.
- Identify the system interface, such as events to which your system reacts.

This tutorial uses the first approach— that is, start by identifying the operating modes of the system to program the chart.

## Design Requirements

This example shows how to build a Stateflow chart using MATLAB as the action language. The model represents a machine on an assembly line that feeds raw material to other parts of the line. This feeder behaves as follows:

- At system initialization, check that the three sensor values are normal.  
  
A positive value means the sensor is working correctly. A zero means that the sensor is not working.
- If all sensor values are normal, transition from "system initialization" to "on".
- If the feeder does not leave initialization mode after 5 seconds, force the feeder into the failure state.
- After the system turns on, it starts counting the number of parts fed.
- At each time step, if any sensor reading is 2 or greater, the part has moved to the next station.
- If the alarm signal sounds, force the system into the failure state.

An alarm signal can occur when an operator opens one of the safety doors on the feeder or a downstream problem occurs on the assembly line, which causes all upstream feeders to stop.

- If the all-clear signal sounds, resume normal operation and reset the number of parts fed to zero.
- The feeder LED changes color to match the system operating mode— orange for "system initialization", green for "on", and red for "failure state".

## Identify System Attributes

Based on the description of feeder behavior, you can identify the key system attributes.

Attribute	Characteristic
Operating modes	<ul style="list-style-type: none"> <li>• <b>System initialization</b>, to perform system checks before turning on the machine</li> <li>• <b>On</b>, for normal operation</li> <li>• <b>System failure</b>, for a recoverable machine failure flagged by an alarm</li> </ul>

Attribute	Characteristic
Transitions	<ul style="list-style-type: none"> <li>• <b>System initialization to On</b></li> <li>• <b>System initialization to Failure state</b></li> <li>• <b>On to Failure state</b></li> <li>• <b>Failure state to System initialization</b></li> </ul>
Parallel Modes	No operating modes run in parallel. Only one mode can be active at any time.
Default Mode	<b>System initialization</b>
Inputs	<ul style="list-style-type: none"> <li>• Three sensor readings to detect if a part has moved to a downstream assembly station</li> <li>• An alarm signal that can take one of two values: 1 for on and 0 for off</li> </ul>
Outputs	<ul style="list-style-type: none"> <li>• Number of parts that have been detected as fed to a downstream assembly station</li> <li>• Color of the LED on the feeder</li> </ul>

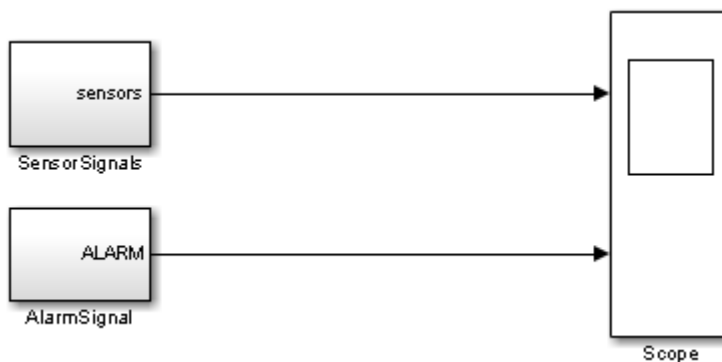
## Build the Model Yourself or Use the Supplied Model

In this exercise, you add a Stateflow chart to a Simulink model that contains sensor and alarm input signals to the feeder.

To implement the model yourself, follow these exercises. Otherwise, you can open the completed model.

### Add a Stateflow Chart to the Feeder Model

- 1 Open the partially built model.



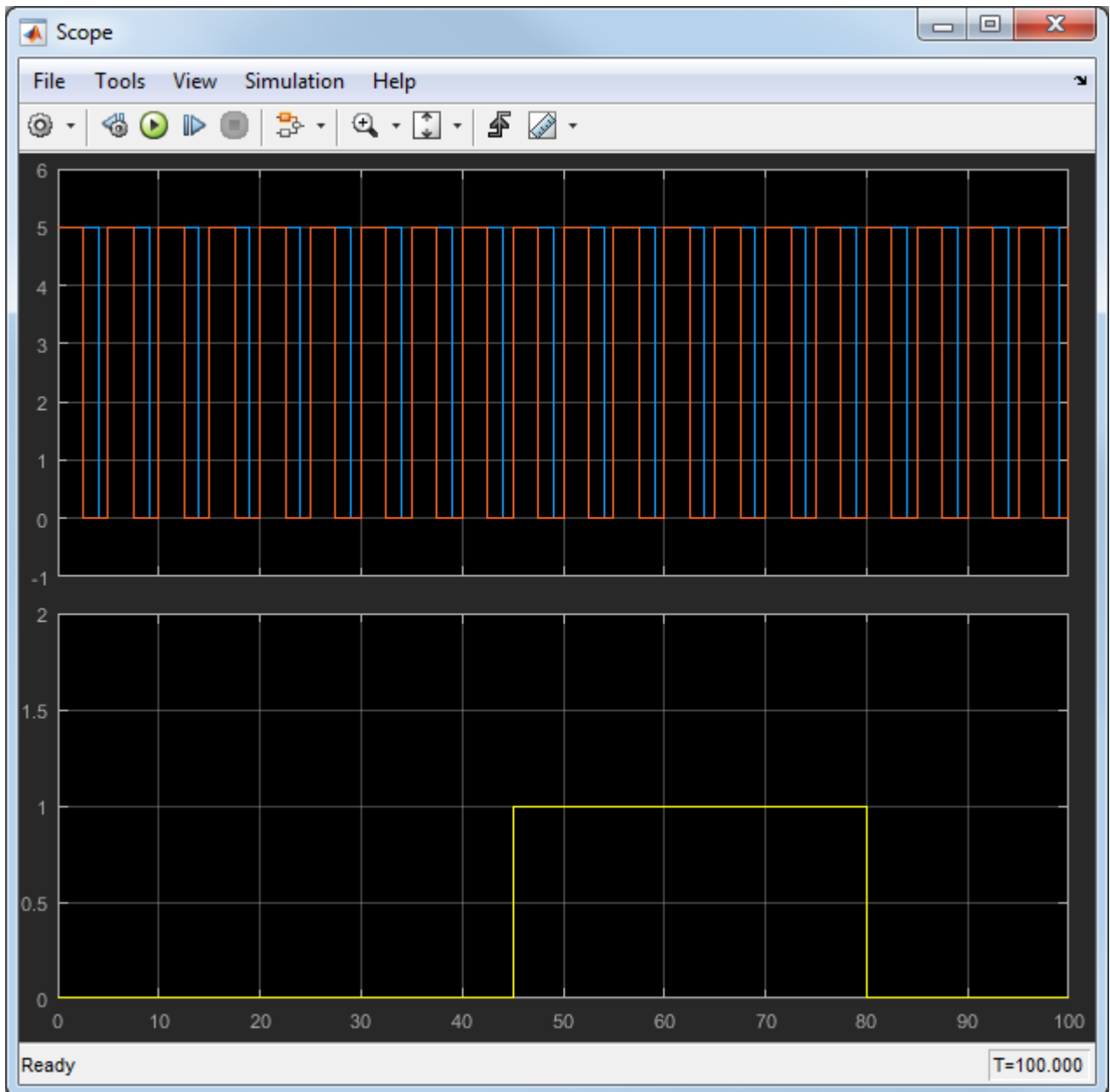
- 2 Double-click the `SensorSignals` block to see the three sensor signals represented by pulse generator blocks.

The `sensors` signal indicates when the assembly part is ready to move to the next station.

- 3 Double-click the `AlarmSignal` block to see the step blocks that represent the alarm signal.

When the `ALARM` signal is active, the machine turns off.

- 4 Run the model to see the output of the sensor and alarm signals in the Scope block.

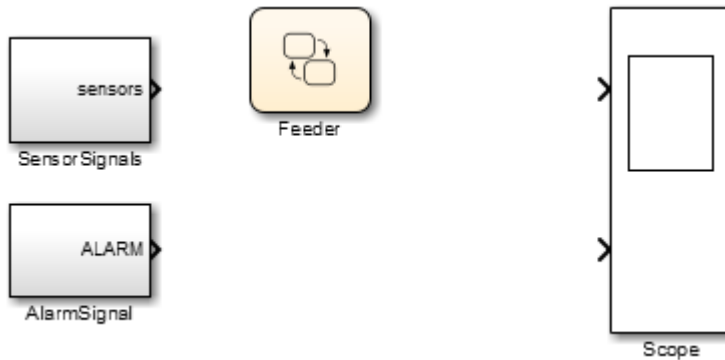


The upper axis shows the sensor signals. Only two sensor signals appear because two of the sensors have the same signal. The lower axis shows the alarm signal which turns the feeder off between the simulation time of 45 to 80 seconds.

- 5 Open the Stateflow Library by executing `sflib` at the MATLAB command prompt.
- 6 Select Chart and drag it into your model.

**Tip** To create a new model with an empty Stateflow chart which uses MATLAB as the action language, use the function `sfnw`.

- 7 Delete the connections from the SensorSignals subsystem to the scope and from the AlarmSignal subsystem to the scope.
- 8 Rename the label Chart located under the Stateflow chart to Feeder. The model should now look like this:



## Add States to Represent Operating Modes

Based on the system attributes previously described, there are three operating modes:

- System initialization
- On
- Failure state

To add states for modeling the behavior of these operating modes:

- 1 Double-click the Feeder Chart to begin adding states.

---

**Note** The MATLAB icon in the lower left corner of the chart indicates that you are using a Stateflow chart with MATLAB syntax.



- 2 Click the State Tool icon to bring a state into the chart.



- 3 Click the upper left corner of the state and type the name, `InitializeSystem`.
- 4 Repeat steps 2 and 3 to add two more states named `On` and `FailState`.

## Implement State Actions

### Decide the Type of State Action

States perform actions at different phases of their execution cycle from the time they become active to the time they become inactive. Three basic state actions are:

Type of Action	When Executed	How Often Executed While State Is Active
Entry	When the state is entered (becomes active)	Once
During	While the state is active and no valid transition to another state is available	At every time step
Exit	Before a transition is taken to another state	Once

For example, you can use entry actions to initialize data, during actions to update data, and exit actions to configure data for the next transition. For more information about other types of state actions, see “Syntax for States and Transitions”.)

- 1 Press return after the `InitializeSystem` state name and add this text to define the state entry action:

```
entry:
Light = ORANGE;
```

An orange LED indicates entry into the `InitializeSystem` state.

### Syntax for an entry action

The syntax for entry actions is:

```
entry: one or more actions;
```

- 2 Add the following code after the `FailState` state name to define the entry action:

```
entry:
Light = RED;
```

A red LED indicates entry in the `FailState`.

- 3 Add the following code after the `On` state name to define the entry action:

```
entry:
Light = GREEN;
partsFed = 0;
```

A green LED indicates entry in the `On` state. The number of parts fed is initialized to 0 each time we enter the `On` state.

- 4 Add the following code to the `On` state after the entry action to check if there is a strong sensor signal and increment the parts fed to the next station:

```
during:
if(any(sensors >= 2))
    partsFed = partsFed + 1;
end
```

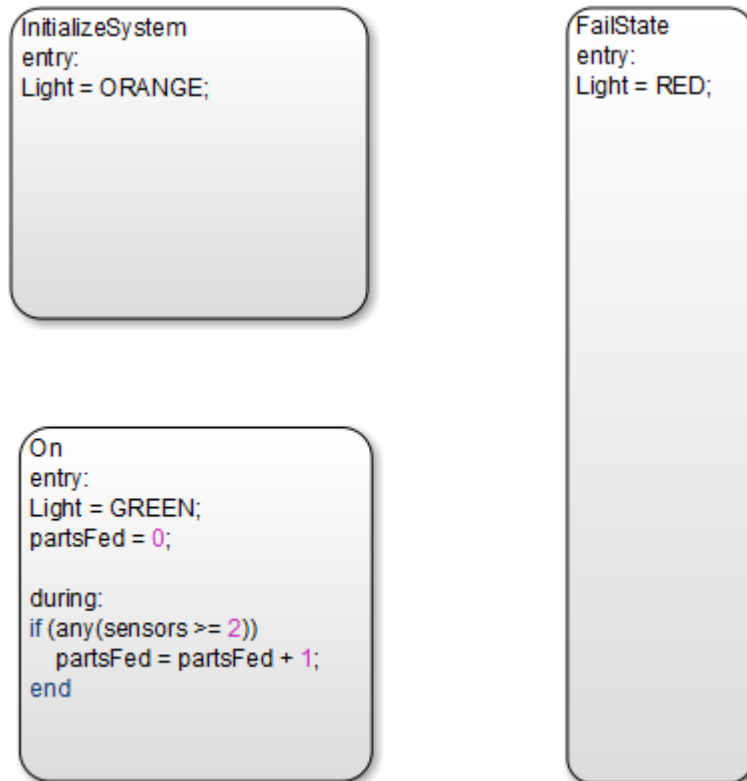
The `On` state checks the sensor signal to determine if a part is ready to be fed to the next assembly station. If the sensor signal is strong (the number of sensors that are on is greater than or equal to 2), then the chart counts the part as having moved on to the next station.

### Syntax for during actions

The syntax for during actions is:

during: *one or more actions*;

The chart should now look like this figure.



### Specify Transition Conditions

Transition conditions specify when to move from one operating mode to another. When the condition is true, the chart takes the transition to the next state. Otherwise, the current state remains active. For more information, see “Transitions” on page 2-21.

Based on the description of feeder behavior, specify the rules for transitions between states:

- 1 Connect a default transition to the `InitializeSystem` state to indicate the chart entry point.



“Default Transitions” on page 2-33 specify where to begin the simulation.

- 2 Draw a transition from the `InitializeSystem` state to the `On` state:
  - a Move the mouse over the lower edge of the `InitializeSystem` state until the pointer shape changes to crosshairs.



- b Click and drag the mouse to the upper edge of the On state. You then see a transition from the InitializeSystem state to the On state.
- c Double-click the transition to add this condition:

```
[all(sensors>0)]
```

This transition condition verifies if all of the sensors have values greater than zero.

- 3 Repeat these steps to create these remaining transition conditions.

Transition	Condition
On to FailState	[Alarm == 1]
FailState to InitializeSystem	[Alarm == 0]

- 4 Draw another transition from InitializeSystem to FailState. On this transition, type the following to create the transition event:

```
after(5,sec)
```

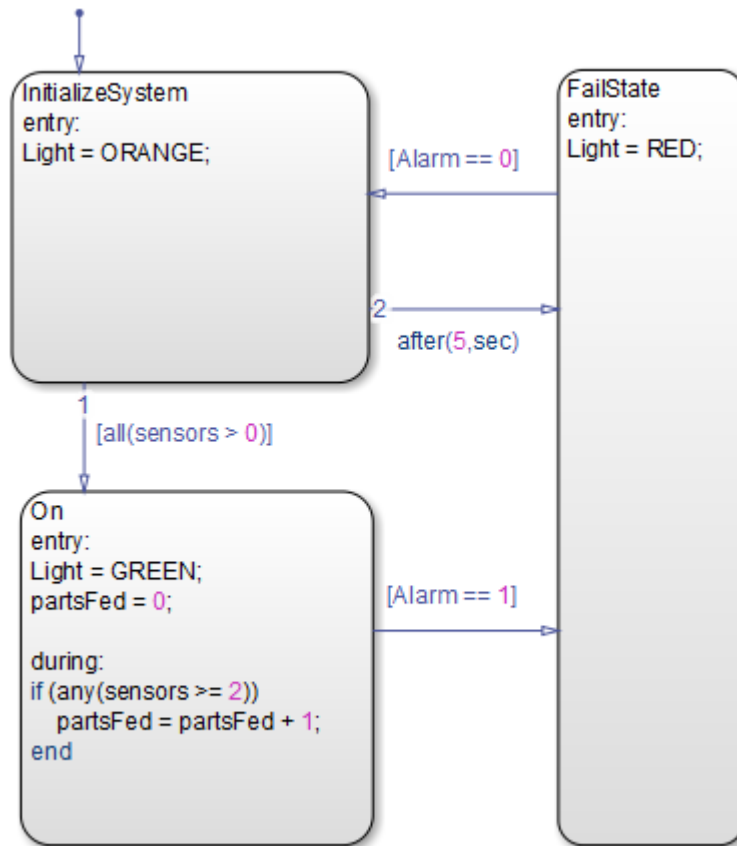
If the sensors have not turned on after 5 seconds, this syntax specifies a transition from InitializeSystem to FailState.

---

**Note** The syntax on this transition is an event rather than a transition condition. For more information, see “Control Chart Execution by Using Temporal Logic” on page 16-36.

---

The chart now looks like this figure.




---

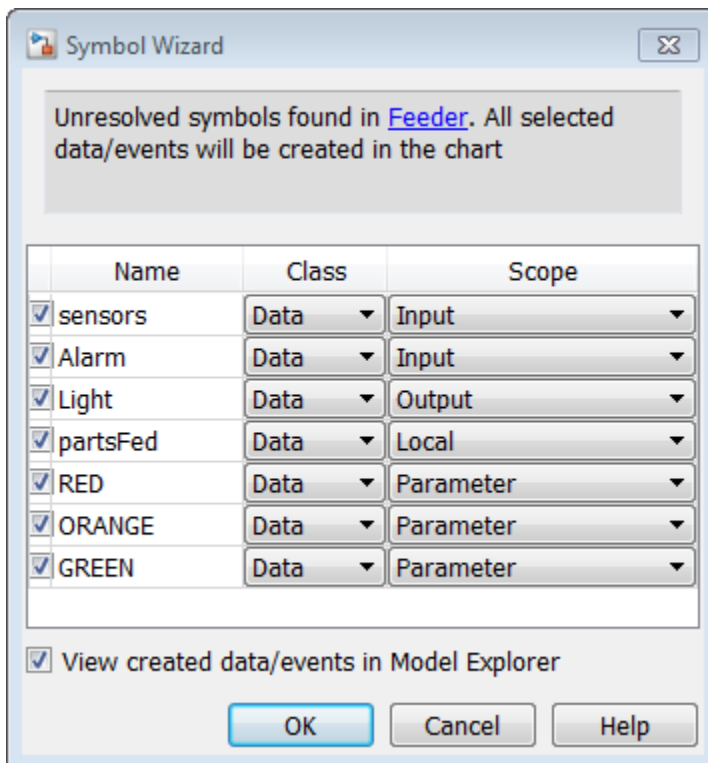
**Note** The outgoing transitions from `InitializeSystem` have a small label 1 and 2 to indicate the order in which transition segments are evaluated. If the numbers from the figure do not match your model, right click the transition and then change it by clicking on `Execution Order`. See “Transition Evaluation Order” on page 3-38 for details.

---

## Define Data for Your System

### Verify the Chart Data Properties

Start the simulation of your model. Errors about unresolved symbols appear, along with the Symbol Wizard.



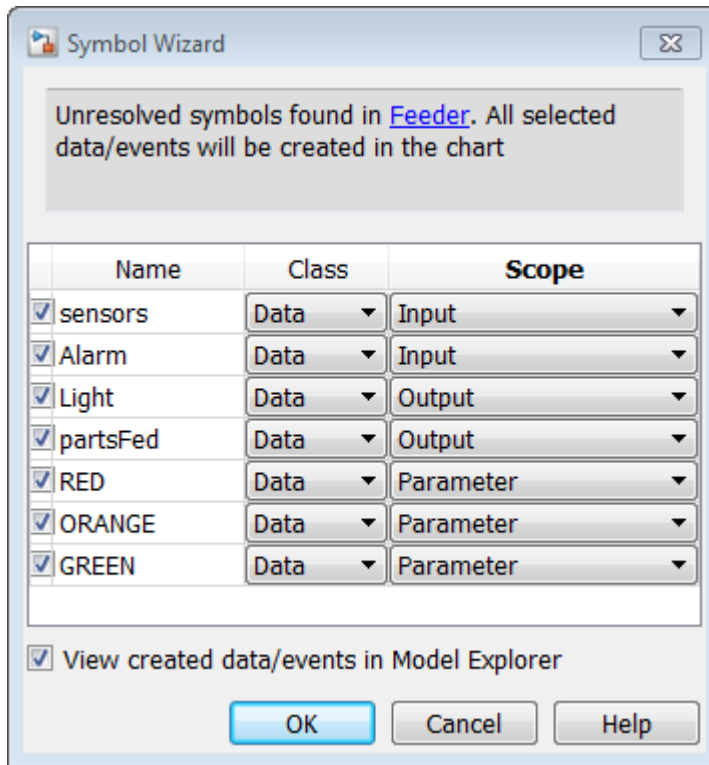
The Symbol Wizard does not automatically add any data to your chart. It identifies the unresolved data and infers the class and scope of that data using the inference rules of MATLAB expressions in Stateflow actions. In the chart:

- Data that is read from but not written to is inferred as *input* data. However, if the name of the data is in all uppercase letters, the Symbol Wizard infers the data as a *parameter*
- Data that is written to but not read from is inferred as *output* data.
- Data that is read from and written to is inferred as *local* data.

The Symbol Wizard infers the scope of the input data in your chart. However, you must fix the data scope for the `partsFed` Output. Follow these steps:

- 1 For the **partsFed** data: in the **Scope** column, select **Output** from the list.

The Symbol Wizard now looks like this figure.



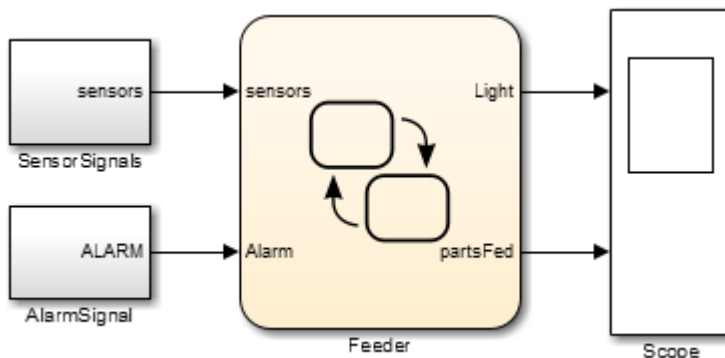
- 2 To add the data that the Symbol Wizard suggests, click **OK**.
- 3 Add initial values for the parameters. At the MATLAB command prompt, enter:

RED = 0;

- 4 Similarly, at the MATLAB command prompt, add the following initial values for the remaining parameters:

Parameter	Value
RED	0
ORANGE	1
GREEN	2

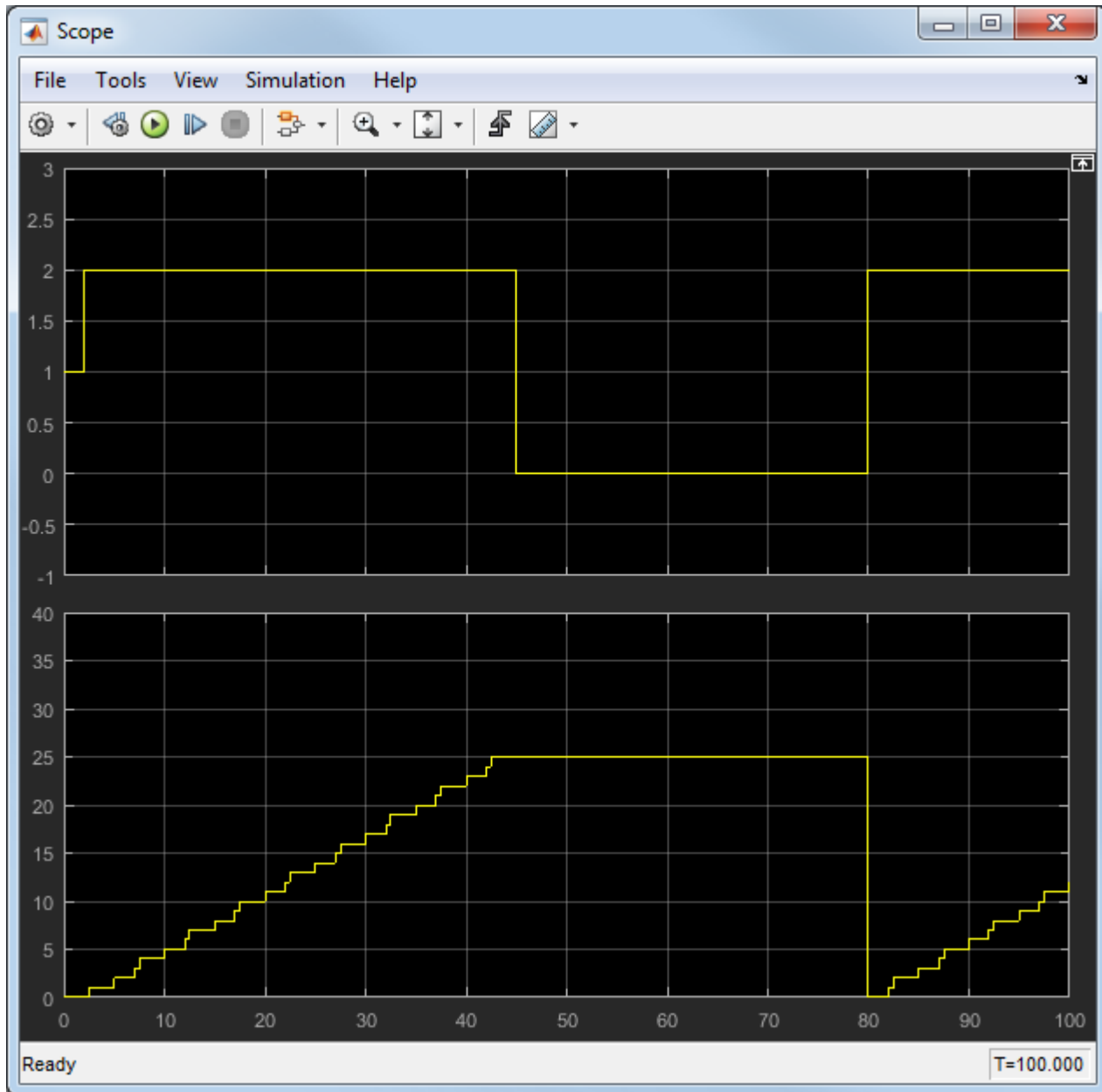
- 5 Return to the model and connect the inputs and outputs to their respective ports.



## Verify the System Representation

- 1 Start the simulation.

Double-click the Scope block to verify that the model captures the expected feeder behavior.



The upper axis shows the LED signal which varies between orange (1), green (2), and red (0) to indicate the current operating mode. The lower axis shows the number of parts fed to the next assembly station, which increases incrementally until the alarm signal turns the machine off and then resets.

## Alternative Approach: Event-Based Chart

Another approach to programming the chart is to start by identifying parts of the system interface, such as events to which your system reacts.

In the previous example, when you use input data to represent an event, the chart wakes up periodically and verifies whether the conditions on transitions are valid. In this case, if `ALARM == 1`, then the transition to the failure state happens at the next time step. However, creating a Stateflow chart which reacts to input events allows you to react to the alarm signal when the event is triggered.

For details on when to use an event-based chart, see “Synchronize Model Components by Broadcasting Events” on page 14-2.

### Identify System Attributes for Event-Driven Systems

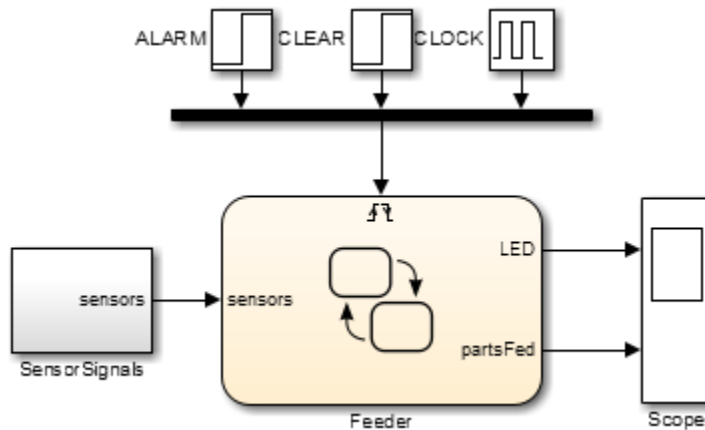
In the event-based approach, the system attributes to consider first are the events, inputs, and outputs.

In the following table, consider the characteristics of the event-driven Feeder Model that are different from the system based on transition conditions.

Attributes	Characteristics
Events	Two asynchronous events: an alarm signal and an all-clear signal
Inputs	Three sensor readings to detect if a part has moved to a downstream assembly station

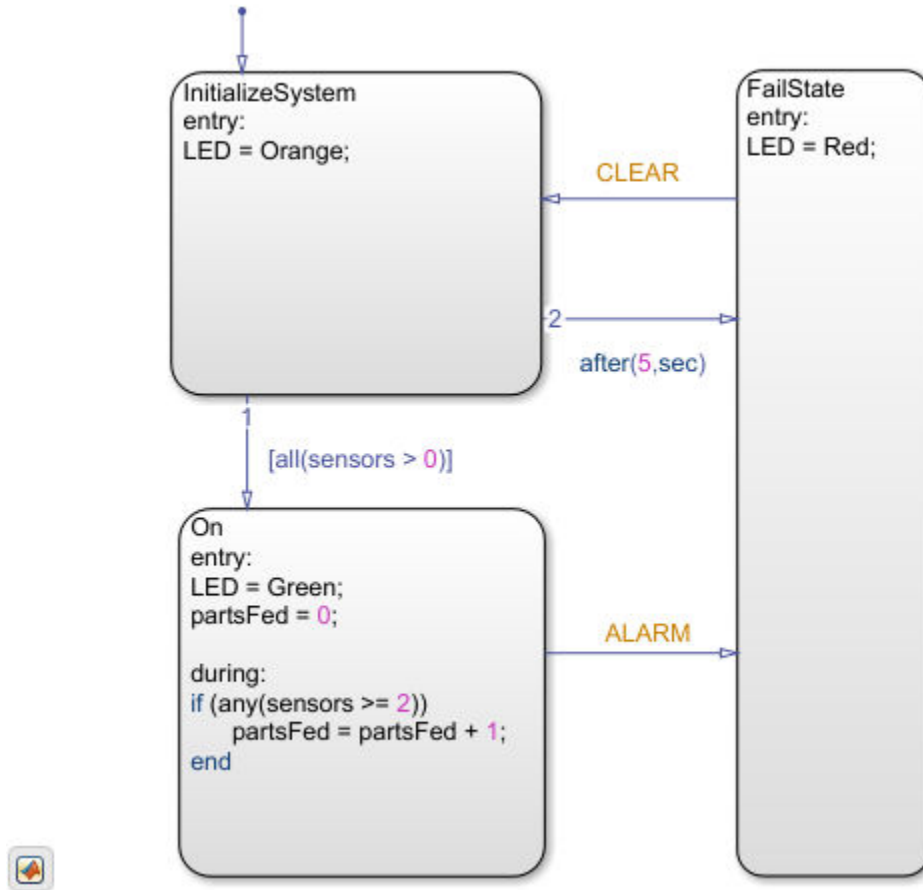
### Feeder Chart Activated by Input Events

In this example, the feeder model reacts to input events using a triggered chart.

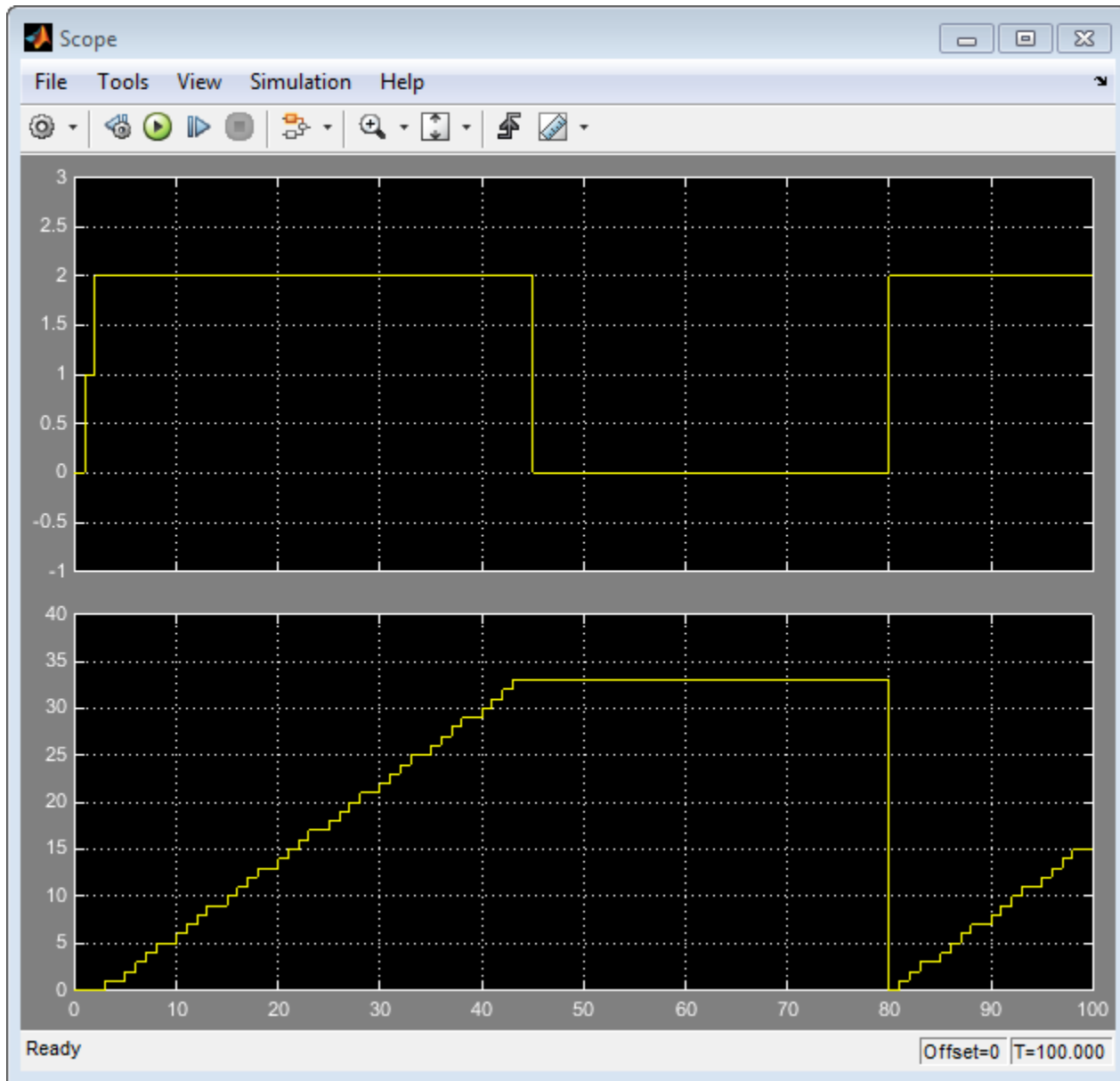


The chart now has only one input port on the left and an event triggered input on the top. For more information on how to create a Stateflow chart activated by events, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7

When the `ALARM` signal triggers the chart, the chart responds to the trigger in that time step. If the current state is `On` when the alarm is triggered, then the current state transitions to `FailState`.



The scope output for the Event-triggered chart is in the following figure.



The upper axis shows the LED signal which varies between red (0), orange (1), and green (2) to indicate the current operating mode. The lower axis shows the number of parts fed to the next assembly station, which increases incrementally until the alarm signal turns the machine off and then resets. However, the event-based simulation feeds more parts to the next assembly station due to clock and solver differences.

### See Also

`sflib` | `sfnew`



# Tabular Expression of Modal Logic

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- “State Transition Tables in Stateflow” on page 18-2
- “State Transition Table Operations” on page 18-7
- “Highlight Flow of Logic in a State Transition Table” on page 18-9
- “State Transition Table Diagnostics” on page 18-11
- “Debug Run-Time Errors in a State Transition Table” on page 18-12
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16
- “Modeling a CD Player/Radio Using State Transition Tables” on page 18-28
- “View Sequential Logic Through State Transition Matrix” on page 18-32

## State Transition Tables in Stateflow

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model.

The benefits of using state transition tables include:

- The ease of modeling train-like state machines, where the modal logic involves transitions from one state to its neighbor
- A concise, compact format for a state machine
- Reduced maintenance of graphical objects
- When you add or remove states from a chart, you have to rearrange states, transitions, and junctions. When you add or remove states from a state transition table, you do not have to rearrange any graphical objects.

State transition tables support using both MATLAB and C as the action language. For more information about the differences between these action languages, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Create a State Transition Table

At the MATLAB command prompt, enter:

- To create a State Transition Table in a new Simulink model, enter:  

```
sfnew -STT
```
- To add a new State Transition Table to an existing model, use the function `add_block`. For example:  

```
add_block('sflib/State Transition Table','myModel/State Transition Table')
```

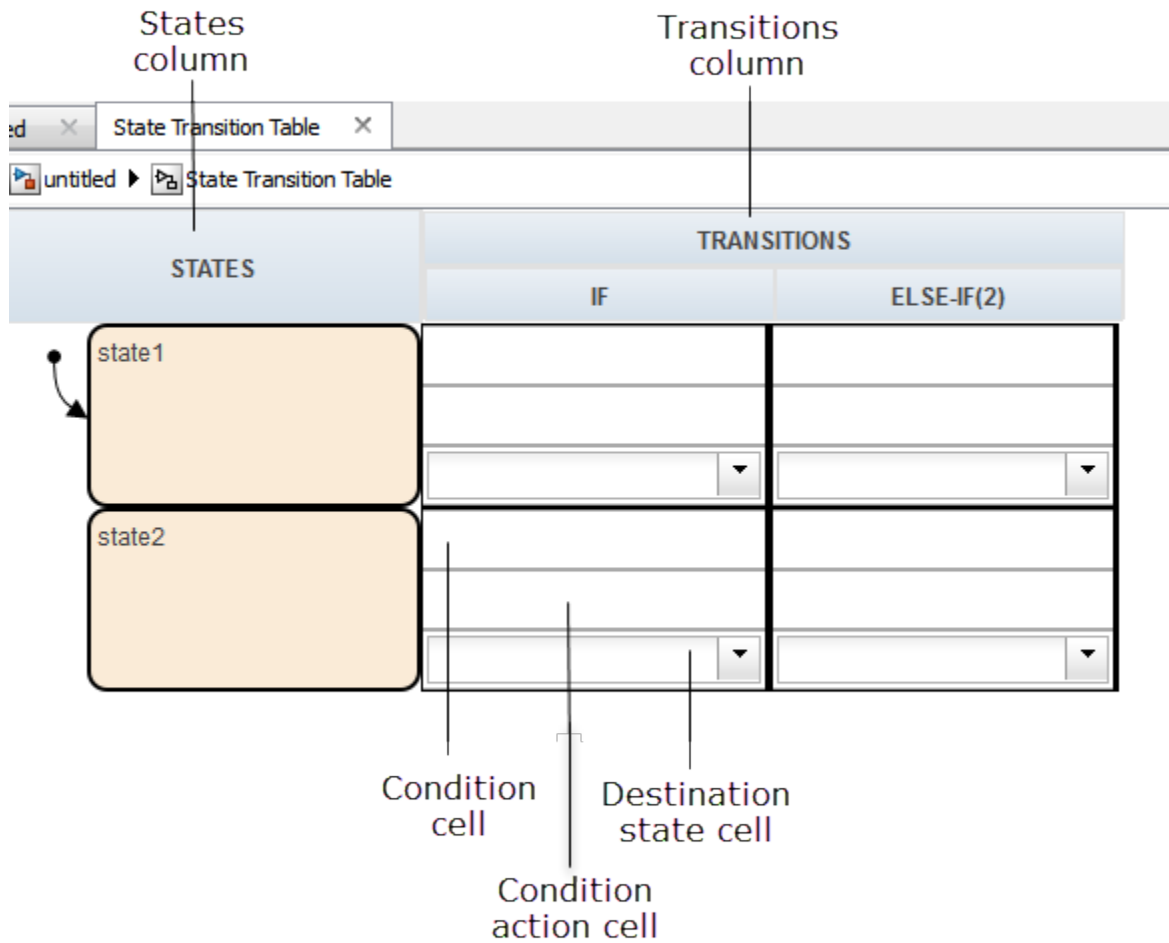
From the Simulink Library Browser:

- 1 Select the Stateflow library.
- 2 Drag a state transition table into your model.



### Anatomy of a State Transition Table

A state transition table contains the following components:

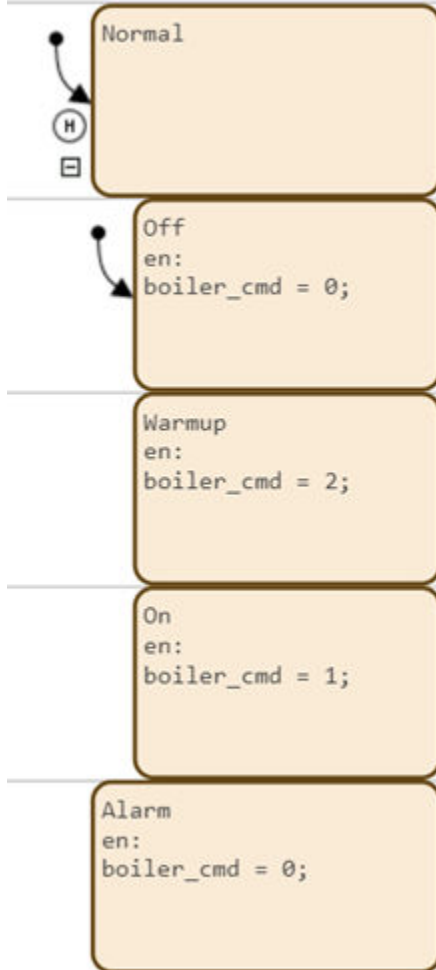


Each transition column contains the following state-to-state transition information:

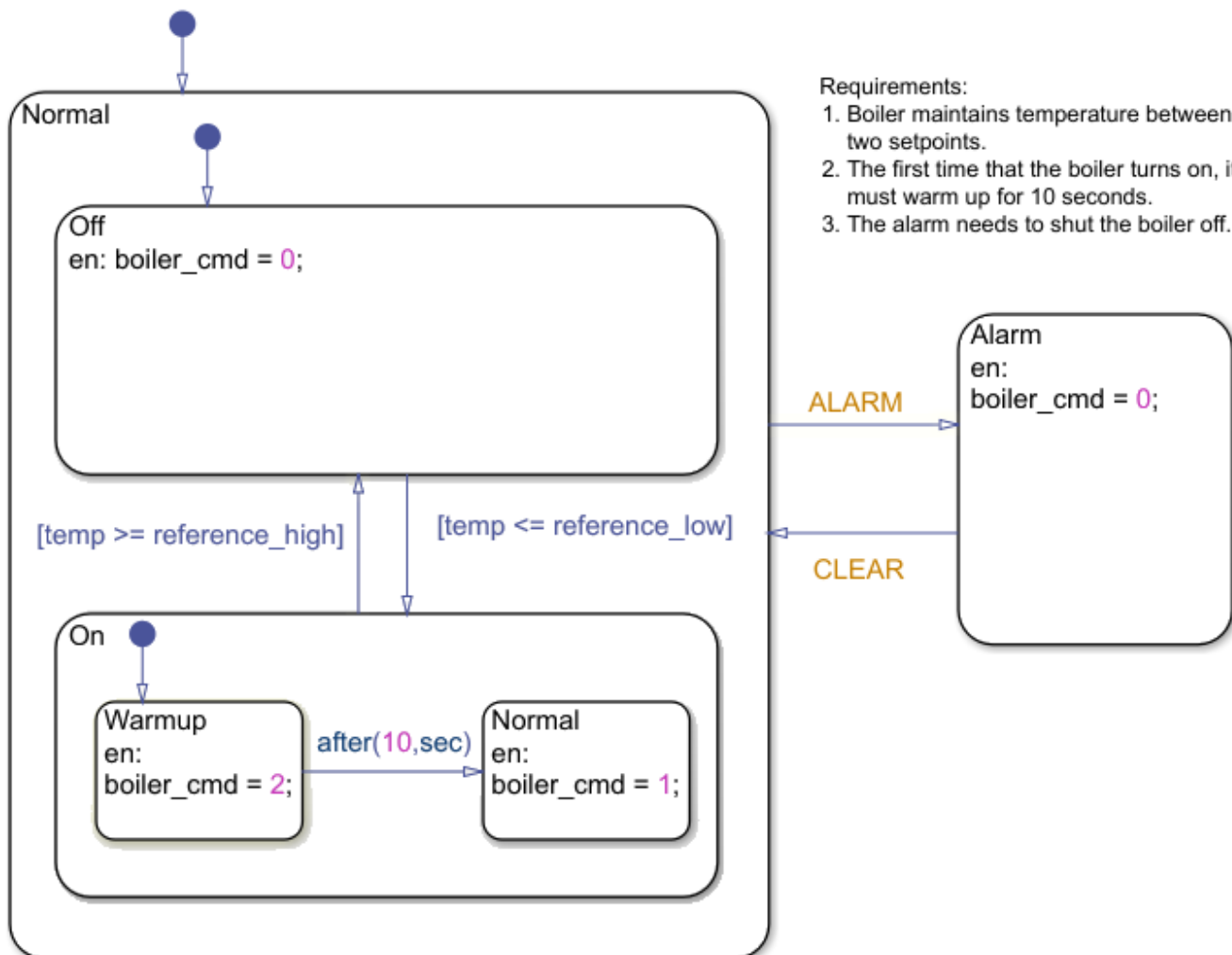
- Condition
- Condition action
- Destination state

### Use a State Transition Chart to Model a Boiler

The following state transition table contains the modal logic for maintaining the temperature of a boiler between two set points:

STATES	TRANSITIONS	
	IF	
 <p>Normal</p>	[ALARM]	
	Alarm	▼
<p>Off en: boiler_cmd = 0;</p>	[temp <= reference_low]	
	Warmup	▼
<p>Warmup en: boiler_cmd = 2;</p>	[after(10,sec)]	
	On	▼
<p>On en: boiler_cmd = 1;</p>	[temp <= reference_high]	
	Off	▼
<p>Alarm en: boiler_cmd = 0;</p>	[CLEAR]	
	Normal	▼

This Stateflow chart represents the same modal logic:



## Differences Between State Transition Tables and Charts

State transition tables support a subset of the most commonly used elements in Stateflow charts. Elements that state transition tables do not support include:

- Supertransitions
- Parallel (AND) decomposition
- Local events
- Flow charts
- Use of chart-level functions (graphical, truth table, MATLAB, and Simulink)

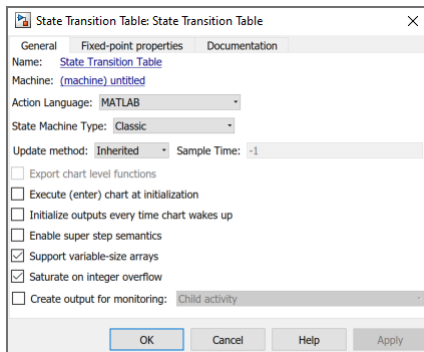
## Guidelines for Using State Transition Tables

- If you specify an action in a transition cell, it must be a condition action.

- State transition tables must have at least one state row and one transition column.

## Specify Properties for State Transition Tables

To open the State Transition Table properties dialog box, in the **Modeling** tab, click **Table Properties**.



The properties for state transition tables are the same as those for charts that use MATLAB as the action language. For a description of each property, see “Specify Properties for Stateflow Charts” on page 28-2.

You can also specify state transition table properties programmatically by using `Stateflow.StateTransitionTableChart` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

## Generate Diagrams from State Transition Tables

Stateflow software automatically generates a read-only state transition diagram from the state transition table you create. As you enter changes to a state transition table, Stateflow incrementally updates the diagram as well. To see the most up-to-date version of the underlying diagram, in the **Debug** tab, click **Show Auto Chart**.

## See Also

State Transition Table

## More About

- “State Transition Table Operations” on page 18-7
- “Debug Run-Time Errors in a State Transition Table” on page 18-12
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16

## State Transition Table Operations

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model. For more information, see “State Transition Tables in Stateflow” on page 18-2.

To create state transition tables, use the Stateflow Editor. You can insert, edit, and move rows and columns. You can also add history junctions and set the default state for the state transition table.

### Insert Rows and Columns

To insert a row:

- 1 Select an existing state.
- 2 In the **Modeling** tab, select one of the following options:

Option	Description
Insert State Row	Inserts a state at the same level of hierarchy.
Insert Child State Row	Inserts a state as a child of the selected state.
Insert Default Transition Path Row	Inserts a row for specifying conditional default transition paths.
Insert Inner Transition Path Row	Inserts a row for specifying inner transitions from the selected parent state to its child states. This row type can only be added to states with children states.

To insert a column:

- 1 In the **Modeling** tab, click **Append Transition Col**. A new `else-if` column appears to the right of the last column.

### Move Rows and Cells

To move a row, click the state cell and drag the row to a new location. As you drag the row, you see a visual indicator of where in the hierarchy the state will appear in its new position.

To move a transition cell, click anywhere in the cell and drag the condition, action, and destination cells as a unit to a new location. The transition cell you displace moves one cell to the right. If column does not exist, Stateflow creates one. The state transition table prevents you from moving cells to an invalid destination and alerts you to the problem.

### Copy Rows and Transition Cells

To copy a row:

- 1 Right-click the state in the row you want to copy and select **Copy**.
- 2 Right-click the state in the destination row and select **Paste**.

The row appears above the destination row.

To copy a transition cell:

- 1 Right-click a cell and select **Copy**.
- 2 Right-click a destination cell of the same type and select **Paste**.

The new content overwrites the existing content at the destination. The state transition table prevents you from copying content to an invalid destination.

## Set Default State

Right-click the state and select **Set to default**.

## Add History Junction

You can add history junctions to states that have children. Right-click the state and select **Add history junction**.

## Print State Transition Tables

To print a copy of the state transition table, press **Ctrl+P (Command+P)**.

## Select and Clear Table Elements

Task	Action
Select a cell for editing	Click the cell.
Exit edit mode in a cell	Press <b>Esc</b> or click another table, cell, row, or column.

## Undo and Redo Edit Operations

To undo the effects of the previous operation, press **Ctrl+Z (Command+Z)**.

To redo the effects of the previous operation, press **Ctrl+Y (Command+Y)**.

You can undo and redo up to 10 operations.

## See Also

### More About

- “State Transition Tables in Stateflow” on page 18-2
- “Debug Run-Time Errors in a State Transition Table” on page 18-12
- “View Sequential Logic Through State Transition Matrix” on page 18-32



## Highlight Flow of Logic in a State Transition Table

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model. For more information, see “State Transition Tables in Stateflow” on page 18-2.

To visualize a flow of logic, you can highlight one transition cell per row in your state transition table. Highlighting can be used to show the primary flow of logic from one state to another or the flow that represents an error condition.

The highlighting persists across MATLAB sessions and appears in the autogenerated state transition diagram and the state transition table.


To highlight transition cells:

- 1 In the transition table editor, right-click the transition cell and select **Mark as primary transition**.

The transition cell appears with a red border.

- 2 To complete the flow, highlight additional cells, one per row.

For example:

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
Normal 	[ALARM]	
	Alarm	
Off entry: boiler_cmd = 0; doneWarmup = false;	[temp <= reference_low]	
	Warmup	
Warmup entry: boiler_cmd = 2;	[doneWarmup]	[after(10, sec)]
	On	{doneWarmup = true;}
On entry: boiler_cmd = 1;	[temp >= reference_high]	
	Off	
Alarm entry: boiler_cmd = 0;	[CLEAR]	
	Normal	

- To view the flow in the autogenerated state diagram, in the **Debug** tab, click **Show Auto Chart**.  
The transitions that represent the flow appear highlighted in the diagram.

## See Also

### More About

- “State Transition Tables in Stateflow” on page 18-2
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16
- “Debug Run-Time Errors in a State Transition Table” on page 18-12

## State Transition Table Diagnostics

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model. For more information, see “State Transition Tables in Stateflow” on page 18-2.

You can run diagnostic checks on a state transition table. From the Stateflow Editor, in the **Debug** tab, select **Update Model > Update Table**.

The diagnostics tool statically parses the table to find errors such as:

- States with no incoming transitions
- Transition cells with conditions or actions, but no destination
- Action text in a condition cell
- States that are unreachable from the default transition
- Default transition row without unconditional transition
- Inner transition row execution order mismatches. The inner transition row for a state must specify destination states from left to right in the same order as the corresponding states appear in the table, from top to bottom.

Each error is reported with a hyperlink to the corresponding object causing the error. These checks are also performed during simulation.

### See Also

#### More About

- “State Transition Tables in Stateflow” on page 18-2
- “Debug Run-Time Errors in a State Transition Table” on page 18-12
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16

## Debug Run-Time Errors in a State Transition Table

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model. For more information, see “State Transition Tables in Stateflow” on page 18-2.

### Create the Model and the State Transition Table

- 1 Create a Simulink model with a new State Transition Table.

`sfnew -STT`

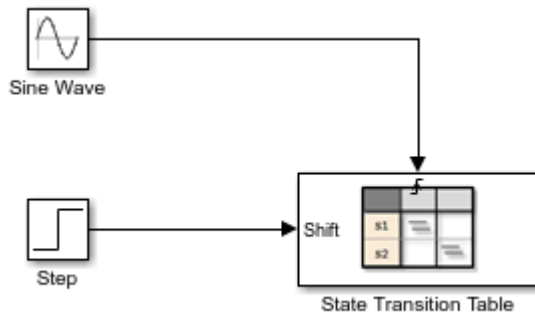
- 2 Add the following states and transitions to your table:

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
Power_off	[SWITCH]	
	Power_on	
Power_on	[SWITCH]	
	Power_off	
First	[Shift == 1]	
	Second	
Second	[Shift == 1]	
	Third	
Third	[Shift == 1]	
	First	

The table has two states at the highest level in the hierarchy, `Power_off` and `Power_on`. By default, `Power_off` is active. The event `SWITCH` toggles the system between the `Power_off` and `Power_on` states. `Power_on` has three substates: `First`, `Second`, and `Third`. By default, when `Power_on` becomes active, `First` also becomes active. When `Shift` equals 1, the system

transitions from *First* to *Second*, *Second* to *Third*, and *Third* to *First*, for each occurrence of the event *SWITCH*. Then the pattern repeats.

- 3 Add two inputs on page 12-2 from Simulink:
  - An event called *SWITCH* with a scope of **Input from Simulink** and a **Rising** edge trigger.
  - A data called *Shift* with a scope of **Input from Simulink**.
- 4 In the model view, connect a Sine Wave block as the *SWITCH* event and a Step block as the *Shift* data for your State Transition Table.




In the model, there is an event input and a data input. A Sine Wave block generates a repeating input event that corresponds with the Stateflow event *SWITCH*. The Step block generates a repeating pattern of 1 and 0 that corresponds with the Stateflow data object *Shift*. Ideally, the *SWITCH* event occurs at a frequency that allows at least one cycle through *First*, *Second*, and *Third*.

## Debug the State Transition Table

To debug the table in “Create the Model and the State Transition Table” on page 18-12, follow these steps:

- 1 Right-click the *Power\_off* state, and select **Set Breakpoint > On State Entry**.
- 2 Start the simulation.

Because you specified a breakpoint on *Power\_off*, execution stops at that point.

- 3 Move to the next step by clicking the Step In button,  .
- 4 To see the data used and the current values, hover your cursor over the different table cells.

Continue clicking the Step In button and watching the animating states. After each step, watch the chart animation to see the sequence of execution. Use the tooltips to see the data values.

Single-stepping shows that the loop from *First* to *Second* to *Third* inside the state *Power\_on* does not occur. The transition from *Power\_on* to *Power\_off* takes priority.

## Correct the Run-Time Error

In “Debug the State Transition Table” on page 18-13, you step through a simulation of a state transition table and find an error. The event SWITCH drives the simulation, but the simulation time passes too quickly for the input data object Shift to have an effect.

To correct this error:

- 1 Stop the simulation so that you can edit the table.
- 2 Add the condition after(20.0, sec) to the transition from Power\_on to Power\_off.

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
Power_off	[SWITCH]	
	Power_on	
Power_on	[SWITCH && after(20.0,sec)]	
	Power_off	
First	[Shift == 1]	
	Second	
Second	[Shift == 1]	
	Third	
Third	[Shift == 1]	
	First	

Now the transition from Power\_on to Power\_off does not occur until 20 seconds have passed.

- 3 Begin simulation.
- 4 Click the Step In button repeatedly to observe the fixed behavior.

## See Also

### Related Examples

- “State Transition Tables in Stateflow” on page 18-2
- “State Transition Table Diagnostics” on page 18-11
- “Model Bang-Bang Controller by Using a State Transition Table” on page 18-16

## Model Bang-Bang Controller by Using a State Transition Table

A state transition table is an alternative way of expressing sequential modal logic. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink model. For more information, see “State Transition Tables in Stateflow” on page 18-2.

### Design Requirements

This example shows how to model a bang-bang controller for temperature regulation of a boiler, using a state transition table. The controller must turn the boiler on and off to meet the following design requirements:

- High temperature cannot exceed 25 degrees Celsius.
- Low temperature cannot fall below 23 degrees Celsius.
- Steady-state operation requires a warm-up period of 10 seconds.
- When the alarm signal sounds, the boiler must shut down immediately.
- When the all-clear signal sounds, the boiler can turn on again.

### Identify System Attributes

You can identify the operating modes and data requirements for the bang-bang controller based on its design requirements.

#### Operating Modes

The high-level operating modes for the boiler are:

- Normal operation, when no alarm signal sounds.
- Alarm state, during an alarm signal.

During normal operation, the boiler can be in one of three states:

- Off, when the temperature is above 25 degrees Celsius.
- Warm-up, during the first 10 seconds of being on.
- On, steady-state after 10 seconds of warm-up, when the temperature is below 23 degrees Celsius.

#### Data Requirements

The bang-bang controller requires the following data.

Scope	Description	Variable Name
Input	High temperature set point	reference_high
Input	Low temperature set point	reference_low
Input	Alarm indicator	ALARM
Input	All-clear indicator	CLEAR
Input	Current temperature of the boiler	temp



Scope	Description	Variable Name
Local	Indicator that the boiler completed warm-up	doneWarmup
Output	Command to set the boiler mode: off, warm-up, or on	boiler_cmd

## Build the Controller or Use the Supplied Model

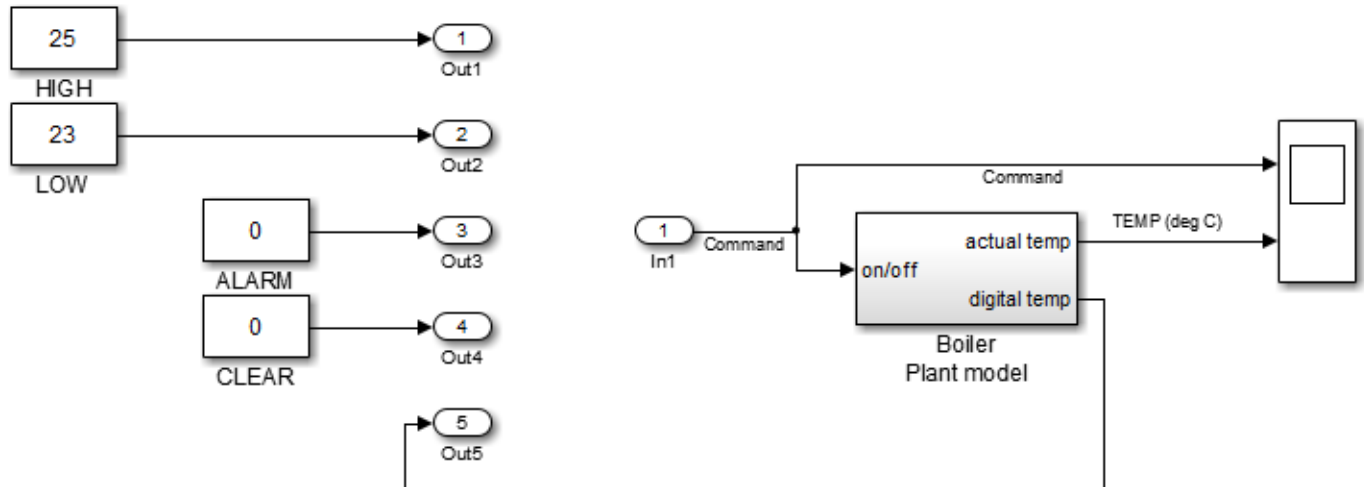
To build the bang-bang controller model yourself using a state transition table, follow these exercises. Otherwise, you can open the completed model.

### Create a New State Transition Table

To represent the bang-bang controller, use a state transition table. Compared to a graphical state transition diagram, the state transition table is a compact way to represent modal logic that involves transitions between neighboring states. For this example, use MATLAB as your action language.

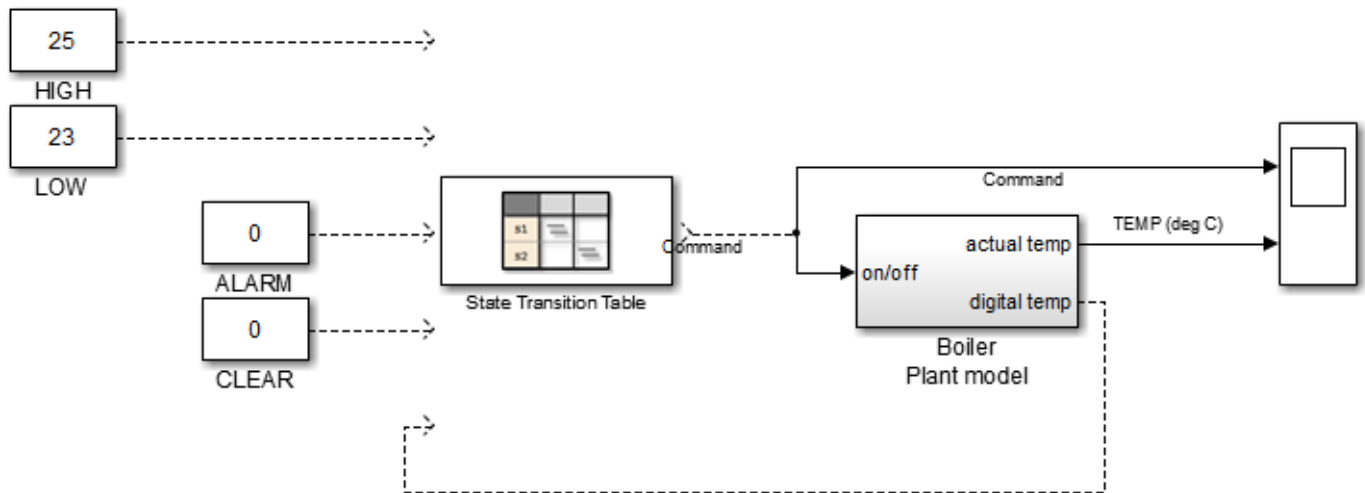
- 1 Open the partially built boiler plant model.

This model contains all required Simulink blocks, except for the bang-bang controller.



- 2 Delete the five output ports and the single input port.
- 3 Open the Library Browser. In the **Simulation** tab, click **Library Browser**.
- 4 In the left pane of the Library Browser, select the Stateflow library, then drag a State Transition Table block from the right pane into your boiler model.

Your model looks like this model.



- 5 Close the Library Browser.

Now you are ready to add states and hierarchy to the state transition table.

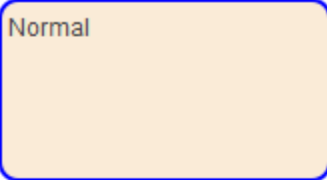

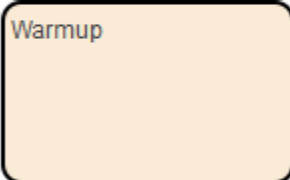
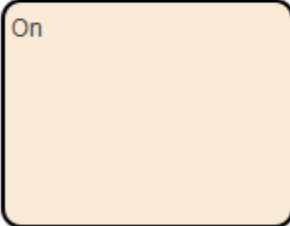

## Add States and Hierarchy

To represent the operating modes of the boiler, add states and hierarchy to the state transition table.

- 1 Open the state transition table.
- 2 Represent the high-level operating modes: normal and alarm.
  - a Double-click `state1` and rename it `Normal`.
  - b Double-click `state2` and rename it `Alarm`.
- 3 Represent the three states of normal operation as substates of `Normal`:
  - a Right-click the `Normal` state, select **Insert Row > Child State Row**, and name the new state `Off`.
  - b Repeat step a two more times to create the child states `Warmup` and `On`, in that order.

By default, when there is ambiguity, the top exclusive (OR) state at every level of hierarchy becomes active first. For this reason, the `Normal` and `Off` states appear with default transitions. This configuration meets the design requirements for this model. To set a default state, right-click the state and select **Set to default**.

Your state transition table looks like this table.

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
 Normal		
 Off		
 Warmup		
 On		
 Alarm		

Now you are ready to specify actions for each state.

### Specify State Actions


To describe the behavior that occurs in each state, specify state actions in the table. In this exercise, you initialize modes of operation as the boiler enters normal and alarm states, using the variables `boiler_cmd` and `doneWarmup` (described in “Data Requirements” on page 18-16).

- 1 In the following states, click after the state name, press **Enter**, and type the specified entry actions.

In State:	Type:	Resulting Behavior
Off	entry: boiler_cmd = 0; doneWarmup = false;	Turns off the boiler and indicates that the boiler has not warmed up.
Warmup	entry: boiler_cmd = 2;	Starts warming up the boiler.
On	entry: boiler_cmd = 1;	Turns on the boiler.
Alarm	entry: boiler_cmd = 0;	Turns off the boiler.

2 Save the state transition table.

Your state transition table looks like this table.

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
Normal 		
Off entry: boiler_cmd = 0; doneWarmup = false;		
Warmup entry: boiler_cmd = 2;		
On entry: boiler_cmd = 1;		
Alarm entry: boiler_cmd = 0;		

Now you are ready to specify the conditions and actions for transitioning from one state to another state.

### Specify Transition Conditions and Actions

To indicate when to change from one operating mode to another, specify transition conditions and actions in the table. In this exercise, you construct statements using variables described in “Data Requirements” on page 18-16.

- 1 In the Normal state row, enter:

<b>if</b>
[ALARM]

if
<b>Alarm</b>

During simulation:

- a When first entered, the chart activates the Normal state.
- b At each time step, normal operation cycles through the Off, Warmup, and On states until the ALARM condition is true.
- c When the ALARM condition is true, the boiler transitions to the Alarm state and shuts down immediately.

2 In the Off state row, enter:

if
[temp <= reference_low]
<b>Warmup</b>

During simulation, when the current temperature of the boiler drops below 23 degrees Celsius, the boiler starts to warm up.

3 In the Warmup state row, enter:

if	else-if
[doneWarmup]	[after(10, sec)]
	{doneWarmup = true;}
<b>On</b>	<b>On</b>

During simulation, the boiler warms up for 10 seconds and then transitions to the On state.

4 In the On state row, enter:

if
[temp >= reference_high]
<b>Off</b>

During simulation, when the current temperature of the boiler rises above 25 degrees Celsius, the boiler shuts off.

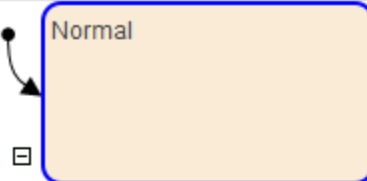
5 In the Alarm state row, enter:

if
[CLEAR]
<b>Normal</b>

During simulation, when the all-clear condition is true, the boiler returns to normal mode.

6 Save the state transition table.

Your state transition table looks like this table.

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
Normal 	[ALARM]	
	Alarm	
Off entry: boiler_cmd = 0; doneWarmup = false;	[temp <= reference_low]	
	Warmup	
Warmup entry: boiler_cmd = 2;	[doneWarmup]	[after(10, sec)]
	On	{doneWarmup = true;}
On entry: boiler_cmd = 1;	[temp >= reference_high]	
	Off	
Alarm entry: boiler_cmd = 0;	[CLEAR]	
	Normal	

Now you are ready to add data definitions using the Symbol Wizard.

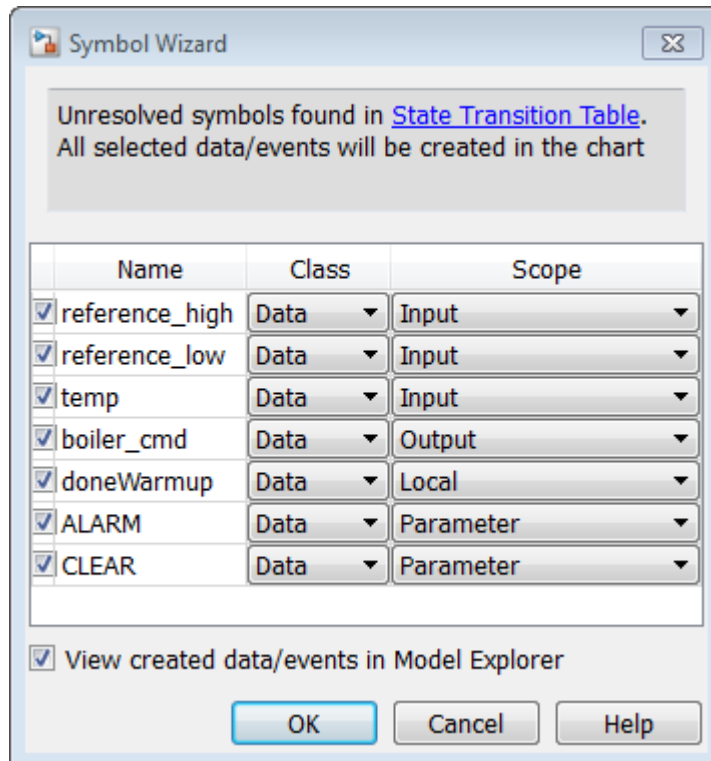
### Define Data

When you create a state transition table that uses MATLAB syntax, there are language requirements for C/C++ code generation. One of these requirements is that you define the size, type, and complexity of all MATLAB variables so that their properties can be determined at compile time. Even though you have not yet explicitly defined the data in your state transition table, you can use the Symbol Wizard. During simulation, the Symbol Wizard alerts you to unresolved symbols, infers their properties, and adds the missing data to your table.

- 1 In the Simulink model , select **Run**.

Two dialog boxes appear:

- The Diagnostic Viewer indicates that you have unresolved symbols in the state transition table.
- The Symbol Wizard attempts to resolve the missing data. The wizard correctly infers the scope of all data except for the inputs **ALARM** and **CLEAR**.



- 2 In the Symbol Wizard, correct the scopes of **ALARM** and **CLEAR** by selecting **Input** from their Scope drop-down lists.
- 3 When the Model Explorer opens, verify that the Symbol Wizard added all required data definitions correctly.

Some of the inputs are assigned to the wrong ports.

- 4 In the Contents pane of the Model Explorer, reassign input ports as follows:

Assign:	To Port:
reference_low	2
reference_high	1
temp	5
ALARM	3
CLEAR	4

- 5 Save the state transition table.

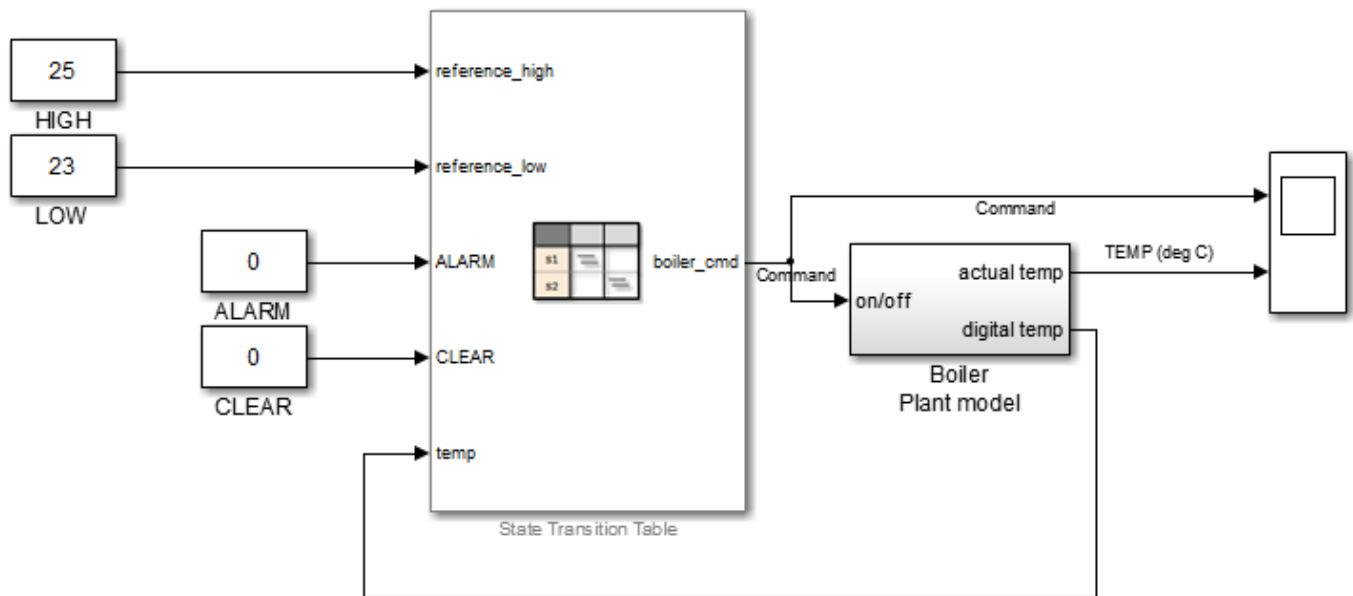


- 6 Close the Diagnostic Viewer and the Model Explorer.

In the Simulink model, the inputs and outputs that you defined appear in the State Transition Table block. Now you are ready to connect these inputs and outputs to the Simulink signals and run the model.

## Connect the Transition Table and Run the Model

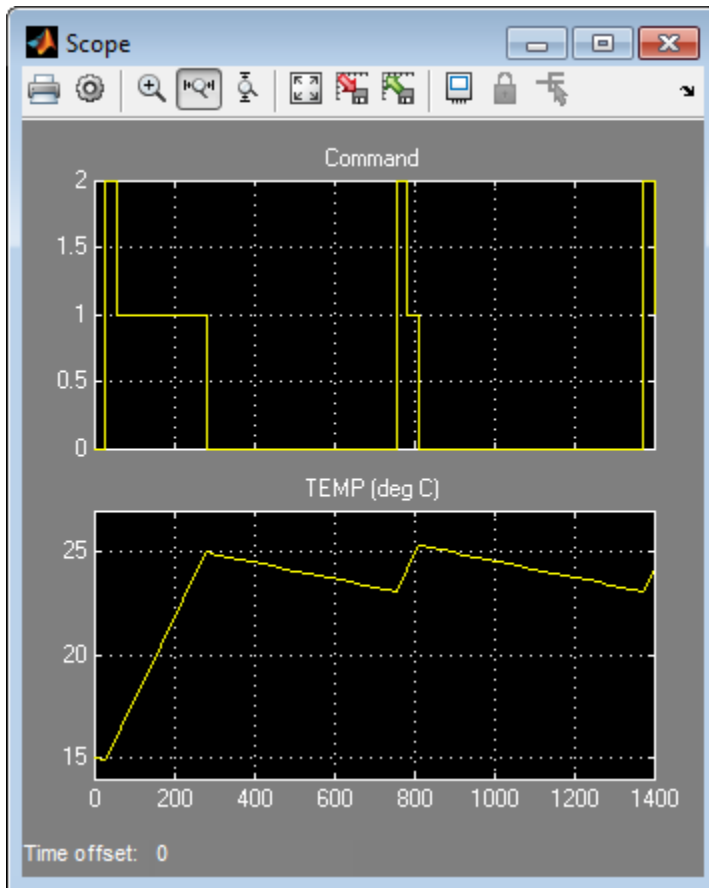
- 1 In the Simulink model, connect the state transition table to the Simulink inputs and outputs:



- 2 Save the model.
- 3 Reopen your state transition table.
- 4 Start the simulation by selecting **Run**.

As the simulation runs, you can watch the animation in the state transition table activate different states.

The following output appears in the Scope block.



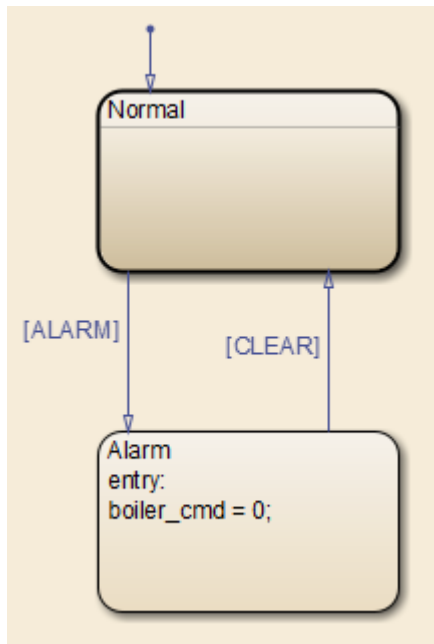
When performing interactive debugging, you can set breakpoints on different states and view the data values at different points in the simulation. For more information about debugging, see “Debugging Stateflow Charts” on page 33-2.

## View the Graphical Representation

Stateflow automatically generates a read-only graphical representation of the state transition table you created.

- 1 In the **Debug** tab, click **Show Auto Chart**.

The top-level state transition diagram:



The Normal state appears as a subchart.

- 2 To view the states and transitions the chart contains, double-click the Normal state.

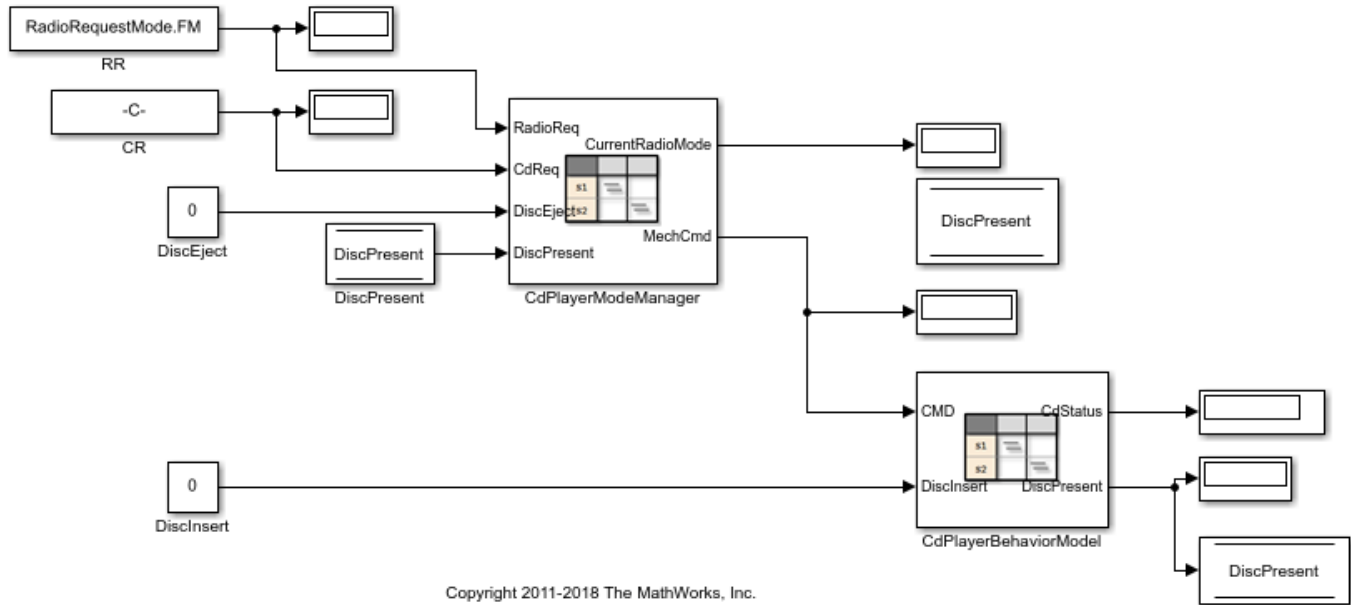
## See Also

### More About

- “State Transition Tables in Stateflow” on page 18-2
- “State Transition Table Operations” on page 18-7
- “Debug Run-Time Errors in a State Transition Table” on page 18-12

## Modeling a CD Player/Radio Using State Transition Tables

This example shows a simple model of a CD Player/Radio logic that uses State Transition Tables in Stateflow®. This model is a reimplement of `sf_cdplayer` using State Transition Tables.



The heart of the logic for controlling the CD Player/Radio is in the "CdPlayerModeManager" chart, which is designed using a State Transition Table. The table is used to represent modal logic in tabular form. It allows us to define various states and their hierarchical structure along with the transitions between the states.

States column

Transitions column

STATES	TRANSITIONS		
	IF	ELSE-IF(2)	ELSE-IF(3)
ModeManager	[DiscEject]		
Standby entry: CurrentRadioMode = RadioRequestMod MechCmd = CdRequestMode.STOP;	Eject		
ON		[RadioReq == RadioRequestMode.OFF]	
Eject entry: MechCmd = CdRequestMode.EJECT;		Standby	

Condition cell

Condition action cell

Destination state cell

### State Cells

The left most column represents all the states in the table. Notice that states can be nested hierarchically. You can choose one of the states to be the default state at any given level. This is represented by a default transition drawn to the left of the state. You can also add a "default transition row" if there is logic involved in choosing the first state to enter.

You can add a history junction to a given state by right-clicking the state and selecting 'Add history junction'. This enables the state to remember the last active state when it is re-entered instead of choosing the default state. For example, states **ModeManager** and **ON** have history junctions. A Stateflow chart can be automatically generated from this table view.

### Transition Cells

The next set of columns represent the outer transitions from a state. Each row represents the outer transitions from a given state. Each of the transition cells is sub-divided into three sub-cells:

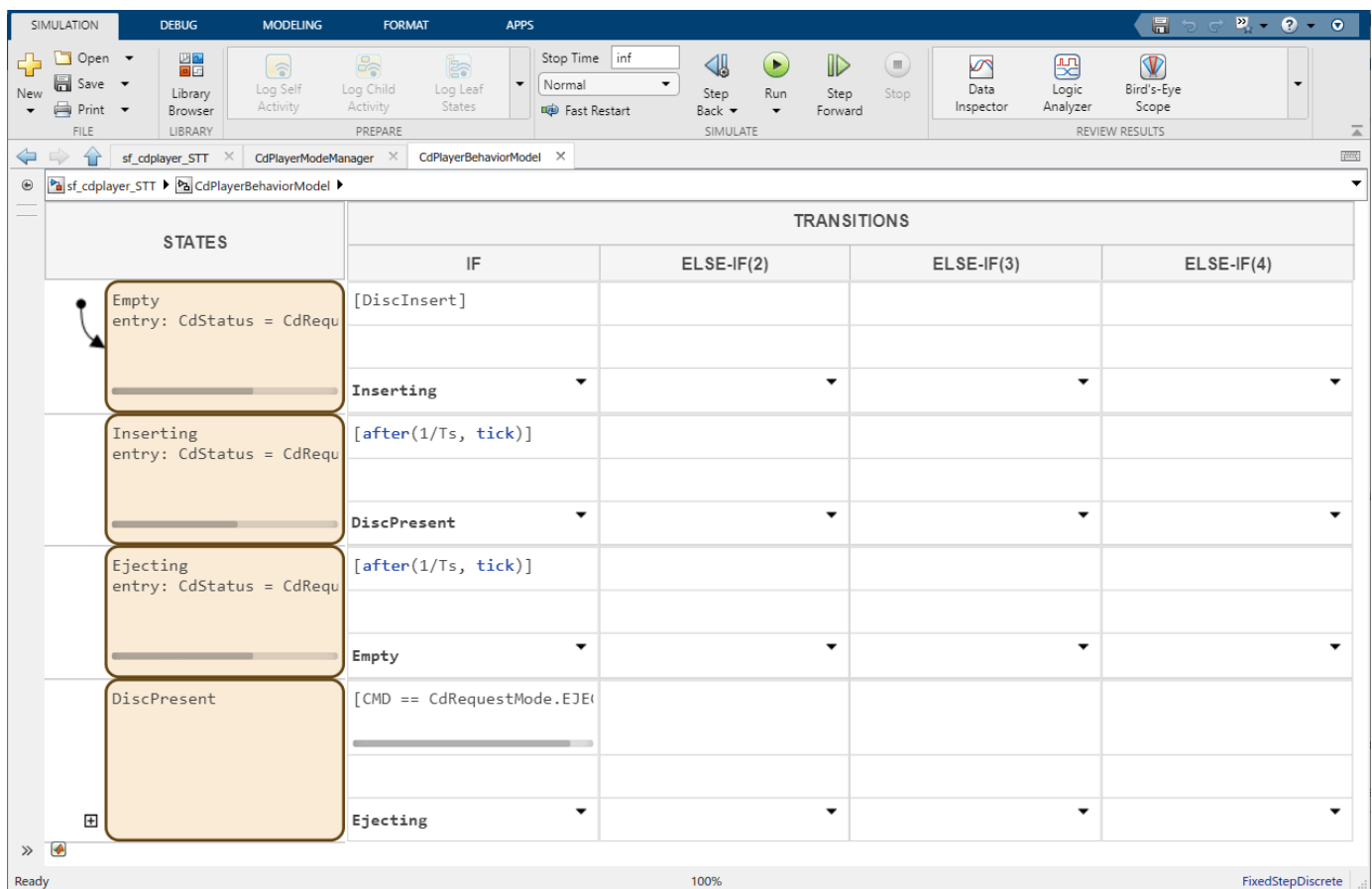
- 1) Condition cell: to specify a boolean condition which specifies when the transition is active

2) Condition Action cell: to specify the action to be taken when the transition is active

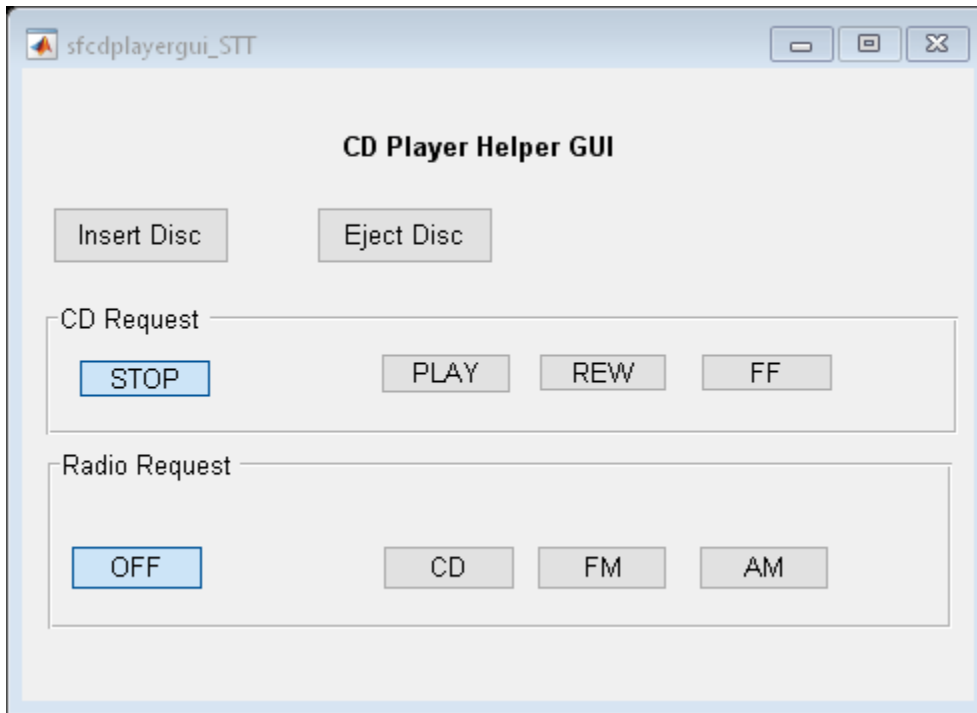
3) Destination cell: to specify the destination state for the transition. Notice that you can use special keywords such as "\$NEXT", "\$PREV" to specify the destination relative to the current state.

This chart receives user inputs, such as whether a disk has been inserted and the choice for the radio mode (FM, AM, or CD). Then the chart determines the mechanical command to output. The data types of input and output data are defined as enumerated data types in the MATLAB® files CdRequestMode.m and RadioRequestMode.m.

The output command from the "CdPlayerModeManager" is processed by the chart "CdPlayerBehaviorModel" which models the behavior of the CD Player mechanism. This logic is also implemented using a State Transition Table.



A MATLAB UI is used to set the various CD/Radio modes.



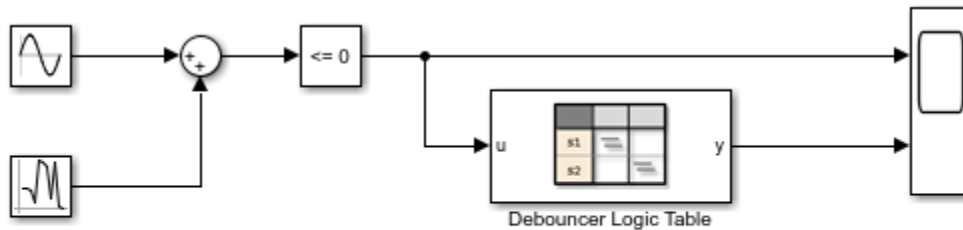
## See Also

### More About

- "State Transition Tables in Stateflow" on page 18-2
- "Model Media Player by Using Enumerated Data" on page 23-15

## View Sequential Logic Through State Transition Matrix

This example shows how to use the State Transition Matrix view for a state transition table in Stateflow®. Instead of drawing states and transitions graphically in a Stateflow chart, use state transition tables to express the modal logic in tabular format. State transition tables are supported only as blocks in a Simulink® model. For more information, see “State Transition Tables in Stateflow” on page 18-2.



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### Generate State Transition Matrix

A *state transition matrix* is an alternative, read-only view of a State Transition Table. This view enables you to analyze how the state transition table responds to various input conditions. For example, this state transition table models debouncing logic that is commonly used to remove jitter in switching logic. The debouncer removes rapid changes in the input  $u$  that last less than 0.1 seconds.

STATES	TRANSITIONS	
	IF	ELSE-IF(2)
ON en: $y = 1;$	$[u == 0]$	
	ON_TO_OFF	
ON_TO_OFF	$after(0.1, sec)$	$[u == 1]$
	OFF	ON
OFF_TO_ON	$after(0.1, sec)$	$[u == 0]$
	ON	OFF
OFF en: $y = 0;$	$[u == 1]$	
	OFF_TO_ON	

To generate the state transition matrix view, on the **Debug** tab, click **Transition Matrix**.



States	after(0.1,sec)	u == 0	u == 1
ON en: y = 1;	X	Action: Destination: ON_TO_OFF	X
ON_TO_OFF	Action: Destination: OFF	X	Action: Destination: ON
OFF_TO_ON	Action: Destination: ON	Action: Destination: OFF	X
OFF en: y = 0;	X	X	Action: Destination: OFF_TO_ON

Each row of the matrix represents a state in the state transition table. These states appear on the left of the matrix in the same order as in the state transition table.

The columns of the matrix correspond to conditions or events. Every unique condition or event used in the state transition table is represented by a separate column. The order of the columns is based on the number of states that respond to each condition or event. Conditions on the left of the matrix impact more states than conditions on the right of the matrix.

The cells in the matrix display how the chart responds to a particular condition or event when a state is active. If a condition or event does not impact a state, the corresponding cell of the matrix appears empty. Empty cells to the left of a nonempty entry appear in light gray. Empty cells to the right of the last nonempty entry in a row appear in dark gray.

If you change the state transition table, you must regenerate the state transition matrix.

### Examine State Reactions

To see the reaction of a state to each event or condition, look at all the entries in a state row. To see how each state responds to an event or condition, look at all the entries in a column.

Each entry in the matrix lists the action and destination for a transition in the state transition table. The execution order of the transition appears in the upper-right corner of each entry. The execution order is displayed in red if it is out of order relative to the matrix columns. Otherwise, the execution order is displayed in blue.

### **Filter by State Name**

To see a subset of state rows, you can filter rows based on state names. In the upper-left corner of the state transition matrix, in the **Filter States** search box, enter a state name or select a name from the drop-down list.

### **Trace Matrix Cells to State Transition Table**

In the state transition matrix, the state names, conditions, actions, and destinations are hyperlinks. To highlight the corresponding state, action, condition, or destination in the state transition table, click one of these hyperlinks.

### **See Also**

#### **More About**

- “State Transition Tables in Stateflow” on page 18-2
- “Reduce Transient Signals by Using Debouncing Logic” on page 30-12

# Make States Reusable with Atomic Subcharts

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- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Rules for Using Atomic Subcharts” on page 19-7
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11
- “Reuse a State Multiple Times in a Chart” on page 19-23
- “Reduce the Compilation Time of a Chart” on page 19-29
- “Divide a Chart into Separate Units” on page 19-32
- “Generate Separate Code for an Atomic Subchart” on page 19-35
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43

## Create Reusable Subcomponents by Using Atomic Subcharts

An *atomic subchart* is a graphical object that helps you to create independent subcomponents in a Stateflow chart. Atomic subcharts are supported only in Stateflow charts in Simulink models.

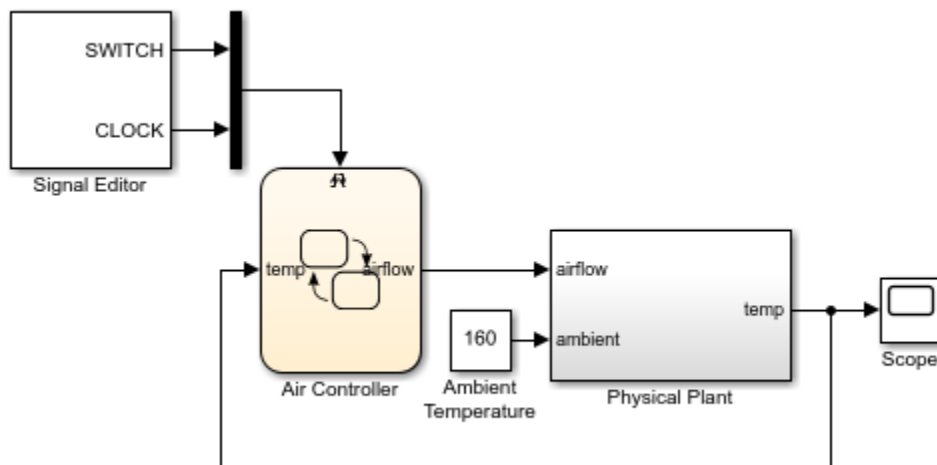
Atomic subcharts allow for:

- Reuse of the same state or subchart across multiple charts and models
- Faster simulation after making small changes to a chart with many states or levels of hierarchy
- Ease of team development when multiple people are working on different parts of the same chart
- Manual inspection of generated code for a specific state or subchart in a chart

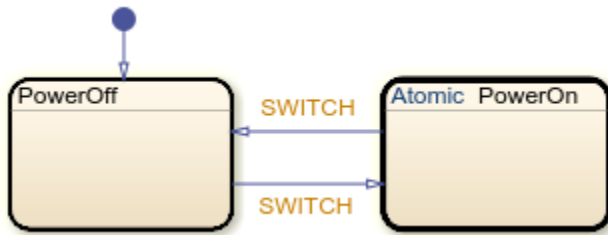
An atomic subchart looks opaque and includes the label **Atomic** in the upper left corner. If you use a linked atomic subchart from a library, the label **Link** appears in the upper left corner.

### Example of an Atomic Subchart

This example illustrates the difference between a normal subchart and an atomic subchart.



In the Air Controller chart, PowerOff is a normal subchart. PowerOn is an atomic subchart. Both subcharts look opaque, but the PowerOn includes the label **Atomic** on the upper left corner.



## Benefits of Using Atomic Subcharts

Atomic subcharts combine the functionality of states on page 2-8, normal subcharts on page 8-10, and atomic subsystems (Simulink). Atomic subcharts:

- Behave as independent charts.
- Support usage as library links.
- Support the generation of reusable code.
- Allow mapping of inputs, outputs, parameters, data store memory, and input events.

Atomic subcharts do not support access to:

- Data at every level of the chart hierarchy.
- Event broadcasts outside the scope of the atomic subchart.

Atomic subcharts do not support explicit specification of sample time.

## Create an Atomic Subchart

You can create an atomic subchart by converting an existing subchart or by linking a chart from a library model. After creating the atomic subchart, update the mapping of variables by right-clicking the atomic subchart and selecting **Subchart Mappings**. For more information, see “Map Variables for Atomic Subcharts and Boxes” on page 19-11.

### Convert a Normal Subchart to an Atomic Subchart

To create an independent component that allows for faster debugging and code generation workflows, convert an existing state or subchart into an atomic subchart. In your chart, right-click a state or a normal subchart and select **Group & Subchart > Atomic Subchart**. The label **Atomic** appears in the upper left corner of the subchart.

The conversion provides the atomic subchart with its own copy of every data object that the subchart accesses in the chart. Local data is copied as data store memory. The scope of other data, including input and output data, does not change.

For more information, see “Restrictions for Converting to Atomic Subcharts” on page 19-9.

---

**Note** If a state or subchart contains messages, you cannot convert it to an atomic subchart.

---

### Link an Atomic Subchart from a Library

To create a subcomponent for reuse across multiple charts and models, create a link from a library model. Copy a chart in a library model and paste it to a chart in another model. If the library chart contains any states, it appears as a linked atomic subchart with the label **Link** in the upper left corner.

This modeling method minimizes maintenance of similar states. When you modify the atomic subchart in the library, your changes propagate to the links in all charts and models.

If the library chart contains only functions and no states, then it appears a linked atomic box in the chart. For more information, see “Reuse Functions by Using Atomic Boxes” on page 8-28.

### Convert an Atomic Subchart to a Normal Subchart

Converting an atomic subchart back to a state or a normal subchart removes all of its variable mappings. The conversion merges subchart-parented data objects with the chart-parented data to which they map.

- 1 If the atomic subchart is a library link, right-click the atomic subchart and select **Library Link > Disable Link**.
- 2 To convert an atomic subchart back to a normal subchart, right-click the atomic subchart and clear the **Group & Subchart > Atomic Subchart** check box.
- 3 To convert the subchart back to a state, right-click the subchart and clear the **Group & Subchart > Subchart** check box.
- 4 If necessary, rearrange graphical objects in your chart.

You cannot convert an atomic subchart to a normal subchart if:

- The atomic subchart maps a parameter to an expression other than a single variable name. For example, mapping a parameter `data1` to one of these expressions prevents the conversion of an atomic subchart to a normal subchart:
  - 3
  - `data2(3)`
  - `data2 + 3`
- Both of these conditions are true:
  - The atomic subchart contains MATLAB functions or truth table functions that use MATLAB as the action language.
  - The atomic subchart does not map each variable to a variable of the same name in the main chart.

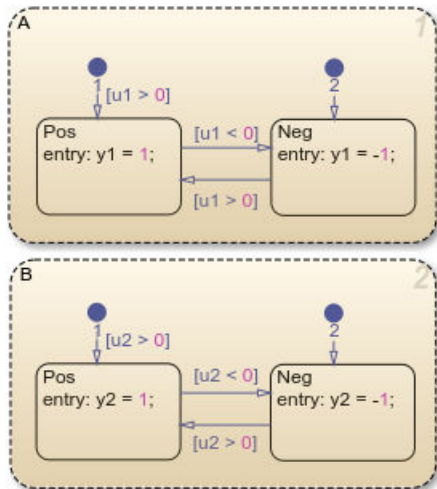
## When to Use Atomic Subcharts

### Reuse State Logic

Suppose that you want to reuse the same state or subchart many times to facilitate large-scale modeling.

If you do not use atomic subcharts, you have to maintain each copy of a subcomponent manually. For example, this chart contains two states with a similar structure. The only difference between the two

states is the names of variables. If you change the logic in state A, then you must make the same change in state B.



To enable reuse of subcomponents by using linked atomic subcharts, create a single copy of state A and store it as a chart in a library model. From that library, copy and paste the atomic subchart twice in your chart. Then update the mapping of subchart variables as needed.

When you change an atomic subchart in a library, the change propagates to all library links. For more information, see “Reuse a State Multiple Times in a Chart” on page 19-23.

### Debug Charts Incrementally

Suppose that you want to test a sequence of changes in a chart that contains many states or several levels of hierarchy.

If you do not use atomic subcharts, when you make a small change to one part of a chart and start simulation, recompilation occurs for the entire chart. Because recompiling the entire chart can take a long time, you decide to make several changes before testing. However, if you find an error, you must step through all of your changes to identify the cause of the error.

In contrast, when you modify an atomic subchart, recompilation occurs for only the subchart and not for the entire chart. Incremental builds for simulation require less time to recompile. This reduction in compilation time enables you to test each individual change instead of waiting to test multiple changes at once. By testing each change individually, you can quickly identify a change that causes an error. For more information, see “Reduce the Compilation Time of a Chart” on page 19-29.

### Develop Charts Used by Multiple People

Suppose that you want to break a chart into subcomponents because multiple people are working on different parts of the chart.

Without atomic subcharts, only one person at a time can edit the model. If someone edits one part of a chart while someone else edits another part of the same chart, you must merge those changes at submission time.

In contrast, you can store different parts of a chart as linked atomic subcharts. Because atomic subcharts behave as independent objects, different people can work on different parts of a chart

without affecting the other parts of the chart. At submission time, no merge is necessary because the changes exist in separate models. For more information, see “Divide a Chart into Separate Units” on page 19-32.

### **Inspect Generated Code**

Suppose that you want to inspect code generated by Simulink Coder or Embedded Coder manually for a specific part of a chart.

If you do not use atomic subcharts, you generate code for an entire model in one file. To find code for a specific part of the chart, you have to look through the entire file.

In contrast, you can specify that the code for an atomic subchart appears in a separate file. This method of code generation enables unit testing for a specific part of a chart. You avoid searching through unrelated code and focus only on the code that interests you. For more information, see “Generate Separate Code for an Atomic Subchart” on page 19-35.

### **See Also**

Atomic Subsystem

### **More About**

- “Encapsulate Modal Logic by Using Subcharts” on page 8-10
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39



## Rules for Using Atomic Subcharts

An atomic subchart is a graphical object that helps you to create independent subcomponents in a Stateflow chart. Atomic subcharts are supported only in Stateflow charts in Simulink models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Chart Properties and Atomic Subcharts

#### Do Not Use Moore Charts as Atomic Subcharts

Moore charts do not have the same simulation behavior as Classic Stateflow charts with the same constructs.

#### Do Not Use Atomic Subcharts in Continuous-Time Charts

Continuous-time charts do not support atomic subcharts.

#### Avoid Using Atomic Subcharts in Charts That Execute at Initialization

You get a warning when the following conditions are true:

- The chart property **Execute (enter) Chart At Initialization** is enabled.
- The default transition path of the chart reaches an atomic subchart.

If an entry action inside the atomic subchart requires access to a chart input or data store memory, you can get inaccurate results. To avoid this warning, you can disable **Execute (enter) Chart At Initialization** or redirect the default transition path away from the atomic subchart.

For more information about execute-at-initialization behavior, see “Execution of a Chart at Initialization” on page 3-21.

#### Use Consistent Settings for Super Step Semantics

When you use linked atomic subcharts, verify that your settings for super step semantics match the settings in the main chart. For more information, see “Super Step Semantics” on page 3-45.

### Data in Atomic Subcharts

#### Define Data in an Atomic Subchart Explicitly

Be sure to define data that appears in an atomic subchart explicitly in the main chart. Atomic subcharts can only access main chart data whose size, type, and complexity are fully specified. For more information, see “Set Data Properties” on page 12-5.

#### Map Variables of Linked Atomic Subcharts

When you use linked atomic subcharts, map the variables so that data in the subchart corresponds to the correct data in the main chart. Map subchart variables manually if, when you add the subchart, the variables do not have the same names as the corresponding symbols in the main chart. For more information, see “Map Variables for Atomic Subcharts and Boxes” on page 19-11.

### Match Size, Type, and Complexity of Variables in Linked Atomic Subcharts

Verify that the size, type, and complexity of variables in a subchart match the settings of the corresponding variables in the main chart. For more information, see “Map Variables for Atomic Subcharts and Boxes” on page 19-11.

### Do Not Use Variable-Size Data in Atomic Subcharts

Atomic subcharts do not support variable-sized arrays. If you select the **Variable Size** property of a subchart data object, an error occurs when you try to update the diagram or simulate the model.

### Do Not Change the First Index of Local Data to a Nonzero Value

When a data store memory in an atomic subchart maps to chart-level local data, the **First index** property of the local data must remain zero. If you change **First index** to a nonzero value, an error occurs when you try to update the diagram or simulate the model.

### Do Not Log Signals from Atomic Subcharts That Map Variables with Different Scopes

If an atomic subchart maps variables to variables at the main chart level with a different scope, you cannot log signals for the chart.

### Restrict Use of Machine-Parented Data

If your chart contains atomic subcharts, do not use machine-parented data with the following properties:

- Imported or exported
- Is 2-D or higher, or uses fixed-point type

Machine-parented data with these properties prevent reuse of generated code and other code optimizations.

### Avoid Using the Names of Subsystem Parameters in Atomic Subcharts

If a parameter in an atomic subchart matches the name of a Simulink built-in subsystem parameter, the only mapping allowed for that parameter is `Inherited`. Specifying any other parameter mapping in the **Mappings** tab of the properties dialog box causes an error. You can, however, change the parameter value at the MATLAB prompt so that all instances of that parameter have the same value.

To get a list of Simulink subsystem parameters, enter:

```
param_list = sort(fieldnames(get_param('built-in/subsystem', 'ObjectParameters')));
```

## Events in Atomic Subcharts

### Do Not Mix Edge-Triggered and Function-Call Input Events in The Same Atomic Subchart

Input events in an atomic subchart must all use edge-triggered type, or they must all use function-call type. This restriction is consistent with the behavior for the container chart. For more information, see “Best Practices for Using Events in Stateflow Charts” on page 14-4.

### Do Not Use Outgoing Transitions When an Atomic Subchart Uses Top-level Local Events

You cannot use outgoing transitions from an atomic subchart that uses local events at the top level of the subchart. Using this configuration causes a simulation error.

### **Match the Trigger Type When Mapping Input Events**

Each input event in an atomic subchart must map to an input event of the same trigger type in the container chart.

### **Do Not Map Multiple Input Events in an Atomic Subchart to the Same Input Event in the Container Chart**

Each input event in an atomic subchart must map to a unique input event in the container chart. You can verify unique mappings of input events by opening the properties dialog box for the atomic subchart and checking the **Input Event Mapping** section of the **Mappings** tab.

## **Functions and Atomic Subcharts**

### **Export Chart-Level Functions If Called from an Atomic Subchart**

If your atomic subchart contains a function call to a chart-level function, export that function by selecting **Export Chart Level Functions**. Do not export graphical functions from an atomic subchart that maps variables to variables at the main chart level with a different scope. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

## **Restrictions for Converting to Atomic Subcharts**

### **Supertransitions**

The state or subchart that you want to convert to an atomic subchart cannot have any supertransitions crossing the boundary.

### **Data, Graphical Functions, and Events**

To convert a state or subchart to an atomic subchart, access to objects not parented by the state or subchart must be one of the following:

- Chart-level data
- Chart-level graphical functions
- Input events

If the state or subchart accesses a chart-level graphical function, the chart must export that function. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

Do not export graphical functions from an atomic subchart that maps variables to variables at the main chart level with a different scope.

### **Local Data with a Nonzero First Index**

The state or subchart that you want to convert to an atomic subchart cannot access local data where the **First index** property is nonzero. For the conversion process to work, the **First index** property of the local data must be zero, which is the default value.

### **Machine-Parented Data**

The state or subchart that you want to convert to an atomic subchart cannot reside in a chart that uses machine-parented data with the following properties:

- Imported or exported
- Is 2-D or higher, or uses a fixed-point type

Machine-parented data with these properties prevent reuse of generated code and other code optimizations.

### **Strong Data Typing with Simulink Inputs and Outputs**

To convert a state or subchart to an atomic subchart, your chart must use strong data typing with Simulink inputs and outputs. For more information, see “Use strong data typing with Simulink I/O” on page 28-4.

### **Event Broadcasts**

The state or subchart that you want to convert to an atomic subchart cannot refer to:

- Local events that are outside the scope of that state or subchart
- Output events

The state or subchart you want to convert can refer to *input* events.

### **Masked Library Chart**

You cannot use a masked library chart containing mask parameters as an atomic subchart.

## **See Also**

### **More About**

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39

## Map Variables for Atomic Subcharts and Boxes

An atomic subchart is a graphical object that helps you create reusable subcomponents in a Stateflow chart. An atomic box is a graphical object that helps you share graphical, truth table, MATLAB, and Simulink functions across several charts. Atomic subcharts and boxes are supported only in Stateflow charts in Simulink models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2 and “Reuse Functions by Using Atomic Boxes” on page 8-28.

To ensure that each symbol in your atomic subchart or box accesses the correct symbol in the main chart, edit the mapping of subchart symbols. Right-click the subchart or box and select **Subchart Mappings**. In the **Mappings** tab of the properties dialog box, use the **Main chart symbol** drop-down list to specify which symbol in the main chart corresponds to each symbol in the subchart. Alternatively, you can type an expression specifying:

- A field of a Stateflow structure. See “Index and Assign Values to Stateflow Structures” on page 29-7.
- An element of a vector or matrix. See “Supported Operations for Vectors and Matrices” on page 21-4.
- Any valid combination of structure fields or matrix indices, such as `struct.field(1,2)` or `struct.field[0][1]`.

If you leave the **Main chart symbol** field empty, then Stateflow attempts to map the atomic subchart symbol to a main chart symbol with the same name.

You can map a symbol in the atomic subchart to a symbol in the main chart that has a different scope. This table lists the possible mappings.

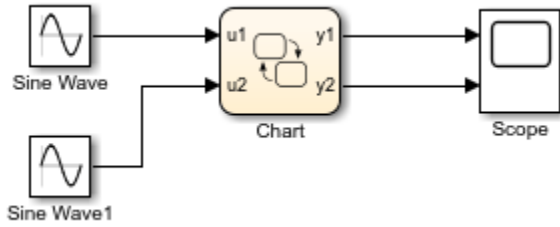
Atomic Subchart Symbol Scope	Main Chart Symbol Scope
Input	Input, Output, Local, Parameter
Output	Output, Local
Parameter	Parameter
Data Store Memory	Data Store Memory, Local
Input Event	Input Event

When you map data store memory in an atomic subchart to local data of enumerated type, you have two options for specifying the initial value of the data store memory:

- In the Data properties dialog box, set the **Initial value** field for the chart-level local data.
- To apply the default value of the enumerated type, leave the **Initial value** field empty.

### Map Input and Output Data for an Atomic Subchart

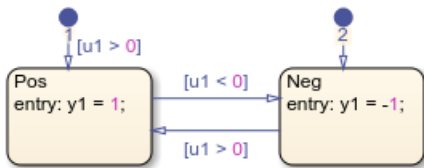
This model contains two Sine Wave blocks that supply input signals to a chart.



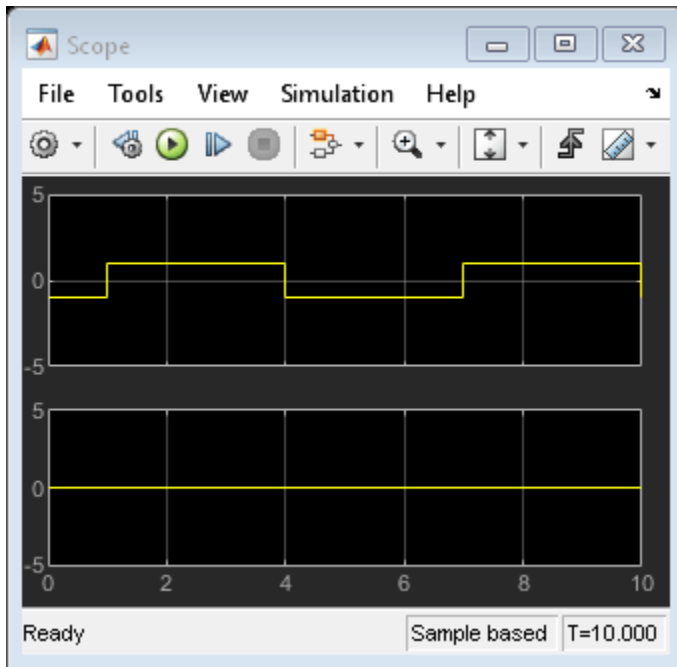
The chart consists of two linked atomic subcharts from the same library.



Both atomic subcharts contain saturator logic to convert an input sine wave to an output square wave of the same frequency.

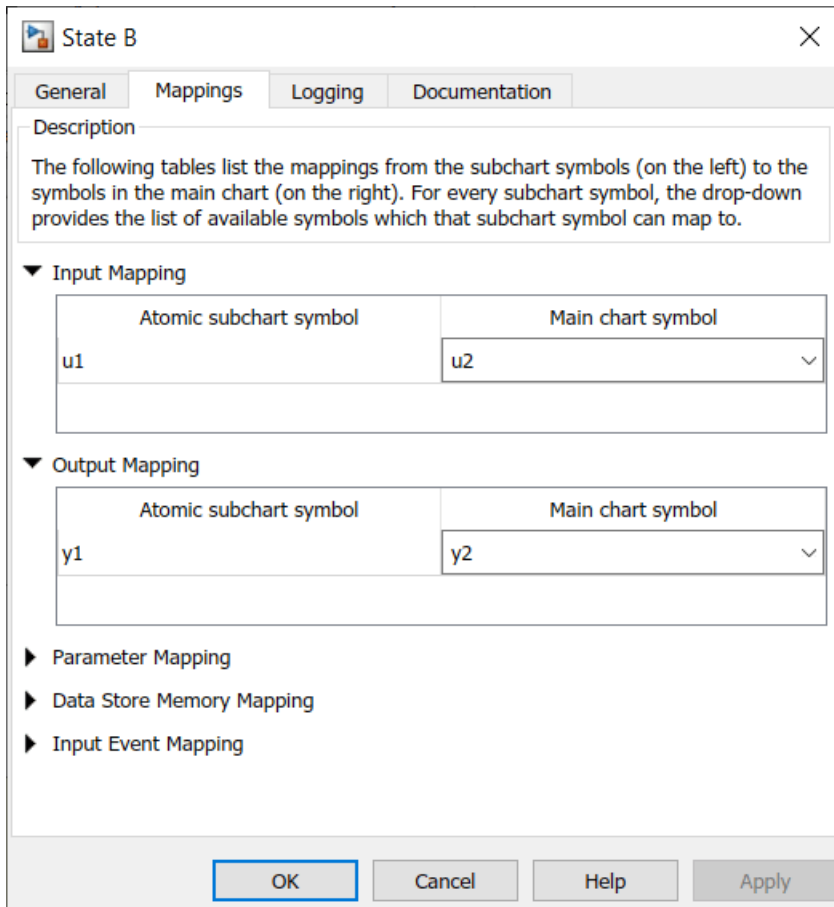


If you simulate the model, the output for y2 is zero.



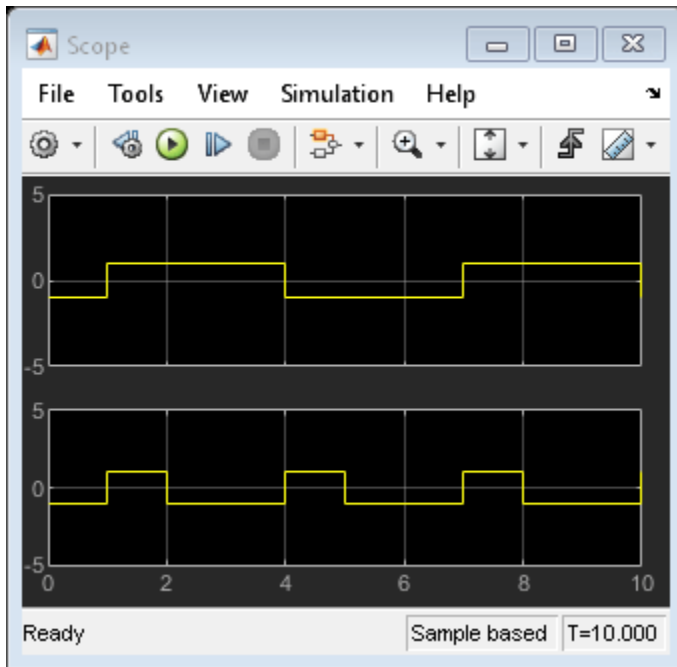
Because the symbols in atomic subchart A have the same name as the symbols  $u1$  and  $y1$  in the main chart, they map to the correct variables. The symbols in atomic subchart B do not map to  $u2$  and  $y2$  in the main chart, so you must edit the mapping.

- 1 Right-click subchart B and select **Subchart Mappings**.
- 2 Under **Input Mapping**, specify the main chart symbol for  $u1$  to be  $u2$ .
- 3 Under **Output Mapping**, specify the main chart symbol for  $y1$  to be  $y2$ .
- 4 Click **OK**.



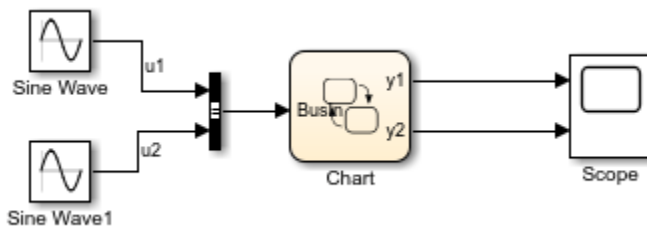
When you run the model again, you get these results.



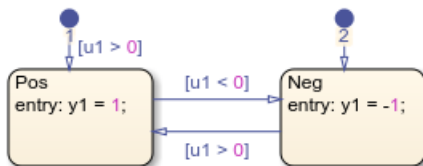


## Map Atomic Subchart Variables to Bus Elements

This model contains two Sine Wave blocks that supply signals through a bus to a chart.



The chart consists of two linked atomic subcharts from the same library. Both atomic subcharts contain saturator logic to convert an input sine wave to an output square wave of the same frequency.

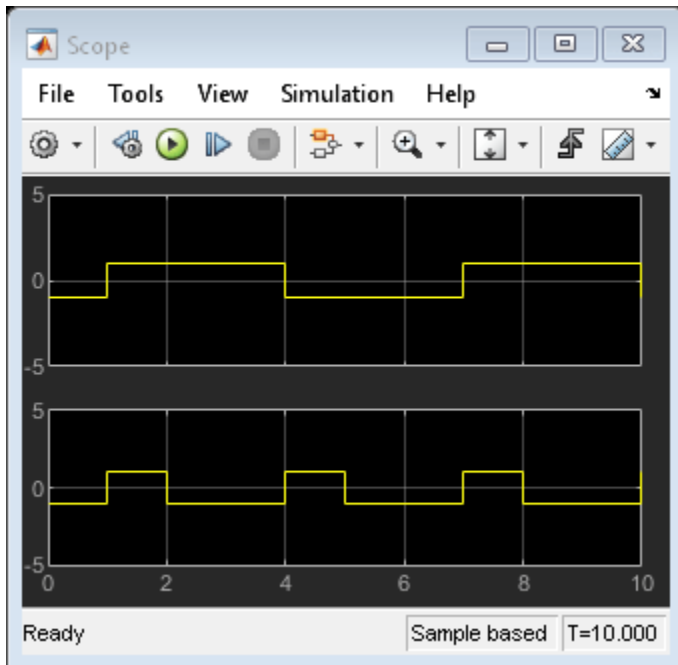


If you simulate the model, you get an error because the `u1` inputs in each subchart do not map to any variables in the main chart. To edit the mapping for `u1` in each subchart:

- 1 Right-click subchart A and select **Subchart Mappings**.
- 2 Under **Input Mapping**, specify the main chart symbol for `u1` to be the first element in the bus: `BusIn.u1`.

- 3 Click **OK**.
- 4 Repeat for subchart B, specifying the main chart symbol for u1 to be the second element in the bus: BusIn.u2.

When you run the model again, you get these results.



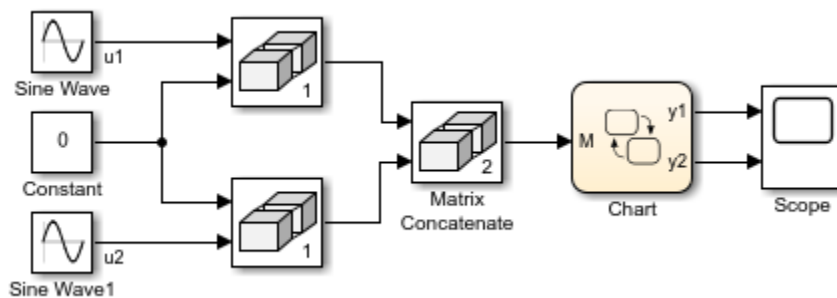
## Map Atomic Subchart Variables to the Elements of a Matrix

When referring to elements of a vector or matrix, regardless of the action language of the chart, use:

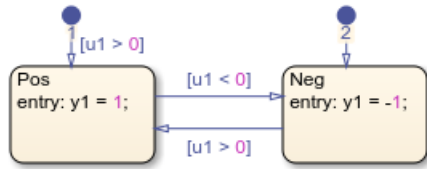
- One-based indexing delimited by parentheses and commas. For example,  $A(4, 5)$ .
- Zero-based indexing delimited by brackets. For example,  $A[3][4]$ .

Indices can be numbers or parameters in the chart. The use of other expressions as indices is not supported.

For example, this model contains two Sine Wave blocks that supply signals through a diagonal matrix to a chart.



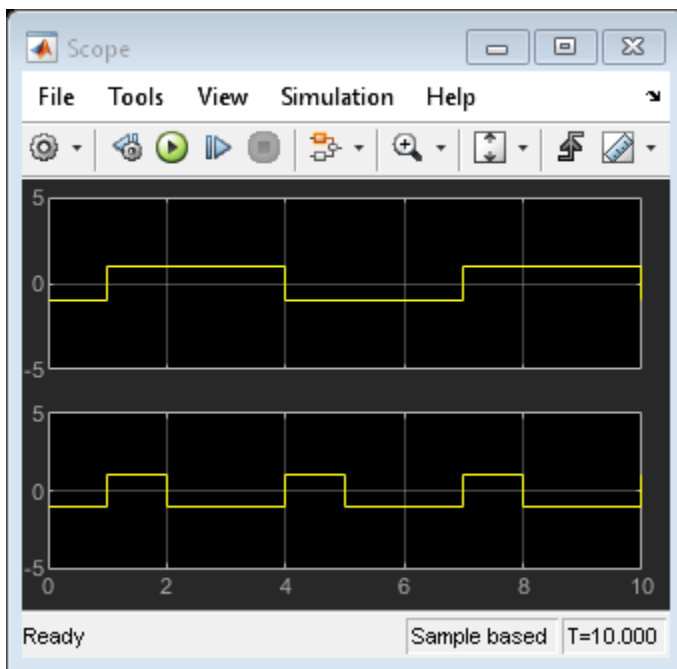
The chart consists of two linked atomic subcharts from the same library. Both atomic subcharts contain saturator logic to convert an input sine wave to an output square wave of the same frequency.



If you simulate the model, you get an error because the `u1` inputs in each subchart do not map to any variables in the main chart. To edit the mapping for `u1` in each subchart:

- 1 Right-click subchart A and select **Subchart Mappings**.
- 2 Under **Input Mapping**, specify the main chart symbol for `u1` to be the top-left element in the matrix. The zero-based indexing format for this element is `M[0][0]`.
- 3 Click **OK**.
- 4 Repeat for subchart B, specifying the main chart symbol for `u1` to be the bottom-right element in the matrix. The one-based indexing format for this element is `M(2,2)`.

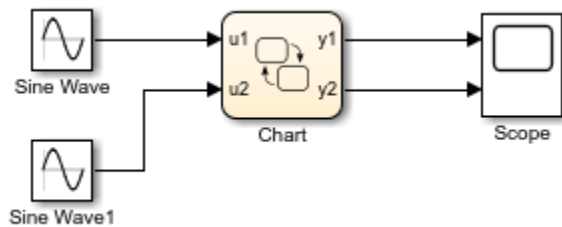
When you run the model again, you get these results.



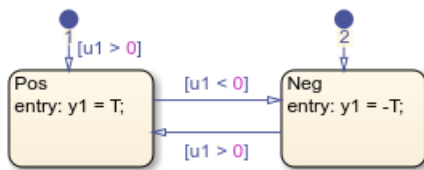
## Map Atomic Subchart Parameters to Expressions

For parameters in an atomic subchart, you can specify an expression that combines constants, variables in the base workspace, and parameters in the main chart.

For example, this model contains two Sine Wave blocks that supply input signals to a chart.

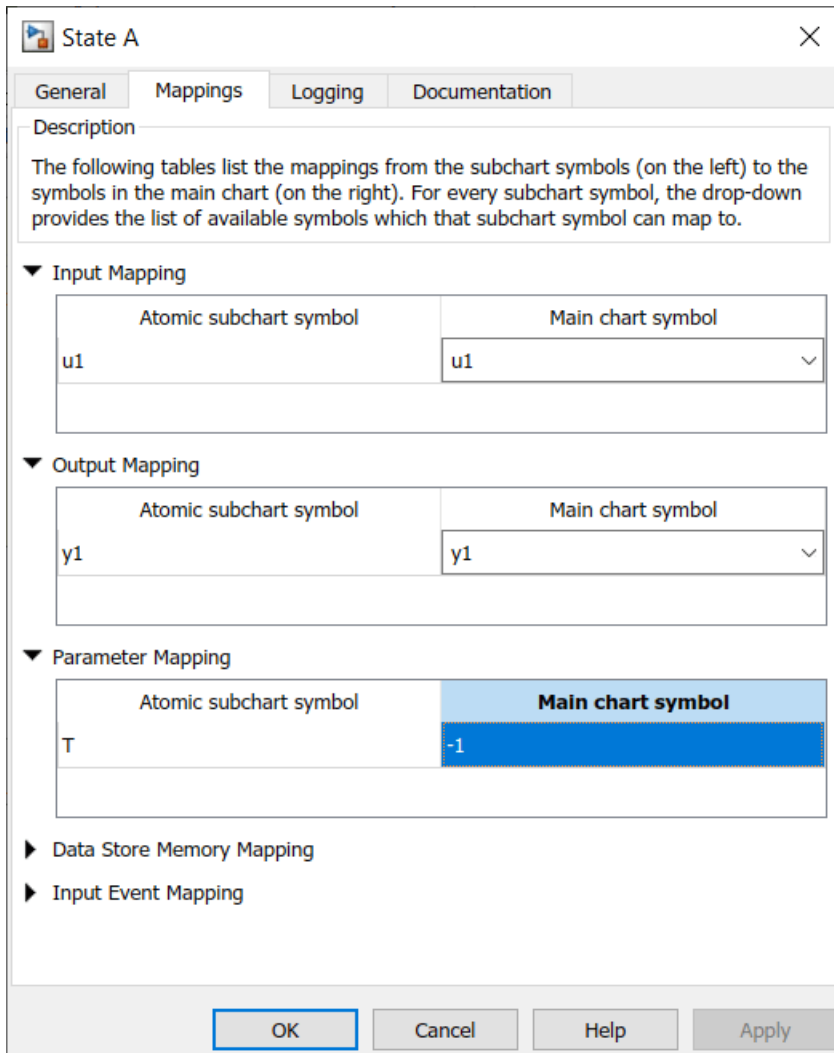


The chart consists of two linked atomic subchart from the same library. Both atomic subcharts contain saturator logic to convert an input sine wave to an output square wave of the same frequency.

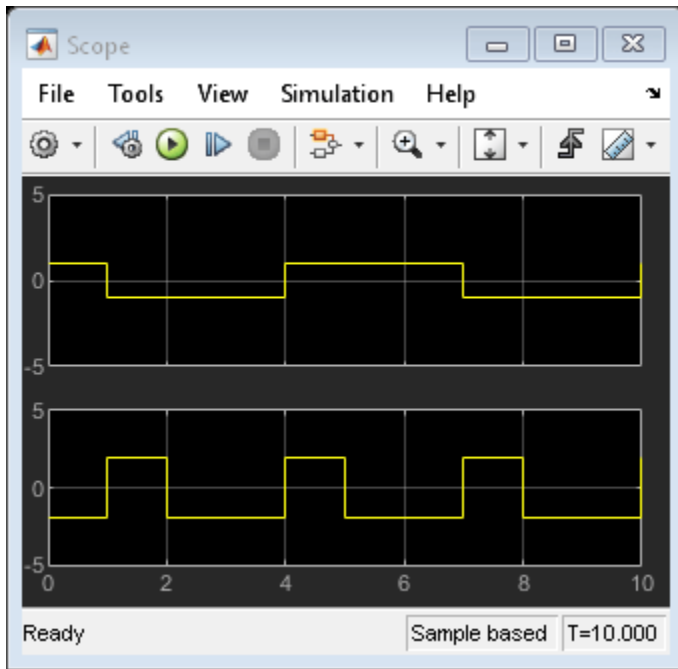


If you simulate the model, you get an error because the parameter T is undefined. To fix this error, specify an expression for T to evaluate in the main chart:

- 1 Right-click subchart A and select **Subchart Mappings**.
- 2 Under **Parameter Mapping**, as the value for T, enter -1.
- 3 Click **OK**.
- 4 Repeat for subchart B, specifying the value of T as 2.

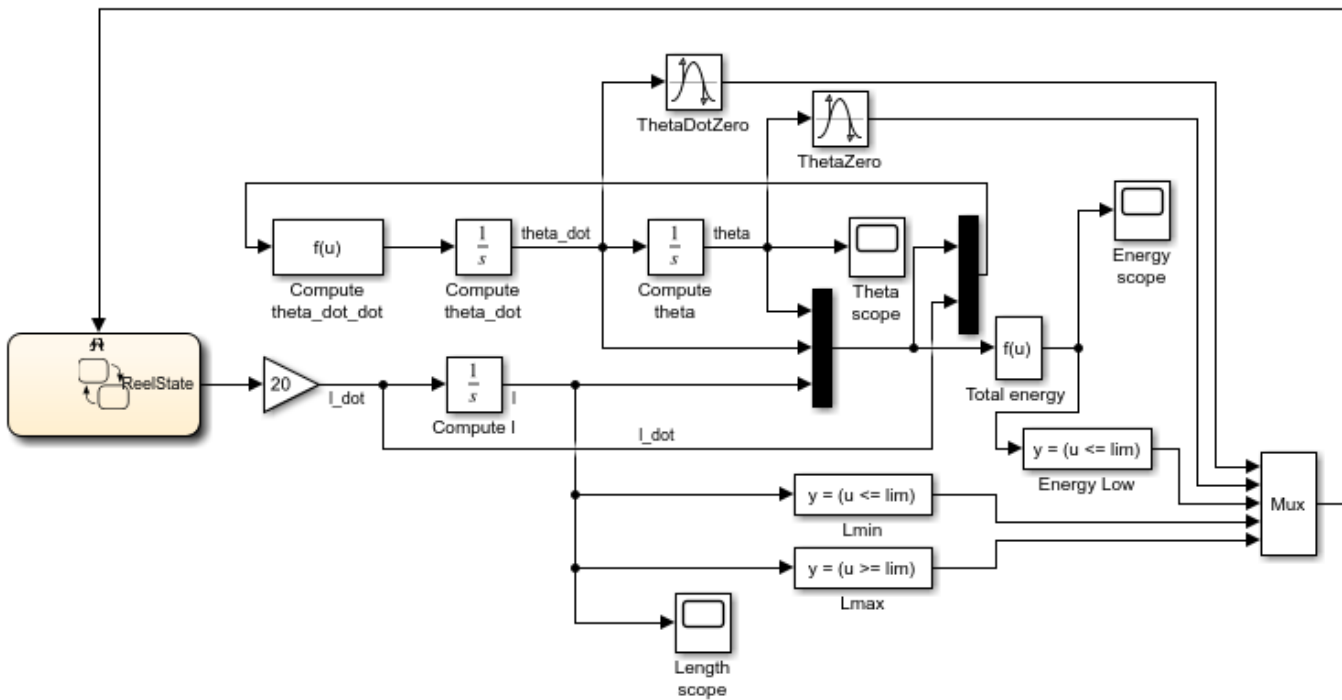


When you run the model again, you get these results.

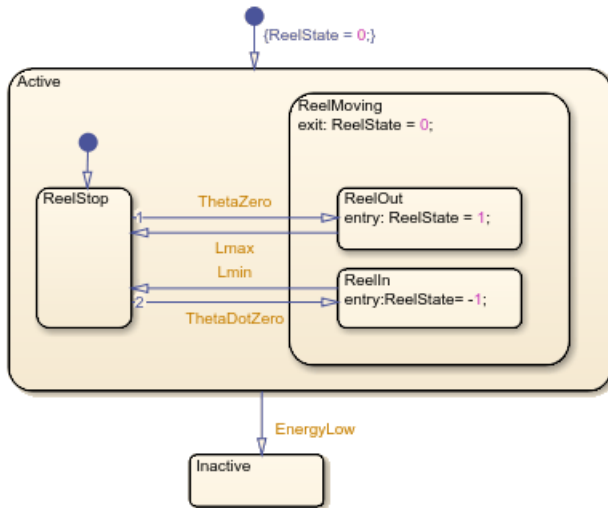


### Map Input Events for an Atomic Subchart

This model contains a Mux block that supplies input events to a chart.

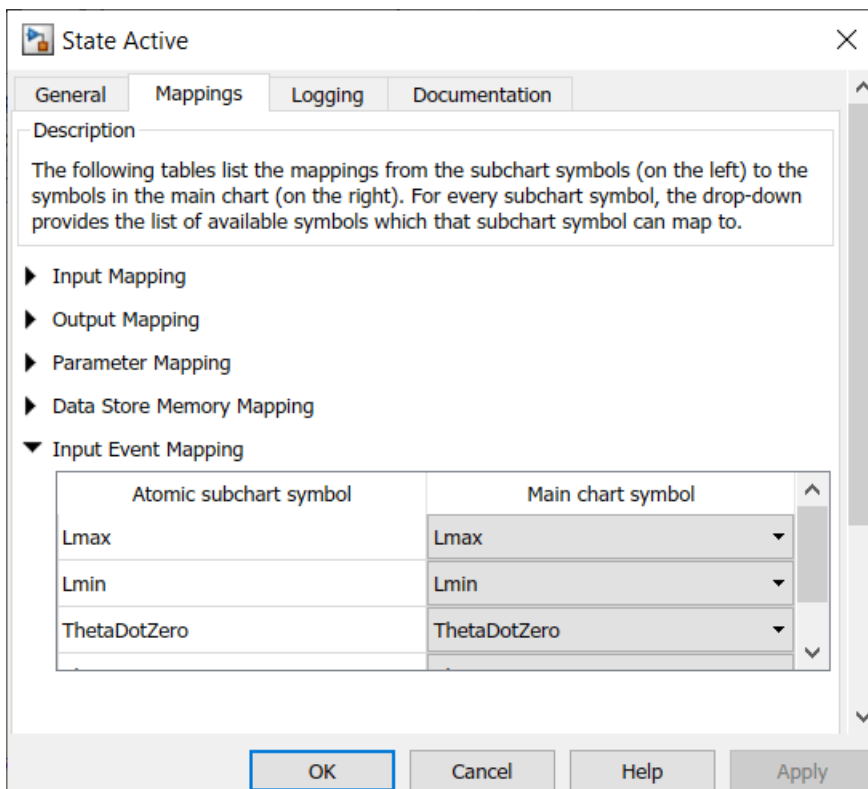


The chart contains two superstates: Active and Inactive. The Active state uses input events to guard transitions between different substates.



To convert the Active state to an atomic subchart:

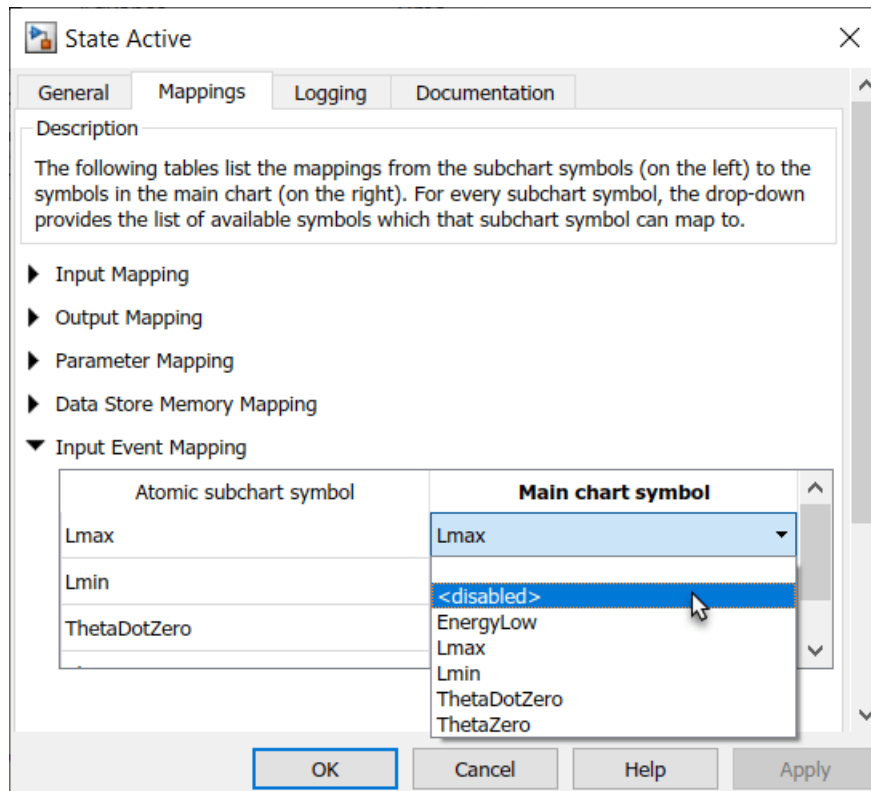
- 1 Right-click the Active state and select **Group & Subchart > Atomic Subchart**.
- 2 Right-click the atomic subchart and select **Subchart Mappings**.
- 3 Under **Input Event Mapping**, map each atomic subchart symbol to the corresponding input event in the main chart.
- 4 Click **OK**.



## Disable Input Events for Atomic Subcharts

Not every input event in an atomic subchart has to correspond to an event in the main chart. For example, you can create a linked atomic subchart that does not use the entire set of events that are defined in the library chart. To disable an input event in an atomic subchart:

- 1 Right-click the atomic subchart and select **Subchart Mappings**.
- 2 Under **Input Event Mapping**, in the **Main chart symbol** drop-down list, select `<disabled>`.
- 3 Click **OK**.



## See Also

### More About

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Reuse Functions by Using Atomic Boxes” on page 8-28
- “Index and Assign Values to Stateflow Structures” on page 29-7
- “Supported Operations for Vectors and Matrices” on page 21-4

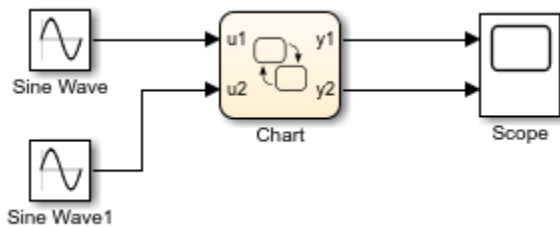


## Reuse a State Multiple Times in a Chart

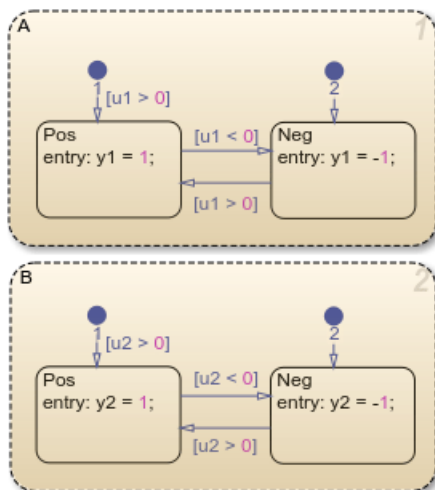
This example shows how to use linked atomic subcharts to repeat the same configuration of states and transitions multiple times in a Stateflow® chart. Atomic subcharts are supported only in Stateflow charts in Simulink® models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Original Model Without Atomic Subcharts

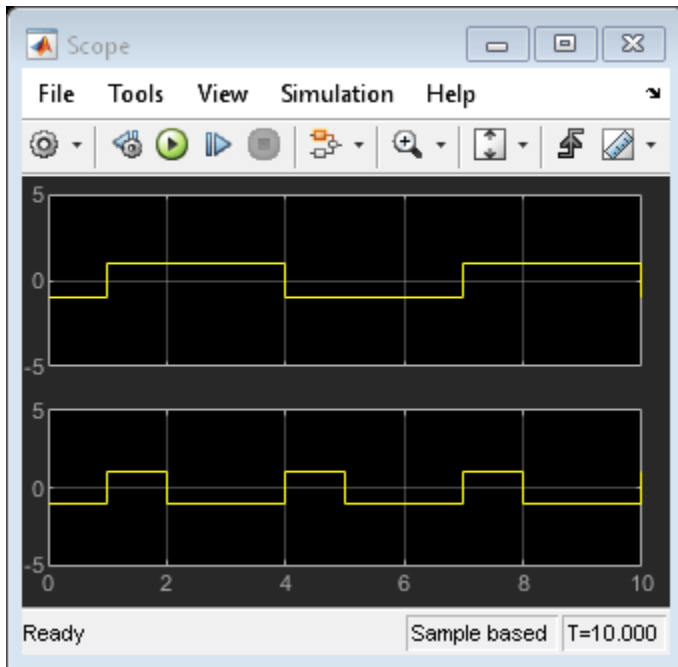
This model contains two Sine Wave (Simulink) blocks: one with a frequency of 1 radian per second, and the other with a frequency of 2 radians per second.



In the chart, each state uses saturator logic to convert the input sine wave to an output square wave of the same frequency. The states perform the same actions and differ only in the names of their input and output data.



Simulating the model produces these results.



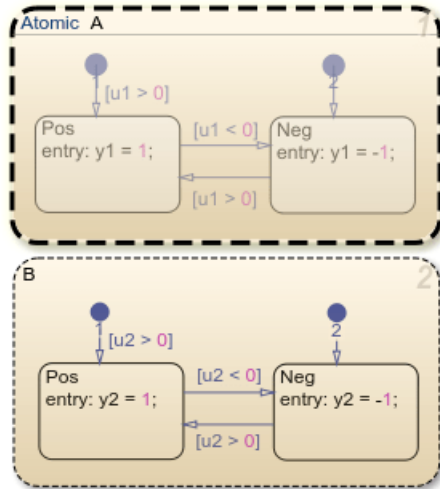
Because this example does not use atomic subcharts, you have to maintain each subcomponent manually. For example, if you change the logic in state A, then you must make the same change in state B.

In contrast, if you replace the states in this example with atomic subcharts, you can reuse the same object in your model and retain the same simulation results. You can save state A as an atomic subchart in a library model and then use multiple linked instances of that subchart in your chart. Changes in the library model propagate to all linked instances of the subchart.

### Edit Model to Use Atomic Subcharts

#### Step 1: Convert a State to an Atomic Subchart

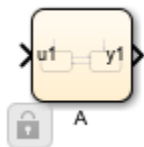
Right-click state A and select **Group & Subchart > Atomic Subchart**. State A changes to an atomic subchart and displays the label **Atomic** in the upper-left corner.



### Step 2: Create a Library for the Atomic Subchart

- 1 Create a new library model.
- 2 Copy the atomic subchart and paste it in your library model.
- 3 Save your library model.

In the library model, the atomic subchart appears as an independent chart with an input port and an output port.



### Step 3: Replace States with Linked Atomic Subcharts

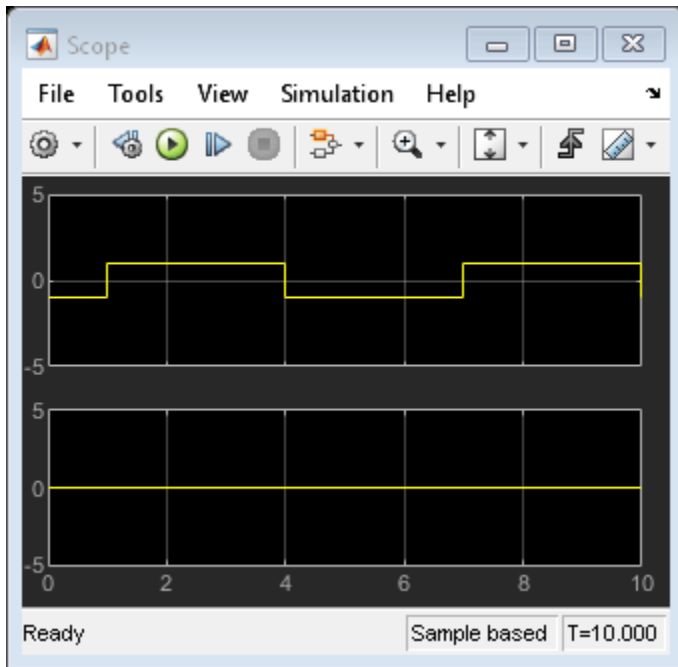
- 1 Delete both states in the chart.
- 2 Copy the atomic subchart in your library and paste it in your chart twice.
- 3 Change the name of the second atomic subchart to B.

Each linked atomic subchart appears opaque and contains the label **Link** in the upper-left corner.



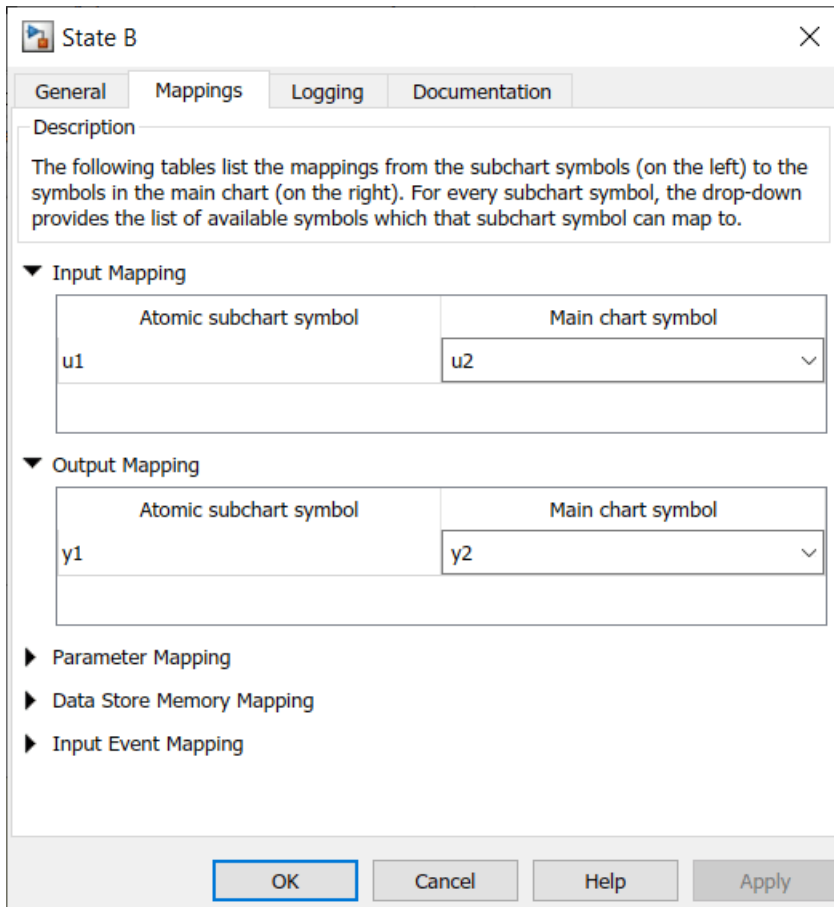
### Step 4: Edit the Mapping of Input and Output Variables

If you simulate the model now, the output for  $y_2$  is zero. You also see warnings about unused data. These warnings appear because atomic subchart B uses  $u_1$  and  $y_1$  instead of  $u_2$  and  $y_2$ .



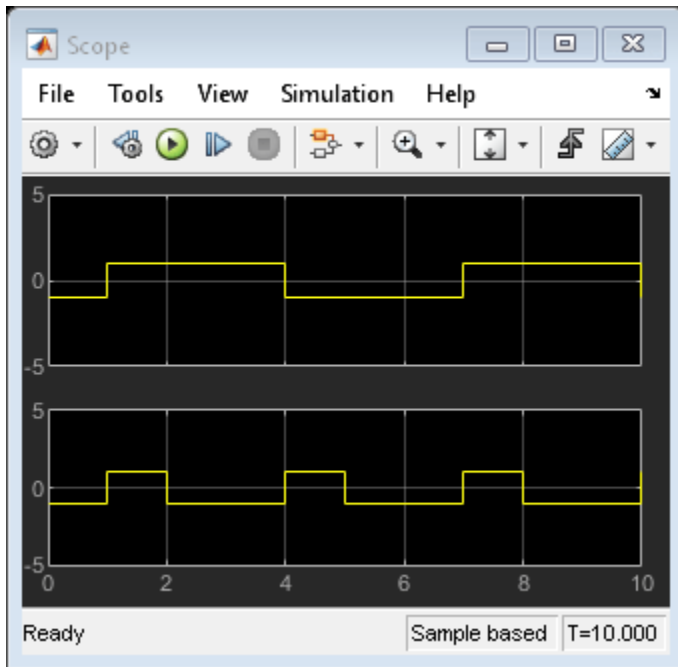
To fix these warnings, you must edit the mapping of input and output variables.

- 1 Right-click subchart B and select **Subchart Mappings**.
- 2 Under **Input Mapping**, specify the main chart symbol for  $u_1$  to be  $u_2$ .
- 3 Under **Output Mapping**, specify the main chart symbol for  $y_1$  to be  $y_2$ .
- 4 Click **OK**.



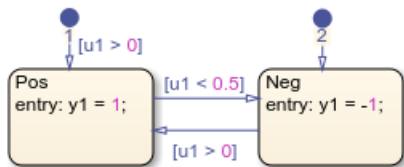
### Run the New Model

When you simulate the new model, the results match those of the original design.



### Propagate a Change in the Library Chart

Suppose that, in the library chart, you edit the transition from Pos to Neg.



This change propagates to all linked atomic subcharts in your main chart. You do not have to update each state individually.

### See Also

Sine Wave

### More About

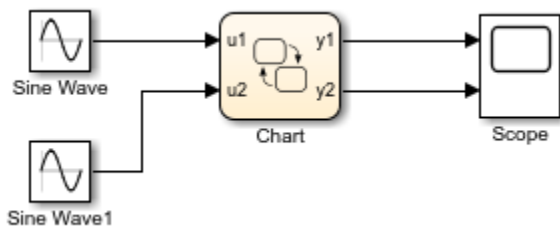
- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39

## Reduce the Compilation Time of a Chart

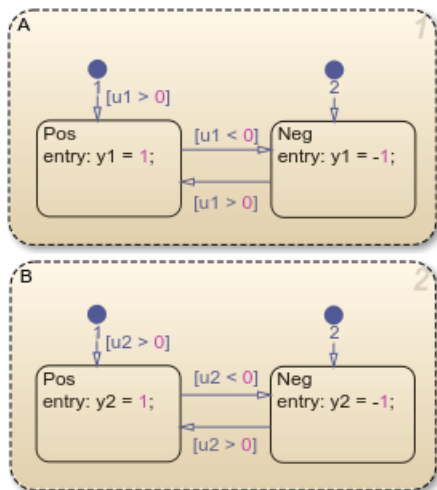
This example shows how to use atomic subcharts to reduce the compilation time when testing a sequence of changes in a Stateflow® chart. Atomic subcharts are supported only in Stateflow charts in Simulink® models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Original Model Without Atomic Subcharts

This model contains two Sine Wave (Simulink) blocks: one with a frequency of 1 radian per second, and the other with a frequency of 2 radians per second.



In the chart, each state uses saturator logic to convert the input sine wave to an output square wave of the same frequency.



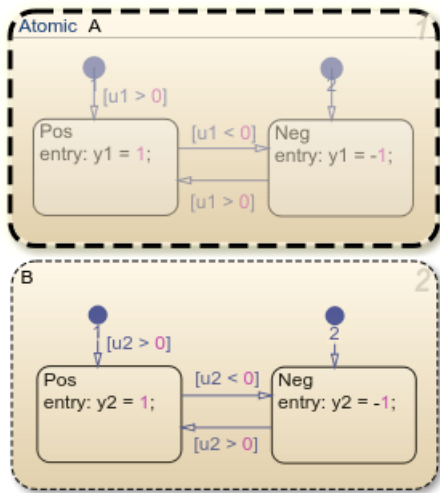
Because this example does not use atomic subcharts, every time that you make a change to the chart and start simulation, recompilation occurs for the entire chart.

In contrast, you can convert state A to an atomic subchart. When you modify the atomic subchart, recompilation occurs for only the subchart and not for the entire chart. As a result, incremental builds for simulation require less time to recompile.

### Edit Model to Use Atomic Subcharts

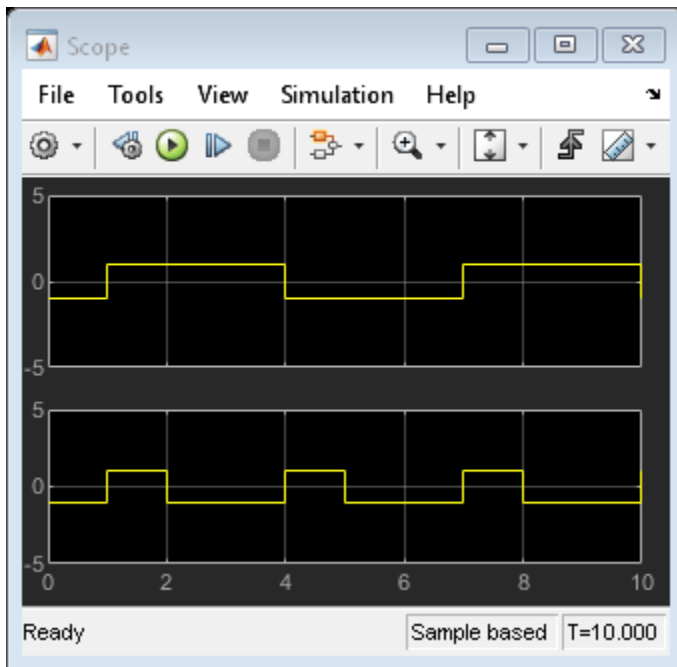
#### Step 1: Convert a State to an Atomic Subchart

Right-click state A and select **Group & Subchart > Atomic Subchart**. State A changes to an atomic subchart and displays the label **Atomic** in the upper-left corner.



### Step 2: Start the Simulation

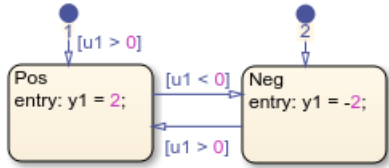
Before simulating, compilation occurs for the entire chart.



### Step 3: Modify the Atomic Subchart

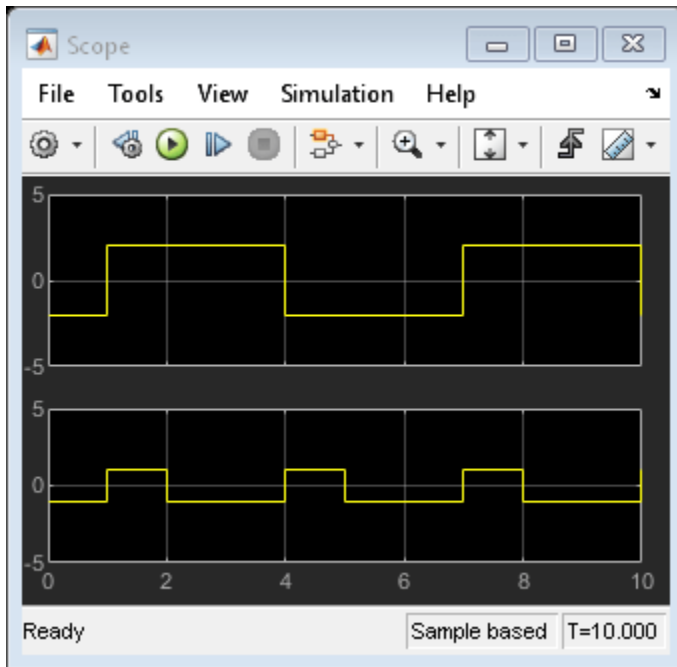
- 1 Double-click the atomic subchart A. The contents of the subchart appear in the Stateflow Editor.
- 2 In the state Pos, change the entry action to  $y1 = 2$ ;
- 3 In the state Neg, change the entry action to  $y1 = -2$ ;





#### Step 4: Restart the Simulation

After the changes to A, recompilation occurs only for the atomic subchart and not the entire chart.



#### See Also

Sine Wave

#### More About

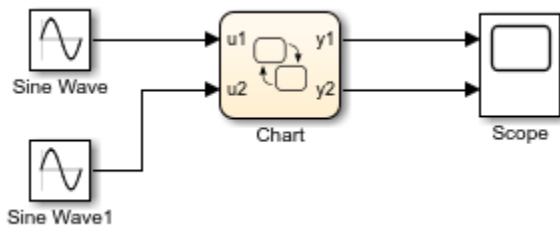
- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Reuse a State Multiple Times in a Chart” on page 19-23
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39

## Divide a Chart into Separate Units

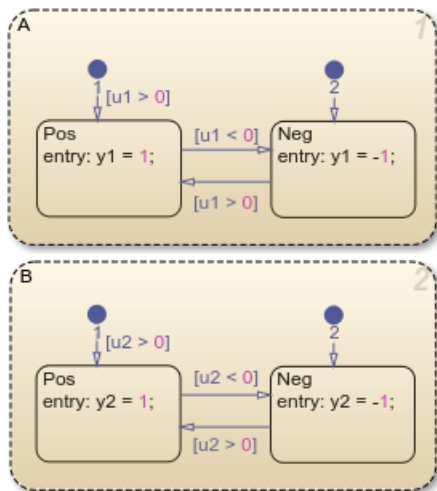
This example shows how to use linked atomic subcharts to break a Stateflow® chart into subcomponents so that multiple people can work on different parts of the chart. Atomic subcharts are supported only in Stateflow charts in Simulink® models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Original Model Without Atomic Subcharts

This model contains two Sine Wave (Simulink) blocks: one with a frequency of 1 radian per second, and the other with a frequency of 2 radians per second.



In the chart, each state uses saturator logic to convert the input sine wave to an output square wave of the same frequency.



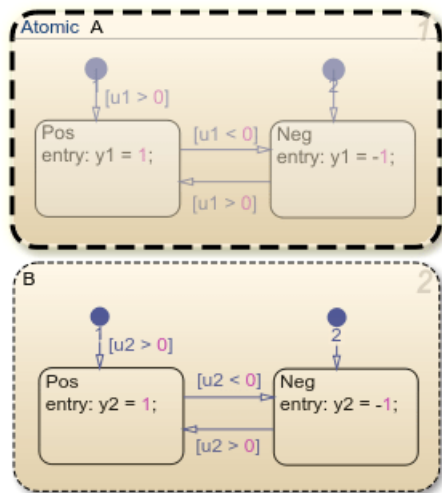
Because this example does not use atomic subcharts, only one person at a time can edit the model. If you edit state A while someone else edits state B, you must merge those changes at submission time.

In contrast, you can store different parts of this example as linked atomic subcharts. Because atomic subcharts behave as independent objects, different people can work on different parts of a chart without affecting the other parts of the chart. At submission time, no merge is necessary because the changes exist in separate models.

### Edit Model to Use Atomic Subcharts

#### Step 1: Convert a State to an Atomic Subchart

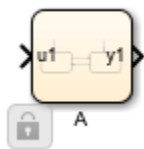
Right-click state A and select **Group & Subchart > Atomic Subchart**. State A changes to an atomic subchart and displays the label **Atomic** in the upper-left corner.



### Step 2: Create a Library for the Atomic Subchart

- 1 Create a new library model.
- 2 Copy the atomic subchart and paste it in your library model.
- 3 Save your library model.

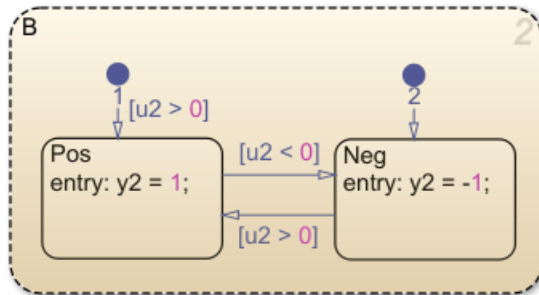
In the library model, the atomic subchart appears as an independent chart with an input port and an output port.



### Step 3: Replace State with Linked Atomic Subchart

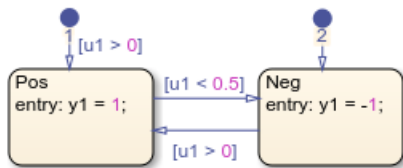
- 1 Delete state A in the chart.
- 2 Copy the atomic subchart in your library and paste it in your chart.

The linked atomic subchart appears opaque and contains the label **Link** in the upper-left corner.



### Propagate a Change in the Library Chart

Suppose that, in the library chart, you edit the transition from Pos to Neg.



This change propagates to the linked atomic subchart in the main chart. If someone else edits the main chart, the changes are merged automatically.

### See Also

Sine Wave

### More About

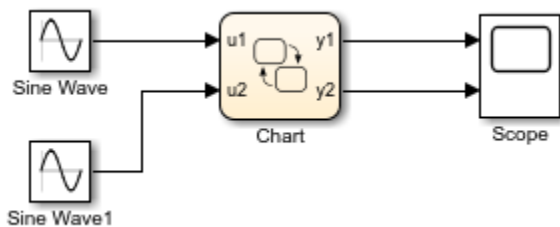
- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Reuse a State Multiple Times in a Chart” on page 19-23
- “Model an Elevator System by Using Atomic Subcharts” on page 19-43
- “Model a Redundant Sensor Pair by Using Atomic Subcharts” on page 19-39

## Generate Separate Code for an Atomic Subchart

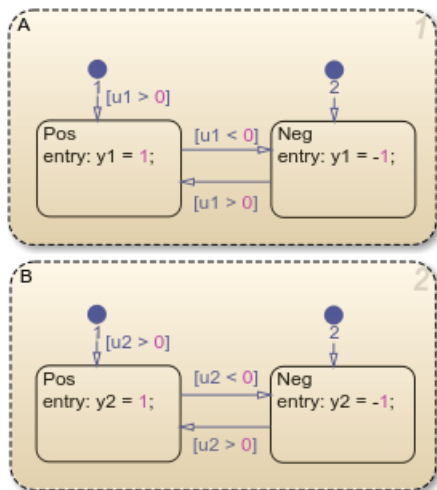
This example shows how to use atomic subcharts to generate code for individual parts of a Stateflow® chart. When you generate code for your chart, a separate file stores the code for the atomic subchart. Atomic subcharts are supported only in Stateflow charts in Simulink® models. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Original Model Without Atomic Subcharts

This model contains two Sine Wave (Simulink) blocks: one with a frequency of 1 radian per second, and the other with a frequency of 2 radians per second.



In the chart, each state uses saturator logic to convert the input sine wave to an output square wave of the same frequency.



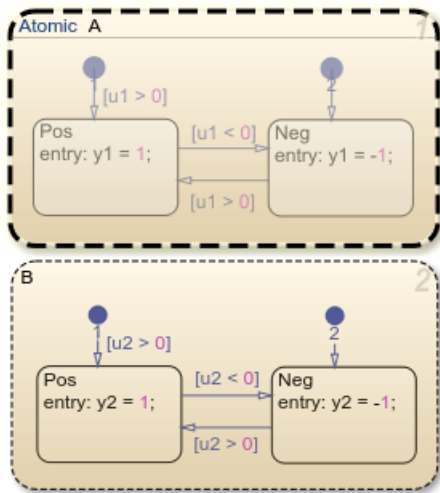
Because this example does not use atomic subcharts, generated code for the entire model is stored in one file. To find code for a specific part of the chart, you have to look through the entire file.

In contrast, you can convert state A to an atomic subchart and specify that the code for the subchart appears in a separate file. This method of code generation enables unit testing for a specific part of a chart. You avoid searching through unrelated code and focus only on the code that interests you.

### Edit Model to Use Atomic Subcharts

#### Step 1: Convert a State to an Atomic Subchart

Right-click state A and select **Group & Subchart > Atomic Subchart**. State A changes to an atomic subchart and displays the label **Atomic** in the upper-left corner.



### Step 2: Set Up a Standalone C File for the Atomic Subchart

- 1 Open the properties dialog box for subchart A by right-clicking the subchart and selecting **Properties**.
- 2 Set the **Code generation function packaging** property to Reusable function.
- 3 Set the **Code generation file name options** property to User specified.
- 4 In the **Code generation file name** box, enter saturator as the name of the file.
- 5 Click **OK**.

### Step 3: Set Up the Code Generation Report

- 1 In the **Modeling** tab, click **Chart Properties > Model Settings** to open the Configuration parameters dialog box.
- 2 In the **Code Generation** tab, set the **System target file** parameter to ert.tlc.
- 3 Under **Code Generation > Report**, select **Create code generation report**.
- 4 Under **Advanced parameters**, select **Model-to-code**.
- 5 Click **Apply**.

### Step 4: Customize the Generated Function Names

In the Configuration Parameters dialog box, in the **Code Generation > Identifiers** tab, set the **Subsystem methods** parameter to the format scheme  $\$R\$N\$M\$F$ , where:

- $\$R$  is the root model name.
- $\$N$  is the block name.
- $\$M$  is the mangle token.
- $\$F$  is the type of interface function for the atomic subchart.

## Generate Code

To generate code for your model by using Embedded Coder®, press **Ctrl+B**.

The code generation report contains links to the code generated from the chart (**Model files**) and the atomic subchart (**Subsystem files**). To inspect the code for the subchart, click the `saturator.c` hyperlink.

The screenshot shows the 'Code Generation Report' window. On the left, there is a 'Contents' pane with links to various reports, and a 'Generated Code' pane listing files under categories: Main file (ert\_main.c), Model files (ex\_reuse\_states.c, ex\_reuse\_states.h, ex\_reuse\_states\_private.h, ex\_reuse\_states\_types.h), Subsystem files (saturator.c, saturator.h), Data files (ex\_reuse\_states\_data.c), and Utility files (1). The main area displays the C code for saturator.c, with line 31 highlighted. The code includes headers, defines constants, and a function `ex_reuse_states_A_during` that handles state transitions based on input values.

```

18
19 #include "saturator.h"
20
21 /* Include model header file for global data */
22 #include "ex_reuse_states.h"
23 #include "ex_reuse_states_private.h"
24
25 /* Named constants for Chart: '<S1>/A' */
26 #define ex_reuse_sta_IN_NO_ACTIVE_CHILD ((uint8_T)0U)
27 #define ex_reuse_states_IN_Neg          ((uint8_T)1U)
28 #define ex_reuse_states_IN_Pos          ((uint8_T)2U)
29
30 /* Function for Chart: '<S1>/A' */
31 void ex_reuse_states_A_during(real_T rtu_u1, real_T *rty_y1,
32     rtDW_A_ex_reuse_states *localDW)
33 {
34     /* During: Chart/A */
35     if (localDW->is_c3_ex_reuse_states == ex_reuse_states_IN_Neg) {
36         /* During 'Neg': '<S2>:9' */
37         if (rtu_u1 > 0.0) {
38             /* Transition: '<S2>:7' */
39             localDW->is_c3_ex_reuse_states = ex_reuse_states_IN_Pos;
40
41             /* Entry 'Pos': '<S2>:8' */
42             *rty_y1 = 1.0;
43         }
44     } else {
45         /* During 'Pos': '<S2>:8' */
46         if (rtu_u1 < 0.0) {
47             /* Transition: '<S2>:6' */
48             localDW->is_c3_ex_reuse_states = ex_reuse_states_IN_Neg;
49
50             /* Entry 'Neg': '<S2>:9' */
51             *rty_y1 = -1.0;
52         }
53     }
54 }
55
56 /* Function for Chart: '<S1>/A' */

```

Line 31 shows that the during function generated for the atomic subchart has the name `ex_reuse_states_A_during`. This name follows the format scheme `$R$N$M$F` specified for Subsystem methods:

- The root model name is `ex_reuse_states`.
- The block name is `A`.
- The mangle token is empty.
- The type of interface function for the atomic subchart is `during`.

**Note:** The line numbers that appear in your code generation report can differ from the numbers shown.

### See Also

Sine Wave

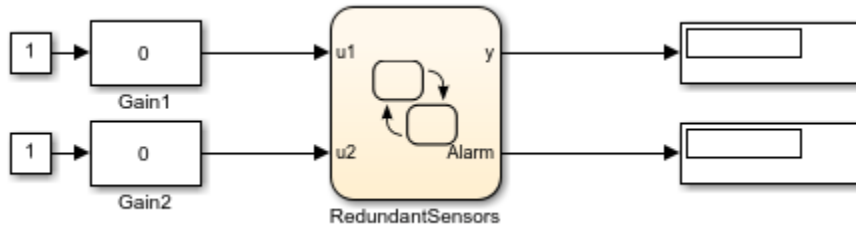
### More About

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Reuse a State Multiple Times in a Chart” on page 19-23
- “Generate Code from Atomic Subcharts” on page 32-14



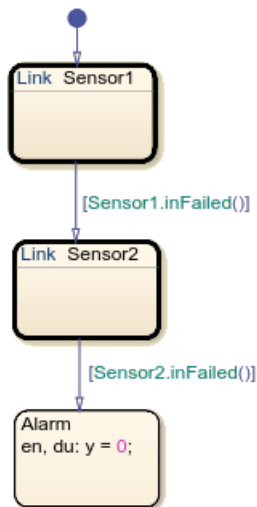
## Model a Redundant Sensor Pair by Using Atomic Subcharts

This model shows how to model a redundant pair of sensors. By using atomic subcharts, you can compose a large Stateflow® chart from other charts that reside in a library file.



### Main Chart

In this model, the chart RedundantSensors contains two linked atomic subcharts (Sensor1 and Sensor2) and a state (Alarm).

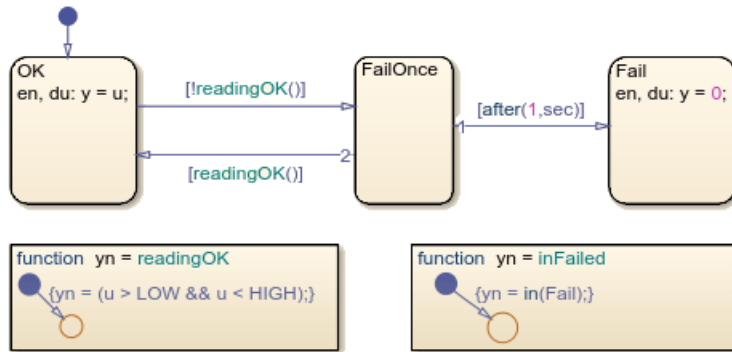


At the start of the simulation, the subchart Sensor1 is active. This atomic subchart reads the input u1. If the input value remains between 75 and -75, Sensor1 passes this value as the output of y. Otherwise, the sensor fails and subchart Sensor2 becomes active.

In a similar way, Sensor2 reads the input u2 and checks that its value remains between 100 and -100. Sensor2 passes this value as the output of y. Otherwise, the sensor fails and the chart transitions to the Alarm state.

### Library Chart

The logic for both Sensor1 and Sensor2 is defined in a library model. In this model, the chart SingleSensor accepts an input u and provides a filtered sensor output y.



The chart detects out-of-range errors in the sensor input  $u$ . Initially, the sensor is in the state `OK`. If  $u$  goes out of range, the chart takes the transition from `OK` to the state `FailOnce`. If  $u$  stays out of range for longer than one second, then the chart transitions to the state `Fail`. In this case, the sensor outputs a constant value of zero. This pattern allows the sensor to ignore transient spikes in the sensor reading.

### Map Inputs, Outputs, and Parameters

The chart `RedundantSensors` has two inputs ( $u1$  and  $u2$ ), while the library chart that defines the atomic subcharts has only one input ( $u$ ). To enable the atomic subcharts to access a different chart input, right-click each subchart and select **Subchart Mappings**. In the **Mappings** tab of the properties dialog box, you can:

- Specify which symbol in the main chart corresponds to each symbol in the subchart.
- Assign values to parameters defined in the subchart.

For example, in the case of subchart `Sensor1`:

- The subchart input  $u$  is mapped to the main chart input  $u1$ .
- The subchart output  $u$  is mapped to the main chart output  $y$ .
- The subchart parameters `HIGH` and `LOW` are assigned the values 75 and -75.

**State Sensor1**

General | **Mappings** | Logging | Documentation

Description

The following tables list the mappings from the subchart symbols (on the left) to the symbols in the main chart (on the right). For every subchart symbol, the drop-down provides the list of available symbols which that subchart symbol can map to.

▼ Input Mapping

Atomic subchart symbol	Main chart symbol
u	u1

▼ Output Mapping

Atomic subchart symbol	Main chart symbol
y	y

▼ Parameter Mapping

Atomic subchart symbol	Main chart symbol
HIGH	75
LOW	-75

▶ Data Store Memory Mapping

▶ Input Event Mapping

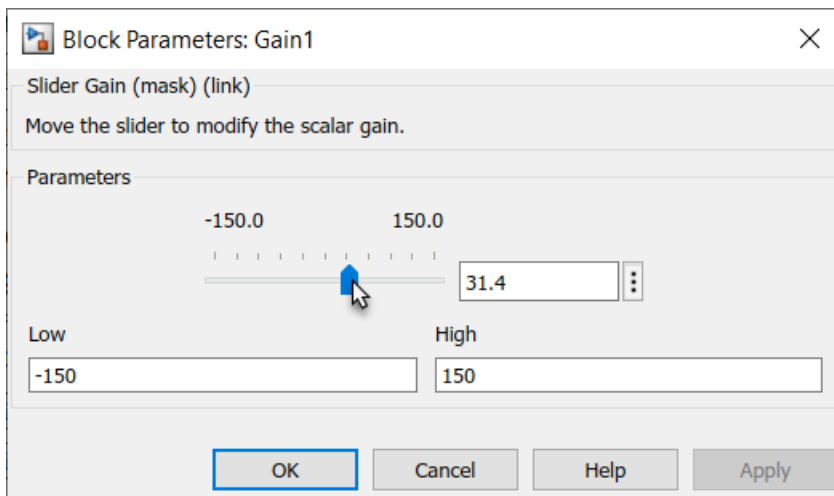
OK Cancel Help Apply

In the case of subchart Sensor2:

- The subchart input *u* is mapped to the main chart input *u2*.
- The subchart output *u* is mapped to the main chart output *y*.
- The subchart parameters *HIGH* and *LOW* are assigned the values 100 and -100.

### Simulation Behavior

Initially, both inputs and both outputs to the chart are zero. To change the value of the chart inputs, double-click the Gain blocks and drag the slider.



As long as the value of  $u1$  is between -75 and 75, the output value  $y$  tracks the input value  $u1$ . If the value of  $u1$  exceeds these bounds, the value of  $y$  begins to track the input value  $u2$ . If the value of  $u2$  falls outside the range from -100 to 100,  $y$  returns a value of zero and  $Alarm$  returns a value of one.

## See Also

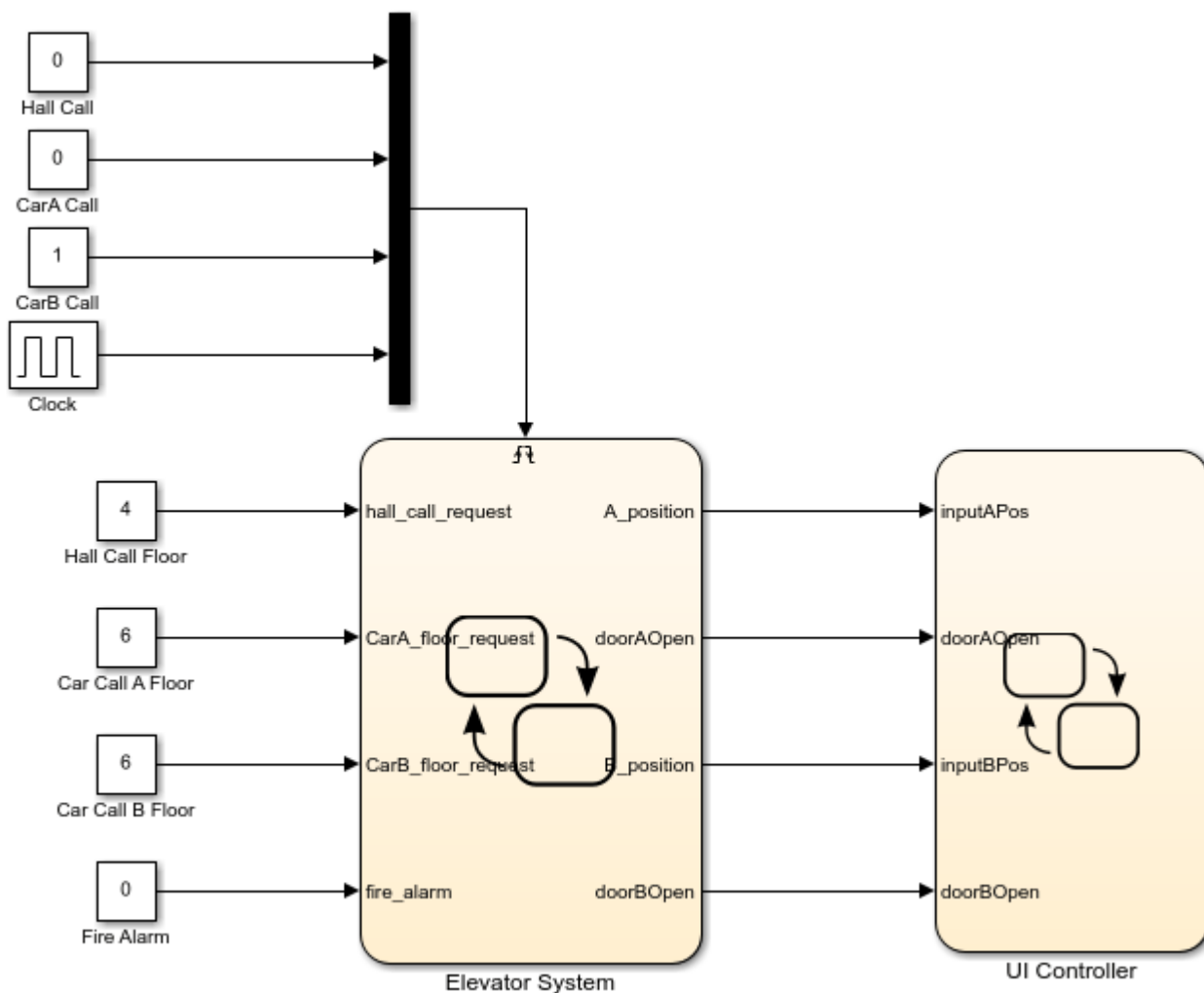
### More About

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18

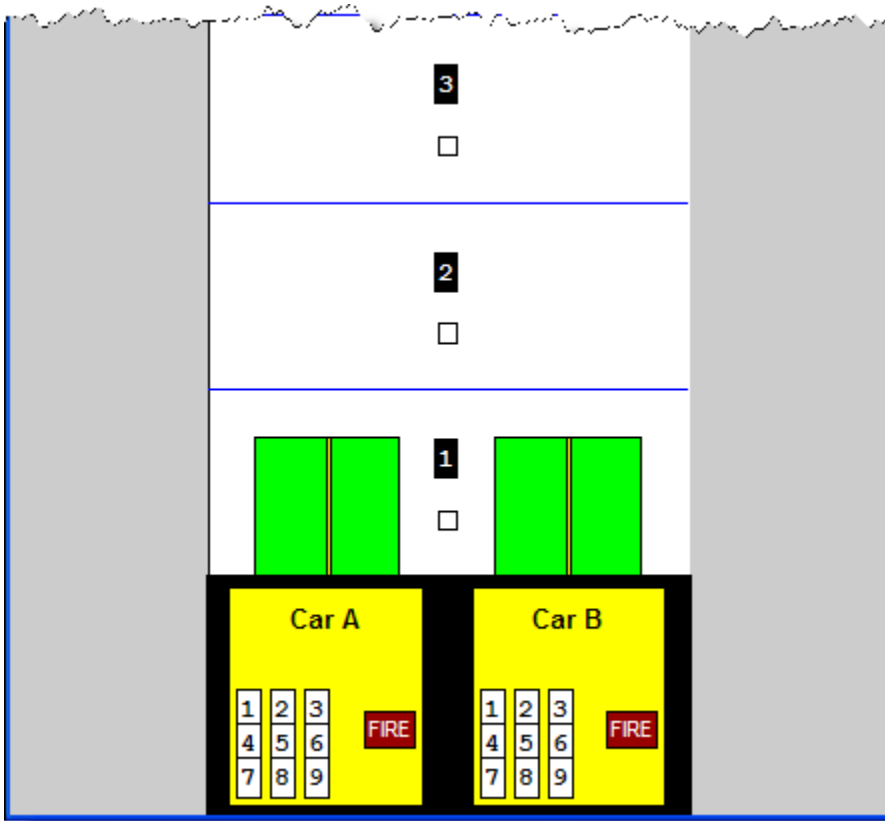
## Model an Elevator System by Using Atomic Subcharts

This example shows how to model a two-car elevator system by using linked atomic subcharts in Stateflow®. The elevator system consists of a Simulink® model and a user interface (UI). The model contains two Stateflow charts:

- Elevator System models the core logic that delegates incoming requests from the UI to the nearest available elevator car. This chart contains a pair of atomic subcharts that implement identical logic for the cars.
- UI Controller processes information from the Elevator System chart and updates the UI display. In this chart, each atomic subchart determines when to move an elevator car and when to open its doors.



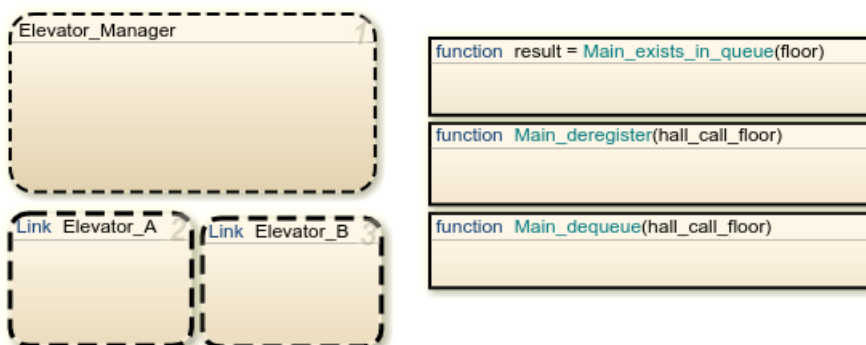
At the start of simulation, the model opens the UI. The UI shows two elevator cars that can stop at nine floors. At the bottom of the UI, two yellow rectangles represent the interior of the elevator cars. While the example is running, you call an elevator car, request a stop at a floor, or set off a fire alarm by clicking the buttons on each floor hallway and inside the elevator cars. The UI responds by modifying the input values and triggering input events for the Elevator System chart.



### Manage Requests from User Interface

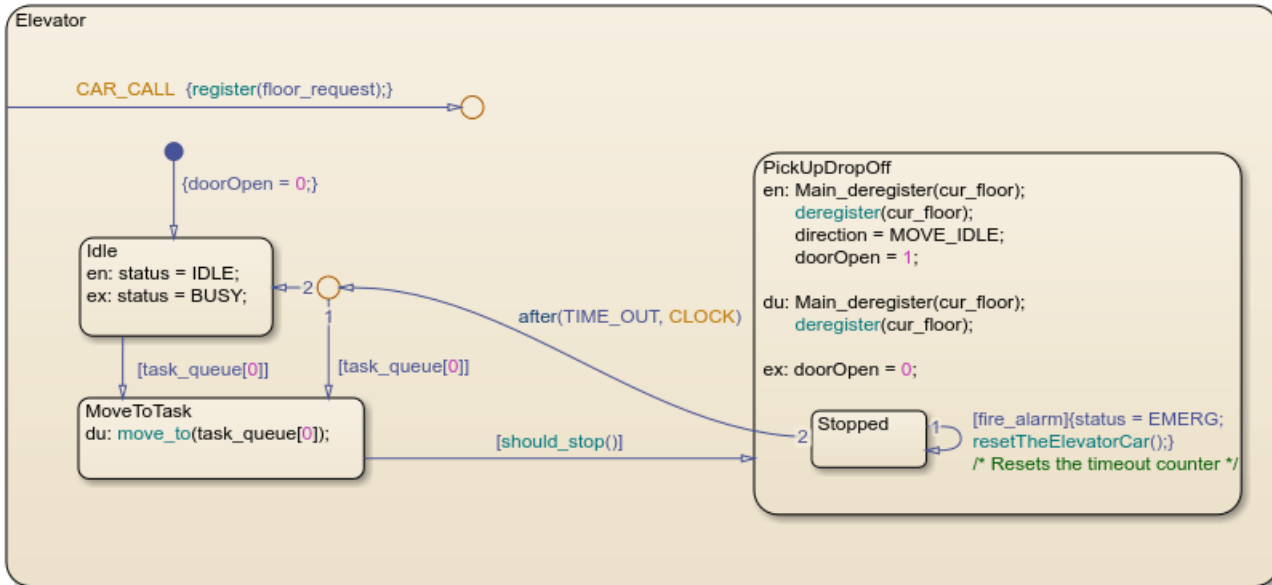
The Elevator System chart consists of three parallel subcharts. Each of these subcharts manages a queue of requests from the UI:

- The Elevator\_Manager subchart implements the main control logic for the elevator system. This subchart manages the hall queue, which holds all the requests that are generated when you click a button in one of the floor hallways. The subchart processes these requests and delegates them to one of the elevator cars, depending on availability and proximity to the request.
- Elevator\_A and Elevator\_B represent the logic for the two elevator cars. Each car has its own queue that holds all of its floor requests. Floor requests are generated when you click a button inside the elevator car or when the Elevator\_Manager delegates a request from the hall queue to the car.



### Reuse Logic Patterns by Using Atomic Subcharts

The elevator cars use identical logic to process their individual request queues. The Elevator System chart models their behavior by using linked atomic subcharts from a library model.



```
truthable ans = should_stop
```

```
truthable move_to(destination)
```

```
function dir = get_direction
```

```
function enqueue(task_floor)
```

```
function register(car_call_floor)
```

```
function pos = get_position
```

```
function dequeue(task_floor)
```

```
function deregister(car_call_floor)
```

```
function stat = get_status
```

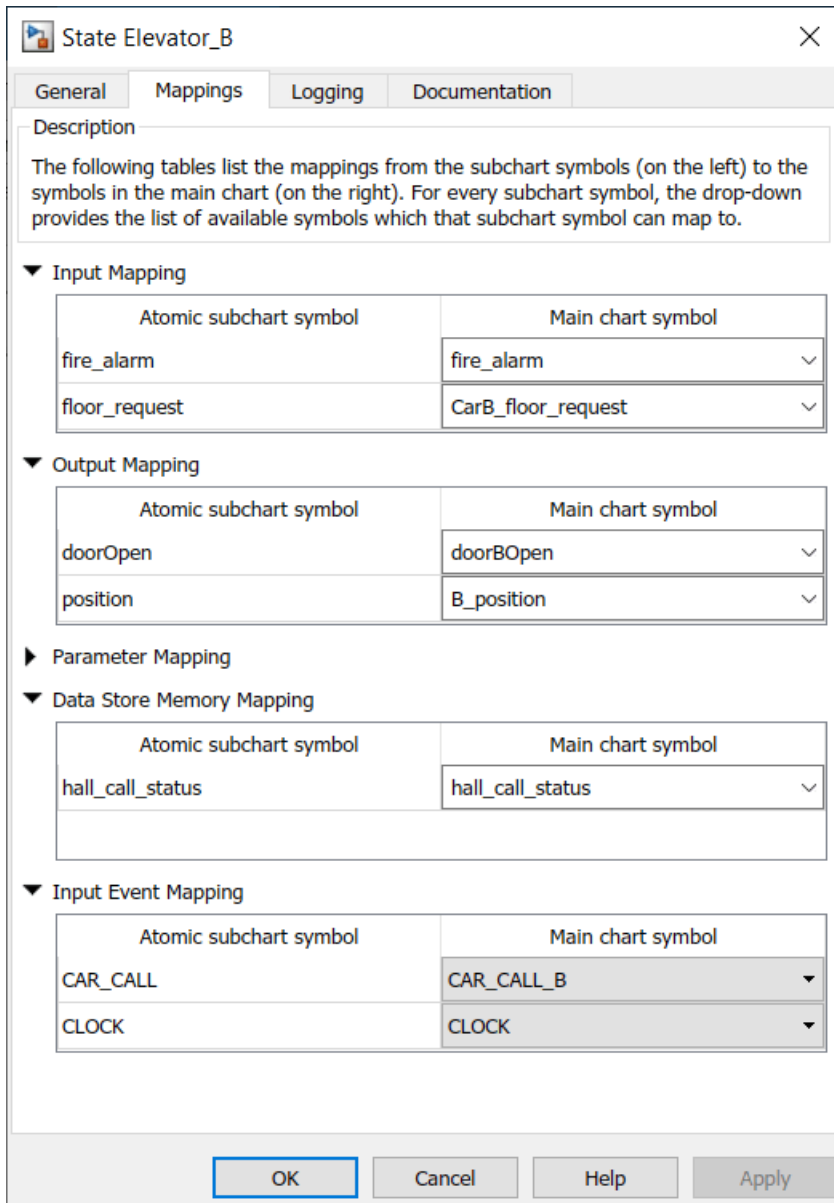
```
MATLAB Function
out = ml_round(inputVal)
```

```
function resetTheElevatorCar
```

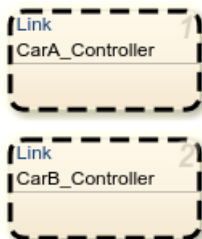
In the library model, the chart Elevator implements the logic for a generic elevator car. To program the subcharts Elevator\_A and Elevator\_B so that they control the appropriate car, you map data and events in each subchart to the corresponding data and events in the main chart. For instance, for Elevator\_B:

- The subchart input floor\_request maps to the chart input CarB\_floor\_request.
- The subchart output position maps to the chart output B\_position.
- The subchart output doorOpen maps to the chart output doorBOpen.
- The subchart event CAR\_CALL maps to the chart event CAR\_CALL\_B.

To see the mappings for each atomic subchart, right-click the subchart and select **Subchart Mappings**.



To control the UI display of each elevator car, the UI Controller chart uses two atomic subcharts linked from a library model.



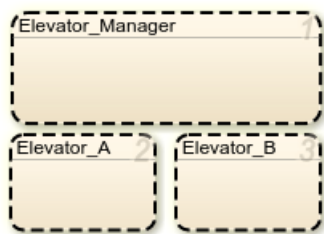


For more information about using atomic subcharts to encapsulate and reuse logic, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Incorporate Atomic Subcharts in Your Design

The model in this example is a redesigned version of an older model that does not use atomic subcharts. The original model uses separate subcharts to manage floor requests (subcharts `Elevator_A` and `Elevator_B` of the `Elevator System` chart) and to control the UI display of elevator cars (subcharts `CarA_Controller` and `CarB_Controller` of the `UI Controller` chart). In each case, the subcharts are nearly identical copies of one another. They differ only in the names of the data and events that they use.

To convert the duplicate subcharts to atomic subcharts, first make a library atomic subchart out of one of the subcharts. Then use linked instances of this library to replace the duplicate subcharts. For example, consider the duplicate elevator car subcharts of the `Elevator System` chart. These subcharts call several functions and local variables that are defined in the `Elevator_Manager` subchart. Before creating an atomic subchart, you must make these subcharts independent and self-contained units.



1. Migrate these functions from the `Elevator_Manager` subchart into the parent chart:

- `exists_in_queue`
- `deregister`
- `dequeue`

Rename these functions to distinguish them from the functions inside the elevator car subcharts.

2. Using the Model Explorer, migrate these variables from the `Elevator_Manager` subchart into the parent chart:

- `hall_call_queue`
- `hall_call_status`

3. In the `Elevator System` chart, set the **Export Chart Level Functions** chart property to `true`. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

4. Modify the `Elevator_Manager` and `Elevator_A` subcharts to use the migrated functions and variables.

5. Create a library atomic subchart from the `Elevator_A` subchart, as described in “Reuse a State Multiple Times in a Chart” on page 19-23.

6. To enable the atomic subchart to pass the position of the elevator car to the containing chart, change the **Scope** of the subchart data position from `Local` to `Output`.

7. Replace the two elevator subcharts with the linked atomic subchart. For each linked atomic subchart, map data and events to the parent chart. For more information, see “Map Variables for Atomic Subcharts and Boxes” on page 19-11.

## **See Also**

### **More About**

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Export Stateflow Functions for Reuse” on page 8-23
- “Reuse a State Multiple Times in a Chart” on page 19-23
- “Map Variables for Atomic Subcharts and Boxes” on page 19-11

# Save and Restore Simulations with Operating Point

---

- “Using Operating Points in Stateflow” on page 20-2
- “Divide a Long Simulation into Segments” on page 20-4
- “Test a Unique Chart Configuration” on page 20-8
- “Test a Chart with Fault Detection and Redundant Logic” on page 20-15
- “Methods for Interacting with the Operating Point of a Chart” on page 20-27
- “Rules for Using the Operating Point of a Chart” on page 20-30
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Using Operating Points in Stateflow

An operating point is a snapshot of the complete state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

An operating point lists Stateflow objects in hierarchical order:

- Graphical objects grouped by type (box, function, or state) and in alphabetical order within each group
- Chart data grouped by scope (block output or local) and in alphabetical order within each group

For example, the following operating point illustrates the hierarchical structure of Stateflow objects.

c =

```
Block:    "shift_logic"    (handle)    (active)
Path:     sf_car/shift_logic
```

Contains:

```
+ gear_state      "State (AND)"      (active)
+ selection_state "State (AND)"      (active)
  gear            "State output data" gearType [1, 1]
  down_th        "Local scope data" double [1, 1]
  up_th          "Local scope data" double [1, 1]
```

The tree structure maps graphical and nongraphical objects to their respective locations in the chart hierarchy. If name conflicts exist, one or more underscores appear at the end of a name so that all objects have unique identifiers in the operating point hierarchy. Stateless flow charts have an empty operating point, because they do not contain states or persistent data.

For information about using an operating point for other blocks in a Simulink model, see “Save and Restore Simulation Operating Point” (Simulink).

## Division of a Long Simulation into Segments

You can save the complete operating point of a model at any time during a long simulation. Then you can load that operating point and run specific segments of that simulation without starting from time  $t = 0$ , which saves time.

For directions, see “Divide a Long Simulation into Segments” on page 20-4.

## Test of a Chart Response to Different Settings

You can modify and load the operating point of a chart to test the response of a chart to different settings. You can change the value of chart local or output data midway through a simulation or change state activity and then test how a chart responds.

Loading and modifying the operating point provides these benefits:

- Enables testing of a hard-to-reach chart configuration by loading a specific operating point
- Enables testing of the same chart configuration with different settings

For directions, see:

- “Test a Unique Chart Configuration” on page 20-8
- “Test a Chart with Fault Detection and Redundant Logic” on page 20-15

## **See Also**

### **More About**

- “Divide a Long Simulation into Segments” on page 20-4
- “Methods for Interacting with the Operating Point of a Chart” on page 20-27
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Divide a Long Simulation into Segments

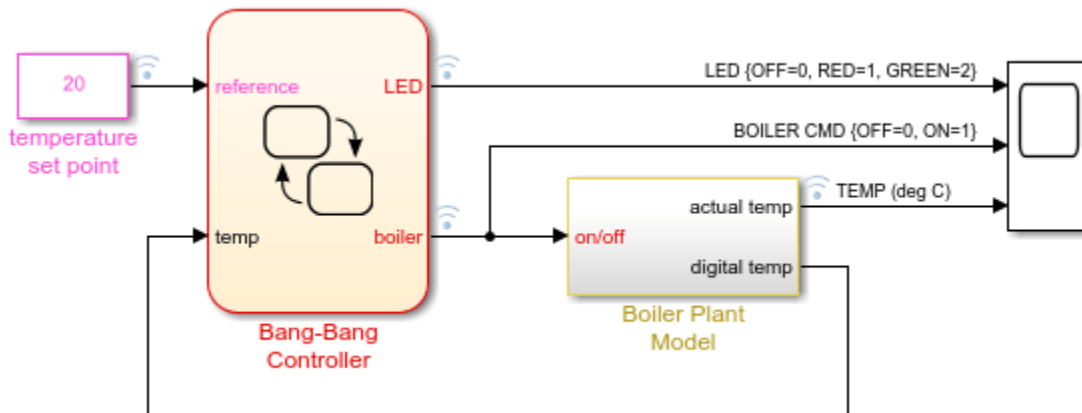
This example shows how to use operating points with Stateflow charts. An operating point is a snapshot of the state of a Simulink® model at a specific time during simulation. For a Stateflow® chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB® functions and Truth Table blocks

For more information, see “Using Operating Points in Stateflow” on page 20-2.

### Goal of the Tutorial

Suppose that you want to simulate this model without starting from time  $t = 0$ .



This model simulates for 1400 seconds, but the output that interests you occurs sometime between  $t = 400$  and  $600$ . You can simulate the model, save the operating point at time  $t = 400$ , and then load that operating point for simulation between  $t = 400$  and  $600$ .

### Step 1: Define the Operating Point

1. Open the sf\_boiler model.
2. Enable saving of an operating point.
  - a. Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
  - b. Select the **Final states** check box.
  - c. Enter a name, such as sf\_boiler\_ctx01.
  - d. Select the **Save final operating point** check box.
  - e. Click **Apply**.

To complete this step programmatically, enter:

```
set_param('sf_boiler', ...
    'SaveFinalState','on', ...
    'FinalStateName','sf_boiler_ctx01', ...
    'SaveOperatingPoint','on');
```

For details about setting model parameters, see `set_param` (Simulink).

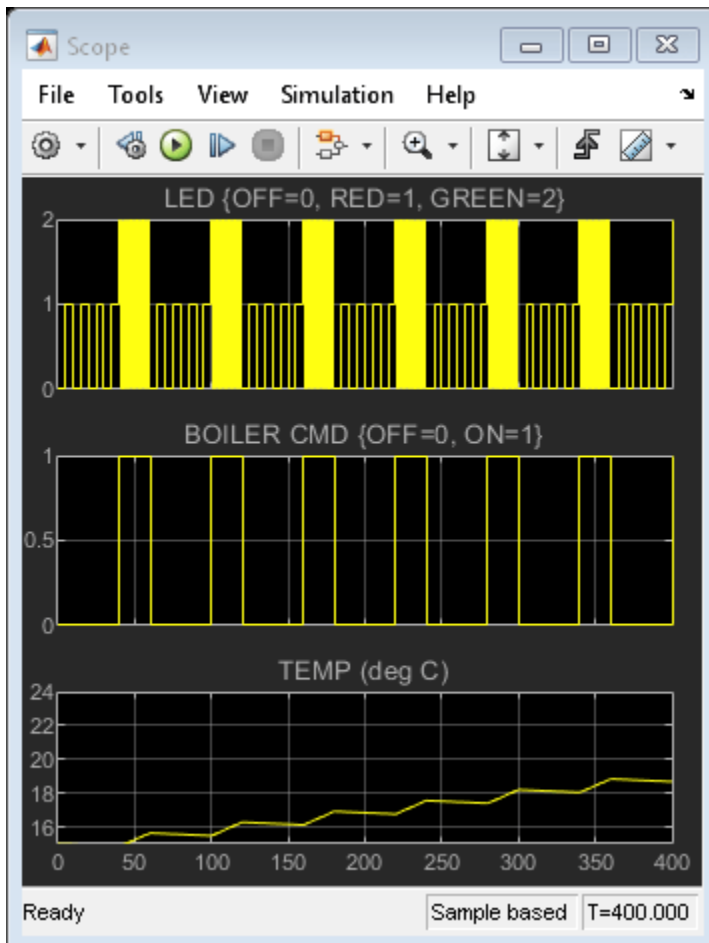
3. Define the start and stop times for this simulation segment.

- a. In the Model Configuration Parameters dialog box, go to the **Solver** pane.
- b. For **Start time**, enter 0.
- c. For **Stop time**, enter 400.
- c. Click **OK**.

To complete this step programmatically, enter:

```
set_param('sf_boiler', ...
    'StartTime','0', ...
    'StopTime','400');
```

4. Start simulation. When you simulate the model, you save the complete operating point at  $t = 400$  in the variable `sf_boiler_ctx01` in the MATLAB base workspace.



5. Disable saving of an operating point. This step prevents you from overwriting the operating point you saved in the previous step.

- a. Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
- b. Clear the **Save final operating point** check box.
- c. Clear the **Final states** check box.
- d. Click **OK**.

To complete this step programmatically, enter:

```
set_param('sf_boiler', ...  
    'SaveOperatingPoint','off', ...  
    'SaveFinalState','off');
```

### Step 2: Load the Operating Point

1. Enable loading of an operating point.

- a. Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
- b. Select the **Initial state** check box.
- c. Enter the variable that contains the operating point of your chart, `sf_boiler_ctx01`.
- d. Click **Apply**.

To complete this step programmatically, enter:

```
set_param('sf_boiler', ...  
    'LoadInitialState','on', ...  
    'InitialState','sf_boiler_ctx01');
```

2. Define the new stop time for this simulation segment. You do not need to enter a new start time because the simulation continues from where it left off.

- a. In the Model Configuration Parameters dialog box, go to the **Solver** pane.
- b. For **Stop time**, enter 600.
- c. Click **OK**.

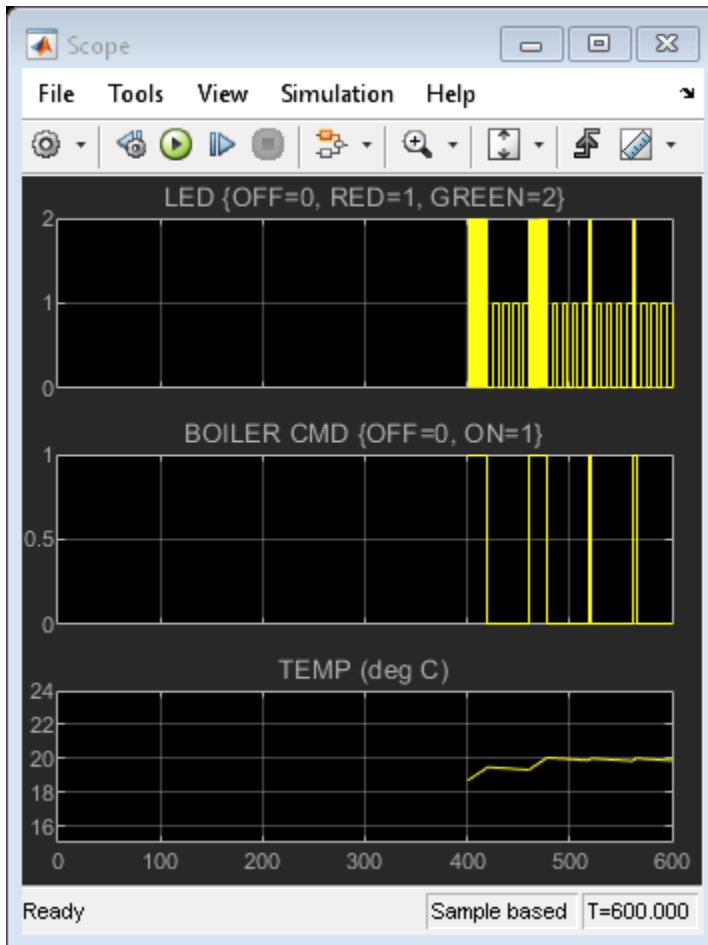
To complete this step programmatically, enter:

```
set_param('sf_boiler','StopTime','600');
```

### Step 3: Simulate the Specific Segment

When you simulate the model, the following output appears in the Scope (Simulink) block.





## See Also

Scope | set\_param

## More About

- “Using Operating Points in Stateflow” on page 20-2
- “Methods for Interacting with the Operating Point of a Chart” on page 20-27
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Test a Unique Chart Configuration

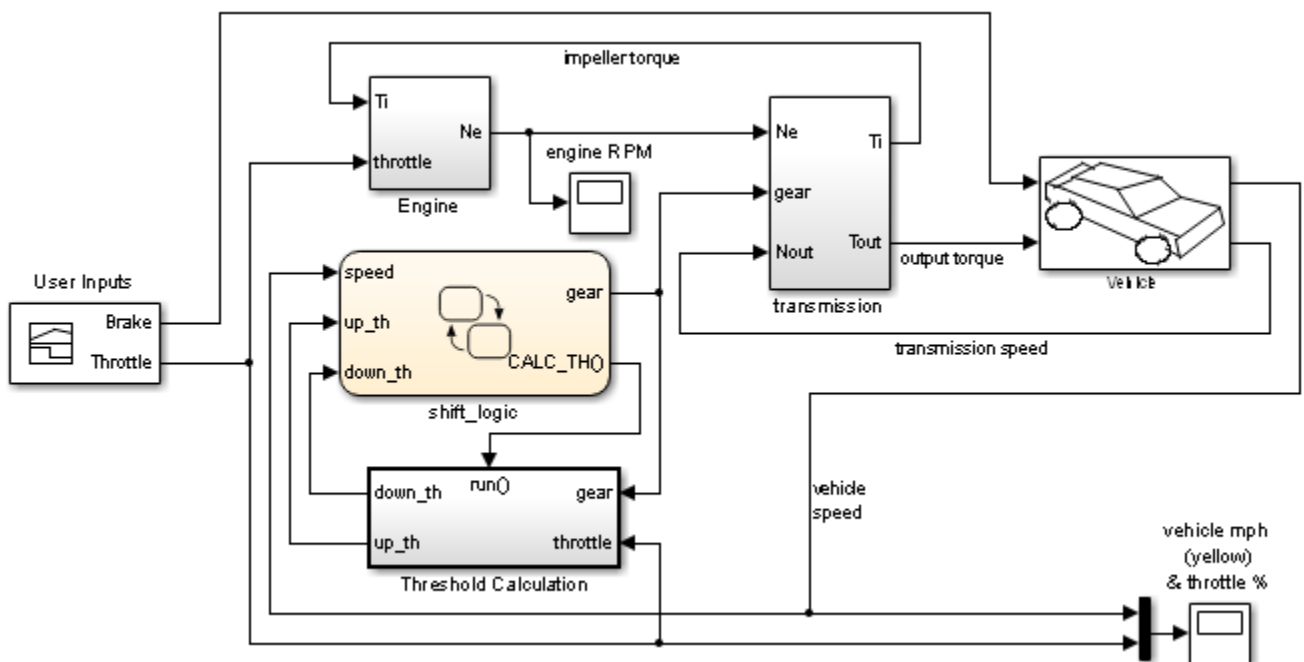
An operating point is a snapshot of the state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

For more information, see “Using Operating Points in Stateflow” on page 20-2.

### Goal of the Tutorial

Suppose that you want to test the response of the `old_sf_car` model to a sudden change in value for `gear`.



This model simulates for 30 seconds, but you want to see what happens when the value of `gear` changes at  $t = 10$ . You can simulate the model, save the operating point at  $t = 10$ , load and modify the operating point, and then simulate again between  $t = 10$  and 20.

Step	Task	Reference
1	Define the operating point for your chart.	“Define the Operating Point” on page 20-9
2	Load the operating point and modify values.	“Load the Operating Point and Modify Values” on page 20-10

Step	Task	Reference
3	Test the modified operating point by running the model.	“Test the Modified Operating Point” on page 20-13

## Define the Operating Point

- 1 Open the model `old_sf_car`.
- 2 Enable saving of an operating point.
  - a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
  - b Select the **Final states** check box.
  - c Enter a name, such as `old_sf_car_ctx01`.
  - d Select the **Save final operating point** check box.
  - e Click **Apply**.

### Programmatic equivalent

You can programmatically enable saving of an operating point:

```
set_param('old_sf_car','SaveFinalState','on', ...
'FinalStateName','old_sf_car_ctx01', ...
'SaveOperatingPoint','on');
```

For details about setting model parameters, see `set_param`.

- 3 Define the start and stop times for this simulation segment.
  - a In the Model Configuration Parameters dialog box, go to the **Solver** pane.
  - b For **Start time**, enter 0.
  - c For **Stop time**, enter 10.
  - d Click **OK**.

### Programmatic equivalent

You can programmatically set the start and stop times:

```
set_param('old_sf_car','StartTime','0', ...
'StopTime','10');
```

- 4 Start simulation.

When you simulate the model, you save the complete operating point at  $t = 10$  in the variable `old_sf_car_ctx01` in the MATLAB base workspace.

At  $t = 10$ , the engine is operating at a steady-state value of 2500 RPM.



- 5 Disable saving of an operating point.

This step prevents you from overwriting the operating point you saved in the previous step.

- a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
- b Clear the **Save final operating point** check box.
- c Clear the **Final states** check box.
- d Click **OK**.

#### Programmatic equivalent

You can programmatically disable saving of an operating point:

```
set_param('old_sf_car','SaveOperatingPoint','off', ...
'SaveFinalState','off');
```

## Load the Operating Point and Modify Values

- 1 Enable loading of an operating point.
  - a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
  - b Select the **Initial state** check box.
  - c Enter the variable that contains the operating point of your chart: `old_sf_car_ctx01`.
  - d Click **OK**.

### Programmatic equivalent

You can programmatically enable loading of an operating point:

```
set_param('old_sf_car','LoadInitialState','on', ...
'InitialState', 'old_sf_car_ctx01');
```

- 2 Define an object handle for the operating point values of the `shift_logic` chart.

At the command prompt, type:

```
blockpath = 'old_sf_car/shift_logic';
c = old_sf_car_ctx01.get(modelOperatingPoint, 'blockpath');
```

---

**Tip** If the chart appears highlighted in the model window, you can specify the block path using `gcb`:

```
c = old_sf_car_ctx01.get(gcb);
```

---

### Copy and reference operating points with the `get` method

The `get` method:

- Makes a copy of the operating point of your chart, which is stored in the final state data of the model.
- Provides a root-level handle or *reference* to the copy of the operating point, which is a hierarchical tree of graphical and nongraphical chart objects.

Each node in this tree is also a handle to a state, data, or other chart object.

---

**Note** Because the entire tree consists of object handles, the following assignment statements do not work:

- `stateCopy = c.state`
- `dataCopy = c.data`
- `operatingPointCopy = c`

These assignments create copies of the object handles, not operating point values. The only way to copy operating point values is to use the `clone` method. For details, see “Methods for Interacting with the Operating Point of a Chart” on page 20-27 and “Rules for Using the Operating Point of a Chart” on page 20-30.

---

- 3 Look at the contents of the operating point.

```
c =
```

```
Block:    "shift_logic"    (handle)    (active)
Path:     old_sf_car/shift_logic
```

```
Contains:
```

```
+ gear_state      "State (AND)"      (active)
+ selection_state "State (AND)"      (active)
```

```
gear "Block output data" double [1, 1]
```

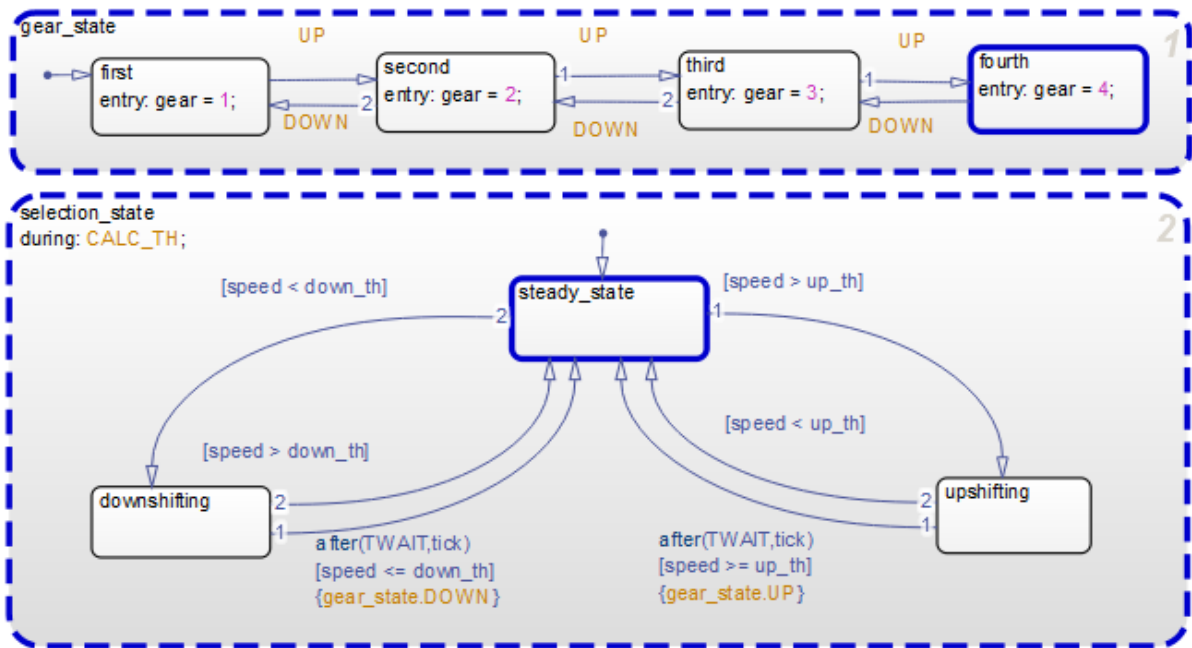
The operating point of your chart contains a list of states and data in hierarchical order.

- Highlight the states that are active in your chart at  $t = 10$ .

At the command prompt, type:

```
c.highlightActiveStates;
```

In the chart, all active states appear highlighted.



**Tip** To check if a single state is active, you can use the `isActive` method. For example, type:

```
c.gear_state.fourth.isActive
```

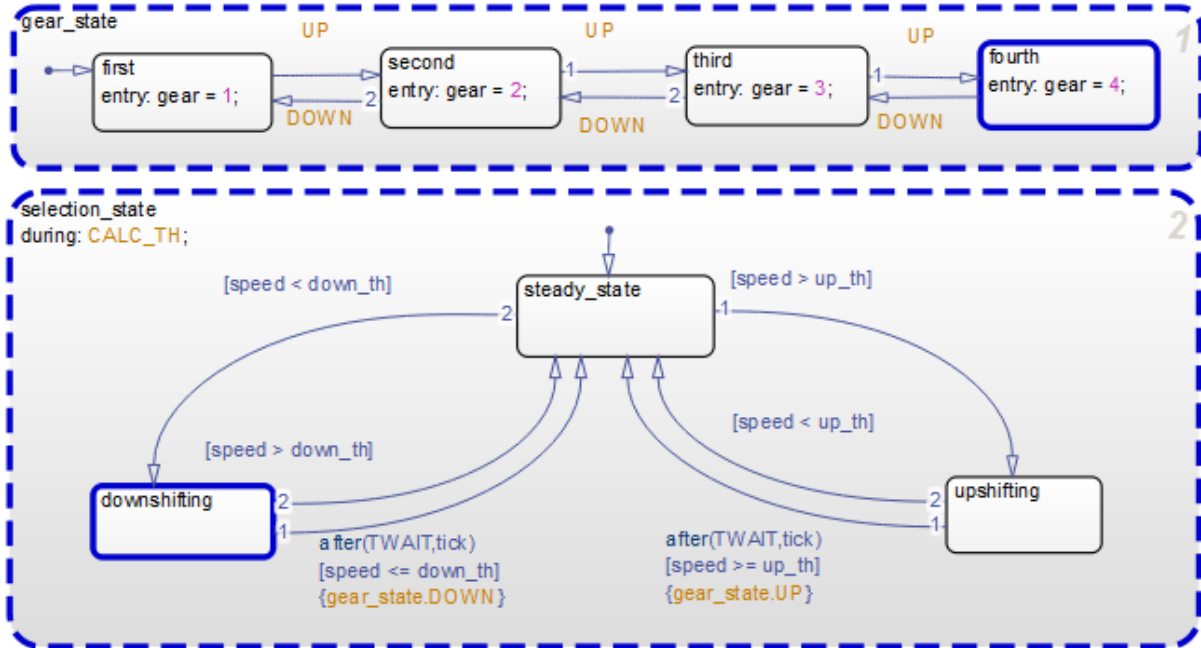
This command returns true (1) when a state is active and false (0) otherwise. For information on other methods, see "Methods for Interacting with the Operating Point of a Chart" on page 20-27.

- Change the active substate of `selection_state` to `downshifting`.

Use this command:

```
c.selection_state.downshifting.setActive;
```

The newly active substate appears highlighted in the chart.



## 6 Change the value of output data gear.

When you type `c.gear` at the command prompt, you see a list of data properties similar to this:

```
>> c.gear
```

```
ans =
```

```

Description: 'Block output data'
DataType: 'double'
Size: '[1, 1]'
Range: [1x1 struct]
InitialValue: [1x0 double]
Value: 4

```

You can change the value of `gear` from 4 to 1 by typing

```
c.gear.Value = 1;
```

However, you cannot change the data type or size of `gear`. Also, you cannot specify a new value that falls outside the range set by the **Minimum** and **Maximum** parameters. For details, see “Rules for Modifying Data Values” on page 20-30 .

## 7 Save the modified operating point.

Use this command:

```
old_sf_car_ctx01 = old_sf_car_ctx01.set(blockpath, c);
```

## Test the Modified Operating Point

### 1 Define the new stop time for the simulation segment to test.

- a In the Model Configuration Parameters dialog box, go to the **Solver** pane.
- b For **Stop time**, enter 20.
- c Click **OK**.

You do not need to enter a new start time because the simulation continues from where it left off.

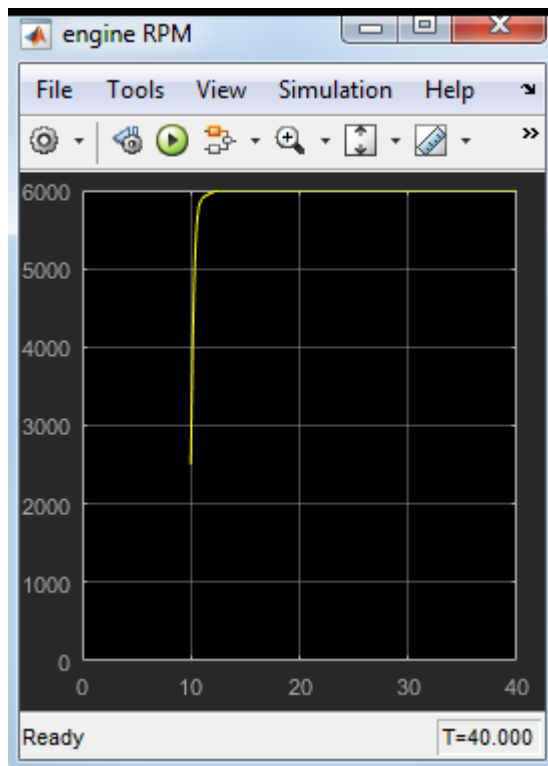
### Programmatic equivalent

You can programmatically set the stop time:

```
set_param('old_sf_car','StopTime','20');
```

- 2 Start simulation.

The engine reacts as follows:



## See Also

### More About

- "Using Operating Points in Stateflow" on page 20-2
- "Methods for Interacting with the Operating Point of a Chart" on page 20-27
- "Best Practices for Saving the Operating Point of a Chart" on page 20-32



## Test a Chart with Fault Detection and Redundant Logic

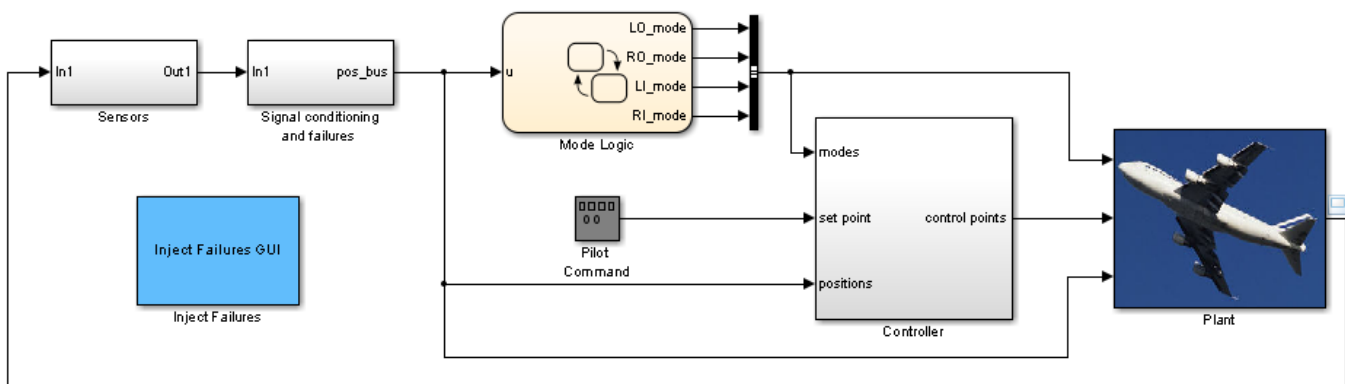
An operating point is a snapshot of the state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

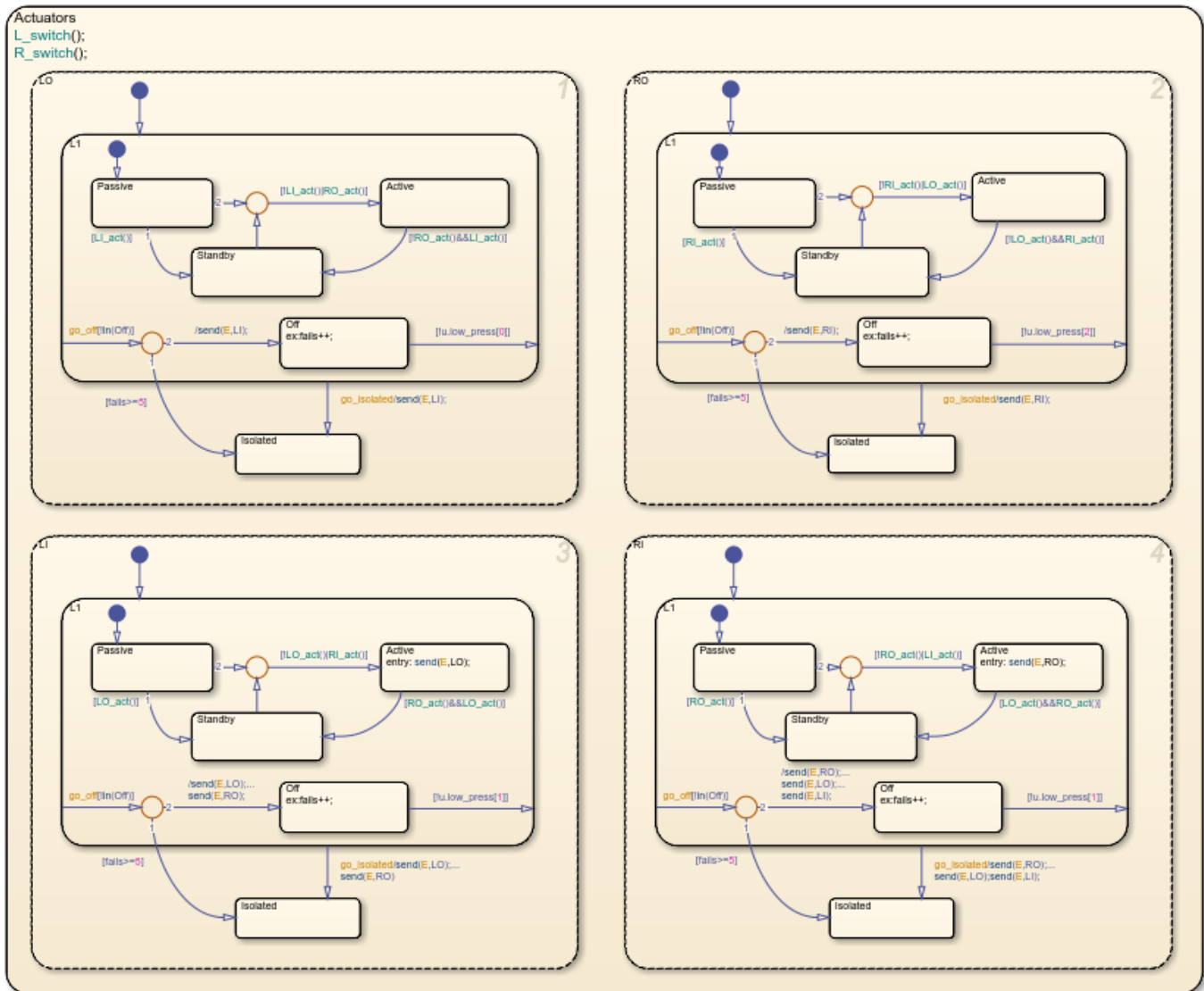
For more information, see “Using Operating Points in Stateflow” on page 20-2.

### Goal of the Tutorial

Suppose that you want to test the response of the `sf_aircraft` model to one or more actuator failures in an elevator system. For details of how this model works, see “Detect Faults in Aircraft Elevator Control System” on page 30-19.



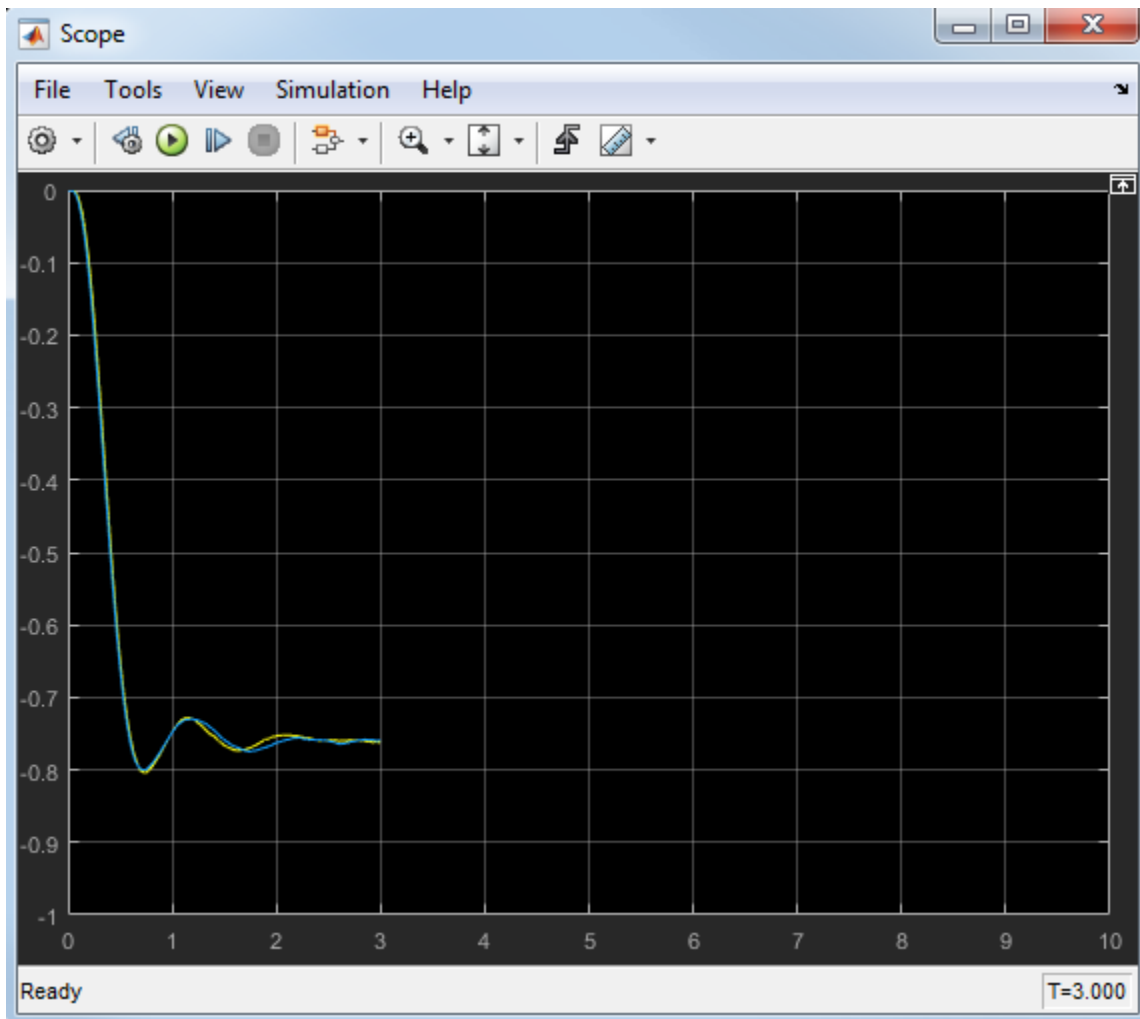
The Mode Logic chart monitors the status of actuators for two elevators. Each elevator has an outer (primary) actuator and an inner (secondary) actuator. In normal operation, the outer actuators are active and the inner actuators are on standby.



truthtable L_switch	truthtable R_switch	function y_act = LO_act	function y_act = LI_act	function y_act = RO_act	function y_act = RI_act
------------------------	------------------------	----------------------------	----------------------------	----------------------------	----------------------------

This mode logic assumes that there are 3 hydraulic lines, one that is connected to the 2 redundant actuators (Left Inner and Right Inner actuators). The other two are connected to the primary actuators Left Outer and Right Outer (1 per actuator).

When the four actuators are working correctly, the left and right elevators reach steady-state positions in 3 seconds.



Suppose that you want to see what happens at  $t = 3$  when at least one actuator fails. You can simulate the model, save the operating point at  $t = 3$ , load and modify the operating point, and then simulate again between  $t = 3$  and 10.

Step	Task	Reference
1	Define the operating point for your chart.	"Define the Operating Point" on page 20-18
2	Load the operating point and modify values for one actuator failure.	"Modify Operating Point Values for One Actuator Failure" on page 20-19
3	Test the modified operating point by running the model.	"Test the Operating Point for One Failure" on page 20-22
4	Modify operating point values for two actuator failures.	"Modify Operating Point Values for Two Actuator Failures" on page 20-24
5	Test the modified operating point by running the model again.	"Test the Operating Point for Two Failures" on page 20-25

## Define the Operating Point

- 1 Open the `sf_aircraft` model.
- 2 Enable saving of an operating point.
  - a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
  - b Select the **Final states** check box.
  - c Enter a name, such as `xFinal`.
  - d Select the **Save final operating point** check box.
  - e Click **Apply**.

### Programmatic equivalent

You can programmatically enable saving of an operating point:

```
set_param('sf_aircraft','SaveFinalState','on', ...  
'FinalStateName', ['xFinal'], ...  
'SaveOperatingPoint','on');
```

For details about setting model parameters, see `set_param`.

- 3 Define the stop time for this simulation segment.
  - a In the Model Configuration Parameters dialog box, go to the **Solver** pane.
  - b For **Stop time**, enter 3.
  - c Click **OK**.

### Programmatic equivalent

You can programmatically set the stop time:

```
set_param('sf_aircraft','StopTime','3');
```

- 4 Start simulation.

When you simulate the model, you save the complete operating point at  $t = 3$  in the variable `xFinal` in the MATLAB base workspace.
- 5 Disable saving of an operating point.

This step prevents you from overwriting the operating point you saved in the previous step.

- a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
- b Clear the **Save final operating point** check box.
- c Clear the **Final states** check box.
- d Click **OK**.

### Programmatic equivalent

You can programmatically disable saving of an operating point:

```
set_param('sf_aircraft','SaveOperatingPoint','off', ...  
'SaveFinalState','off');
```

## Modify Operating Point Values for One Actuator Failure

- 1 Enable loading of an operating point.
  - a Open the Model Configuration Parameters dialog box and go to the **Data Import/Export** pane.
  - b Select the **Initial state** check box.
  - c Enter the variable that contains the operating point of your chart: `xFinal`.
  - d Click **OK**.

### Programmatic equivalent

You can programmatically enable loading of an operating point:

```
set_param('sf_aircraft','LoadInitialState','on', ...
'InitialState', ['xFinal']);
```

- 2 Define an object handle for the operating point values of the Mode Logic chart.

At the command prompt, type:

```
blockpath = 'sf_aircraft/Mode Logic';
c = xFinal.get(blockpath);
```

---

**Tip** If the chart appears highlighted in the model window, you can specify the block path using `gcb`:

```
c = xFinal.get(gcb);
```

---

### Use the get method for Operating Points

The `get` method:

- Makes a copy of the operating point of your chart, which is stored in the final state data of the model.
- Provides a root-level handle or *reference* to the copy of the operating point, which is a hierarchical tree of graphical and nongraphical chart objects.

Each node in this tree is also a handle to a state, data, or other chart object.

---

**Note** Because the entire tree consists of object handles, the following assignment statements do not work:

- `stateCopy = c.state`
- `dataCopy = c.data`
- `operatingPointCopy = c`

These assignments create copies of the object handles, not operating point values. The only way to copy operating point values is to use the `clone` method. For details, see “Methods for Interacting with the Operating Point of a Chart” on page 20-27 and “Rules for Using the Operating Point of a Chart” on page 20-30.

---

- 3 Look at the contents of the operating point.

```
c =
```

```
Block: "Mode Logic" (handle) (active)
```

```
Path: sf_aircraft/Mode Logic
```

```
Contains:
```

```
+ Actuators "State (OR)" (active)
+ LI_act "Function"
+ LO_act "Function"
+ L_switch "Function"
+ RI_act "Function"
+ RO_act "Function"
+ R_switch "Function"
+ LI_mode "State output data" sf_aircraft_ModeType [1,1]
+ LO_mode "State output data" sf_aircraft_ModeType [1,1]
+ RI_mode "State output data" sf_aircraft_ModeType [1,1]
+ RO_mode "State output data" sf_aircraft_ModeType [1,1]
```

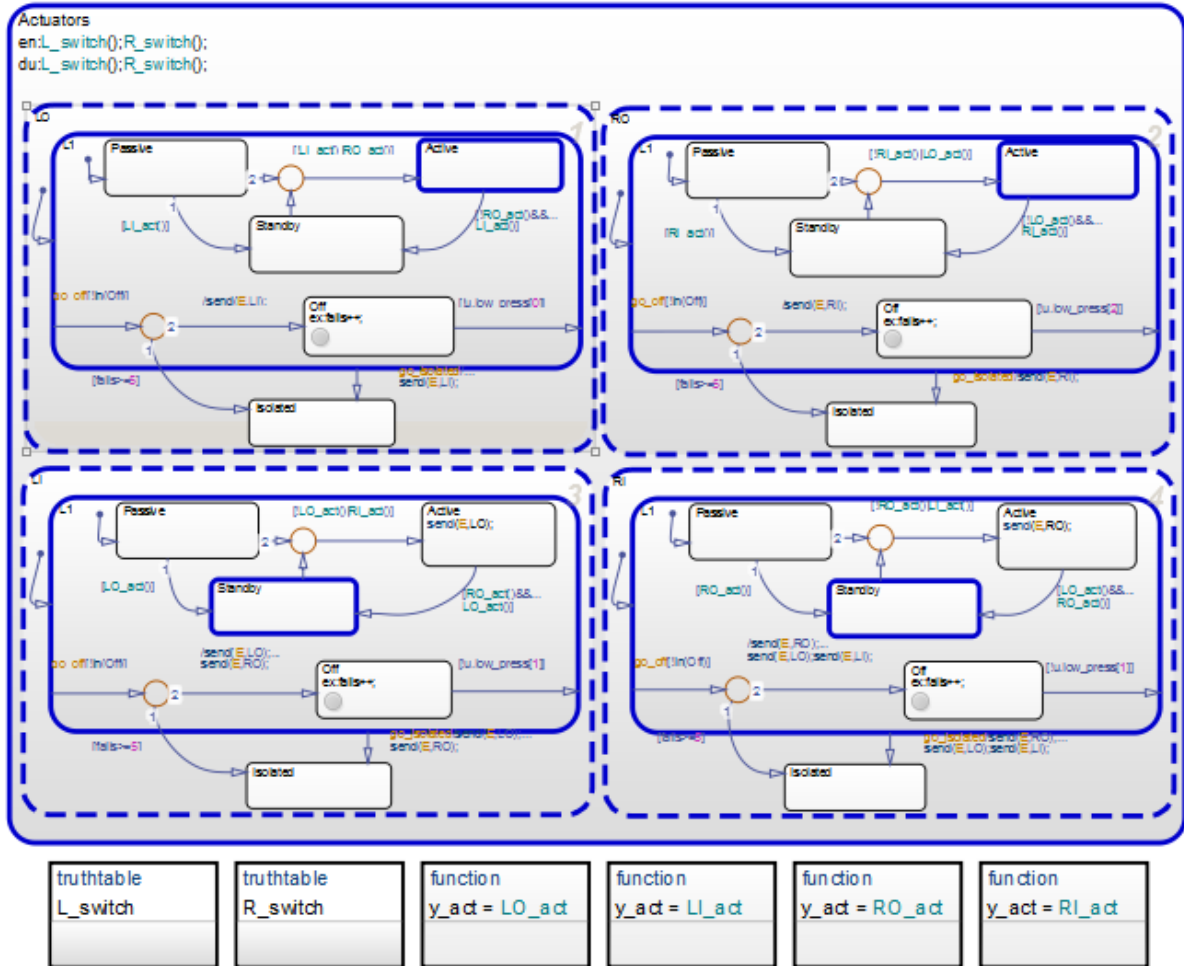
The operating point of your chart contains a list of states, functions, and data in hierarchical order.

- 4 Highlight the states that are active in your chart at  $t = 3$ .

At the command prompt, type:

```
c.highlightActiveStates;
```

Active states appear highlighted. By default, the two outer actuators are active and the two inner actuators are on standby.



**Tip** To check if a single state is active, you can use the `isActive` method. For example, type:

```
c.Actuators.LI.L1.Standby.isActive
```

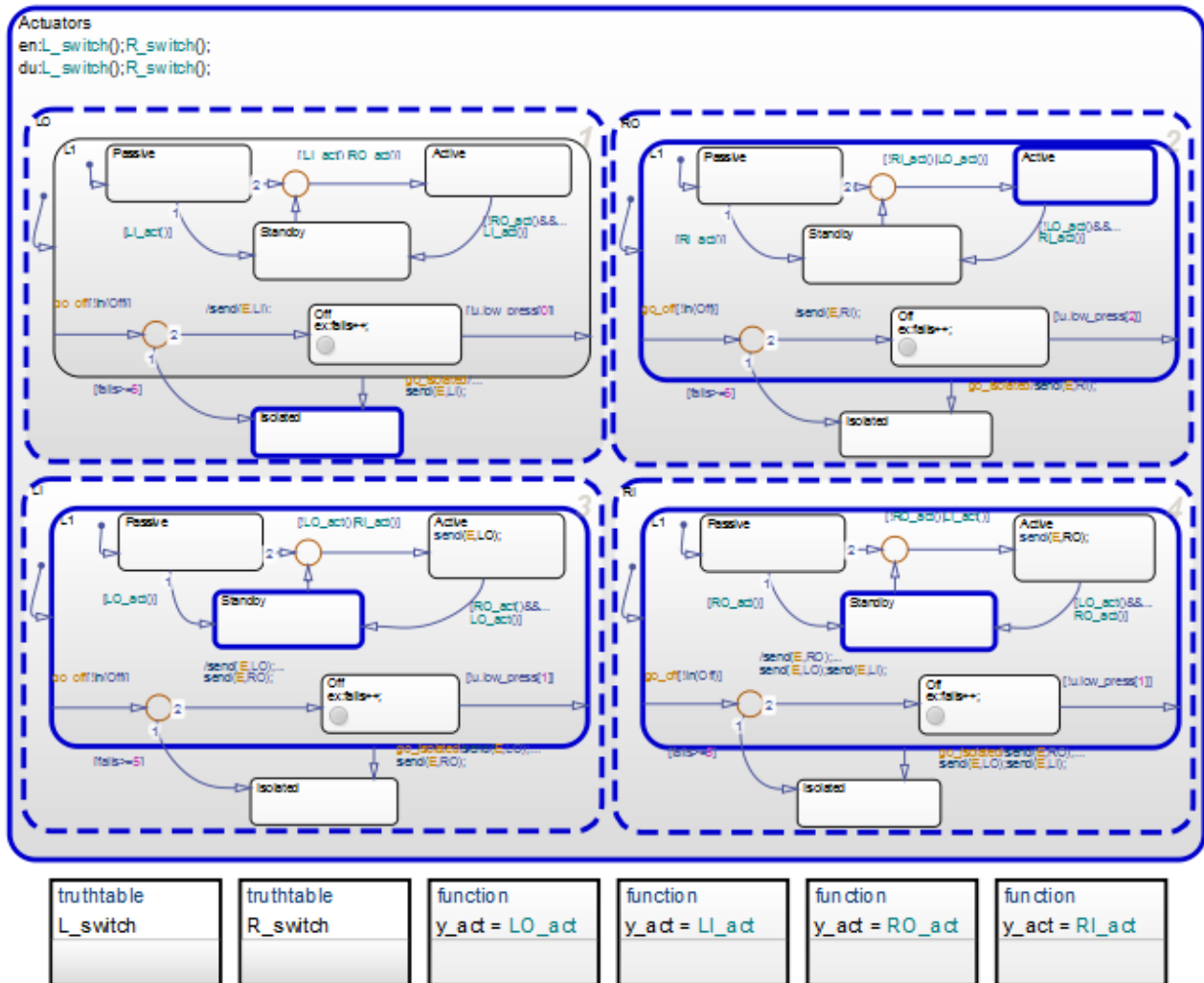
This command returns true (1) when a state is active and false (0) otherwise. For information on other methods, see “Methods for Interacting with the Operating Point of a Chart” on page 20-27.

- 5 Change the state activity in the chart to reflect one actuator failure.

Assume that the left outer (LO) actuator fails. To change the state, use this command:

```
c.Actuators.LO.Isolated.setActive;
```

The newly active substate appears highlighted in the chart.



This mode logic assumes that there are 3 hydraulic lines, one that is connected to the 2 redundant actuators (Left Inner and Right Inner actuators). The other two are connected to the primary actuators Left Outer and Right Outer (1 per actuator).

The setActive method ensures that the chart exits and enters the appropriate states to maintain state consistency. However, the method does not perform entry actions for the newly active substate. Similarly, the method does not perform exit actions for the previously active substate.

- 6 Save the modified operating point by using this command:

```
xFinal = xFinal.set(blockpath, c);
```

### Test the Operating Point for One Failure

- 1 Define the new stop time for the simulation segment to test.
  - a Go to the **Solver** pane of the Model Configuration Parameters dialog box.
  - b For **Stop time**, enter 10.
  - c Click **OK**.



You do not need to enter a new start time because the simulation continues from where it left off.

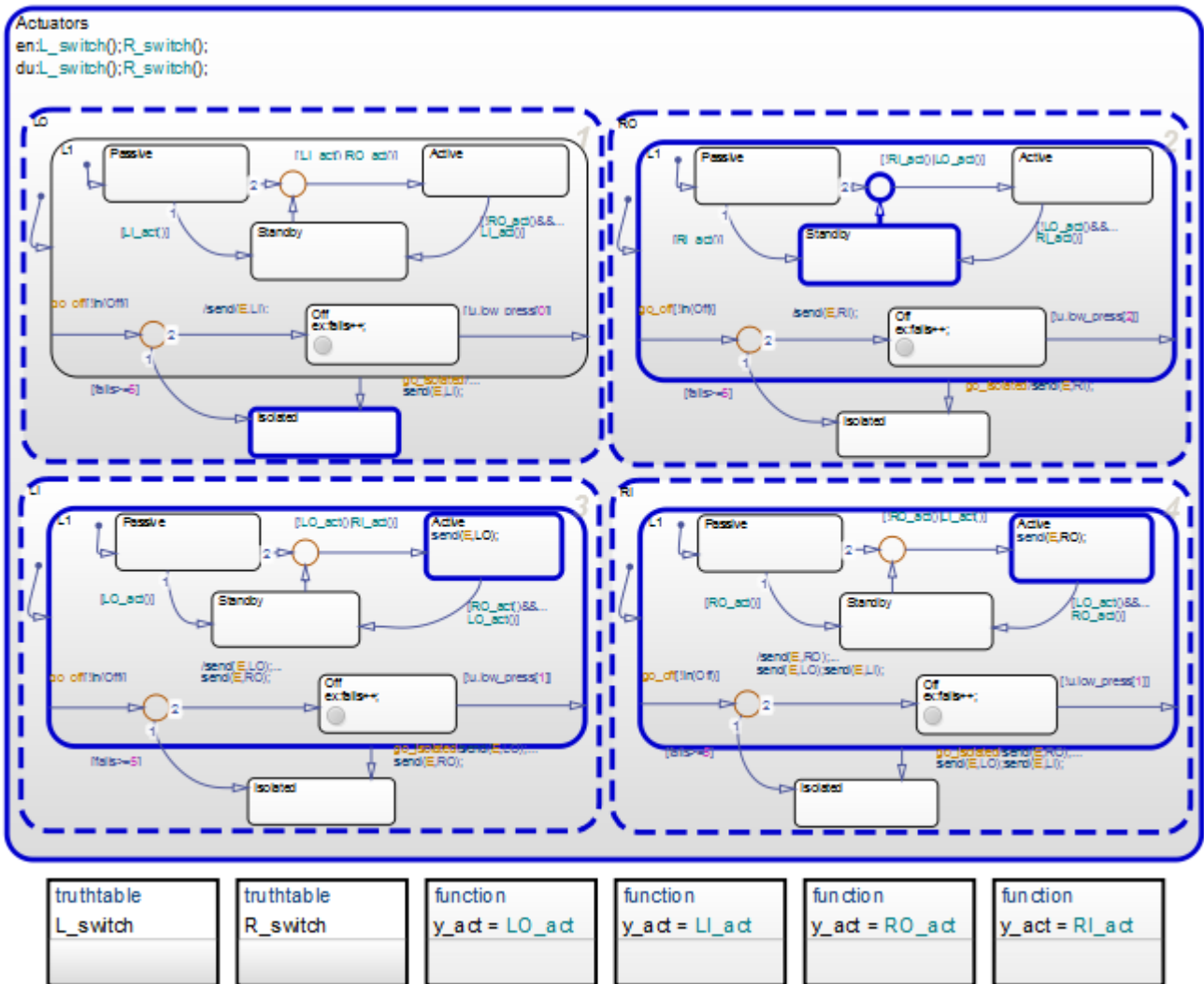
**Programmatic equivalent**

You can programmatically set the stop time:

```
set_param('sf_aircraft','StopTime','10');
```

- 2 Start simulation.

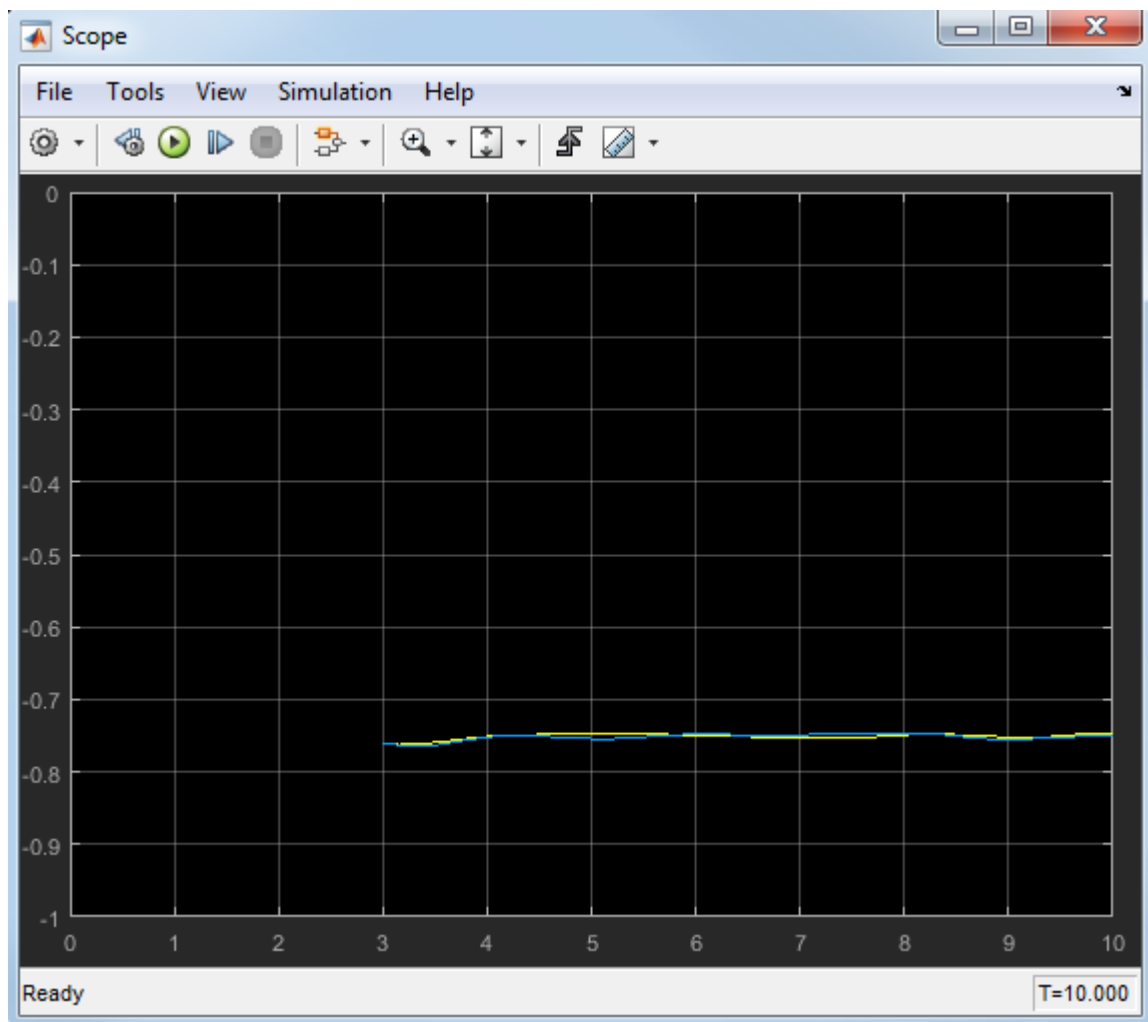
Chart animation shows that the other three actuators react appropriately to the failure of the left outer (LO) actuator.



*This mode logic assumes that there are 3 hydraulic lines, one that is connected to the 2 redundant actuators (Left Inner and Right Inner actuators). The other two are connected to the primary actuators Left Outer and Right Outer (1 per actuator).*

This actuator...	Switches from...	Because...
Left inner (LI)	Standby to active	The left elevator must compensate for the left outer (LO) actuator failure.
Right inner (RI)	Standby to active	The same hydraulic line connects to both inner actuators.
Right outer (RO)	Active to standby	Only one actuator per elevator can be active.

Both elevators continue to maintain steady-state positions.



## Modify Operating Point Values for Two Actuator Failures

- 1 Change the state activity in the chart to reflect two actuator failures.

Assume that the left inner (LI) actuator also fails. To change the state, use this command:

```
c.Actuators.LI.Isolated.setActive;
```

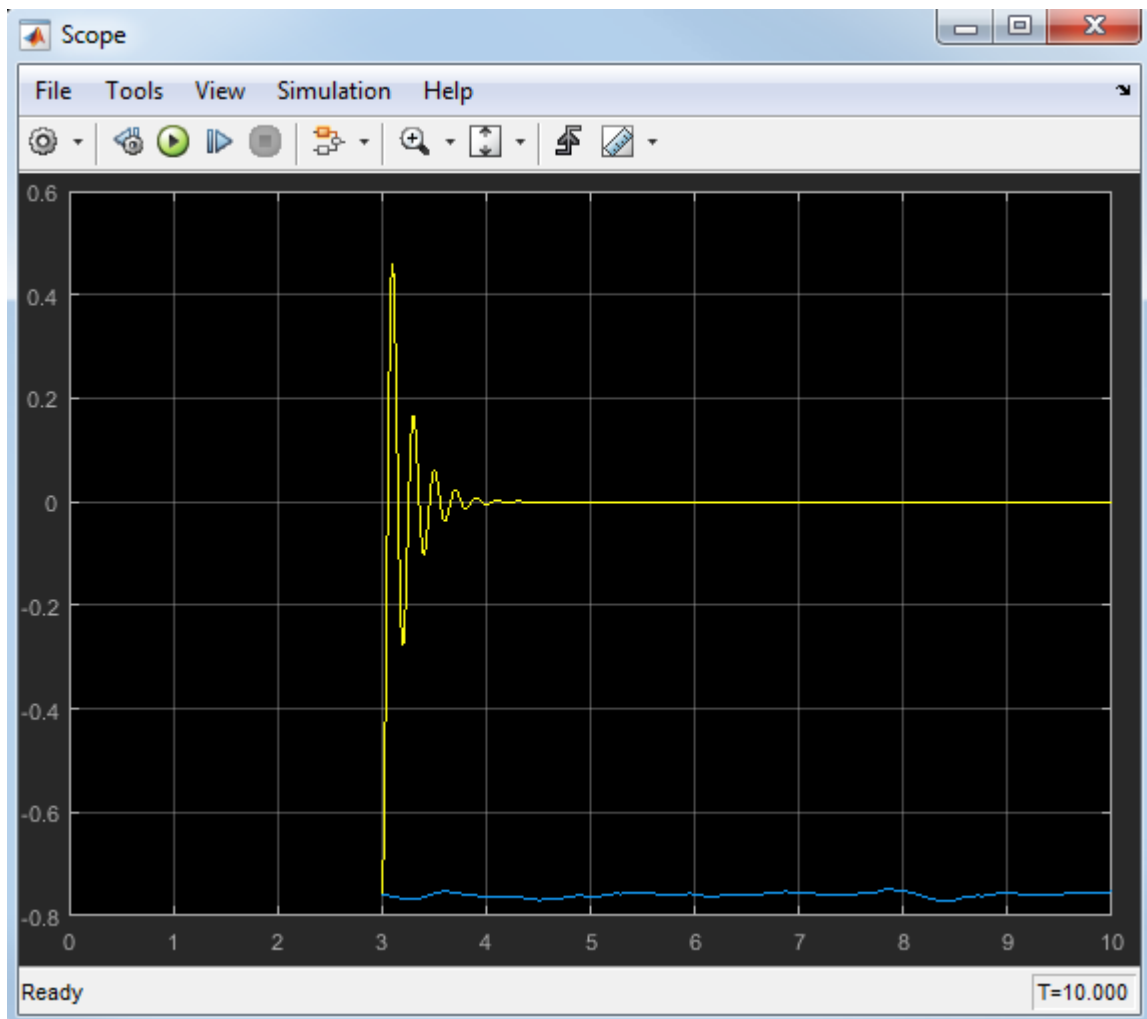
- 2 Save the modified operating point by using this command:

```
xFinal = xFinal.set(blockpath, c);
```

## Test the Operating Point for Two Failures

- 1 In the Model Configuration Parameters dialog box, verify that the stop time is 10.
- 2 Restart simulation.

Because of failures in both actuators, the left elevator stops working. The right elevator maintains a steady-state position.



If you modify the operating point of your chart to test the response of the right elevator to actuator failures, you get similar results.

## **See Also**

### **More About**

- “Using Operating Points in Stateflow” on page 20-2
- “Methods for Interacting with the Operating Point of a Chart” on page 20-27
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Methods for Interacting with the Operating Point of a Chart

An operating point is a snapshot of the state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

For more information, see “Using Operating Points in Stateflow” on page 20-2.

You can use the following methods to interact with the operating point of a chart. Assume that *ch* is a handle to the operating point of your chart, which you obtain using the `get` method.

Type of Object	Method	Description	Example
All chart objects	<code>open</code>	<p>For graphical objects, highlights the object in the Stateflow Editor.</p> <p>For nongraphical objects, highlights the object in the Model Explorer.</p> <p><b>Note</b> For persistent data in MATLAB functions, this method opens the function editor and highlights the persistent data at the exact line in the script.</p>	<code>ch.data.open</code>

Type of Object	Method	Description	Example
Chart	checkStateConsistency	<p>Verifies that all states in a chart are consistent.</p> <ul style="list-style-type: none"> <li>• If a state is inactive, no substates are active.</li> <li>• If a state with parallel decomposition is active, all substates are active.</li> <li>• If a state with exclusive decomposition is active, only one substate is active.</li> </ul>	<i>ch.checkStateConsistency</i>
Chart	clone	Copies the entire chart operating point to a new variable.	<i>newOperatingPoint = ch.clone</i>
Chart	highlightActiveStates	Highlights all active states in the Stateflow Editor.	<i>ch.highlightActiveStates</i>
Chart	isStateConsistent	Returns true (1) if all states pass a consistency check and false (0) otherwise.	<i>ch.isStateConsistent</i>
Chart	removeHighlighting	Removes all highlighting in the Stateflow Editor.	<i>ch.removeHighlighting</i>
State	isActive	Returns true (1) if a state is active and false (0) otherwise.	<i>ch.state.isActive</i>
State Must be an exclusive leaf state	setActive	<p>Sets a state to be active.</p> <p>This method ensures that no other exclusive states at that level are active.</p>	<i>ch.state.substate.setActive</i>

Type of Object	Method	Description	Example
State Must have a history junction and exclusive substates	getPrevActiveChild	Returns the previously active substate.	<code>ch.state.getPrevActiveChild</code>
State Must be inactive; must have a history junction and exclusive substates	setPrevActiveChild	Sets the previously active substate.	<code>ch.state.setPrevActiveChild('B')</code> <b>Note</b> The argument must be the name of a substate (in quotes), or the full operating point path to a substate (without quotes).

## See Also

### More About

- “Using Operating Points in Stateflow” on page 20-2
- “Divide a Long Simulation into Segments” on page 20-4
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Rules for Using the Operating Point of a Chart

An operating point is a snapshot of the state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

For more information, see “Using Operating Points in Stateflow” on page 20-2.

### Limitations on Values You Can Modify

An operating point does not include information about these elements:

- Machine-parented data
- Persistent data in custom C code
- Persistent data in external MATLAB code

Therefore, you cannot modify the values of those elements.

### Rules for Modifying Data Values

These rules apply when you modify data values:

- You cannot change the data type or size. Scalar data must remain scalar. Vector and matrix data must keep the same dimensions. The only exception to this rule is Stateflow data of `ml` type (see “ml Data Type” on page 16-23 for details).
- For enumerated data types, you can choose only enumerated values from the type definition. For other data types, new values must fall within the range that you specify in the **Minimum** and **Maximum** parameters.
- Use one-based indexing to define rows and columns of a matrix.

Suppose that you want to change the value of an element in a 21-by-12 matrix. To modify the element in the first row and second column, type:

```
c.state_name.data_name.Value(1,2) = newValue;
```

### Rules for Modifying State Activity

These rules apply when you use the `setActive` method on an exclusive (OR) leaf state:

- State-parented local data does not reinitialize.
- The newly active state does not execute any entry actions. Similarly, the previously active state does not execute any exit actions.

If you want these state actions to occur, you must execute them separately. For example, if your state actions assign values to data, you must assign the values explicitly.



- The `setActive` method tries to maintain state consistency by:
  - Updating state activity for parent, grandparent, and sibling states
  - Resetting temporal counters for newly active states
  - Updating values of state output data (read-only)
  - Enabling or disabling function-call subsystems and Simulink functions that bind to states
- The `highlightActiveStates` method also executes when these conditions are true:
  - The model is open.
  - The chart is visible.
  - The `highlightActiveStates` method has executed at least once, but not the `removeHighlighting` method.

## Restriction on Continuous-Time Charts

After you load an operating point for a continuous-time chart, you can restart simulation from a nonzero time. However, you cannot modify the state activity or any data values, because the operating point for a continuous-time chart is read-only. For more information, see “Continuous-Time Modeling in Stateflow” on page 25-2.

## No Partial Loading of a Operating Point

When you load an operating point, the complete operating point is available as a variable in the MATLAB base workspace. You cannot perform partial loading of an operating point for a subset of chart objects.

## Restriction on Copying Operating Point Values

Use the `clone` method to copy an entire operating point to a new variable (see “Methods for Interacting with the Operating Point of a Chart” on page 20-27). You cannot copy a subset of operating point values, because the `clone` method works only at the chart level.

Suppose that you obtain a handle to the operating point of your chart using these commands:

```
blockpath = 'model/chart';
c = xFinal.get(modelOperatingPoint, blockpath);
```

Assignment statements such as `stateCopy = c.state`, `dataCopy = c.data`, and `operatingPointCopy = c` do not work. These assignments create copies of object handles, not operating point values.

## See Also

### More About

- “Using Operating Points in Stateflow” on page 20-2
- “Divide a Long Simulation into Segments” on page 20-4
- “Best Practices for Saving the Operating Point of a Chart” on page 20-32

## Best Practices for Saving the Operating Point of a Chart

An operating point is a snapshot of the state of a Simulink model at a specific time during simulation. For a Stateflow chart, an operating point includes:

- Activity of chart states
- Values of chart local data
- Values of chart output data
- Values of persistent data in MATLAB functions and Truth Table blocks

For more information, see “Using Operating Points in Stateflow” on page 20-2.

### Use MAT-Files to Save a Operating Point for Future Use

To save an operating point from the MATLAB base workspace, save the variable with final state data in a MAT-file.

For example, type at the command prompt:

```
save('sf_car_ctx01.mat', 'sf_car_ctx01')
```

For more information, see `save` in the MATLAB documentation.

### Use Scripts to Save Operating Point Commands for Future Use

To save a list of operating point commands for future use, copy them from a procedure and paste them in a MATLAB script.

For example, to reuse the commands in “Divide a Long Simulation into Segments” on page 20-4, you can store them in a script named `sf_boiler_operatingpoint_commands.m`:

```
% Open the model.
sf_boiler;

% Set parameters to save the operating point at the desired time.
set_param('sf_boiler','SaveFinalState','on','FinalStateName',...
'sf_boiler_ctx01','SaveOperatingPoint','on');

% Specify the start and stop times for the simulation segment.
set_param('sf_boiler','StartTime','0','StopTime','400');

% Simulate the model.
sim('sf_boiler');

% Disable saving of the operating point to avoid overwriting.
set_param('sf_boiler','SaveOperatingPoint','off', ...
'SaveFinalState','off');

% Load the operating point.
set_param('sf_boiler','LoadInitialState','on', ...
'InitialState','sf_boiler_ctx01');

% Specify the new stop time for the simulation segment.
set_param('sf_boiler','StopTime','600');
```

```
% Simulate the model.  
sim('sf_boiler');
```

The start time does not change, but the operating point restore fast forwards the simulation to the time of the snapshot.

## See Also

### More About

- “Using Operating Points in Stateflow” on page 20-2
- “Divide a Long Simulation into Segments” on page 20-4
- “Rules for Using the Operating Point of a Chart” on page 20-30



# Vectors and Matrices in Stateflow Charts

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- “Vectors and Matrices in Stateflow Charts” on page 21-2
- “Supported Operations for Vectors and Matrices” on page 21-4

## Vectors and Matrices in Stateflow Charts

Vectors and matrices combine scalar data into a single, multidimensional data object. You can modify individual elements or perform arithmetic on entire vectors and matrices. For more information, see “Supported Operations for Vectors and Matrices” on page 21-4.

### Define Vector and Matrix Data

- 1 Add a data object to your chart, as described in “Add Stateflow Data” on page 12-2.
- 2 Set the **Size** property for the data object as the dimensions of the vector or matrix. See “Specify Size of Stateflow Data” on page 12-33. For example:
  - To specify a 4-by-1 column vector, enter 4.
  - To specify a 1-by-4 row vector, enter [1 4].
  - To specify a 3-by-3 matrix, enter [3 3].
- 3 Set the **Initial value** property for the data object. See “Initial Value” on page 12-8.
  - To specify a value of zero for all elements of the vector or matrix, leave the **Initial value** empty. If you do not specify an initial value, all elements are initialized to 0.
  - To specify the same value for all elements of the vector or matrix, enter a scalar value. All elements are initialized to the scalar value you specify.
  - To specify a different value for each element of the vector or matrix, enter an array of real values. For example:
    - To initialize a 4-by-1 column vector, you can enter [1; 2; 3; 4].
    - To initialize a 1-by-4 row vector, you can enter [1 2 3 4].
    - To initialize a 3-by-3 matrix, you can enter [1 2 3; 4 5 6; 7 8 9].
- 4 Set the name, scope, base type, and other properties for the data object, as described in “Set Data Properties” on page 12-5.

You can specify the size and initial value of a vector or matrix by using an expression. Expressions can contain a mix of numeric values, constants, parameters, variables, arithmetic operations, and calls to MATLAB functions. For more information, see “Specify Data Properties by Using MATLAB Expressions” on page 12-17.

### Where You Can Use Vectors and Matrices

You can define vectors and matrices at these levels of the Stateflow hierarchy:

- Charts
- Subcharts
- States
- Functions

You can use vectors and matrices to define:

- Input data
- Output data

- Local data
- Function inputs
- Function outputs

You can also use vectors and matrices as arguments for:

- State actions
- Transition actions
- MATLAB functions
- Truth table functions
- Graphical functions
- Simulink functions
- Change detection operators

## Rules for Vectors and Matrices in Stateflow Charts

### Use Operands of Equal Dimensions for Element-Wise Operations

If you perform element-wise operations on vectors or matrices with unequal dimensions, the chart generates a size mismatch error when you simulate the model. For more information, see “Supported Operations for Vectors and Matrices” on page 21-4.

### Do Not Define Vectors and Matrices with the ml Base Type

The `ml` base type supports only scalar data. If you define a vector or matrix with the `ml` base type, the chart generates an error when you simulate the model. For more information, see “ml Data Type” on page 16-23.

### Do Not Use Complex Numbers to Set the Initial Values of Vectors and Matrices

If you initialize an element of a vector or matrix by using a complex number, the chart generates an error when you simulate the model. You can set the values of vectors and matrices to complex numbers after initialization. For more information, see “Complex Data in Stateflow Charts” on page 27-2.

### Do Not Use Vectors and Matrices in Temporal Logic Operators

Because time is a scalar quantity, you cannot use a vector or matrix as an argument for a temporal logic operator. For more information, see “Control Chart Execution by Using Temporal Logic” on page 16-36.



## See Also

### More About

- “Supported Operations for Vectors and Matrices” on page 21-4
- “Specify Size of Stateflow Data” on page 12-33
- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
- “Declare Variable-Size Data in Stateflow Charts” on page 22-2

## Supported Operations for Vectors and Matrices

Stateflow charts in Simulink models have an action language property that defines the syntax that you use to compute with vectors and matrices. The action language properties are:

-  MATLAB as the action language.
-  C as the action language.

For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Indexing Notation

In charts that use MATLAB as the action language, refer to elements of a vector or matrix by using one-based indexing delimited by parentheses. Separate indices for different dimensions with commas.

In charts that use C as the action language, refer to elements of a vector or matrix by using zero-based indexing delimited by brackets. Enclose indices for different dimensions in their own pair of brackets.

Example	MATLAB as the Action Language	C as the Action Language
The first element of a vector $V$	$V(1)$	$V[0]$
The $i^{\text{th}}$ element of a vector $V$	$V(i)$	$V[i-1]$
The element in row 4 and column 5 of a matrix $M$	$M(4,5)$	$M[3][4]$
The element in row $i$ and column $j$ of a matrix $M$	$M(i,j)$	$M[i-1][j-1]$

### Binary Operations

This table summarizes the interpretation of all binary operations on vector and matrix operands according to their order of precedence (1 = highest, 3 = lowest). Binary operations are left associative so that, in any expression, operators with the same precedence are evaluated from left to right. Except for the matrix multiplication and division operators in charts that use MATLAB as the action language, all binary operators perform element-wise operations.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a * b$	1	Matrix multiplication.	Element-wise multiplication. For matrix multiplication, use the $*$ operation in a MATLAB function. See “Perform Matrix Arithmetic by Using MATLAB Functions” on page 21-7.
$a .* b$	1	Element-wise multiplication.	Not supported. Use the operation $a * b$ .



Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a / b$	1	Matrix right division.	Element-wise right division. For matrix right division, use the <code>/</code> operation in a MATLAB function. See “Perform Matrix Arithmetic by Using MATLAB Functions” on page 21-7.
$a ./ b$	1	Element-wise right division.	Not supported. Use the operation $a / b$ .
$a \setminus b$	1	Matrix left division.	Not supported. Use the <code>\</code> operation in a MATLAB function. See “Perform Matrix Arithmetic by Using MATLAB Functions” on page 21-7.
$a .\setminus b$	1	Element-wise left division.	Not supported. Use the <code>.\</code> operation in a MATLAB function. See “Perform Matrix Arithmetic by Using MATLAB Functions” on page 21-7.
$a + b$	2	Addition.	Addition.
$a - b$	2	Subtraction.	Subtraction.
$a == b$	3	Comparison, equal to.	Comparison, equal to.
$a ~= b$	3	Comparison, not equal to.	Comparison, not equal to.
$a != b$	3	Not supported. Use the operation $a ~= b$ .	Comparison, not equal to.
$a <> b$	3	Not supported. Use the operation $a ~= b$ .	Comparison, not equal to.

## Unary Operations and Actions

This table summarizes the interpretation of all unary operations and actions on vector and matrix operands. Unary operations:

- Have higher precedence than the binary operators.
- Are right associative so that, in any expression, they are evaluated from right to left.
- Perform element-wise operations.

Example	MATLAB as the Action Language	C as the Action Language
$\sim a$	Logical NOT. For bitwise NOT, use the <code>bitcmp</code> function.	<ul style="list-style-type: none"> <li>• Bitwise NOT (default). Enable this operation by selecting the <b>Enable C-bit operations</b> chart property.</li> <li>• Logical NOT. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property.</li> </ul> <p>For more information, see “Bitwise Operations” on page 16-9 and “Enable C-bit operations” on page 28-4.</p>

Example	MATLAB as the Action Language	C as the Action Language
!a	Not supported. Use the operation ~a.	Logical NOT.
-a	Negative.	Negative.
a++	Not supported.	Increment all elements of the vector or matrix. Equivalent to $a = a+1$ .
a--	Not supported.	Decrement all elements of the vector or matrix. Equivalent to $a = a-1$ .

## Assignment Operations

This table summarizes the interpretation of assignment operations on vector and matrix operands.

Operation	MATLAB as the Action Language	C as the Action Language
a = b	Simple assignment.	Simple assignment.
a += b	Not supported. Use the expression $a = a + b$ .	Equivalent to $a = a+b$ .
a -= b	Not supported. Use the expression $a = a - b$ .	Equivalent to $a = a-b$ .
a *= b	Not supported. Use the expression $a = a*b$ .	Equivalent to $a = a*b$ .
a /= b	Not supported. Use the expression $a = a/b$ .	Equivalent to $a = a/b$ .

## Assign Values to Individual Elements of a Matrix

You can assign a value to an individual entry of a vector or matrix by using the indexing syntax appropriate to the action language of the chart.

Example	MATLAB as the Action Language	C as the Action Language
Assign the value 10 to the first element of the vector V.	$V(1) = 10;$	$V[0] = 10;$
Assign the value 77 to the element in row 2 and column 9 of the matrix M.	$M(2,9) = 77;$	$M[1][8] = 77;$

## Assign Values to All Elements of a Matrix

In charts that use MATLAB as the action language, you can use a single action to specify all of the elements of a vector or matrix. For example, this action assigns each element of the 2-by-3 matrix A to a different value:

```
A = [1 2 3; 4 5 6];
```

In charts that use C as the action language, you can use scalar expansion to set all of the elements of a vector or matrix to the same value. Scalar expansion converts scalar data to match the dimensions of vector or matrix data. For example, this action sets all of the elements of the matrix A to 10:

```
A = 10;
```

Scalar expansion applies to all graphical, truth table, MATLAB, and Simulink functions. Suppose that you define the formal arguments of a function  $f$  as scalars. This table describes the rules of scalar expansion for the function call  $y = f(u)$ .

Output $y$	Input $u$	Result
Scalar	Scalar	No scalar expansion occurs.
Scalar	Vector or matrix	The chart generates a size mismatch error.
Vector or matrix	Scalar	The chart uses scalar expansion to assign the scalar output value of $f(u)$ to every element of $y$ : $y[i][j] = f(u)$
Vector or matrix	Vector or matrix	The chart uses scalar expansion to compute an output value for each element of $u$ and assign it to the corresponding element of $y$ : $y[i][j] = f(u[i][j])$  If $y$ and $u$ do not have the same size, the chart generates a size mismatch error.

For functions with multiple outputs, the same rules apply unless the outputs and inputs are all vectors or matrices. In this case, the chart generates a size mismatch error and scalar expansion does not occur.

Charts that use MATLAB as the action language do not support scalar expansion.

## Perform Matrix Arithmetic by Using MATLAB Functions

In charts that use C as the action language, the operations  $*$  and  $/$  perform element-wise multiplication and division. To perform standard matrix multiplication and division in a C chart, use a MATLAB function.

Suppose that you want to perform these operations on the square matrices  $u1$  and  $u2$ :

- Compute the standard matrix product  $y1 = u1 * u2$ .
- Solve the equation  $u1 * y2 = u2$ .
- Solve the equation  $y3 * u1 = u2$ .

To complete these calculations in a C chart, add a MATLAB function that runs this code:

```
function [y1, y2, y3] = my_matrix_ops(u1, u2)
%#codegen

y1 = u1 * u2; % matrix multiplication
y2 = u1 \ u2; % matrix division from the right
y3 = u1 / u2; % matrix division from the left
```

Before calling the function, specify the properties for the input and output data, as described in “Set Data Properties” on page 12-5.

In charts that use MATLAB as the action language, the operations  $*$ ,  $/$ , and  $\backslash$  perform standard matrix multiplication and division. You can use these operations directly in state and transition actions.

### See Also

### More About

- “Vectors and Matrices in Stateflow Charts” on page 21-2
- “Specify Size of Stateflow Data” on page 12-33

# Variable-Size Data in Stateflow Charts

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- “Declare Variable-Size Data in Stateflow Charts” on page 22-2
- “Compute Output Based on Size of Input Signal” on page 22-4

## Declare Variable-Size Data in Stateflow Charts

Variable-size data is data whose size can change at run time. In contrast, fixed-size data is data whose size is known and locked at compile time and does not change at run time. Use variable-size data if the output from a Stateflow chart in a Simulink model is an array whose size depends on the state of the chart.

### Enable Support for Variable-Size Data

Support for variable-size data is enabled by default. To enable or disable this option for individual charts, modify the chart property **Support variable-size arrays**, as described in “Specify Properties for Stateflow Charts” on page 28-2.

### Declare Variable-Size Inputs and Outputs

After enabling support at the chart level, you can declare variable-size data by following these steps:

- 1 Add a data object to the chart, as described in “Add Stateflow Data” on page 12-2.
- 2 Set **Scope** property as **Local**, **Input**, or **Output**.

---

**Note** Charts that use C as the action language do not support variable-size local data.

---

- 3 Select the **Variable size** check box.
- 4 Use the **Size** property to explicitly specify the maximum size for the data. For example, to specify a 2-D matrix where the maximum size is 2 for the first dimension and 4 for the second dimension, in the **Size** field, enter [2 4].

The screenshot shows the 'Data data' dialog box with the following configuration:

- Name:** data
- Scope:** Input
- Port:** 1
- Size:** [2 4]
- Variable size:**
- Complexity:** Off
- Type:** Inherit: Same as Simulink
- Lock data type against Fixed-Point tools:**
- Unit (e.g., m, m/s<sup>2</sup>, N\*m):** inherit
- Limit range:** Minimum:  Maximum:

Buttons: OK, Cancel, Help, Apply

## Guidelines for Using Variable-Size Data

Stateflow charts that use MATLAB as the action language can access and modify variable-size input, output, and local data in state and transition actions.

In contrast, charts that use C as the action language can only exchange variable-size input and output data with other charts and Simulink blocks by using:

- MATLAB functions
- Simulink functions
- Truth tables that use MATLAB as the action language

When you use variable-size data in a C chart, these guidelines apply:

- Declare variable-size data as chart inputs and outputs only, and not as local data.
- To define variable-size chart inputs that inherit their size from the Simulink model, set the **Size** property to `-1`.
- All computations with variable-size data must occur inside functions, and not directly in states or transitions.
- You can pass variable-size data as inputs and outputs to these functions from state and transition actions. In addition, MATLAB functions can access the chart-level, variable-size data directly.

## See Also

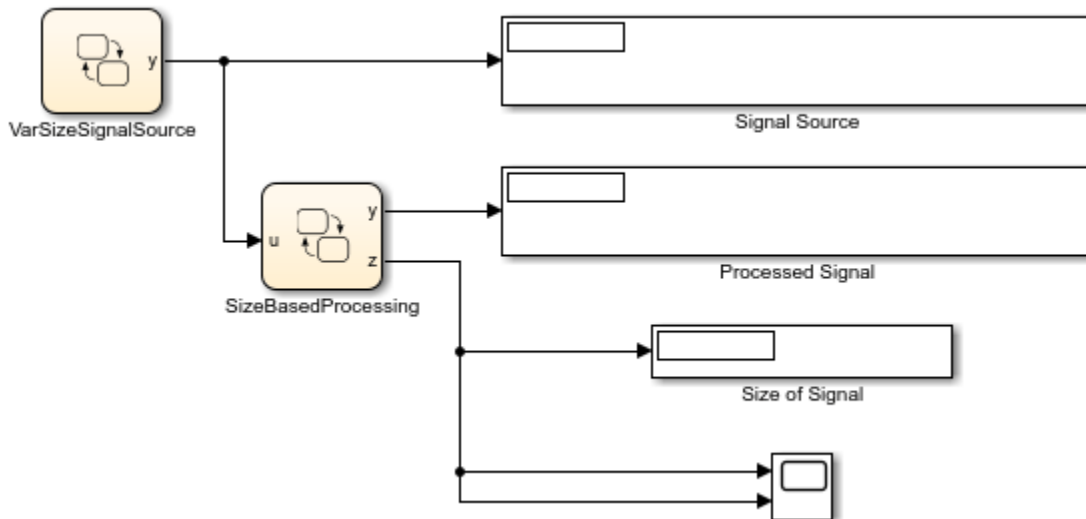
### More About

- “Compute Output Based on Size of Input Signal” on page 22-4
- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2
- “Reuse Simulink Components in Stateflow Charts” on page 11-2
- “Use Truth Tables to Model Combinatorial Logic” on page 10-2

## Compute Output Based on Size of Input Signal

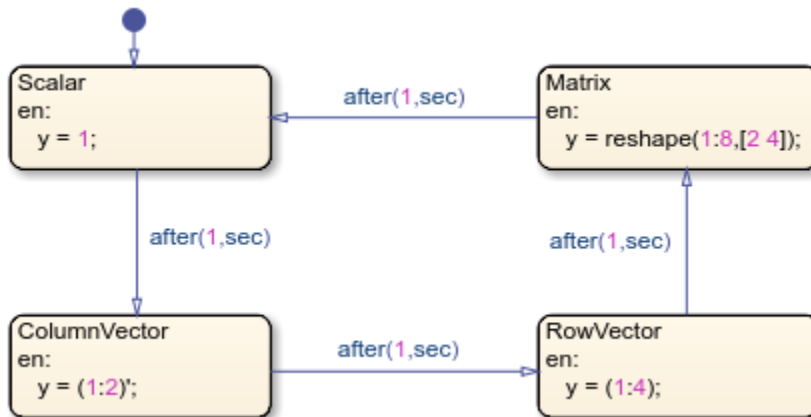
This example shows how to modify the size of output data in a Stateflow® chart during simulation.

In this model, a Stateflow chart called `VarSizeSignalSource` uses temporal logic to generate a variable-size signal. A second chart called `SizeBasedProcessing` computes the output based on the size of the signal generated by the first chart. Display blocks show the values and size of the signals.



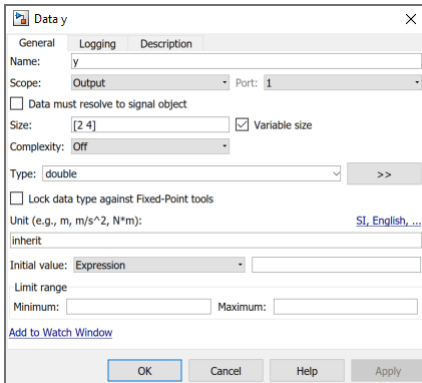
### Generate Variable-Size Output Data

The Stateflow chart `VarSizeSignalSource` uses MATLAB® as the action language. The temporal logic in this chart triggers the transitions between four states. Each state generates an output value with a different size: a scalar, a two-element column vector, a four-element row vector, and a 2-by-4 matrix.



The chart behaves like a source block. It has no input and one variable-size output, `y`. For variable-size outputs, you must explicitly specify the size and upper bounds for each dimension. In this case, the **Variable size** property for `y` is enabled and its **Size** property is set to `[2 4]`, the maximum size for the signal.

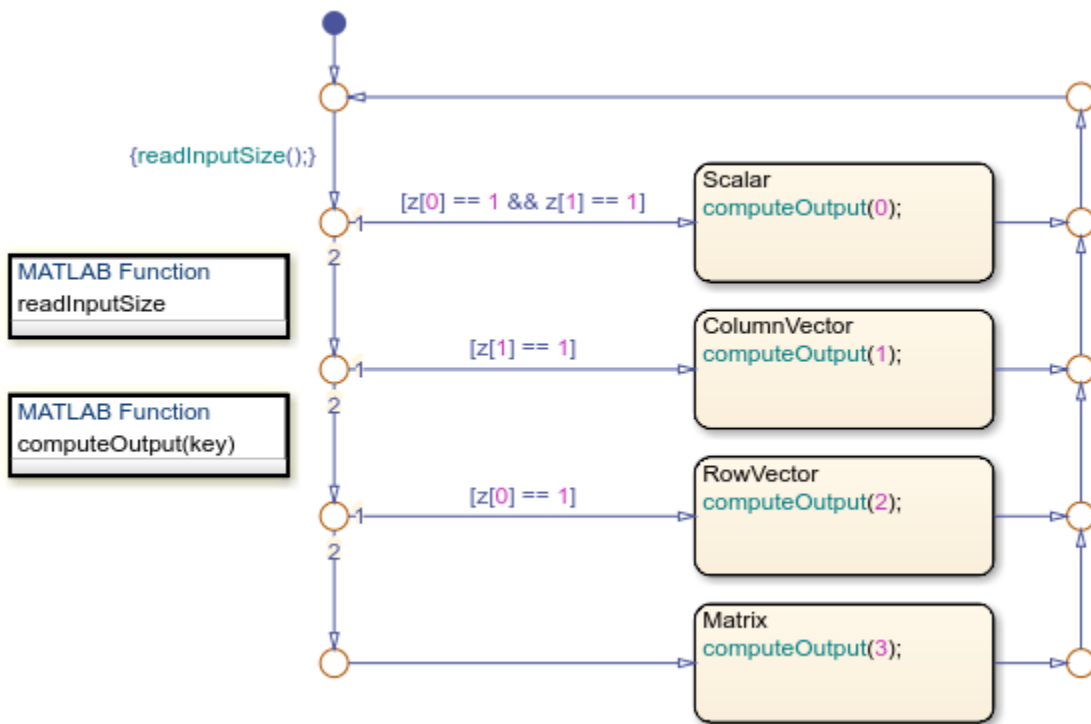




In charts that use MATLAB as the action language, state and transition actions can read and write directly to variable-size data. For example, the entry actions of the states in this chart explicitly compute the value of *y*.

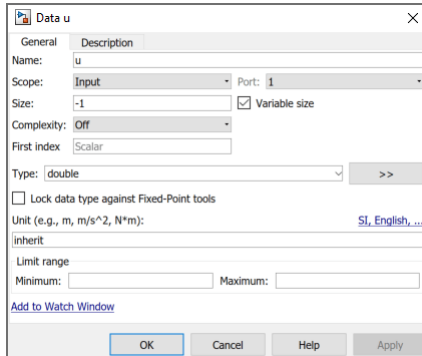
### Process Variable-Size Input Data

The Stateflow chart `SizeBasedProcessing` uses C as the action language. These charts can exchange variable-size data with other charts and blocks in the model. However, state and transition actions in C charts cannot read from or write to variable-size data directly. All computations involving variable-size data must occur in MATLAB functions, Simulink® functions, and MATLAB truth tables in the chart.

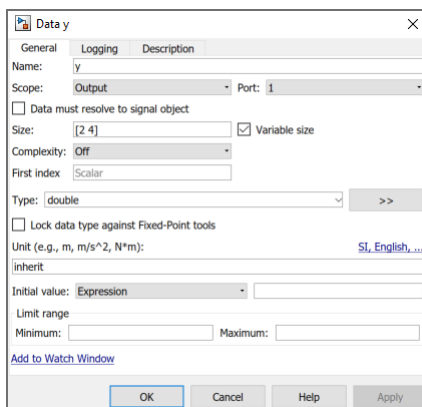


This chart has two variable-size data objects:

- Input  $u$  is the variable-size signal generated by the `VarSizeSignalSource` chart. The **Size** property for  $u$  is set to `-1` to indicate that this input inherits its size from the Simulink model. Note that only inputs to C charts can inherit their size.



- Output  $y$  is a variable-size signal whose size and value depends on whether  $u$  is a scalar, a vector, or a matrix. The **Size** property for  $y$  is set to `[2 4]`, the maximum size for the signal.



Because this chart uses C as the action language, the names of the variable-size data do not appear in the state actions or transition logic. Instead, the transition logic in the chart calls the MATLAB function `readInputSize` to determine the size of the input  $u$ . Similarly, the actions in the states call the MATLAB function `computeOutput` to produce values of various size for the variable-size output  $y$ . Because MATLAB functions can access chart-level data directly, you do not have to pass the variable-size data as inputs or outputs to these functions.

### Determine Size of Input

The MATLAB function `isScalarInput` determines the size of the chart input  $u$ . This signal, which is generated by chart `VarSizeSignalSource`, can be a scalar, a 2-by-1 column vector, a 1-by-4 row vector, or a 2-by-4 matrix. The function stores the dimensions of  $u$  as the chart-level output  $z$ .

```
function readInputSize
%#codegen
z = size(u);
end
```

### Produce Variable-Size Output

The MATLAB function `computeOutput` computes the value of the chart output  $y$  based on the size and value of the chart input  $u$ .

- If  $u$  is a scalar, the function assigns to  $y$  a scalar value of zero.
- If  $u$  is a column vector, the function computes of the sine of each of its elements and stores them in  $y$ .
- If  $u$  is a row vector, the function computes of the cosine of each of its elements and stores them in  $y$ .
- If  $u$  is a matrix, the function computes of the square root of each of its elements and stores them in  $y$ .

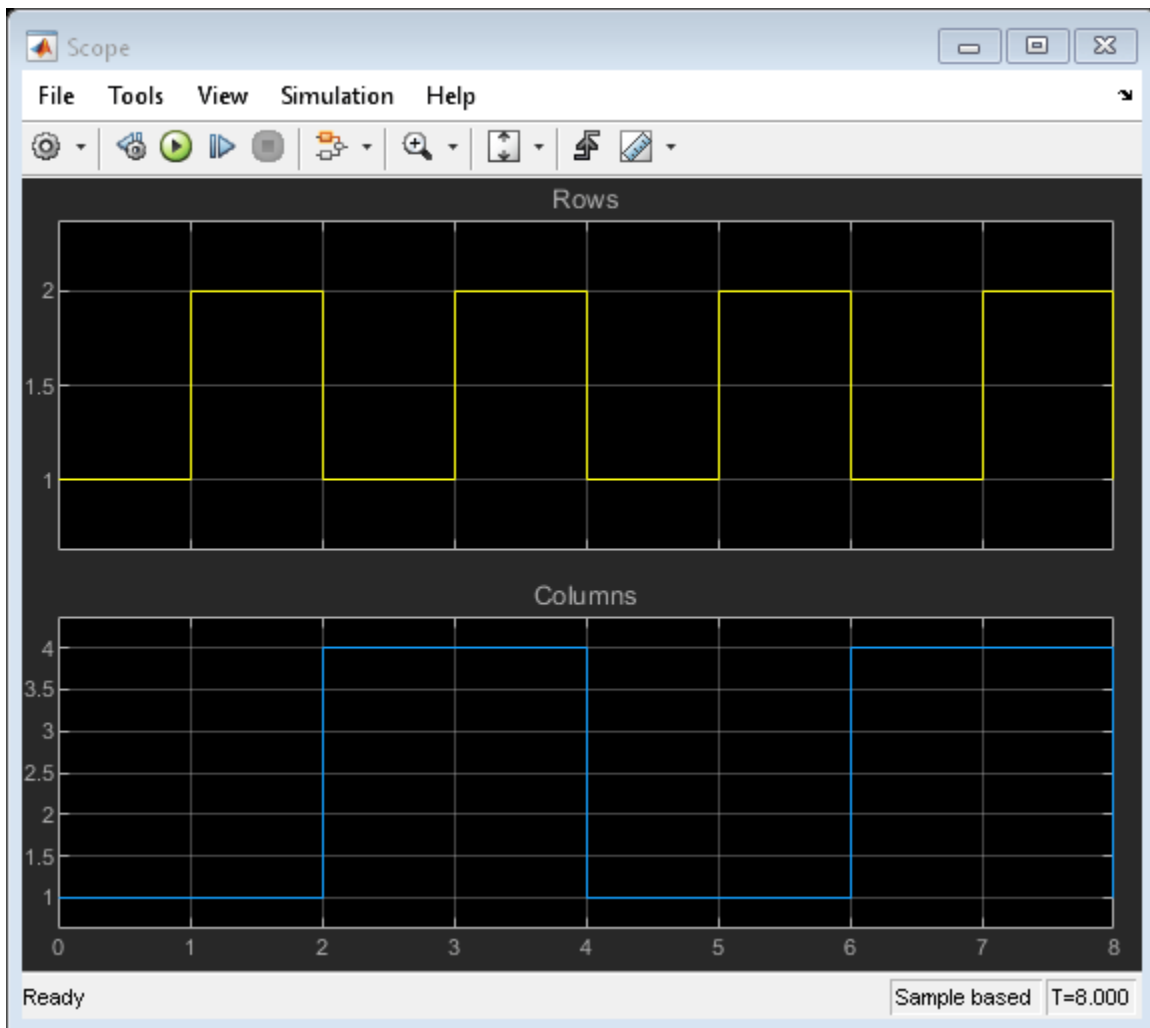
In each case, the value of the output  $y$  has the same size as the input  $u$ .

```
function computeOutput(key)
%#codegen
switch key
    case 0 % scalar
        y = 0;
    case 1 % column vector
        y = sin(u);
    case 2 % row vector
        y = cos(u);
    case 3 % matrix
        y = sqrt(u);
end
end
```

### Simulate the Model

The tabs located above the Explorer Bar enable you to switch between the Simulink model and the two Stateflow charts. During simulation:

- The chart animations show the active state for each chart cycling between the `Scalar`, `ColumnVector`, `RowVector`, and `VectorPartial`, and `Matrix` states.
- In the Simulink model, the display blocks `Signal Source` and `Processed Signal` periodically show between one and eight values for the variable-size signals.
- The display block `Size of Signal` and the Scope block show the number of rows and columns in the variable-size signals.



## See Also

after

## More About

- "Declare Variable-Size Data in Stateflow Charts" on page 22-2
- "Control Chart Execution by Using Temporal Logic" on page 16-36
- "Reuse MATLAB Code by Defining MATLAB Functions" on page 9-2

# Enumerated Data in Charts

---

- “Reference Values by Name by Using Enumerated Data” on page 23-2
- “Define Enumerated Data Types” on page 23-5
- “Best Practices for Using Enumerated Data” on page 23-8
- “Assign Enumerated Values in a Chart” on page 23-11
- “Model Media Player by Using Enumerated Data” on page 23-15

## Reference Values by Name by Using Enumerated Data

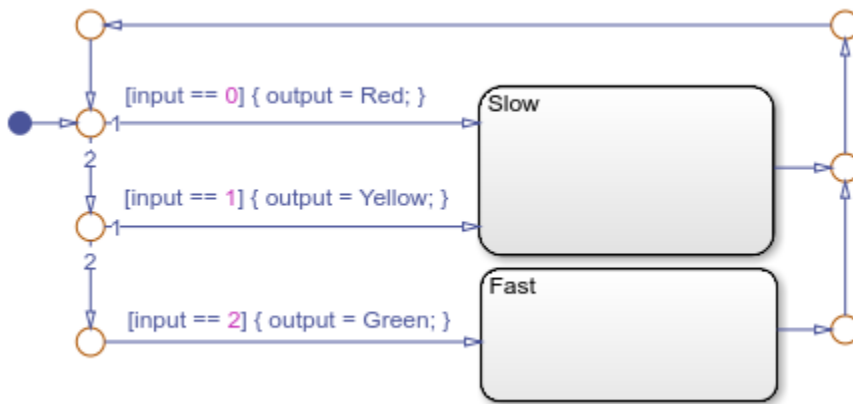
To enhance the readability of a Stateflow chart, use enumerated data. With enumerated data, you can:

- Create a restricted set of values and refer to those values by name.
- Group related values into separate data types.
- Avoid defining a long list of constants.

Enumerated data is supported in Stateflow charts in Simulink models.

### Example of Enumerated Data

An enumerated data type is a finite collection of *enumerated values* consisting of a name and an underlying integer value. For example, this chart uses enumerated data to refer to a set of colors.



The enumerated data output is restricted to a finite set of values. You can refer to these values by their names: Red, Yellow, and Green.

Enumerated Value	Name	Integer Value
Red(0)	Red	0
Yellow(1)	Yellow	1
Green(2)	Green	2

This MATLAB file defines the enumerated data type BasicColors referenced by the chart.

```
classdef BasicColors < Simulink.IntEnumType
    enumeration
        Red(0)
        Yellow(1)
        Green(2)
    end
end
```

### Computation with Enumerated Data

An enumerated data type does not function as a numeric type despite the existence of the underlying integer values. You cannot use enumerated values directly in a mathematical computation. You can

use enumerated data to control chart behavior based on assignments and comparisons. To assign or compare enumerated data, use the operations listed in this table.

Example	Description
<code>a = exp</code>	Assignment of <code>exp</code> to <code>a</code> . <code>exp</code> must evaluate to an enumerated value.
<code>a == b</code>	Comparison, equality.
<code>a != b</code>	Comparison, inequality.

In a chart that uses C as the action language, you can compare enumerated data with different data types. Before the comparison, the chart casts the enumerated data to their underlying integer values.

Charts that use MATLAB as the action language cannot compare enumerated data with different data types.

## Notation for Enumerated Values

To refer to an enumerated value, use prefixed or nonprefixed identifiers.

### Prefixed Identifiers

To prevent name conflicts when referring to enumerated values in Stateflow charts, you can use prefixed identifiers of the form *Type.Name*. *Type* is an enumerated data type and *Name* is an enumerated value name. For example, suppose that you define three data types (`Colors`, `Temp`, and `Code`) that contain the enumerated name `Red`. By using prefixed notation, you can distinguish `Colors.Red` from `Temp.Red` and `Code.Red`.

### Nonprefixed Identifiers

To minimize identifier length when referring to unique enumerated values, you can use nonprefixed enumerated value names. For example, suppose that the enumerated name `Red` belongs only to the data type `Colors`. You can then refer to this value with the nonprefixed identifier `Red`.

If your chart uses data types that contain identical enumerated names (such as `Colors.Red` and `Temp.Red`), use prefixed identifiers to prevent name conflicts.

## Where to Use Enumerated Data

Use enumerated data at these levels of the Stateflow hierarchy:

- Chart
- Subchart
- State

Use enumerated data as arguments for:

- State actions
- Condition and transition actions
- Vector and matrix indexing
- MATLAB functions

- Graphical functions
- Simulink functions
- Truth Table blocks and truth table functions

If you have Simulink Coder installed, you can use enumerated data for simulation and code generation.

## **See Also**

### **More About**

- “Define Enumerated Data Types” on page 23-5
- “Assign Enumerated Values in a Chart” on page 23-11
- “Best Practices for Using Enumerated Data” on page 23-8
- “Simulink Enumerations” (Simulink)
- “Use Enumerated Data in Simulink Models” (Simulink)



## Define Enumerated Data Types

To enhance the readability of a Stateflow chart, use enumerated data. With enumerated data, you can:

- Create a restricted set of values and refer to those values by name.
- Group related values into separate data types.
- Avoid defining a long list of constants.

Enumerated data is supported in Stateflow charts in Simulink models. For more information, see “Reference Values by Name by Using Enumerated Data” on page 23-2.

Before you can add enumerated data to a Stateflow chart, you must define an enumerated data type in a MATLAB class definition file. Create a different file for each enumerated type.

### Elements of an Enumerated Data Type Definition

The enumerated data type definition consists of three sections of code.

Section of Code	Required?	Purpose
<code>classdef</code>	Yes	Provides the name of the enumerated data type
<code>enumeration</code>	Yes	Lists the enumerated values that the data type allows
<code>methods</code>	No	Provides methods that customize the data type

### Define an Enumerated Data Type

- 1 Open a new file in which to store the data type definition. From the **Home** tab on the MATLAB toolstrip, select **New > Class**.
- 2 Complete the `classdef` section of the definition.

```
classdef BasicColors < Simulink.IntEnumType
    ...
end
```

The `classdef` section defines an enumerated data type with the name `BasicColors`. Stateflow derives the data type from the built-in type `Simulink.IntEnumType`. The enumerated data type name must be unique among data type names and workspace variable names.

- 3 Define enumerated values in an `enumeration` section.

```
classdef BasicColors < Simulink.IntEnumType
    enumeration
        Red(0)
        Yellow(1)
        Green(2)
    end
end
```

An enumerated type can define any number of values. The `enumeration` section lists the set of enumerated values that this data type allows. Each enumerated value consists of a name and an underlying integer value. Each name must be unique within its type, but can also appear in other

enumerated types. The default value is the first one in the list, unless you specify otherwise in the methods section of the definition.

- 4 (Optional) Customize the data type by using a methods section. The section can contain these methods:
  - `getDefaultValue` specifies a default enumerated value other than the first one in the list of allowed values.
  - `getDescription` specifies a description of the data type for code generated by Simulink Coder.
  - `getHeaderFile` specifies custom header file that contains the enumerated type definition in code generated by Simulink Coder.
  - `getDataScope` enables exporting or importing the enumerated type definition to or from a header file in code generated by Simulink Coder.
  - `addClassNameToEnumNames` enhances readability and prevents name conflicts with identifiers in code generated by Simulink Coder.

For example, this MATLAB file presents a customized definition for the enumerated data type `BasicColors` that:

- Specifies that the default enumerated value is the last one in the list of allowed values.
- Includes a short description of the data type for code generated by Simulink Coder.
- Imports the definition of the data type from a custom header file to prevent Simulink Coder from generating the definition.
- Adds the name of the data type as a prefix to each enumeration member name in code generated by Simulink Coder.

```
classdef BasicColors < Simulink.IntEnumType
    enumeration
        Red(0)
        Yellow(1)
        Green(2)
    end

    methods (Static = true)
        function retVal = getDefaultValue()
            % GETDEFAULTVALUE Specifies the default enumeration member.
            % Return a valid member of this enumeration class to specify the default.
            % If you do not define this method, Simulink uses the first member.
            retVal = BasicColors.Green;
        end

        function retVal = getDescription()
            % GETDESCRIPTION Specifies a string to describe this enumerated type.
            retVal = 'This defines an enumerated type for colors';
        end

        function retVal = getHeaderFile()
            % GETHEADERFILE Specifies the file that defines this type in generated code.
            % The method getDataScope determines the significance of the specified file.
            retVal = 'imported_enum_type.h';
        end

        function retVal = getDataScope()
```

```

    % GETDATASCOPE Specifies whether generated code imports or exports this type.
    % Return one of these strings:
    % 'Auto':    define type in model_types.h, or import if header file specified
    % 'Exported': define type in a generated header file
    % 'Imported': import type definition from specified header file
    % If you do not define this method, DataScope is 'Auto' by default.
    retVal = 'Imported';
end

function retVal = addClassNameToEnumNames()
    % ADDCLASSNAMETOENUMNAMES Specifies whether to add the class name
    % as a prefix to enumeration member names in generated code.
    % Return true or false.
    % If you do not define this method, no prefix is added.
    retVal = true;
end % function
end % methods
end % classdef

```

- 5 Save the file on the MATLAB path. The name of the file must match exactly the name of the data type. For example, the definition for the data type `BasicColors` must reside in a file named `BasicColors.m`.

---

**Tip** To add a folder to the MATLAB search path, type `addpath pathname` at the command prompt.

---

## Specify Data Type in the Property Inspector

When you add enumerated data to your chart, specify its type in the Property Inspector.

- 1 In the **Type** field, select Enum: <class name>.
- 2 Replace <class name> with the name of the data type. For example, you can enter Enum: `BasicColors` in the **Type** field.
- 3 (Optional) Enter an initial value for the enumerated data by using a prefixed identifier. The initial value must evaluate to a valid MATLAB expression.

## See Also

### More About

- “Assign Enumerated Values in a Chart” on page 23-11
- “Best Practices for Using Enumerated Data” on page 23-8
- “Use Enumerated Data in Simulink Models” (Simulink)
- “Customize Simulink Enumeration” (Simulink)

## Best Practices for Using Enumerated Data

To enhance the readability of a Stateflow chart, use enumerated data. With enumerated data, you can:

- Create a restricted set of values and refer to those values by name.
- Group related values into separate data types.
- Avoid defining a long list of constants.

Enumerated data is supported in Stateflow charts in Simulink models. For more information, see “Reference Values by Name by Using Enumerated Data” on page 23-2.

### Guidelines for Defining Enumerated Data Types

#### Use Unique Name for Each Enumerated Type

To avoid name conflicts, the name of an enumerated data type cannot match the name of:

- Another data type
- A data object in the Stateflow chart
- A variable in the MATLAB base workspace

#### Use Same Name for Enumerated Type and Class Definition File

To enable resolution of enumerated data types for Simulink models, the name of the MATLAB file that contains the type definition must match the name of the data type.

#### Apply Changes in Enumerated Type Definition

When you update an enumerated data type definition for an open model, the changes do not take effect immediately. To see the effects of updating a data type definition:

- 1 Save and close the model.
- 2 Delete all instances of the data type from the MATLAB base workspace. To find these instances, type `whos` at the command prompt.
- 3 Open the model and start simulation or generate code by using Simulink Coder.

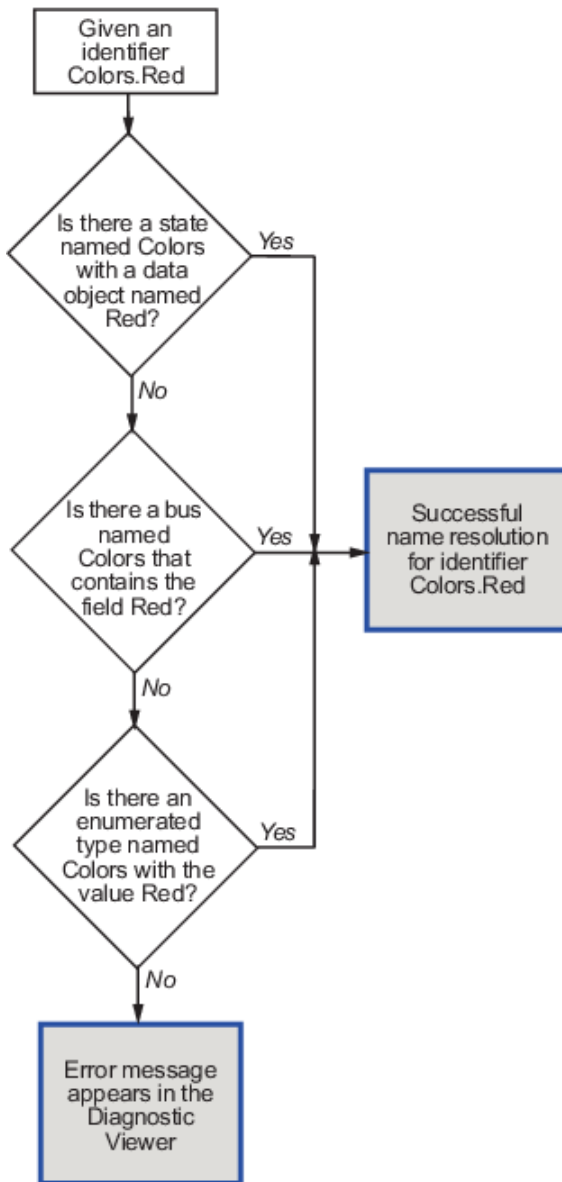
### Guidelines for Referencing Enumerated Data

#### Ensure Unique Name Resolution for Nonprefixed Identifiers

If you use nonprefixed identifiers to refer to enumerated values in a chart, ensure that each enumerated name belongs to a unique enumerated data type.

#### Use Unique Identifiers for Enumerated Values

If an enumerated value uses the same identifier as a data object or a bus field, the chart does not resolve the identifier correctly. For example, this diagram shows the stages in which a chart tries to resolve the identifier `Colors.Red`.



### Set Initial Values of Enumerated Data by Using Prefixed Identifiers

If you choose to set an initial value for enumerated data, you must use a prefixed identifier in the **Initial value** field of the Property Inspector. For example, `BasicColors.Red` is a valid identifier, but `Red` is not. The initial value must evaluate to a valid MATLAB expression.

### Enhance Readability of Generated Code by Using Prefixed Identifiers

If you add prefixes to enumerated names in the generated code, you enhance readability and avoid name conflicts with global symbols. For details, see “Use Enumerated Data in Generated Code” (Simulink Coder).

## Guidelines and Limitations for Enumerated Data

### Do Not Enter Minimum or Maximum Values for Enumerated Data

For enumerated data, leave the **Minimum** and **Maximum** fields of the Property Inspector empty. The chart ignores any values that you enter in these fields.

Whether these fields appear in the Property Inspector depends on which **Type** field option you use to define enumerated data.

Type Field Option	Appearance of the Minimum and Maximum Fields
Enum: <class name>	Not available
<data type expression> or Inherit from Simulink	Available

### Do Not Assign Enumerated Values to Constant Data

Because enumerated values are constants, assigning these values to constant data is redundant and unnecessary. If you try to assign enumerated values to constant data, an error appears.

### Do Not Use ml Namespace Operator to Access Enumerated Data

The ml operator does not support enumerated data.

### Do Not Define Enumerated Data at Machine Level of Hierarchy

Machine-parented data is not supported for enumerated types.

## See Also

### More About

- “Reference Values by Name by Using Enumerated Data” on page 23-2
- “Define Enumerated Data Types” on page 23-5
- “Assign Enumerated Values in a Chart” on page 23-11

## Assign Enumerated Values in a Chart

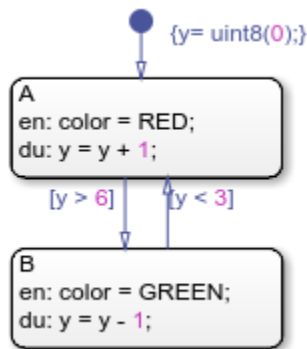
To enhance the readability of a Stateflow chart, use enumerated data. With enumerated data, you can:

- Create a restricted set of values and refer to those values by name.
- Group related values into separate data types.
- Avoid defining a long list of constants.

Enumerated data is supported in Stateflow charts in Simulink models. For more information, see “Reference Values by Name by Using Enumerated Data” on page 23-2.

### Chart Behavior

This example shows how to build a chart that uses enumerated values to issue a status keyword.



During simulation, the chart action alternates between states A and B.

#### Execution of State A

- At the start of the simulation, state A is entered.
- State A executes the entry action by assigning the value RED to the enumerated data color.
- The data y increments once per time step (every 0.2 seconds) until the condition [y > 6] is true.
- The chart takes the transition from state A to state B.

#### Execution of State B

- After the transition from state A occurs, state B is entered.
- State B executes the entry action by assigning the value GREEN to the enumerated data color.
- The data y decrements once per time step (every 0.2 seconds) until the condition [y < 3] is true.
- The chart takes the transition from state B back to state A.

## Build the Chart

### Add States and Transitions to the Chart

- 1 To create a Simulink model with an empty chart, at the MATLAB command prompt, enter `sfnew`.
- 2 In the empty chart, add states A and B. At the text prompt, enter the appropriate action statements.
- 3 Add a default transition to state A and transitions between states A and B.
- 4 Double-click each transition. At the text prompt, enter the appropriate condition.

### Define an Enumerated Data Type for the Chart


- 1 To create a file in which to store the data type definition, from the **Home** tab on the MATLAB toolstrip, select **New > Class**.
- 2 In the MATLAB Editor, enter:

```
classdef TrafficColors < Simulink.IntEnumType
    enumeration
        RED(0)
        GREEN(10)
    end
end
```

The `classdef` section defines an integer-based enumerated data type named `TrafficColors`. The `enumeration` section contains the enumerated values that this data type allows followed by their underlying numeric value.

- 3 Save your file as `TrafficColors.m` in a folder on the MATLAB search path.

### Define Chart Data

- 1 To resolve the undefined data, in the Symbols pane, click the **Resolve undefined symbols** icon . The Stateflow Editor assigns an appropriate scope to each symbol in the chart.


Symbol	Scope
color	Output Data
y	Local Data
GREEN	Parameter Data
RED	Parameter Data

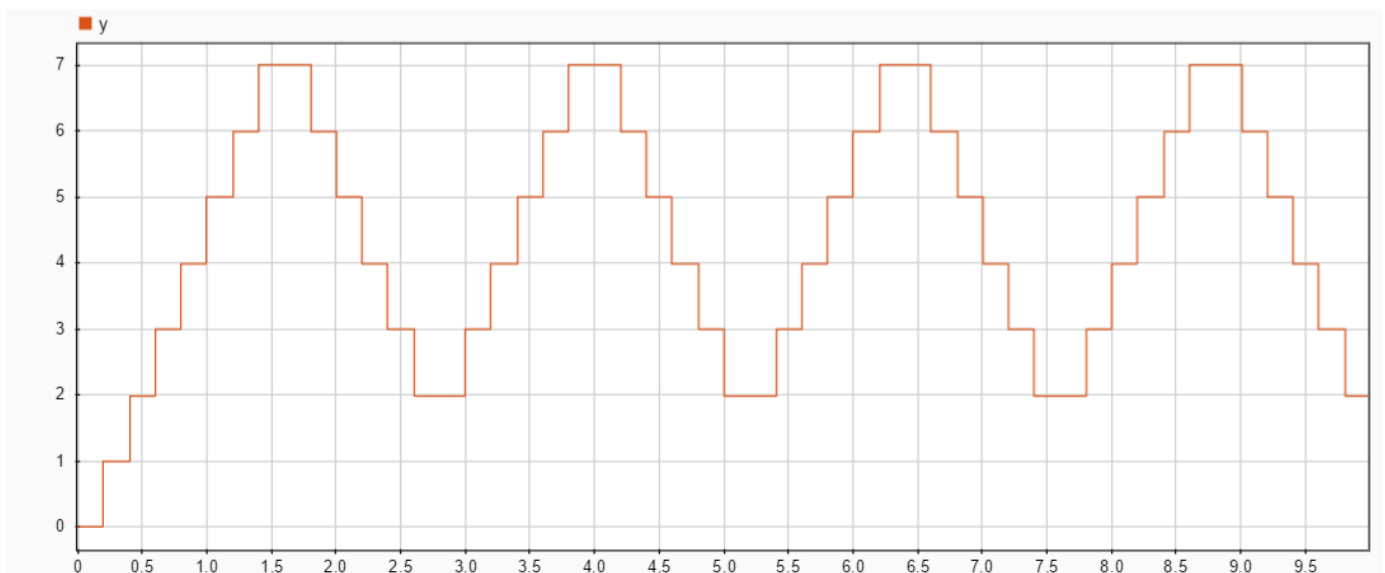
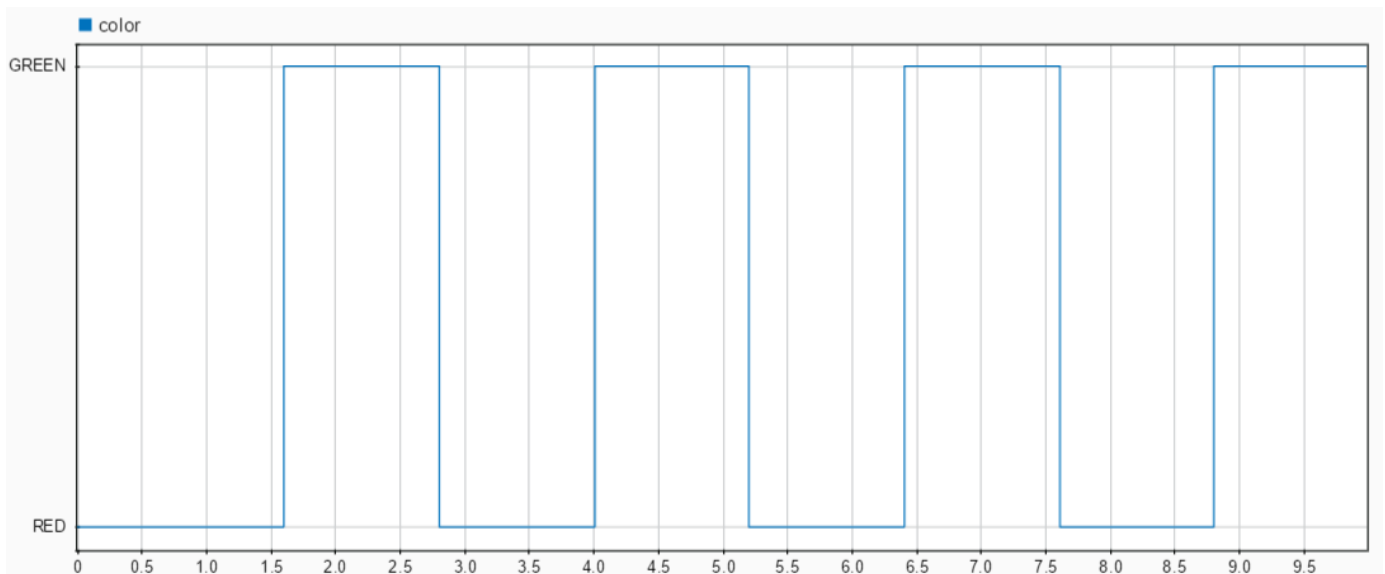
- 2 To specify `color` as enumerated data, in the Property Inspector:
  - In the **Type** field, select Enum: `<class name>`. Replace `<class name>` with `TrafficColors`, the name of the data type that you defined previously.
  - Under **Logging**, select the **Log signal data** check box.
- 3 To set the scope and type of `y`, in the Property Inspector:
  - In the **Scope** field, select Output.
  - In the **Type** field, select `uint8`.
  - Under **Logging**, select the **Log signal data** check box.



- 4 In the Symbols pane, delete the symbols GREEN and RED. The Stateflow Editor incorrectly identified these symbols as parameters before you specified color as enumerated data.

## View Simulation Results

- 1 When you simulate the model, the **Simulation Data Inspector** icon  is highlighted to indicate that it has new simulation data. To open the Simulation Data Inspector, click the icon.
- 2 In the Simulation Data Inspector, select the check boxes for the color and y signals so that they are displayed on separate axes.



- 3 To access the logged data in the MATLAB workspace, call the signal logging object `logout`. For example, at the command prompt, enter:

```
logout = out.logout;  
colorLog = logout.getElement('color');  
Tbl = table(colorLog.Values.Time,colorLog.Values.Data);  
Tbl.Properties.VariableNames = {'SimulationTime','Color'}
```

Tbl =

9x2 table

SimulationTime	Color
0	RED
1.6	GREEN
2.8	RED
4	GREEN
5.2	RED
6.4	GREEN
7.6	RED
8.8	GREEN
10	RED

## See Also

### More About

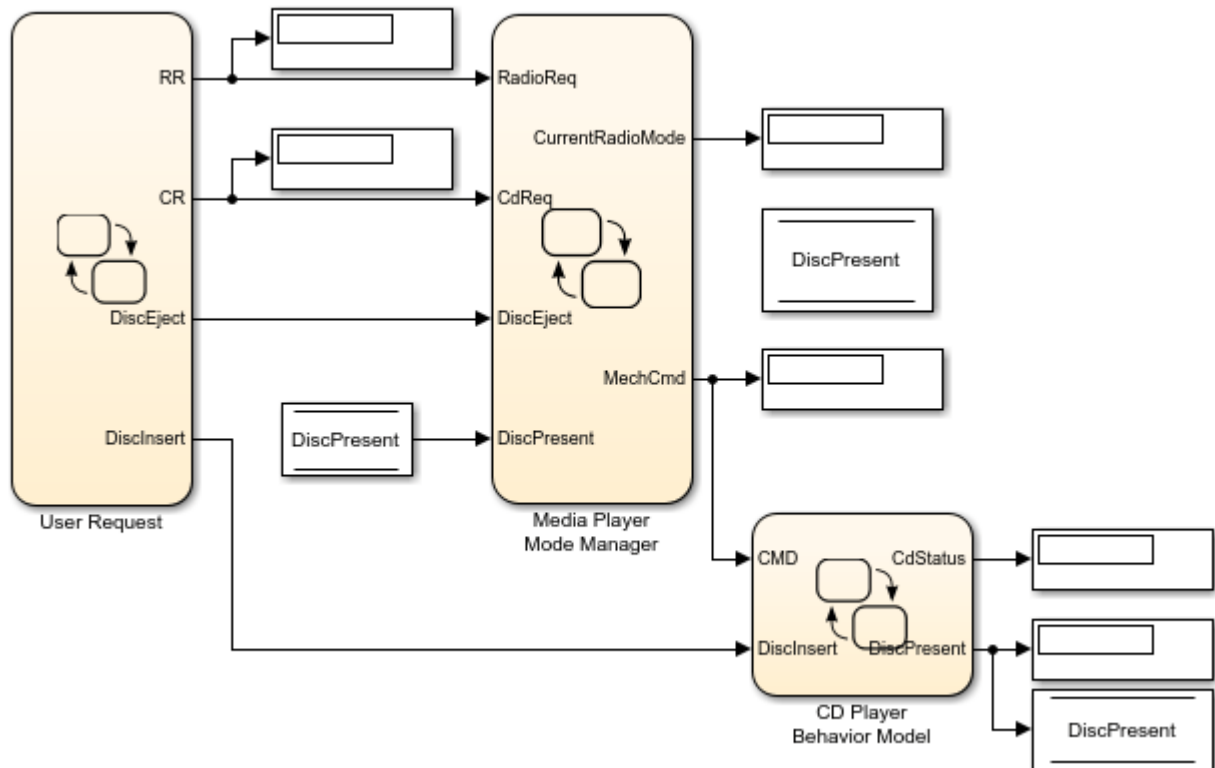
- “Define Enumerated Data Types” on page 23-5
- “Log Simulation Output for States and Data” on page 33-43
- “View Data in the Simulation Data Inspector” (Simulink)
- “Export Signal Data Using Signal Logging” (Simulink)

## Model Media Player by Using Enumerated Data

This example shows how to model a media player by using enumerated data in Stateflow®. The media player consists of a Simulink® model and a MATLAB® user interface (UI). The model has these components:

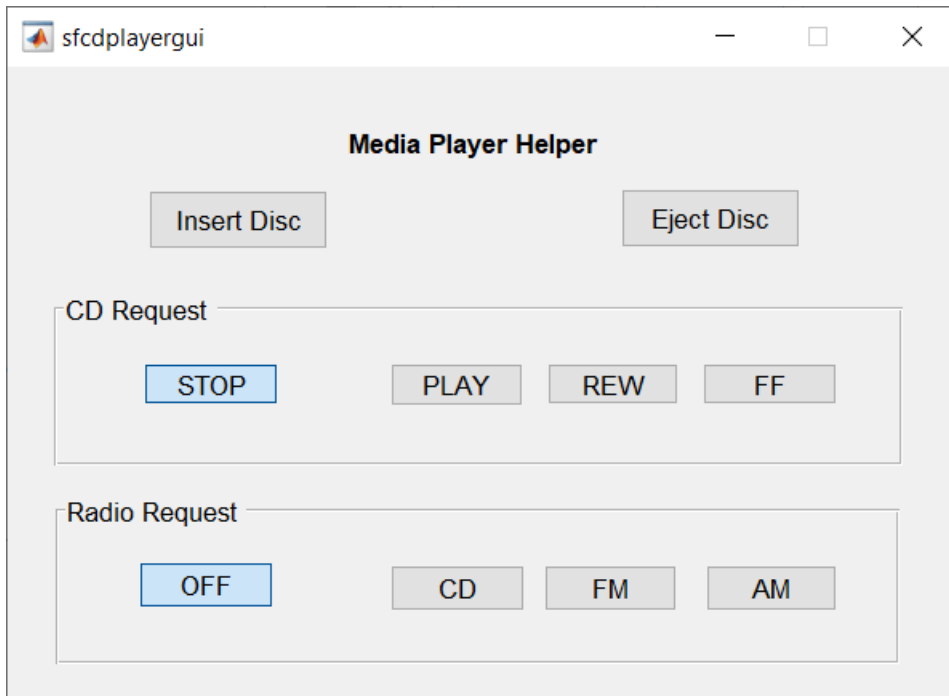
- User Request is a Stateflow chart that reads and stores user inputs from UI.
- Media Player Mode Manager is a Stateflow chart that determines whether the media player operates in AM radio, FM radio, or CD player mode.
- CD Player Behavior Model is a Stateflow chart that describes the behavior of the CD player component.

These charts use enumerated data to group related values into separate data types, reduce the amount of data, and enhance readability. For more information, see “Reference Values by Name by Using Enumerated Data” on page 23-2.



### Create Groups of Related Data Values

The model uses two enumerated data types to group the possible operating modes for the media player and for its CD player component. The Media Player Helper UI separates these modes into two groups of buttons.



The **Radio Request** section contains buttons for selecting an operating mode for the media player. The enumerated values for the data type `RadioRequestMode` correspond to these media player operating modes:

- OFF(0)
- CD(1)
- FM(2)
- AM(3)

The **CD Request** section contains buttons for selecting an operating mode for the CD player component. The **Insert Disc** and **Eject Disc** buttons also affect this operating mode. The enumerated values for the data type `CdRequestMode` correspond to these CD player operating modes:

- EMPTY(-2)
- DISCINSERT(-1)
- STOP(0)
- PLAY(1)
- REW(3)
- FF(4)
- EJECT(5)

At the start of the model simulation, the Display blocks show the default settings of the media player. To change the enumerated values in the Display blocks, use the Media Player Helper to select other operating modes. For example:

- 1 In the **Radio Request** section, click **CD**. The Display blocks for enumerated data `RR` and `CurrentRadioMode` change from `OFF` to `CD`.

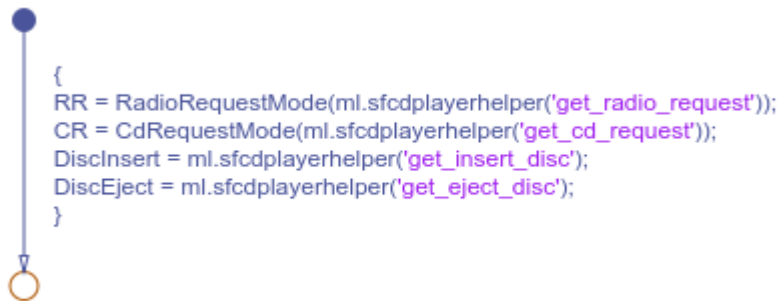
- 2 Click **Insert Disc**. The Display block for enumerated data CdStatus changes from EMPTY to DISCINSERT to STOP.
- 3 In the **CD Request** section, click **PLAY**. The Display blocks for enumerated data CR, MechCmd, and CdStatus change from STOP to PLAY.

### Read Input from User Interface

The User Request chart reads requests from the Media Player Helper UI and stores the information as these outputs:

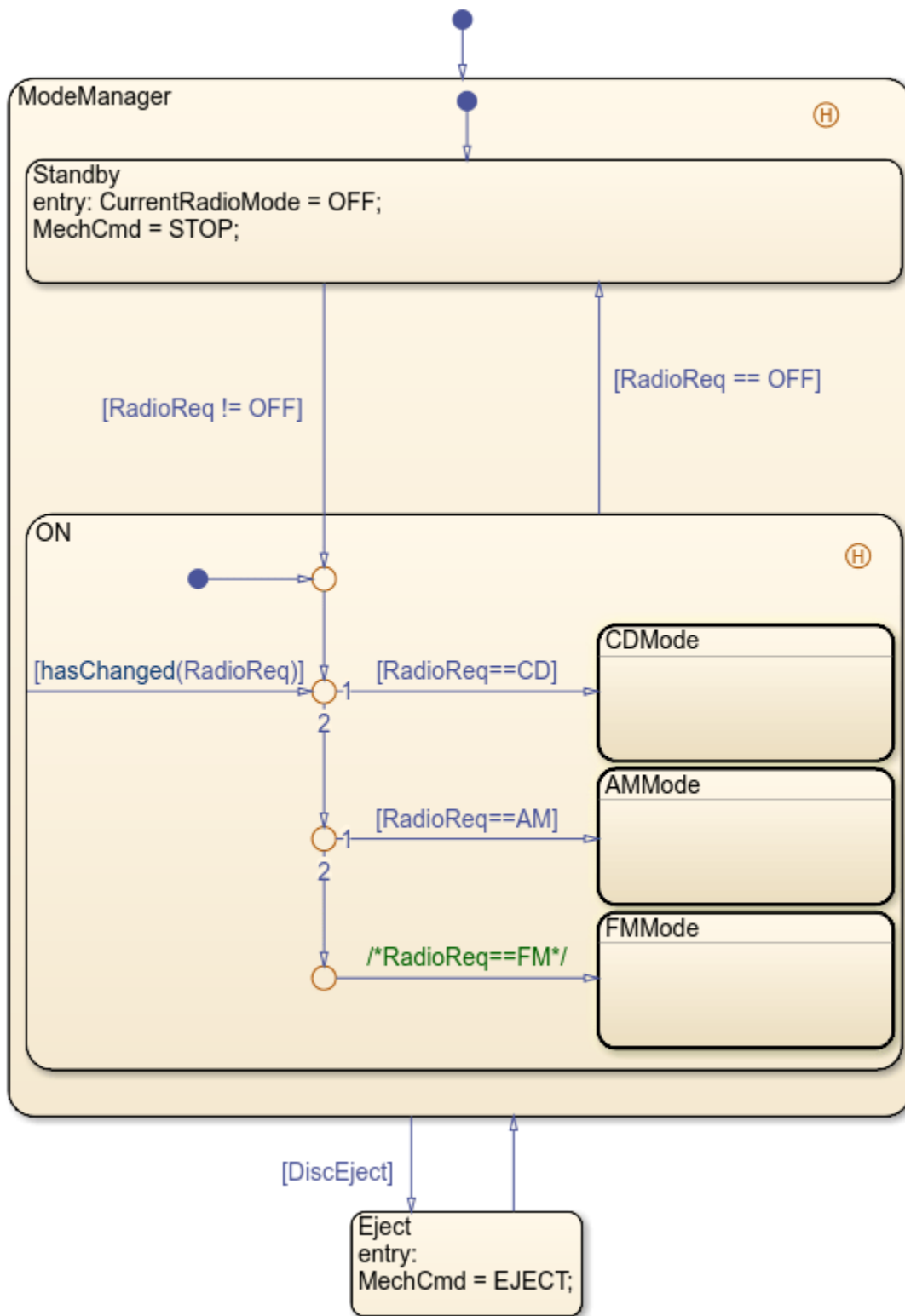
- RR: Enumerated data representing a **Radio Request** button.
- CR: Enumerated data representing a **CD Request** button.
- DiscInsert: Boolean data representing the **Insert Disc** button.
- DiscEject: Boolean data representing the **Eject Disc** button.

To read the input from the UI, the chart uses the `ml` namespace operator to call the function `sfcplayerhelper` on the MATLAB path. For more information, see “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20.



### Select Mode Based on Changes in Enumerated Data

The Media Player Mode Manager chart activates a subcomponent of the media player depending on the input from the User Request chart.



At the start of the model simulation, the `ModeManager` state is active. If the Boolean input data `DiscEject` becomes `true`, a transition to the `Eject` state occurs, followed by a transition back to the `ModeManager` state.

When `ModeManager` is active, the previously active substate (`Standby` or `ON`, as recorded by the history junction) becomes active. Subsequent transitions between the `Standby` and `ON` substates depend on the enumerated input data `RadioReq`:

- If `RadioReq` is `OFF`, the `Standby` substate is activated.
- If `RadioReq` is not `OFF`, the `ON` substate is activated.

In the `ON` substate, three subcharts represent the operating modes of the media player: CD player, AM radio, and FM radio. Each subchart corresponds to a different value of enumerated input data `RadioReq`:

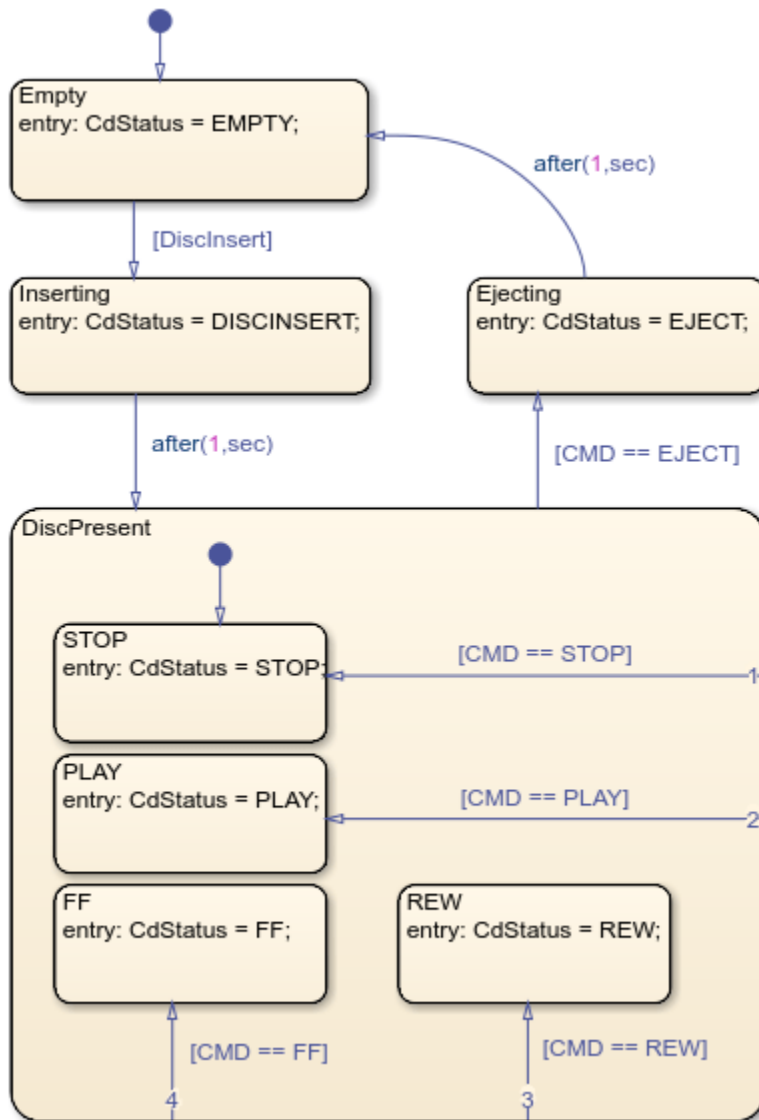
- If `RadioReq` is `CD`, the `CDMode` subchart is activated. The subchart outputs `PLAY`, `REW`, `FF`, and `STOP` commands to the `CD Player Behavior Model` chart.
- If `RadioReq` is `AM`, the `AMMode` subchart is activated. The subchart outputs a `STOP` command to the `CD Player Behavior Model` chart.
- If `RadioReq` is `FM`, the `FMMode` subchart is activated. The subchart outputs a `STOP` command to the `CD Player Behavior Model` chart.

To scan for changes in the value of `RadioReq`, the inner transition inside the `ON` state calls the change detection operator `hasChanged` at every time step.

### Control Timing of Transitions

The `CD Player Behavior Model` chart implements the behavior of the CD player mechanism depending on the input from the `User Request` and `Media Player Mode Manager` charts. To model the mechanical delays in the CD player, the chart uses the absolute-time temporal logic operator `after`. For instance:

- At the start of the model simulation, the `Empty` state is activated. If the Boolean input data `DiscInsert` is `true`, a transition to the `Inserting` state occurs. After a one-second delay, a transition to the `DiscPresent` state occurs.
- The `DiscPresent` state remains active until the input data `CMD` becomes `EJECT`. At that point, a transition to the `Ejecting` state occurs. After a one-second delay, a transition to the `Empty` state occurs.



Whenever a state transition occurs, the enumerated output data `CdStatus` changes value to reflect the status of the CD player:

- `CdStatus = EMPTY` when the active substate is `Empty` (CD player is empty).
- `CdStatus = DISCINSERT` when the active substate is `Inserting` (CD player is loading a disc).
- `CdStatus = EJECT` when the active substate is `Ejecting` (CD player is ejecting a disc).
- `CdStatus = STOP` when the active substate is `DiscPresent.STOP` (CD player is stopped).
- `CdStatus = PLAY` when the active substate is `DiscPresent.PLAY` (CD player is playing).
- `CdStatus = REW` when the active substate is `DiscPresent.REW` (CD player is rewinding).
- `CdStatus = FF` when the active substate is `DiscPresent.FF` (CD player is fast-forwarding).

## See Also

`after` | `hasChanged`



## **More About**

- “Reference Values by Name by Using Enumerated Data” on page 23-2
- “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20
- “Detect Changes in Data Values” on page 16-64
- “Control Chart Execution by Using Temporal Logic” on page 16-36



# String Data in Charts

---

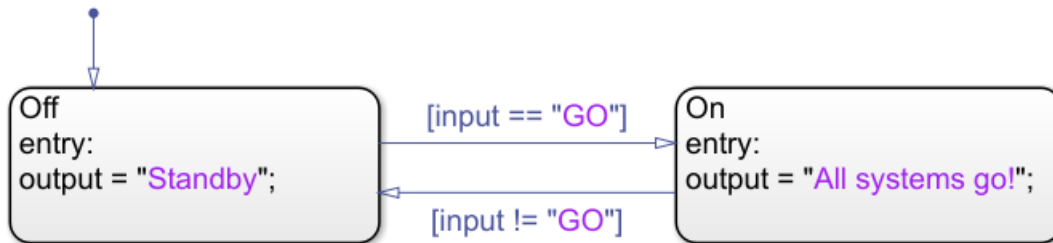
- “Manage Textual Information by Using Strings” on page 24-2
- “Log String Data to the Simulation Data Inspector” on page 24-6
- “Send Messages with String Data” on page 24-10
- “Share String Data with Custom C Code” on page 24-13
- “Simulate a Media Player” on page 24-17

## Manage Textual Information by Using Strings

To use textual data to control chart behavior and to manipulate text to create natural language output, use *strings*. String data is available only in Stateflow charts that use C as the action language.

### Example of String Data

In Stateflow, a string is a piece of text surrounded by quotes ("..." or '...'). For example, this chart takes string data as input. Based on that input, the chart produces a corresponding string output.



To specify a string symbol, set its **Type** field to `string`. Stateflow dynamically allocates memory space for this type of data.

Alternatively, you can create string data with a maximum number of characters. To specify a string symbol with a buffer size of  $n$  characters, set its **Type** field to `stringtype(n)`. The text of the string can be shorter than the buffer, but if it exceeds the buffer size, then the text in the string is truncated. For instance, if the symbol `output` in the previous chart is specified as `stringtype(10)`, then its value in the state `On` is truncated to "All system". Depending on the configuration parameter **String truncation checking**, you can halt simulation and diagnose truncation of string data.

String Truncation Checking	Description
error	Simulation stops with an error.
warning	String is truncated. Simulation continues with a warning.
none	String is truncated. Simulation continues with no error or warning.

**Note** Unlike C or C++, Stateflow interprets escape sequences as literal characters. For example, the string `"\n"` contains two characters, backslash and `n`, and not a newline character.

### Computation with Strings

To manipulate string data in a Stateflow chart, use the operators listed in this table.

Operator	Syntax	Description	Example
<code>strcpy</code>	<code>strcpy(dest, src)</code>	An alternative way to execute <code>dest = src</code> .	Assign string data to <code>s1</code> , <code>s2</code> , and <code>s3</code> .  <pre>strcpy(s1, 'So long'); strcpy(s2, "Farewell"); strcpy(s3, s2);</pre>

Operator	Syntax	Description	Example
	<code>dest = src</code>	Assigns string <code>src</code> to <code>dest</code> .	Assign string data to <code>s4</code> , <code>s5</code> , and <code>s6</code> .  <pre>s4 = 'Auf Wiedersehen'; s5 = "Adieu"; s6 = s4;</pre>
<code>strcat</code>	<code>dest = strcat(s1, ..., sN)</code>	Concatenates strings <code>s1, ..., sN</code> .	Concatenate strings to form "Stateflow".  <pre>s1 = "State"; s2 = "flow"; dest = strcat(s1,s2);</pre>
<code>substr</code>	<code>dest = substr(str,i,n)</code>	Returns the substring of length <code>n</code> starting at the <code>i</code> -th character of string <code>str</code> . Use zero-based indexing.	Extract substring "Stateflow" from a longer string.  <pre>str = "Stateflow, rule the waves!"; dest = substr(str,0,9);</pre>
<code>tostring</code>	<code>dest = tostring(X)</code>	Converts numeric, Boolean, or enumerated data to string.	Convert numeric value to string "1.2345".  <pre>dest = tostring(1.2345);</pre> Convert Boolean value to string "true".  <pre>dest = tostring(1==1);</pre> Convert enumerated value to string "RED".  <pre>dest = tostring(RED);</pre>
<code>strcmp</code>	<code>tf = strcmp(s1,s2)</code>	Compares strings <code>s1</code> and <code>s2</code> . Returns 0 if the two strings are identical. Otherwise returns a nonzero integer.  <ul style="list-style-type: none"> <li>The sign of the output value depends on the lexicographic ordering of the input strings <code>s1</code> and <code>s2</code>.</li> <li>The magnitude of the output value depends on the compiler that you use. This value can differ in simulation and generated code.</li> </ul> <p>Strings are considered identical when they have the same size and content.</p> <p>This operator is consistent with the C library function <code>strcmp</code> or the C++ function</p>	Return a value of 0 (strings are equal).  <pre>tf = strcmp("abc","abc");</pre>

Operator	Syntax	Description	Example
		<code>string.compare</code> , depending on the compiler that you select for code generation. The operator behaves differently than the function <code>strcmp</code> in MATLAB.	Return a nonzero value (strings are not equal). <pre>tf = strcmp("abc","abcd");</pre>
	<code>s1 == s2</code>	An alternative way to execute <code>strcmp(s1,s2) == 0</code> .	Return a value of <code>true</code> . <pre>"abc" == "abc";</pre>
	<code>s1 != s2</code>	An alternative way to execute <code>strcmp(s1,s2) != 0</code> .	Return a value of <code>true</code> . <pre>"abc" != "abcd";</pre>
	<code>tf = strcmp(s1,s2,n)</code>	Returns <code>0</code> if the first <code>n</code> characters in <code>s1</code> and <code>s2</code> are identical.	Return a value of <code>0</code> (substrings are equal). <pre>tf = strcmp("abc","abcd",3);</pre>
<code>strlen</code>	<code>L = strlen(str)</code>	Returns the number of characters in the string <code>str</code> .	Return a value of <code>9</code> . <pre>L = strlen("Stateflow");</pre>
<code>str2double</code>	<code>X = str2double(str)</code>	Converts the text in string <code>str</code> to a double-precision value.  <code>str</code> contains text that represents a number. Text that represents a number can contain: <ul style="list-style-type: none"> <li>• Digits</li> <li>• A decimal point</li> <li>• A leading + or - sign</li> <li>• An <code>e</code> preceding a power of 10 scale factor</li> </ul> If <code>str2double</code> cannot convert text to a number, then it returns a <code>NaN</code> value.	Return a value of <code>-12.345</code> . <pre>X = str2double("-12.345");</pre> Return a value of <code>123400</code> . <pre>X = str2double("1.234e5");</pre>
<code>str2ascii</code>	<code>A = str2ascii(str,n)</code>	Returns array of type <code>uint8</code> containing ASCII values for the first <code>n</code> characters in <code>str</code> , where <code>n</code> is a positive integer. Use of variables or expressions for <code>n</code> is not supported.	Return <code>uint8</code> array <code>{72,101,108,108,111}</code> . <pre>A = str2ascii("Hello",5);</pre>
<code>ascii2str</code>	<code>dest = ascii2str(A)</code>	Converts ASCII values in array <code>A</code> of type <code>uint8</code> to string.	Return string <code>"Hi!"</code> . <pre>A[0] = 72; A[1] = 105; A[2] = 33; dest = ascii2str(A);</pre>

## Where to Use Strings

Use string data at these levels of the Stateflow hierarchy:

- Chart
- Subchart
- State

Use string data as arguments for:

- State actions
- Condition and transition actions
- Graphical functions
- Simulink functions
- Truth table functions that use C as the action language

If you have Simulink Coder installed, you can use string data for simulation and code generation.

## See Also

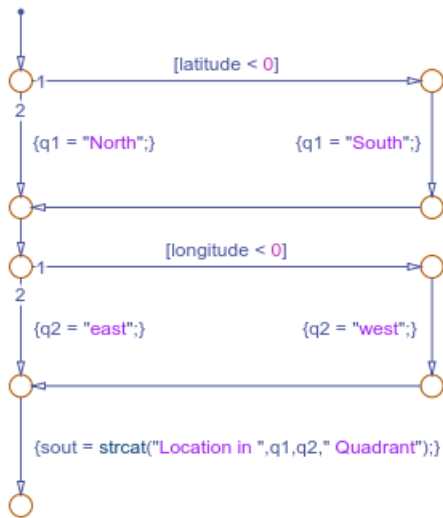
`ascii2str` | `str2ascii` | `str2double` | `strcat` | `strcmp` | `strcpy` | `strlen` | `substr` | `tostring`

## More About

- “Log String Data to the Simulation Data Inspector” on page 24-6
- “Send Messages with String Data” on page 24-10
- “Share String Data with Custom C Code” on page 24-13
- “Simulate a Media Player” on page 24-17
- “Simulink Strings” (Simulink)

## Log String Data to the Simulation Data Inspector

This example shows how to build a Stateflow chart that, based on numeric input data, concatenates string data into natural language output text. You can view the output text in the Simulation Data Inspector and in the MATLAB workspace. For more information on string data, see “Manage Textual Information by Using Strings” on page 24-2.



### Chart Behavior

During simulation, Sine Wave blocks provide the position of a point moving along a closed path in terms of latitude and longitude coordinates. The chart examines these coordinates and assigns the strings q1 and q2 according to the information in this table.

Latitude	Longitude	q1	q2
positive	positive	"North"	"east"
positive	negative	"North"	"west"
negative	positive	"South"	"east"
negative	negative	"South"	"west"

Then, the statement

```
sout = strcat("Location in ", q1, q2, " Quadrant");
```

concatenates these strings into an output string.

### Create the Model

#### Add Junctions and Transitions


- 1 To create a Simulink model with an empty chart that uses the C action language, at the MATLAB command prompt, enter

```
sfnew -C
```



- In the empty chart, place a default transition. A junction appears. Point and drag from the edge of the junction to add other transitions and junctions.
- Double-click each transition. At the text prompt, enter the appropriate condition or action statement.

### Define Chart Data

- To resolve the undefined data, in the Symbols pane, click the **Resolve undefined symbols** icon . The Stateflow Editor assigns an appropriate scope to each symbol in the chart.

Symbol	Scope
latitude	Input Data
longitude	Input Data
q1	Local Data
q2	Local Data
sout	Output Data

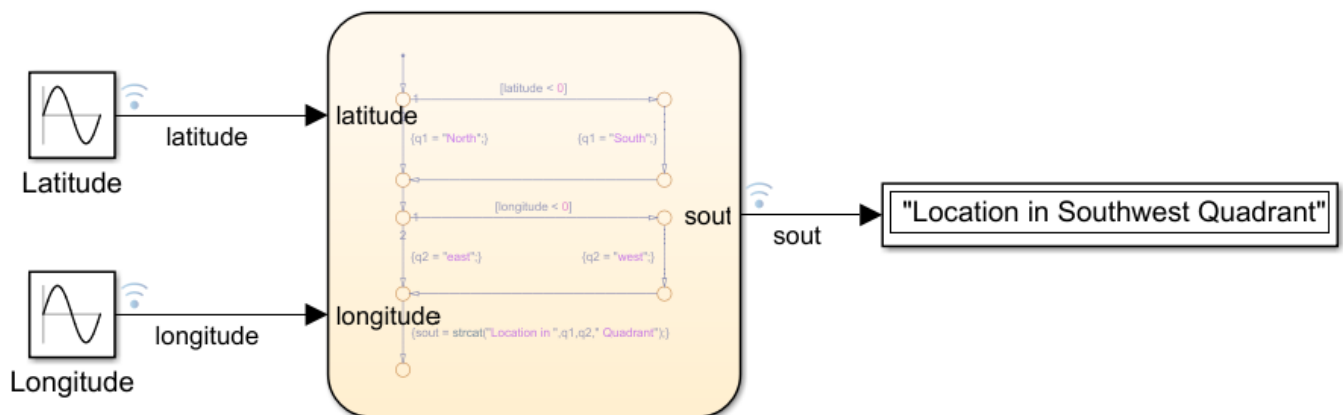
- To specify q1 as string data, in the **Type** field of the Property Inspector, select `string`. Repeat that specification for q2 and sout.

Alternatively, to create string data with a maximum number of characters, specify each string as `stringtype(n)` using a suitable buffer size  $n$  to avoid truncation of its contents. For instance, this table lists suitable buffer sizes for the string data in the chart.

Symbol	Number of Characters	String Data Type
q1	5	<code>stringtype(5)</code>
q2	5	<code>stringtype(5)</code>
sout	30	<code>stringtype(30)</code>

### Add Sources and Sinks to the Model

- In the Simulink model, add two Sine Wave blocks and a Display block. Connect the blocks to the chart input and output ports.




- Set the Sine Wave block parameters as indicated in this table.

Block	Amplitude	Bias	Frequency	Phase
Latitude	50	0	1	0
Longitude	50	0	1	$\pi/2$

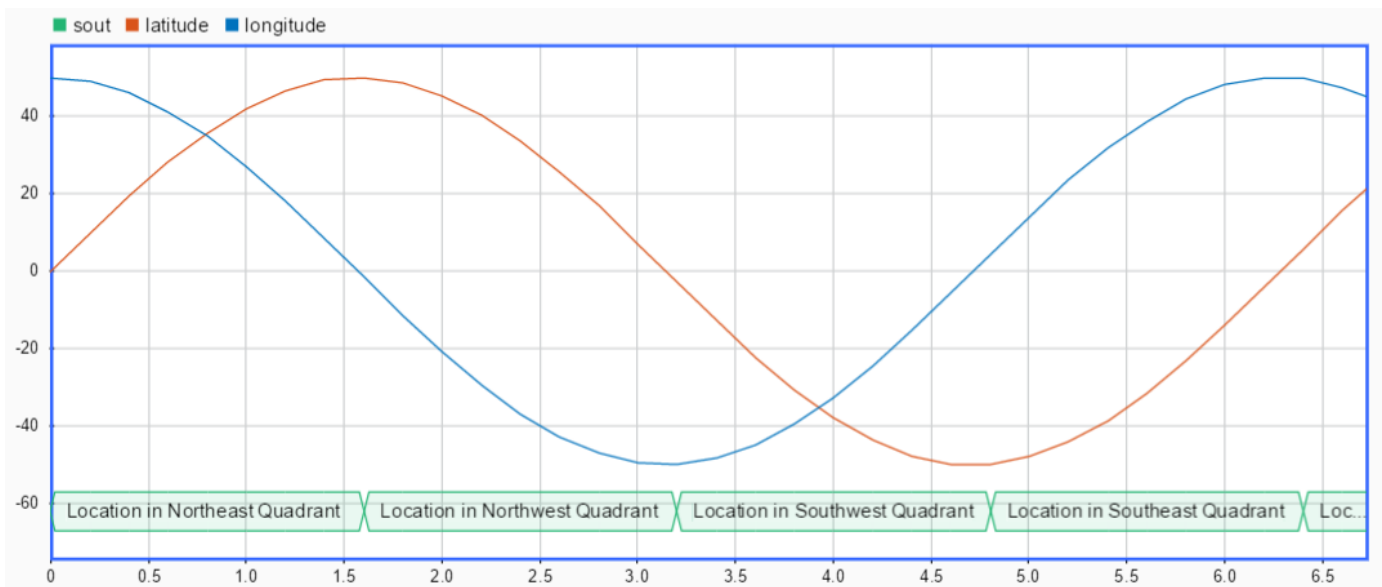
- Label the signals in the model as `latitude`, `longitude`, and `sout`. Right-click each signal and select **Log Selected Signals**.

## View Simulation Results

1

When you simulate the model, the **Simulation Data Inspector** icon  is highlighted to indicate that it has new simulation data. To open the Simulation Data Inspector, click the icon.

- In the Simulation Data Inspector, select the check boxes for the `latitude`, `longitude`, and `sout` signals so that they are displayed on the same set of axes. The `latitude` and `longitude` signals appear as sinusoidal curves. The `sout` signal is shown as a transition plot. The value of the string is displayed inside a band and criss-crossed lines mark the changes in value.



- To access the logged data in the MATLAB workspace, call the signal logging object `logout`. Stateflow exports the string data `sout` as a MATLAB string scalar. For example, at the command prompt, enter:

```
logout = out.logout;
Tbl = table(logout.get('latitude').Values.Data, ...
    logout.get('longitude').Values.Data, ...
    logout.get('sout').Values.Data);
Tbl.Properties.VariableNames = ...
    {'Latitude', 'Longitude', 'QuadrantInfo'};
Tbl([4:8:30],:)
```

ans =

```
4x3 table
```

---

Latitude	Longitude	QuadrantInfo
28.232	41.267	"Location in Northeast Quadrant"
40.425	-29.425	"Location in Northwest Quadrant"
-30.593	-39.548	"Location in Southwest Quadrant"
-38.638	31.735	"Location in Southeast Quadrant"

## See Also

`get` | `strcat` | `table`

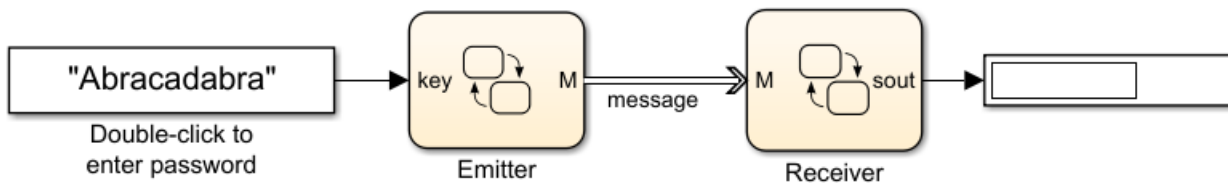
## More About

- “Manage Textual Information by Using Strings” on page 24-2
- “Log Simulation Output for States and Data” on page 33-43
- “View Data in the Simulation Data Inspector” (Simulink)
- “Export Signal Data Using Signal Logging” (Simulink)

## Send Messages with String Data

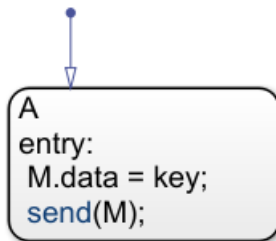
This example shows how to configure a pair of Stateflow charts that communicate by sending messages that carry string data. For more information, see “Communicate with Stateflow Charts by Sending Messages” on page 15-2.

This model contains two charts that use C as the action language. During simulation, the Emitter chart reads an input string `key` from the String Constant block and sends a message to the Receiver chart. The message data consists of the input string `key`. The Receiver chart compares the string with a constant keyword and returns an output string that grants or denies access.



### Emitter Chart

The Emitter chart consists of a single state A. When the state becomes active, it sets the data for the message M to the input value `key` and sends the message to the Receiver chart.



This table lists the scope and type for the symbols in the chart.

Symbol	Scope	Type
key	Input Data	Inherit: Same as Simulink
M	Output Message	string

### Receiver Chart

The chart consists of two states joined by a transition. The input message M guards the transition. If there is a message present and its data value equals the constant string `lock`, then the state activity transitions from Off to On. The chart outputs the string value 'Access Granted'. If there is no message present, or if the data value does not equal `lock`, the chart does not take the transition and the output value is 'Access Denied'.



This table lists the scope and type for the symbols in the chart.

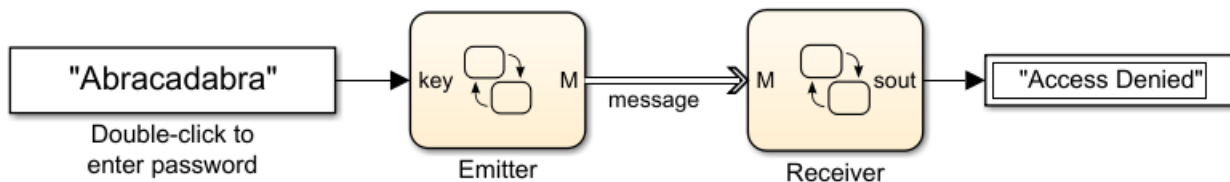
Symbol	Scope	Type
M	Input Message	Inherit: Same as Simulink
lock	Constant Data	string
sout	Output Data	string

The constant string `lock` contains a secret password, initially set to 'Open Sesame'. You can change the value of `lock` in the **Initial value** field of the Property Inspector.

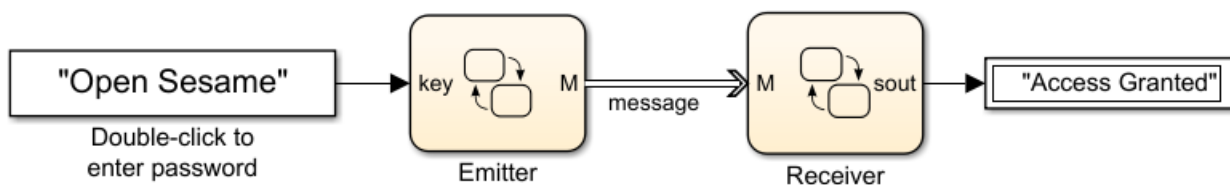
## View Simulation Results

During simulation, the model responds to the password that you enter in the String Constant block:

- If you enter an incorrect password, such as "Abracadabra", then the model displays the output string "Access Denied".



- If you enter the correct password, in this case, "Open Sesame", then the model displays the output string "Access Granted".



## See Also

send

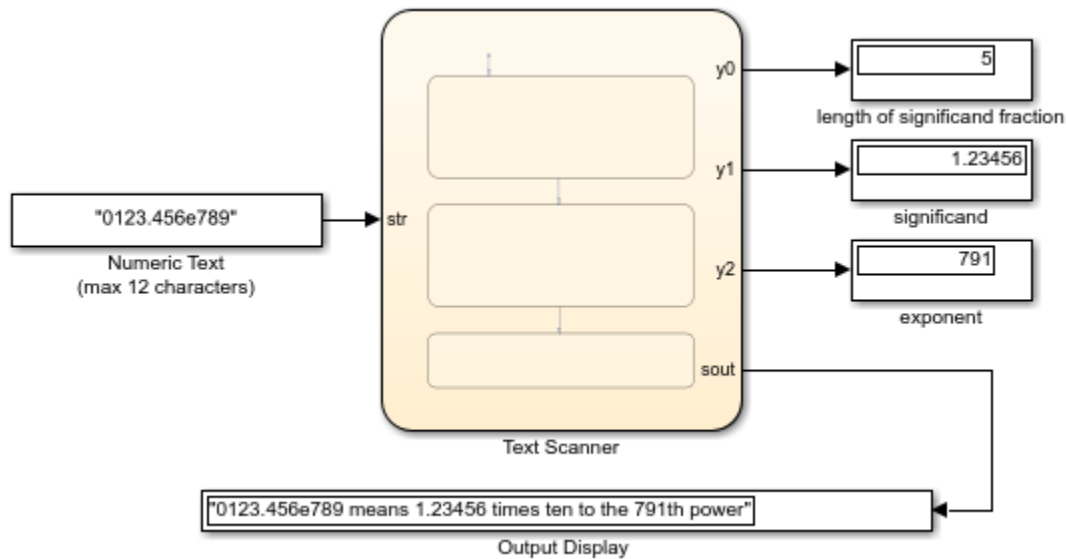
## More About

- "Manage Textual Information by Using Strings" on page 24-2

- “Log String Data to the Simulation Data Inspector” on page 24-6
- “Share String Data with Custom C Code” on page 24-13
- “Simulate a Media Player” on page 24-17
- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “View Differences Between Stateflow Messages, Events, and Data” on page 15-14

## Share String Data with Custom C Code

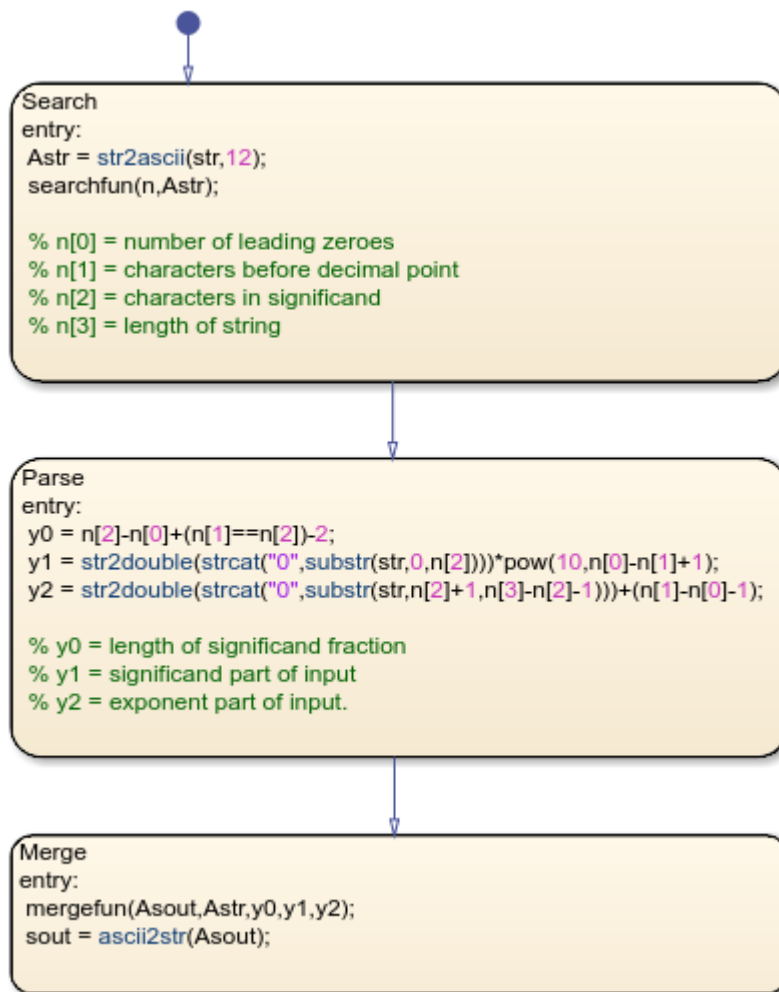
This example shows how to share string data between a Stateflow® chart and custom C code. You can export string data from a Stateflow chart to a C function by using the `str2ascii` operator. You can import the output of your C code as string data in a Stateflow chart by using the `ascii2str` operator. By sharing data with custom code, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.



This model contains a Stateflow chart that calls two functions from custom C code. During simulation, the chart takes as its input a string that contains text representing a floating-point number in exponential form. The chart consists of three states that:

- Search the input string for leading zeroes, a decimal point, and an e.
- Parse the string into double-precision numbers representing the significand and exponent parts of the input.
- Merge the numeric information into an output string expressing the input in scientific notation.

For example, if the input string is "0123.456e789", then the chart outputs the string "0123.456e789 means 1.23456 times ten to the 791th power".



### Export String Data from Stateflow to C

You can use the `str2ascii` operator to convert string data into an array that you can export from a Stateflow chart to a custom C code function.

- 1 In the custom code function, declare the input variable as having type `char*`.
- 2 In the Stateflow chart, convert the string to an array of type `uint8` by calling the operator `str2ascii`.
- 3 Call the custom code function by passing the `uint8` array as an input.

For example, in the previous chart, the `Search` state converts the input string `str` to the `uint8` array `Asrt`. The `Search` state passes this array as an input to the custom code function `searchfun`:

```

extern void searchfun(int* nout, char* strin)
{
    nout[0] = strspn(strin,"0");
    nout[1] = strcspn(strin,".e");
    nout[2] = strcspn(strin,"e");
    nout[3] = strlen(strin);
}

```



The `Search` state calls this function with the command `searchfun(n, Astr)`. The function populates the integer array `n` with these values:

- `n[0]` contains the number of leading zeroes in the input string `str`.
- `n[1]` contains the number of characters before the first instance of a decimal point or `e`. This result provides the number of characters before the decimal point in `str`.
- `n[2]` contains the number of characters before the first instance of `e`. This result provides the number of characters in the significand in `str`.
- `n[3]` contains the length of the input string `str`.

The `Parse` state uses these results to extract the values of the significand and exponent parts of the input.

### Import String Data from C to Stateflow

You can import string data to a Stateflow chart by passing a pointer to an array of type `uint8` as an input to a custom C function.

- 1 In the custom code function, declare the input variable containing the pointer as having type `char*`.
- 2 Save the output string data from the custom code function at the location indicated by the pointer.
- 3 In the Stateflow chart, convert the `uint8` array to a string by calling the operator `ascii2str`.

For example, in the previous chart, the `Merge` state consolidates the numeric information obtained by the `Parse` state into an output string by calling the custom code function `mergefun`:

```
extern void mergefun(char* strout, char* strin, int in0, double in1, double in2)
{
    sprintf(strout, "%s means %1.*f times ten to the %dth power", strin, in0, in1, (int) in2);
}
```

The `Merge` state calls the `mergefun` function with the command `mergefun(Asout, Astr, y0, y1, y2)`:

- `Asout` is an array of type `uint8` pointing to the output of the custom function.
- `Astr` is an array of type `uint8` corresponding to the input string to the chart.
- `y0` is an integer containing the number of digits to the right of the decimal point in the significand.
- `y1` and `y2` are double-precision numbers representing the significand and exponent parts of the input.

The function `mergefun` calls the C library function `sprintf`, merging the contents of `Astr`, `y1`, and `y2` and storing the result in the memory location indicated by `Aout`. The chart uses the operator `ascii2str` to convert this output to the string `sout`. In this way, the model imports the string constructed by the custom code function back into Stateflow.

### See Also

`ascii2str` | `str2ascii` | `str2double` | `strcat` | `substr`

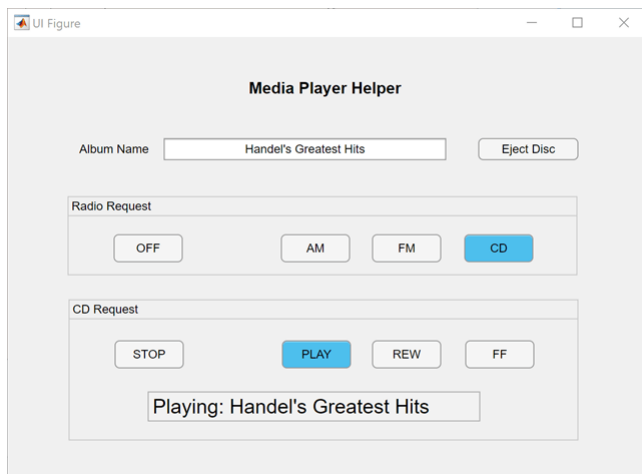
### **More About**

- “Manage Textual Information by Using Strings” on page 24-2
- “Log String Data to the Simulation Data Inspector” on page 24-6
- “Send Messages with String Data” on page 24-10
- “Simulate a Media Player” on page 24-17
- “Reuse Custom Code in Stateflow Charts” on page 31-23

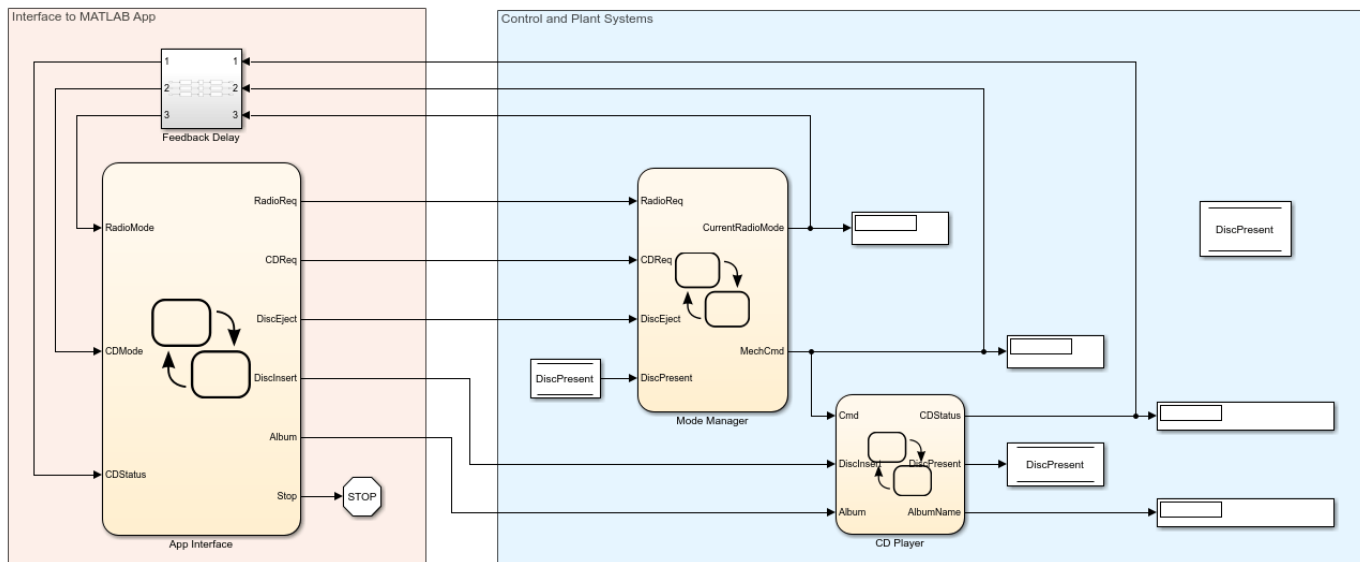
## Simulate a Media Player

This example shows how to create an interface between a Stateflow® chart that uses C as the action language and a MATLAB® app created in App Designer. For more information on connecting a Stateflow chart that uses MATLAB as the action language to a MATLAB app, see “Model a Power Window Controller” on page 30-50.

In this example, a MATLAB app models the front end of a media player. During simulation, you can choose between the AM radio, FM radio, and CD player components of the media player. When the CD player is on, you can also select the playback mode.



The Stateflow chart `App Interface` provides a bidirectional connection between the MATLAB app and the control and plant systems in the Simulink® model. When you interact with the widgets in the app, the chart sends a corresponding command to the other charts in the model. These charts use strings to control the behavior of the media player and to provide natural language output messages that indicate its status. When the status of the media player changes, the chart changes the color of the buttons and updates the text field at the bottom of the app.



### Run the Media Player Model

- 1 Open the Simulink model and click **Run**. The Media Player Helper app opens. The text field at the bottom of the app shows the status of the media player, **Standby (OFF)**.
- 2 In the **Radio Request** section, click **CD**. The media player status changes to **CD Player: Empty**.
- 3 Click **Insert Disc**. The media player status briefly says **Reading: Handel's Greatest Hits** before changing to **CD Player: Stopped**.
- 4 In the **CD Request** section, click **PLAY**. The media player status changes to **Playing: Handel's Greatest Hits** and music begins to play.
- 5 In the **CD Request** section, click **FF**. The music stops and chirping sounds begin. The media status changes to **Forward >> Handel's Greatest Hits**. The album name in this message scrolls forward across the display.
- 6 Use the Media Player Helper app to select other operating modes or to enter a different album name. For example, try playing to the albums **Training Deep Networks** or **Fun With State Machines**. To stop the simulation, close the Media Player Helper app.

### Connect Chart to MATLAB App

The chart App Interface is already configured to communicate with the MATLAB app `sf_mediaplayer_app`. To create a bidirectional connection between your MATLAB app and a Stateflow chart that uses C as the action language, follow these steps. In the MATLAB app:

- 1 Create a custom property to interface with the chart during simulation. The app uses this property to access chart inputs, chart outputs, and local data. For more information, see “Share Data Within App Designer Apps”.
- 2 Modify the `startupFcn` callback for the app by adding a new input argument and storing its value as the property that you created in the previous step. For more information, see “Write Callbacks in App Designer”.

In the Stateflow chart:

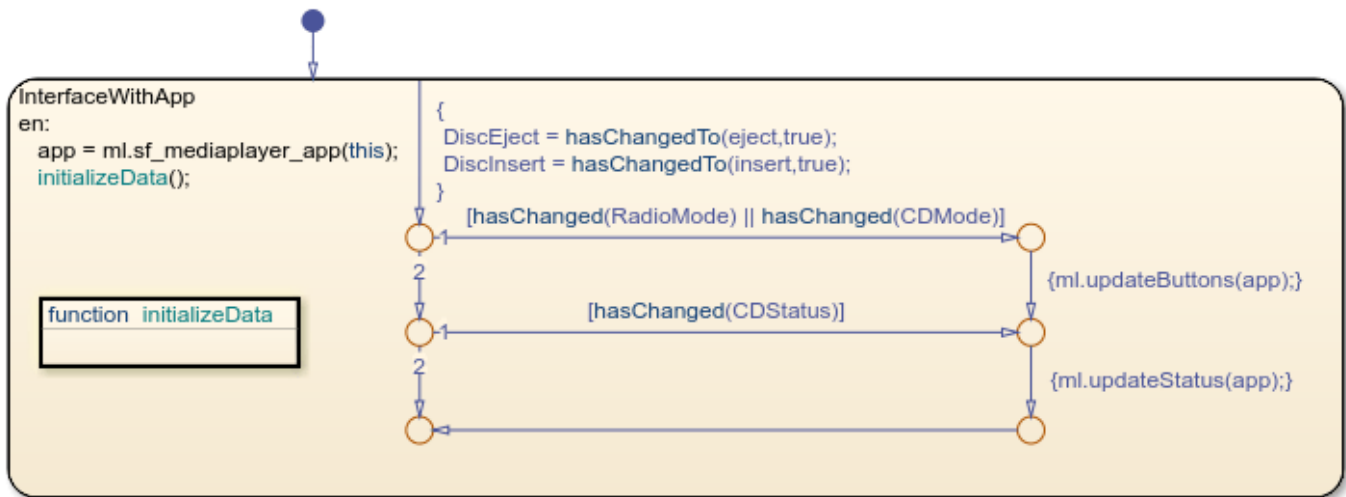
- 1 Create a local data object to interface with the app. The chart uses this local data object as an argument when it calls helper functions in the app.
- 2 Set the type of the local data object you created in the previous step to `m1`. For more information, see “Specify Type of Stateflow Data” on page 12-27.
- 3 Run the app using the `m1` namespace operator to indicate that the app is extrinsic MATLAB code. Pass the keyword `this` as an argument to give the app access to the chart during simulation. Store the value returned by the function call to the app as the local data object that you created to interface with the app. For more information, see “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20.

In this example, the Media Player Helper app uses a property called `chart` to interface with the chart App Interface. The app callbacks use this property to write to the chart outputs:

- When you insert or eject a disc, the `EjectButtonPushed` callback sets the values of `insert`, `eject`, and `Album`.
- When you click a button in the **Radio Request** section of the app, the corresponding callbacks set the value of `RadioReq`.
- When you click a button in the **CD Request** section of the app, the corresponding callbacks set the value of `CDReq`.

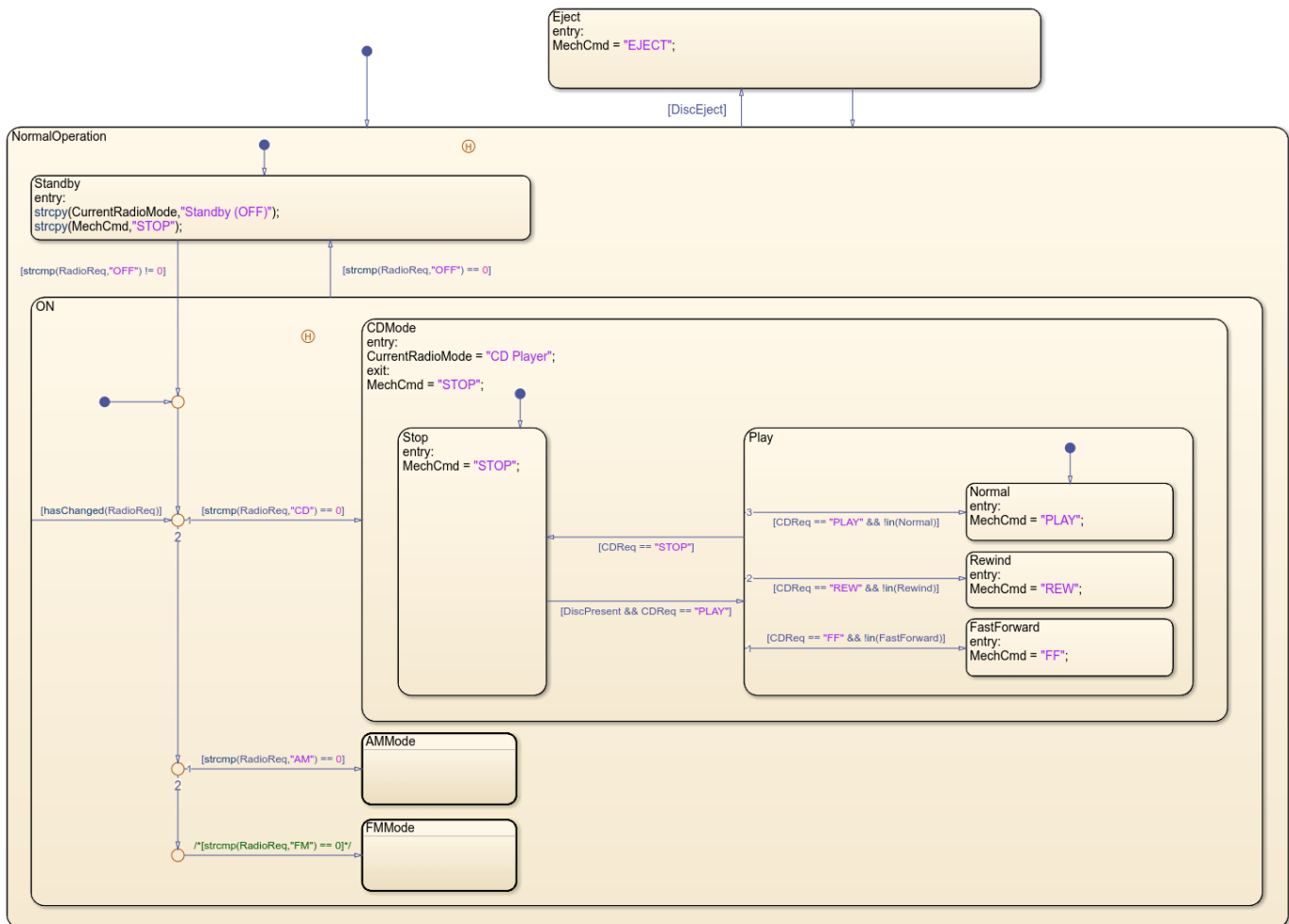
- When you close the app, the `UIFigureCloseRequest` callback sets the value of `Stop` to `true`.

Conversely, in the chart, the entry actions in the `InterfaceWithApp` state run the app `sf_mediaplayer_app` and store the returned value as the local data object `app`. The chart uses this local data object when it calls the helper functions `updateButtons` and `updateStatus`. In the app, these helper functions change the color of the buttons and update the text field at the bottom of the app based on the value of the chart inputs `RadioMode`, `CDMode`, and `CDStatus`.



### Manage Media Player Modes

The Mode Manager chart activates the appropriate subcomponent of the media player (AM radio, FM radio, or CD player) depending on the inputs received from the App Interface chart. The chart inputs `RadioReq` and `CDReq` contain string data that control the behavior of the chart. To evaluate the string data, the chart uses the string operator `strcmp` and its equivalent shorthand form `==`. The chart output `CurrentRadioMode` provides natural language output to the app, while `MechCmd` controls the behavior of the CD player subcomponent. To assign values to these outputs, the chart uses the string operator `strcpy` and its equivalent shorthand form `=`.



At the start of simulation, the `NormalOperation` state becomes active. If the Boolean data `DiscEject` is true, a transition to the `Eject` state occurs, followed by a transition back to the `NormalOperation` state.

When `NormalOperation` is active, the previously active substate (`Standby` or `ON`) recorded by the history junction becomes active. Subsequent transitions between the `Standby` and `ON` substates depend on the value of the expression `strcmp(RadioReq, "OFF")`:

- If `strcmp` returns a value of zero, then `RadioReq` is "OFF" and the `Standby` substate is activated.
- If `strcmp` returns a nonzero value, then `RadioReq` is not "OFF" and the `ON` substate is activated.

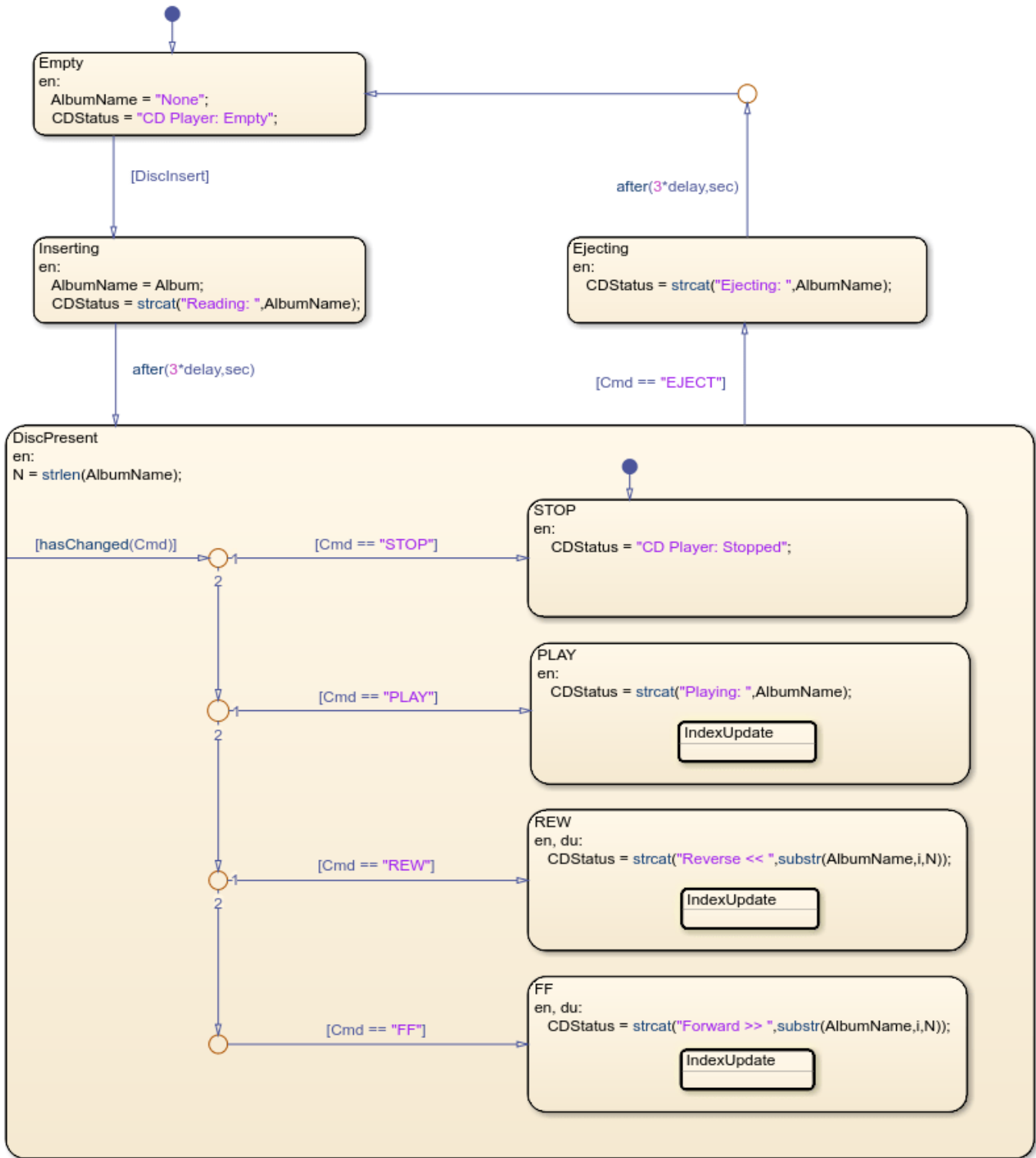
In the `ON` substate, three substates represent the operating modes of the media player: CD player, AM radio, and FM radio. Each substate corresponds to a different value of the input `RadioReq`. The inner transition inside the `ON` state uses the operator `hasChanged` to continually scan for changes in the value of `RadioReq`.

- If the value of `RadioReq` is "CD", then the substate `CDMode` becomes active and the media player switches to CD player mode. The `Mode Manager` chart outputs "PLAY", "REW", "FF", and "STOP" commands to the `CD Player` chart through the string data `MechCmd`.

- If the value of `RadioReq` is "AM", then the substate `AMMode` becomes active and the media player switches to AM radio mode. The `Mode Manager` chart outputs a "STOP" command to the `CD Player` chart through the string data `MechCmd`.
- If the value of `RadioReq` is "FM", then the substate `FMMode` becomes active and the media player switches to FM radio mode. The `Mode Manager` chart outputs a "STOP" command to the `CD Player` chart through the string data `MechCmd`.

### **Manage CD Player Modes**

The `CD Player` chart activates the appropriate operating mode for the CD player depending on the input received from the `App Interface` and `Mode Manager` charts. The chart inputs `Cmd` and `Album` contain string data that control the behavior of the chart. The chart output `AlbumName` provides natural language output to the app. To assign and compare the values of string data, the chart uses the shorthand operations `=` (see `strcpy`) and `==` (see `strcmp`). To produce text in the output string `CDStatus`, the chart uses the string operators `strcat`, `strlen`, and `substr`.



At the start of simulation, the Empty state is activated.



If the Boolean data `DiscInsert` is `true`, a transition to the `Inserting` state occurs. After a short time delay, a transition to the `DiscPresent` state occurs. The `DiscPresent` state remains active until the data `Cmd` becomes "EJECT". At that point, a transition to the `Ejecting` state occurs. After a short time delay, a transition to the `Empty` state occurs. The temporal logic operator `after` controls the timing of the transitions during disc insertion and ejection.

When a state transition occurs, the entry action in the new state changes the value of `CDStatus` to reflect the status of the CD player. In the `FF` or `REW` substates, the `during` actions continually change the value of `CDStatus` to produce a scrolling motion effect.

- When the active state is `Empty`, the value of `CDStatus` is "CD Player: Empty".
- When the active state is `Inserting`, the value of `CDStatus` is "Reading: *AlbumName*".
- When the active state is `Ejecting`, the value of `CDStatus` is "Ejecting: *AlbumName*".
- When the active state is `DiscPresent.STOP`, the value of `CDStatus` is "CD Player: Stopped".
- When the active state is `DiscPresent.PLAY`, the value of `CDStatus` is "Playing: *AlbumName*".
- When the active state is `DiscPresent.REW`, the value of `CDStatus` is "Reverse << *AlbumName*", where *AlbumName* scrolls backward across the display.
- When the active state is `DiscPresent.FF`, the value of `CDStatus` is "Forward >> *AlbumName*", where *AlbumName* scrolls forward across the display.

## See Also

`after` | `hasChanged` | `strcat` | `strcmp` | `strcpy` | `strlen` | `substr`

## More About

- "Manage Textual Information by Using Strings" on page 24-2
- "Detect Changes in Data Values" on page 16-64
- "Control Chart Execution by Using Temporal Logic" on page 16-36
- "Access MATLAB Functions and Workspace Data in C Charts" on page 16-20
- "Record and Play Audio"
- "Simulink Strings" (Simulink)



# Continuous-Time Systems in Stateflow Charts

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- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Store Continuous State Information in Local Variables” on page 25-8
- “Model a Bouncing Ball in Continuous Time” on page 25-10
- “Model a DC Motor in Stateflow” on page 25-14
- “Model the Dynamics of Moving Billiard Balls” on page 25-16
- “Model Newton's Cradle” on page 25-21
- “Modeling Newton's Cradle with Virtual Reality” on page 25-25

## Continuous-Time Modeling in Stateflow

Hybrid systems use modal logic to transition from one mode to another in response to physical events and conditions. In these systems, continuous-time dynamics govern each mode. A simple example of this type of hybrid system is a bouncing ball. The ball moves continuously through the air until it hits the ground, at which point a mode change or discontinuity occurs. As a result, the ball suddenly changes direction and velocity. For more information, see “Model a Bouncing Ball in Continuous Time” on page 25-10.

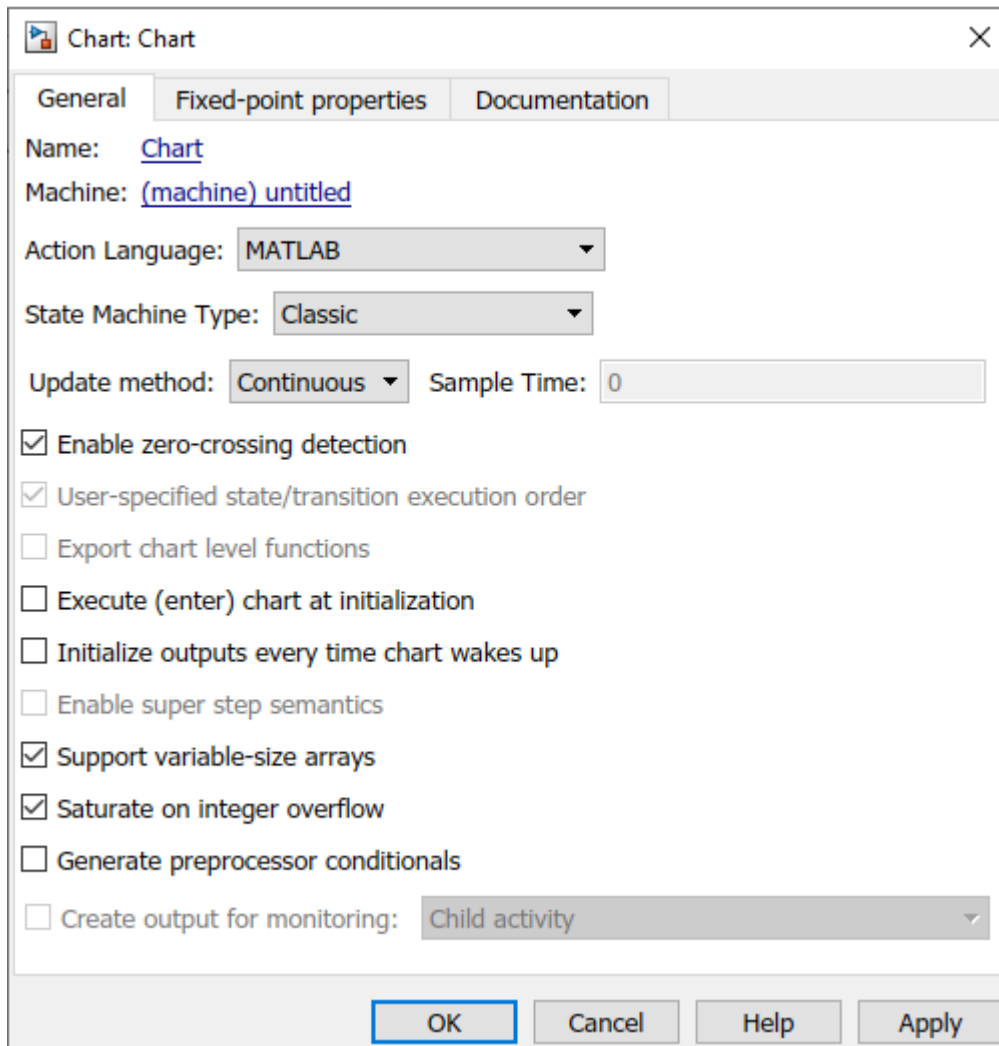
Simulate hybrid systems that respond to continuous and discrete mode changes by configuring Stateflow charts for continuous-time modeling. In a Stateflow chart, you can represent modal logic succinctly and intuitively as a series of states, transitions, or flow charts. You can also represent state information as continuous local variables with automatic access to time derivatives.

Continuous-time simulation is supported only in Stateflow charts in Simulink models. If your continuous system does not contain modal logic, consider using a Simulink model. For more information, see “Model a Continuous System” (Simulink).

### Configure a Stateflow Chart for Continuous-Time Simulation

Continuous updating is a Stateflow chart property.

- 1 Right-click inside a chart and select **Properties** from the context menu.
- 2 In the Chart Properties dialog box, set the **Update method** field to **Continuous**. When you select this option:
  - The **Enable zero-crossing detection** check box is selected.
  - The **Enable super step semantics** check box is unavailable.



- 3 (Optional) By default, zero-crossing detection is enabled. To disable this option, clear the **Enable zero-crossing detection** check box. For more information, see “Disable Zero-Crossing Detection” on page 25-4.
- 4 Click **OK**.

---

**Note** You cannot use Moore charts for continuous-time modeling.

---

## Interaction with Simulink Solver

### Maintain Mode in Minor Time Steps

During continuous-time simulation, a Stateflow chart updates its mode only in major time steps. In a minor time step, the chart computes outputs based on the state of the chart during the last major time step. For more information, see “Continuous Sample Time” (Simulink).

### Compute Continuous State at Each Time Step

When you define local continuous variables, the Stateflow chart provides programmatic access to their derivatives. The Simulink solver computes the continuous state of the chart at the current time step based on the values of these variables and their derivatives at the previous time step. For more information, see “Continuous Versus Discrete Solvers” (Simulink).

### Register Zero Crossings on State Transitions

To determine when a state transition occurs, a Stateflow chart registers a zero-crossing function with the Simulink solver. When Simulink detects a change of mode, the solver searches forward from the previous major time step to detect when the state transition occurred. For more information, see “Zero-Crossing Detection” (Simulink).

### Disable Zero-Crossing Detection

Zero-crossing detection on state transitions can present a tradeoff between accuracy and performance. When detecting zero crossings, a Simulink model accurately simulates mode changes without unduly reducing step size. For systems that exhibit *chattering*, or frequent fluctuations between two modes of continuous operation, zero-crossing detection can potentially impact simulation time. Chattering requires a Simulink model to check for zero crossings in rapid succession, which can slow simulation. In these situations, you can:

- Disable zero-crossing detection.
- Choose a different zero-crossing detection algorithm for your chart.
- Modify parameters that control the frequency of zero crossings in your Simulink model.

You can choose from different zero-crossing detection algorithms on the **Solver** pane in the Model Configuration Parameters dialog box. For more information, see “Zero-Crossing Detection” (Simulink).

### Guidelines for Continuous-Time Simulation

To maintain the integrity and smoothness of the results of a continuous-time simulation, constrain your charts to a restricted subset of Stateflow chart semantics. By restricting the semantics, the inputs do not depend on unpredictable factors such as:

- The number of minor intervals that the Simulink solver uses in each major time step.
- The number of iterations required to stabilize the integration and zero-crossings algorithms.

By minimizing these side effects, a Stateflow chart can maintain its state at minor time steps and update its state only during major time steps. Therefore, a Stateflow chart can compute outputs based on a constant state for continuous time.

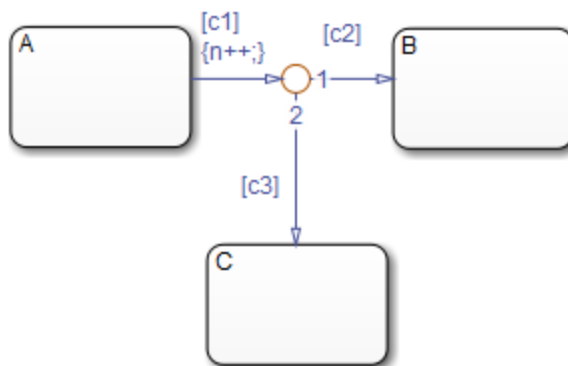
### Continuous-Time Charts Must Have at Least One State

During continuous-time simulation, a chart updates its outputs at minor time steps corresponding to the *during* actions of the active state. A chart with no states produces no output. To mimic the behavior of a stateless chart in continuous time, create a single state that calls a graphical function in its *during* action.

### Update Local Data in entry, exit, and Transition Actions

To maintain precision in continuous-time simulation, update discrete and continuous local data only during major time steps corresponding to state transitions. During state transitions, only these types of actions occur:

- State `exit` actions, which occur before leaving the state at the beginning of the transition.
- State `entry` actions, which occur after entering the new state at the end of the transition.
- Transition actions, which occur during the transition.
- Condition actions on a transition, but only if the transition directly reaches a state. For example, this chart executes the action `n++` even when conditions `c2` and `c3` are false. Because there is no state transition, the condition action updates `n` in a minor time step and results in an error.



Do not write to local continuous data in state during actions because these actions occur in minor time steps.

### Compute Derivatives in State during Actions

In minor time steps, a continuous-time chart executes only state during actions. Because Simulink models read continuous-time derivatives during minor time steps, compute derivatives in `during` actions to provide the most current calculation.

### Do Not Read Outputs or Derivatives in State during Actions or in Transition Conditions

In minor time steps, it is possible that outputs and derivatives do not reflect their most current values. To provide smooth outputs, compute values from local discrete data, local continuous data, and chart inputs.

### Do Not Call Simulink Functions in State during Actions or in Transition Conditions

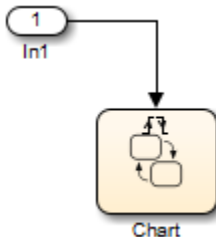
You cannot call Simulink functions during minor time steps. Instead, call Simulink functions only in actions that occur during major time steps: state `entry` or `exit` actions and transition actions. Calling Simulink functions in state during actions or in transition conditions results in an error during simulation. For more information, see “Reuse Simulink Components in Stateflow Charts” on page 11-2.

### Use Discrete Variables to Govern Conditions in during Actions

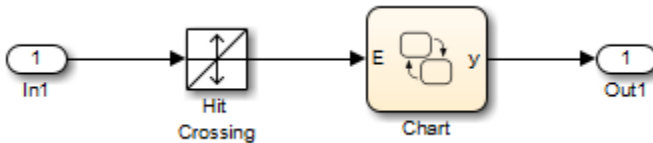
To prevent mode changes between major time steps, conditions that affect control flow in `during` actions depend on discrete variables. Discrete variables do not change value between major time steps.

### Do Not Use Input Events

The presence of input events makes a chart behave like a triggered subsystem and unable to simulate in continuous time. For example, this model generates an error if the chart uses a continuous update method.



To mimic the behavior of an input event, pass the input signal through a Hit Crossing block as an input to the continuous-time chart.



### Do Not Use Inner Transitions

When a mode change occurs during continuous-time simulation, the entry action of the destination state indicates to the Simulink model that a state transition occurred. With an inner transition, the chart never executes the entry action. For more information, see “Inner Transitions” on page 3-25.

### Limit Use of Temporal Logic

Do not use event-based temporal logic because in continuous-time simulation, there is no concept of a tick. Use only absolute-time temporal logic for continuous-time simulation. For more information, see “Control Chart Execution by Using Temporal Logic” on page 16-36.

### Do Not Use Change Detection Operators

To implement change detection, Stateflow buffers variables in a way that affects the behavior of charts between a minor time step and the next major time step.

### Do Not Modify Operating Point Values

Modifying the operating point of a continuous-time chart is not supported. If you load the operating point for a continuous-time chart, you cannot modify the activity of states or any values of local or output chart data. For more information, see “Rules for Using the Operating Point of a Chart” on page 20-30.



## See Also

### More About

- “Model a Bouncing Ball in Continuous Time” on page 25-10
- “Store Continuous State Information in Local Variables” on page 25-8
- “Compare Solvers” (Simulink)
- “Zero-Crossing Detection” (Simulink)

## Store Continuous State Information in Local Variables

To compute a continuous state, you must determine its time derivative. You can represent this information by using local variables that are updated in continuous time. Continuous-time simulation is supported only in Stateflow charts in Simulink models. For more information, see “Continuous-Time Modeling in Stateflow” on page 25-2.

### Define Continuous-Time Variables

- 1 Configure the chart to update in continuous time, as described in “Configure a Stateflow Chart for Continuous-Time Simulation” on page 25-2.
- 2 Add a data object to your chart, as described in “Add Stateflow Data” on page 12-2.
- 3 Set the **Scope** property for the data object to `Local`.
- 4 Set the **Update Method** property for the data object to `Continuous`.

In a Stateflow chart, continuous-time variables always have type `double`.

### Compute Implicit Time Derivatives

For each continuous-time variable, Stateflow implicitly creates a variable to represent its time derivative. A chart denotes time derivative variables as `variable_name_dot`. For example, `data_dot` represents the time derivative of a continuous variable `data`. You can write to the time derivative variable in the `during` action of a state. The time derivative variable does not appear in the Symbols pane or in the Model Explorer.

---

**Note** Do not explicitly define variables with the suffix `_dot` in a chart configured for continuous-time simulation.

---

### Expose Continuous State to a Simulink Model

In a Stateflow chart, you represent the continuous state by using local variables rather than inputs or outputs. To expose the continuous state to a Simulink model, you must explicitly assign the local variables to Stateflow outputs in the `during` action of a state.

### Guidelines for Continuous-Time Variables

- Scope for continuous-time variables can be `Local` or `Output`.
- Define continuous-time variables at the chart level or below in the Stateflow hierarchy.
- Expose the continuous state of a chart by assigning the local continuous-time variable to a Stateflow output.

### See Also

#### More About

- “Continuous-Time Modeling in Stateflow” on page 25-2

- “Model a Bouncing Ball in Continuous Time” on page 25-10

## Model a Bouncing Ball in Continuous Time

This example shows how to configure a Stateflow® chart that simulates a bouncing ball in continuous time. The ball moves continuously through the air until it hits the ground, at which point a discontinuity occurs. As a result, the ball suddenly changes direction and velocity. For more information, see “Continuous-Time Modeling in Stateflow” on page 25-2.

The model `sf_bounce` contains a chart that updates in continuous-time. Local variables describe the dynamics of a free-falling ball in terms of position and velocity. During simulation, the model uses zero-crossing detection to determine when the ball hits the ground.

### Dynamics of a Bouncing Ball

You can specify how a ball falls freely under the force of gravity in terms of position  $p$  and velocity  $v$  with this system of first-order differential equations.

$$\dot{p} = v$$

$$\dot{v} = -9.81$$

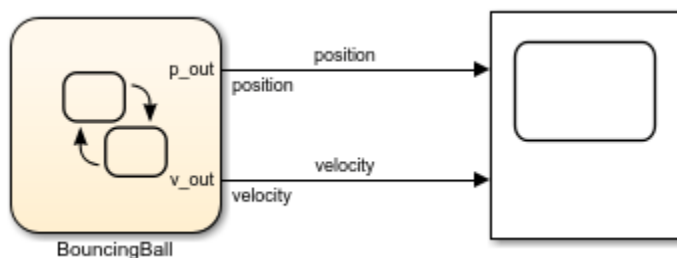
When  $p \leq 0$ , the ball hits the ground and bounces. You can model the bounce by updating the position and velocity of the ball:

- Reset the position to  $p = 0$ .
- Reset the velocity to the negative of its value just before the ball hit the ground.
- To account for energy loss, multiply the new velocity by a coefficient of distribution (-0.8).

### Configure Chart for Continuous-Time Simulation

In the model, the BouncingBall chart implements modal logic to simulate the continuous dynamics of free fall and the discrete changes associated with bouncing. In the Chart properties dialog box, these settings enable the BouncingBall chart to simulate in continuous time:

- **Update method** is **Continuous** so the chart employs continuous-time simulation to model the dynamics of the bouncing ball.
- **Enable zero-crossing detection** is selected so the Simulink® solver can determine exactly when the ball hits the ground. Otherwise, the Simulink model cannot simulate the physics accurately and the ball appears to descend below ground.



### Define Continuous-Time Variables

The BouncingBall chart has two continuous-time variables:  $p$  for position and  $v$  for velocity. For each one of these variables:

- **Scope** is Local.
- **Type** is double.
- **Update Method** is Continuous.

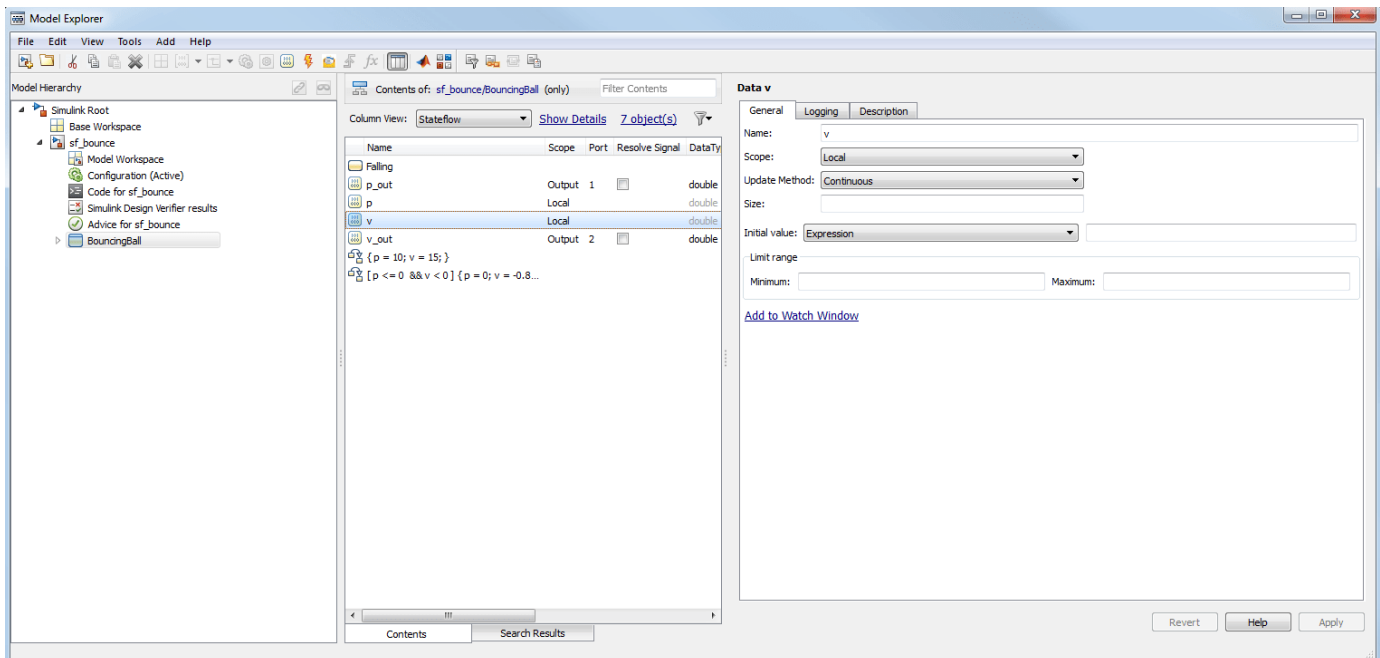
To expose the continuous state of the chart to the Simulink model, the BouncingBall chart has two output variables:  $p\_out$  and  $v\_out$ . For each one of these variables:

- **Scope** is Output.
- **Type** is double.
- **Update Method** is Discrete.

The chart defines the time derivative of continuous-time variables implicitly:

- $p\_dot$  is the derivative of position  $p$ .
- $v\_dot$  as the derivative of velocity  $v$ .

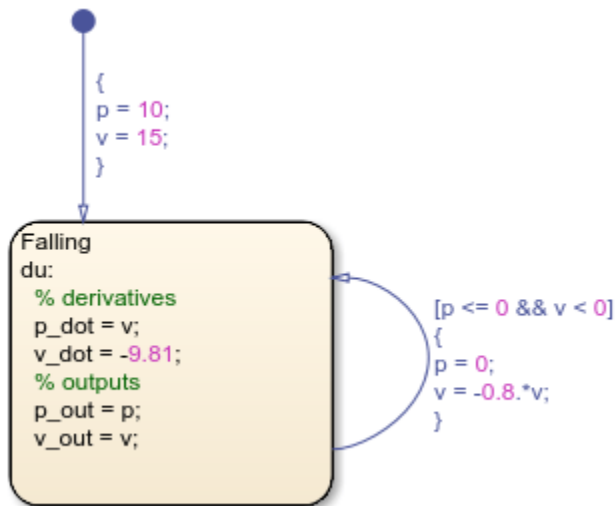
In the Model Explorer, you can view the continuous-time local variables and the corresponding outputs in the chart. Implicit derivative variables do not appear in the Model Explorer or in the Symbols pane.



### Model Continuous Dynamics of Free Fall

The BouncingBall chart consists of a single state **Falling** that numerically solves the differential equations for free fall. The default transition into the state sets the initial position to 10 m and the initial velocity to 15 m/s. The during actions in the state:

- Define the derivatives of position and velocity.
- Assign the values of the position and velocity of the ball to the output variables  $p\_out$  and  $v\_out$ .



### Model Discrete Effects of the Bounce

The `Falling` state has a self-loop transition that models the discontinuity of the bounce as an instantaneous mode change when the ball suddenly reverses direction. The condition on the transition determines when the ball hits the ground by checking its position  $p \leq 0$  and velocity  $v < 0$ . If the condition is valid, the condition action resets the position and velocity when the ball hits the ground.

#### Why Not Check for $p == 0$ ?

The ball hits the ground when position  $p$  is exactly zero. By relaxing the condition, you increase the tolerance within which the Simulink solver can detect when the position changes sign.

#### Why Check for $v < 0$ ?

The second part of the condition helps maintain the efficiency of the Simulink solver by minimizing the frequency of zero crossings. Without the second check, the condition remains true after the state transition, resulting in two successive zero crossings.

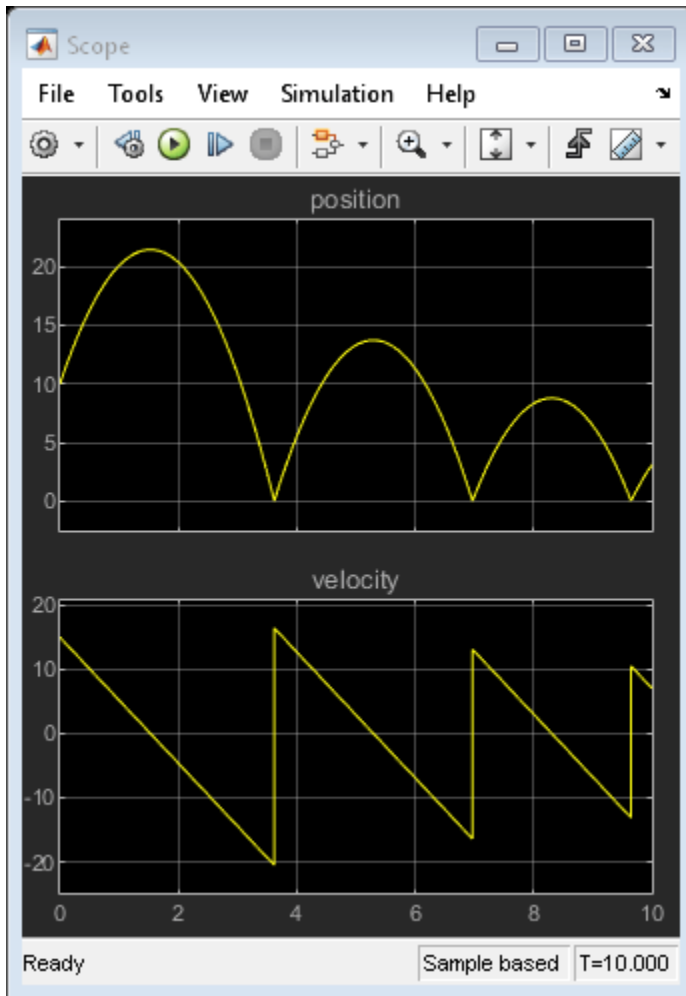
### Validate Chart Semantics

The `BouncingBall` chart meets the design requirements defined in “Guidelines for Continuous-Time Simulation” on page 25-4. In particular, the chart:

- Initializes the local variables  $p$  and  $v$  on the default transition.
- Assigns values to the derivatives  $p\_dot$  and  $v\_dot$  in a during action.
- Writes to local variables  $p$  and  $v$  in a transition action.
- Does not contain events, inner transitions, event-based temporal logic, or change detection operators.

### View Simulation Results

After you run the model, the scope shows the graphs of position and velocity. The position graph exhibits the expected bounce pattern.



## See Also

### More About

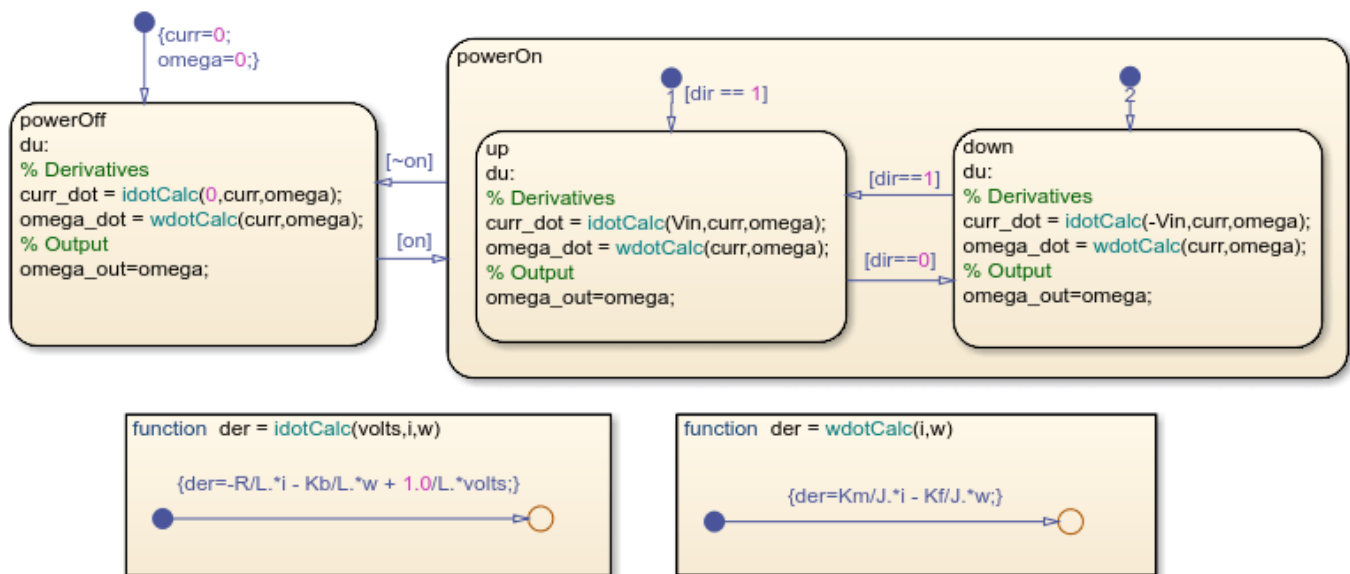
- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Store Continuous State Information in Local Variables” on page 25-8

## Model a DC Motor in Stateflow

This example shows the model of a permanent magnet DC motor. The mode logic and dynamics of the DC motor are both modeled using Stateflow®.

The DC motor state chart consists of two superstates: powerOn and powerOff. If the motor is powered on, it can be in one of two substates: up or down, signifying the direction of movement.

Note: This is a simplistic model of a DC motor. You can build more sophisticated DC motor models using Simscape™, which extends Simulink® with tools for modeling and simulating multidomain physical systems, such as those with mechanical, hydraulic, and electrical components.



The dynamics of the motor are defined directly in the state chart using graphical functions and change depending on the state of the motor. For example, when the motor is in the powerOff state, the voltage applied is equal to zero. When the motor is in the powerOn state, the voltage applied is either positive or negative, depending on the direction of the motor.

To review, the differential equations defining a permanent magnet DC motor are as follows:

$$\frac{di}{dt} = \frac{v_{app}(t) - R \cdot i(t) - K_b \cdot \omega(t)}{L}$$

$$\frac{d\omega}{dt} = \frac{K_m \cdot i(t) - K_f \cdot \omega(t)}{J}$$

where

$i$  = current

$R$  = resistance

$L$  = inductance

$K_b$  = EMF constant



$\omega$  = rotational speed of motor

$v_{app}$  = applied voltage

$K_f$  = damping constant

$K_m$  = torque constant

## See Also

### More About

- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Simscape”

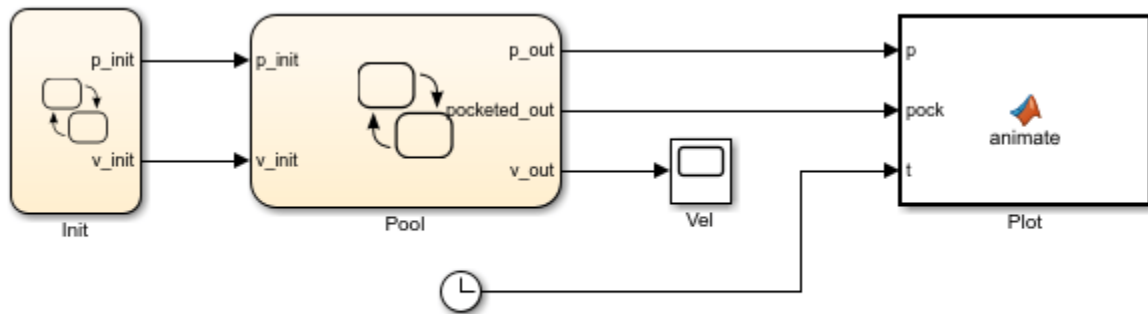
## Model the Dynamics of Moving Billiard Balls

This example shows how to model the opening shot in a billiards game by using continuous-time matrix variables. In the model, a Stateflow® chart simulates the dynamics of a hybrid system that has a large number of discontinuities. For more information, see “Continuous-Time Modeling in Stateflow” on page 25-2.

When the simulation starts, a MATLAB® user interface (UI) shows a pool table with 15 billiard balls arranged in a triangular rack. The UI then prompts you to select the initial position and velocity of the cue ball. When the cue ball is released, the UI animates the motion of the billiard balls as they undergo a sequence of rapid collisions.

The model consists of:

- The Stateflow chart `Init`, which calls the function `sf_pool_plotter.m` to initialize the position and velocity of the cue ball based on the input from the UI.
- The Stateflow chart `Pool`, which calculates the two-dimensional dynamics of each billiard ball.
- The MATLAB Function block `Plot`, which calls the function `sf_pool_plotter.m` to animate the motion of the billiard balls during the simulation.
- The Scope block `Vel`, which displays the velocity of each billiard ball during the opening shot.



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### Calculate Continuous-Time Dynamics

To represent the dynamics of the billiard balls, the `Pool` chart makes several assumptions.

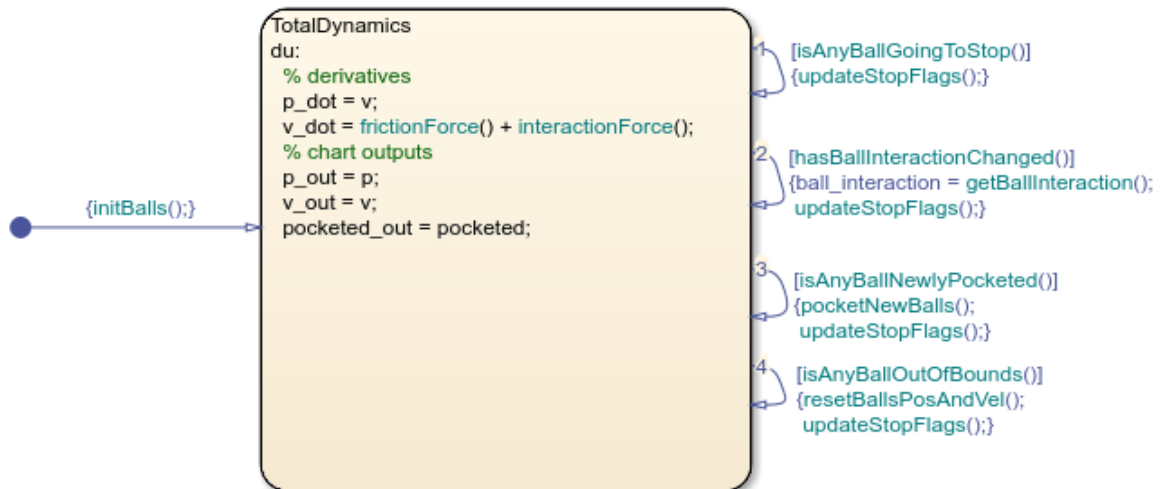
#### Continuous-Time Variables

The chart ignores the spin of the balls, so the state of the system is described completely by the positions and velocities of the balls. Each ball is assumed to have unit mass, so its position and velocity are described by the system of differential equations

$$\begin{cases} \dot{\mathbf{p}} = \mathbf{v} \\ \dot{\mathbf{v}} = \mathbf{F}_{\text{friction}} + \mathbf{F}_{\text{interaction}}, \end{cases}$$

where  $\mathbf{F}_{\text{friction}}$  and  $\mathbf{F}_{\text{interaction}}$  are the forces caused by friction with the pool table and by collisions with other balls.

To track the positions and velocities of the balls, the chart stores a pair of 16-by-2 matrices in the continuous-time variables  $p$  and  $v$ . In each matrix, the  $i^{\text{th}}$  row represents the two-dimensional position or velocity of the  $i^{\text{th}}$  ball.



MATLAB Function initBalls	MATLAB Function f = frictionForce	MATLAB Function f = interactionForce
MATLAB Function yn = isAnyBallGoingToStop	MATLAB Function yn = hasBallInteractionChanged	MATLAB Function yn = isAnyBallNewlyPocketed
MATLAB Function yn = isAnyBallOutOfBounds	MATLAB Function yn = nearHole(pp)	MATLAB Function balli = getBallInteraction
MATLAB Function updateStopFlags	MATLAB Function pocketNewBalls	MATLAB Function resetBallsPosAndVel

### Friction Model

To calculate the force of friction acting on each ball, the chart calls the MATLAB function `frictionForce`. This function implements a simplified friction model. Friction acts on each moving ball with a constant force opposite to the direction of motion. Because friction does not act on stationary balls, the force of friction on each ball is inherently modal:

$$\mathbf{F}_{\text{friction}} = \begin{cases} -\mu g \frac{\mathbf{v}}{\|\mathbf{v}\|} & \|\mathbf{v}\| > 0 \\ 0 & \text{otherwise,} \end{cases}$$

where  $\mu$  is the coefficient of friction and  $g$  is the acceleration due to gravity.

### Collision Dynamics

To determine the interactions caused by collisions between balls, the chart calls the MATLAB function `interactionForce`. This function implements a simple restoring force model when two balls come in contact with each other. The interaction force between the  $i^{\text{th}}$  and  $j^{\text{th}}$  balls is modal:

$$\mathbf{F}_{\text{interaction}}(i, j) = \begin{cases} k_p(2R - \|\Delta\mathbf{p}\|) \frac{\Delta\mathbf{p}}{\|\Delta\mathbf{p}\|} - k_v\Delta\mathbf{v} & \|\Delta\mathbf{p}\| < 2R \\ 0 & \text{otherwise,} \end{cases}$$

where:

- $R$  is the radius of each ball.
- $k_p$  and  $k_v$  are constants of elasticity.
- $\Delta\mathbf{p} = \mathbf{p}_i - \mathbf{p}_j$  is the relative separation of the centers of the two balls.
- $\Delta\mathbf{v} = \mathbf{v}_i - \mathbf{v}_j$  is the relative difference in velocity between the two balls.

Because the balls are free to move in two dimensions, the chart uses the 16-by-16 Boolean matrix `ball_interaction` to account for all potential collisions. For example, when the  $i^{\text{th}}$  and  $j^{\text{th}}$  balls are touching, the value of `ball_interaction(i, j)` is `true`. Otherwise, this value is `false`. Because collisions are symmetric in nature, the chart uses only the upper triangular portion of the matrix.

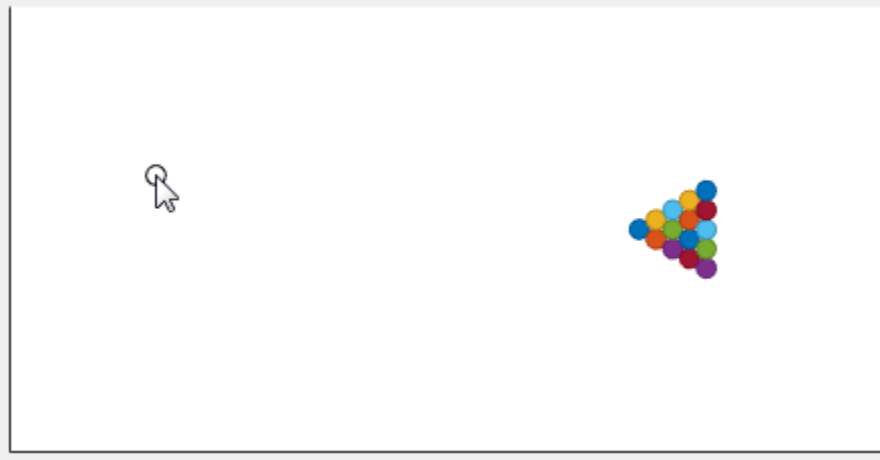
### Perform Matrix Calculations in MATLAB Functions

To compute the two-dimensional dynamics of the billiard balls, the Pool chart calls several MATLAB functions that perform matrix calculations.

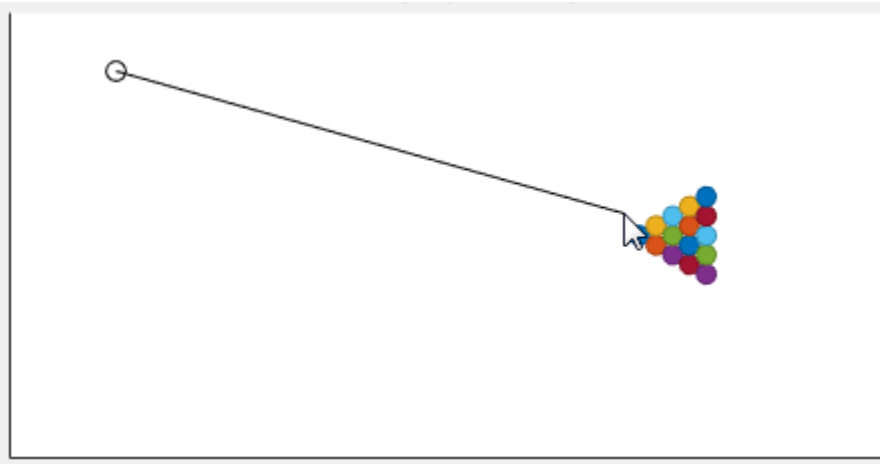
- `initBalls` initializes the position and velocity of every ball on the pool table.
- `frictionForce` calculates the friction force acting on each ball.
- `interactionForce` calculates the interaction force acting on each ball.
- `isAnyBallGoingToStop` returns a value of 1 if any ball stops moving. Otherwise, the function returns a value of 0.
- `hasBallInteractionChanged` returns a value of 1 if any ball interactions change. Otherwise, the function returns a value of 0.
- `isAnyBallNewlyPocketed` returns a value of 1 if any ball falls in a pocket. Otherwise, the function returns a value of 0.
- `isAnyBallOutOfBounds` returns a value of `true` if any ball lies outside the boundary of the pool table. Otherwise, the function returns a value of `false`.
- `nearHole` returns a value of `true` if a ball is near a pocket on the pool table. Otherwise, the function returns a value of `false`.
- `getBallInteraction` returns a Boolean matrix that specifies whether any balls are in contact with each other.
- `updateStopFlags` keeps track of which balls have stopped moving and stores the result in the vector `stopped`.
- `pocketNewBalls` sets the velocity of each pocketed ball to 0.
- `resetBallsPosAndVel` resets the position and velocity of any ball that lies outside the boundary of the pool table.

### View the Simulation Results

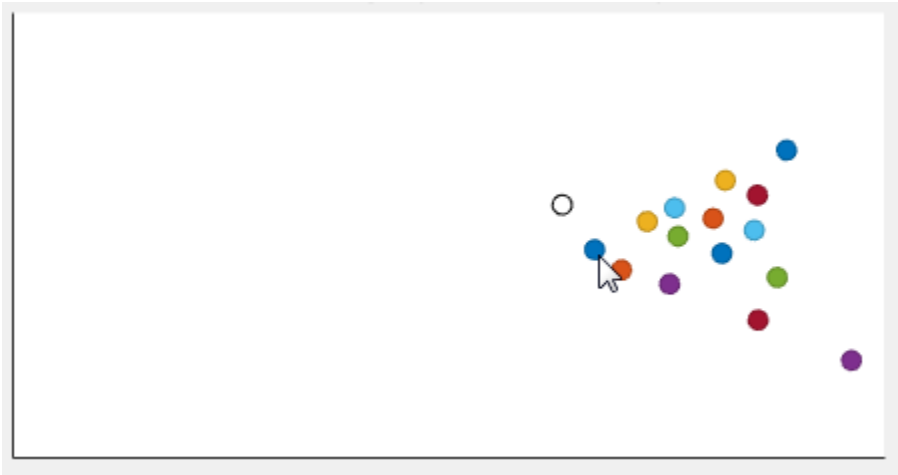
When you start the simulation, a UI shows a pool table with 15 billiard balls arranged at one end of the table. To specify the initial position of the cue ball, click anywhere on the pool table.



To specify the initial velocity of the cue ball, click a different spot on the pool table.



The model simulates the dynamics of the system and animates the motion of the billiard balls.



To stop the simulation, close the UI.

## See Also

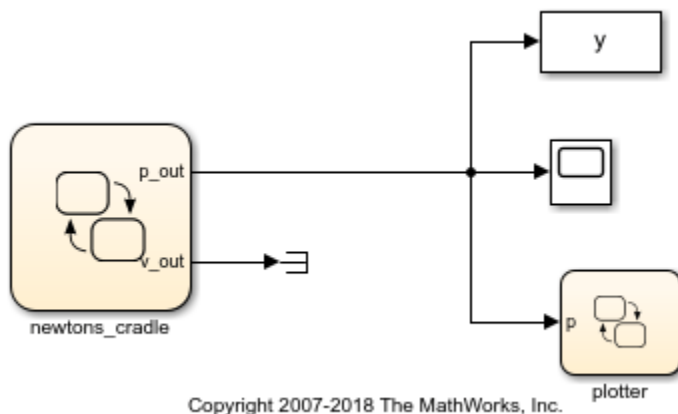
### More About

- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Vectors and Matrices in Stateflow Charts” on page 21-2
- “Supported Operations for Vectors and Matrices” on page 21-4
- “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2

## Model Newton's Cradle

This example shows how to model a popular toy called "Newton's cradle" which consists of a row of seven identical balls which are hung from a common height. At rest they are arranged such that they just touch each other. One or more balls from one end are then raised from their rest position and released.

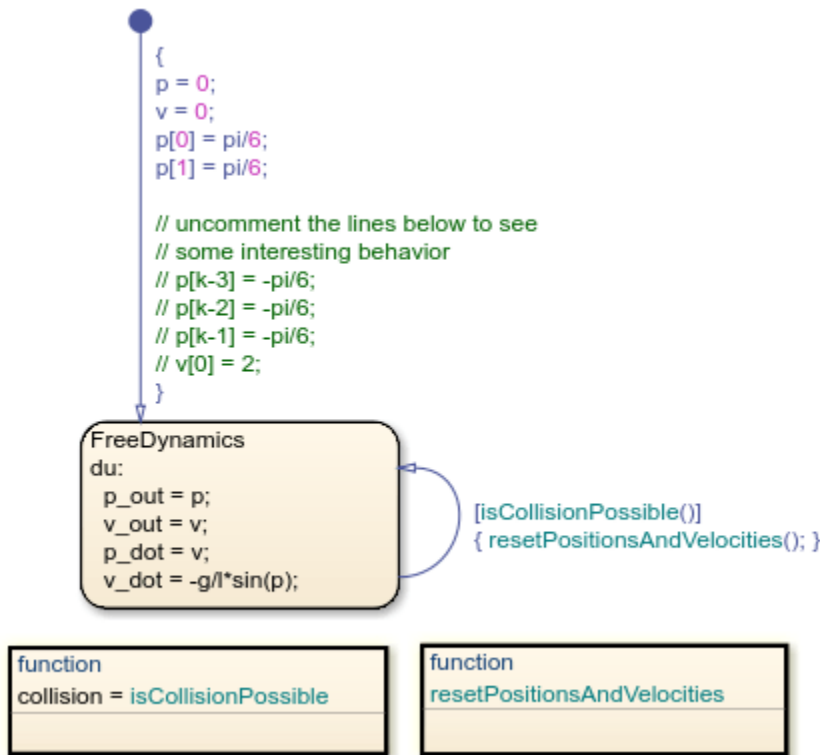
An interesting consequence of elastic collisions between the balls is that the balls which are released seem to come to a stop and an equal number of balls from the other end get released (with almost the same energy as the incoming balls). The balls in the middle do not seem to move, although they are responsible for transferring momentum from one end to another.



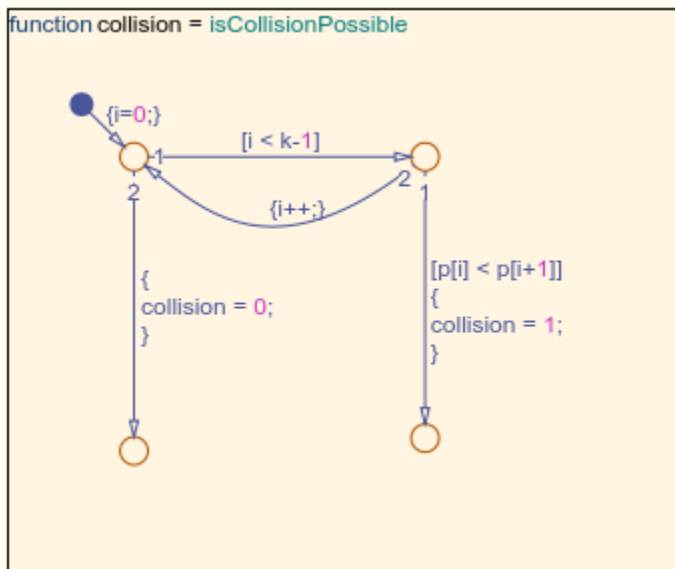
This model uses a simple elastic collision model to describe the interactions between the balls. The Stateflow® chart uses local variables to depict the continuous states of the system, namely the position  $p$  and the velocity  $v$ . Note that both these local variables are defined to have **Update method** as **continuous**. This allows you to refer to their derivatives as  $p\_dot$  and  $v\_dot$  respectively. Since the nominal dynamics of all the balls are identical, this example uses these vector assignments to represent the motion of all of the balls:

```
p_dot = v;
v_dot = -g/l*sin(p);
```

Note that  $p\_dot$  and  $v\_dot$  are not chart local variables. They are automatically created because  $p$  and  $v$  are defined to be continuous.

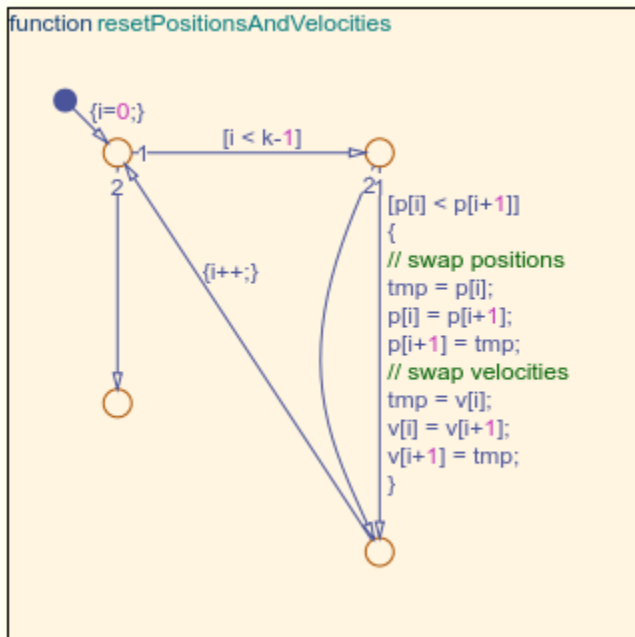


The model uses a simple for-loop to detect collisions between balls. In a one-dimensional setting, the chart only models collisions between successive balls with a single for loop.

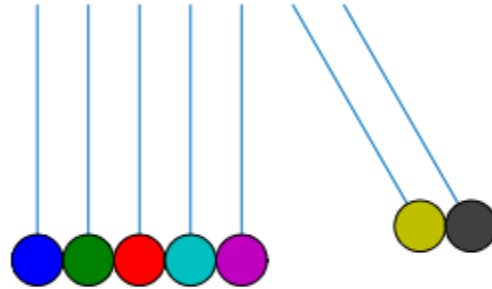


The response to a collision is also expressed simply. Each collision is treated as a perfectly elastic instantaneous collision. The position and velocity are exchanged for each of the balls involved in the collision.





Simulating this model brings up a simple UI that shows the motion of the balls.



## See Also

### More About

- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18
- “Modeling Newton's Cradle with Virtual Reality” on page 25-25

## Modeling Newton's Cradle with Virtual Reality

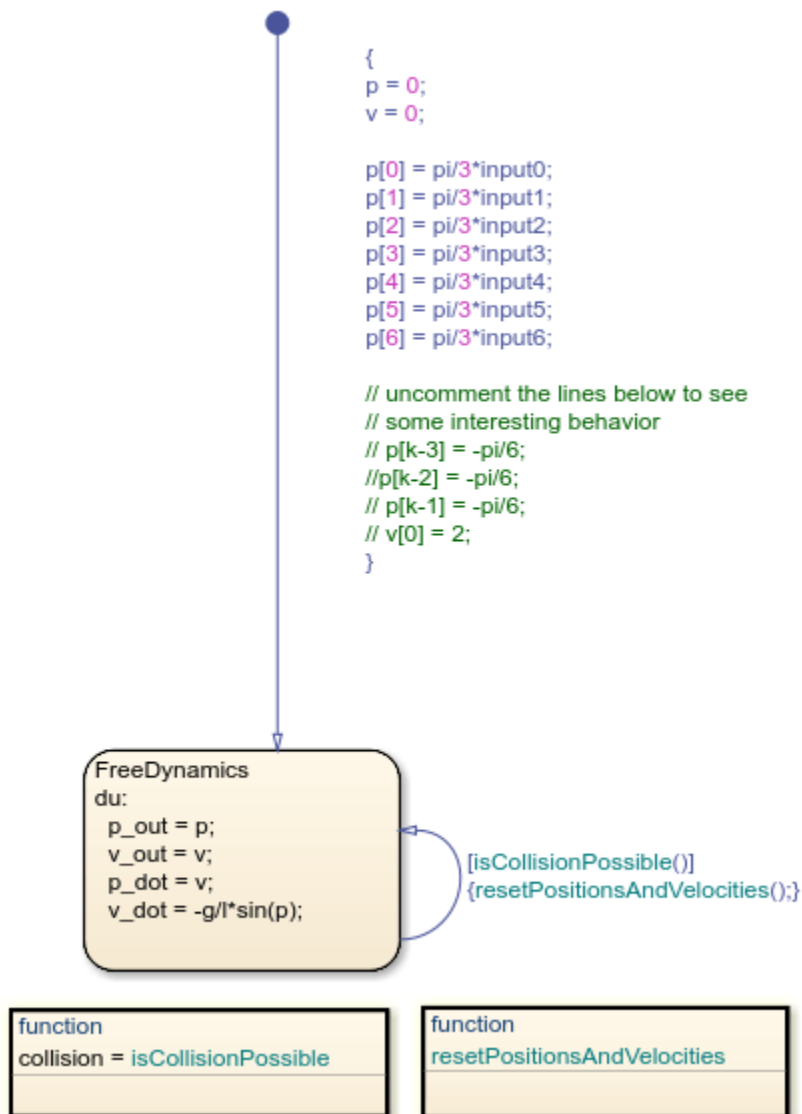
This example shows how to model a popular toy called "Newton's cradle" which consists of a row of seven identical balls which are hung from a common height. At rest they are arranged such that they just touch each other. One or more balls from one end are then raised from their rest position and released.

An interesting consequence of elastic collisions between the balls is that the balls which are released seem to come to a stop and an equal number of balls from the other end get released (with almost the same energy as the incoming balls). The balls in the middle do not seem to move, although they are responsible for transferring momentum from one end to another.

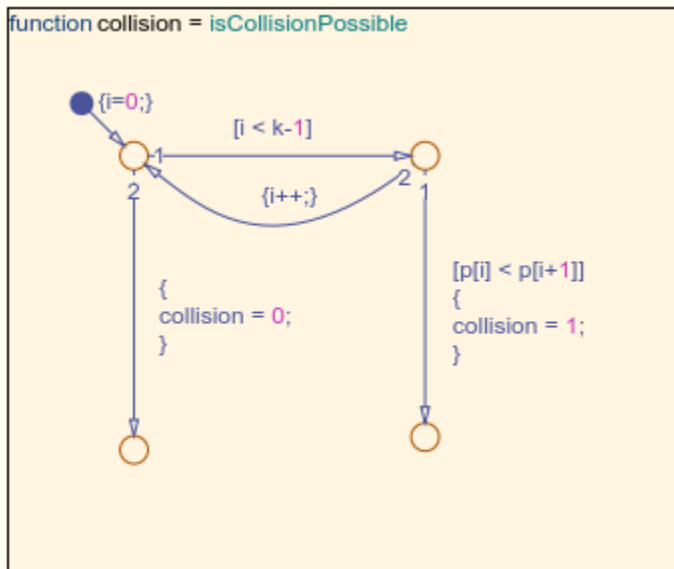
This example uses a simple elastic collision model to describe the interactions between the balls. The Stateflow® chart uses local variables to depict the continuous states of the system, namely the position  $p$  and the velocity  $v$ . Note that both these local variables are defined to have **Update method** as `continuous`, so you can refer to their derivatives as  $p\_dot$  and  $v\_dot$  respectively. Since the nominal dynamics of all the balls are identical, this example uses these vector assignments to represent the motion of all of the balls:

```
p_dot = v;  
v_dot = -g/l*sin(p);
```

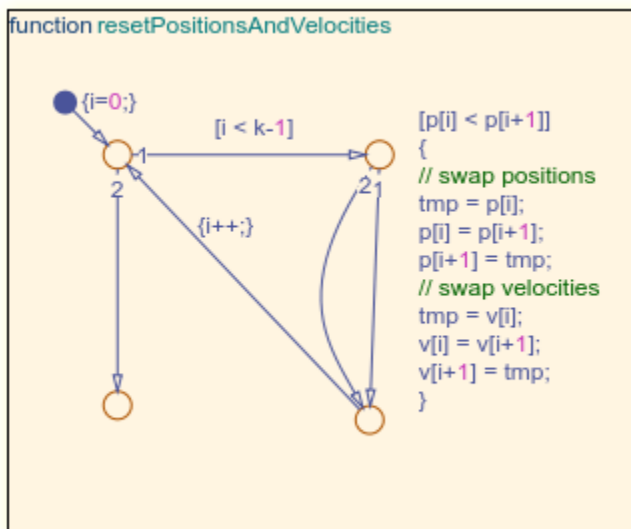
Note that  $p\_dot$  and  $v\_dot$  are not chart local variables. They are automatically created because  $p$  and  $v$  are defined to be continuous.



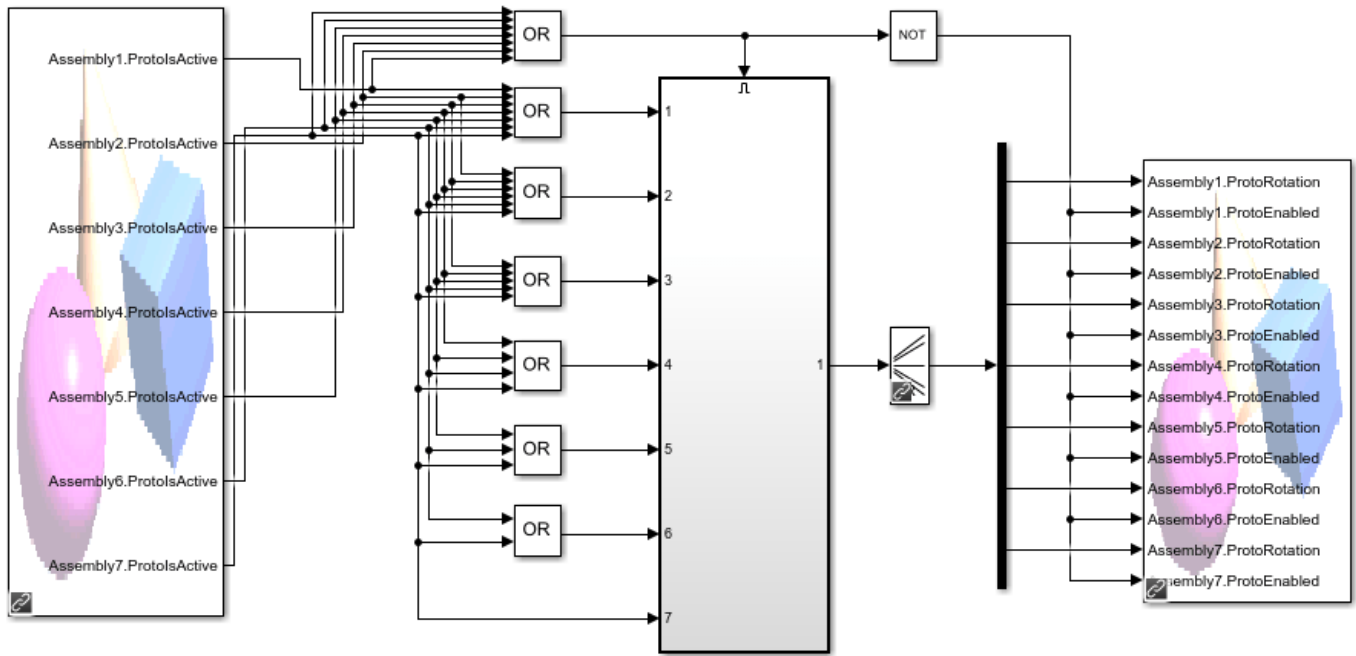
The model uses a simple for-loop to detect collisions between balls. In a one-dimensional setting, the chart only models collisions between successive balls with a single for loop.

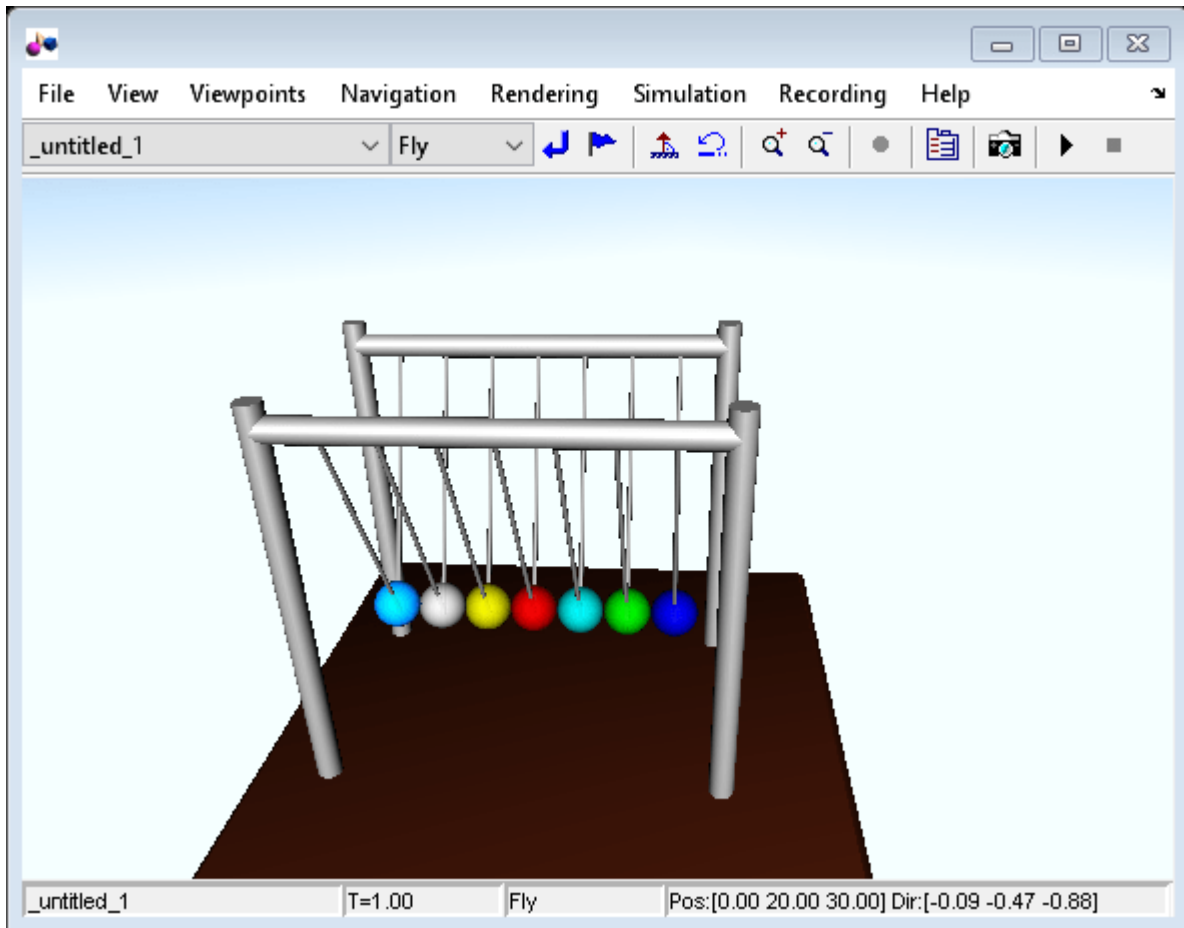


The response to a collision is also expressed simply. Each collision is treated as a perfectly elastic instantaneous collision. The position and velocity are exchanged for each of the balls involved in the collision.



Simulating this model creates a Simulink® 3D Animation™ which shows the motion of the balls. Double-click on any ball to start the simulation.





## See Also

### More About

- "Continuous-Time Modeling in Stateflow" on page 25-2
- "Reuse Logic Patterns by Defining Graphical Functions" on page 8-18
- "Model Newton's Cradle" on page 25-21
- "Simulink 3D Animation"





# Fixed-Point Data in Stateflow Charts

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- “Fixed-Point Data in Stateflow Charts” on page 26-2
- “Build a Low-Pass Filter by Using Fixed-Point Data” on page 26-8
- “Supported Operations for Fixed-Point Data” on page 26-12
- “Fixed-Point Operations in Stateflow Charts” on page 26-19
- “Fixed-Point Mandelbrot Set” on page 26-25
- “Using Multiword Fixed-Point Data” on page 26-26

## Fixed-Point Data in Stateflow Charts

Fixed-point numbers use integers and integer arithmetic to approximate real numbers. They are an efficient means for performing computations involving real numbers without requiring floating-point support in underlying system hardware.

### Fixed-Point Numbers

Fixed-point numbers represent real numbers by using the encoding scheme:

$$V \approx V_{approx} = SQ + B.$$

- $V$  is a precise real-world value that you want to approximate with a fixed-point number.
- $V_{approx}$  is the approximate real-world value that results from the fixed-point representation.
- $Q$  is an integer that encodes the fixed-point number. This value is called the *quantized integer*.
- $S$  is a coefficient that determines the precision of the fixed-point representation. This value is called the *slope*.
- $B$  is an additive correction called the *bias*.

The quantized integer  $Q$  is the only part of the fixed-point representation that varies in value. In the generated code, the quantities  $S$  and  $B$  are constant and appear only as literal numbers or expressions. If a fixed-point number changes, its quantized integer  $Q$  changes but  $S$  and  $B$  remain unchanged.

To determine the quantized integer  $Q$  corresponding to a real-world value  $V$ , round the quantity  $(V - B)/S$  to an integer. For example, to represent the number  $V = 15.345$  in a fixed-point type with slope  $S = 0.5$  and bias  $B = 0.1$ , you use the quantized integer

$$Q = \text{round}((V - B)/S) = \text{round}((15.345 - 0.1)/0.5) = \text{round}(30.49) = 30.$$

Because you round  $Q$  to an integer, you lose some precision in representing the number 15.345. The number that  $Q$  actually represents is

$$V_{approx} = SQ + B = 0.5 \square 30 + 0.1 = 15.1.$$

Using fixed-point numbers to represent real numbers with integers involves the loss of some precision. However, with a suitable choice of  $S$  and  $B$ , you can minimize this loss to acceptable levels. For instance, by changing the coding scheme to use  $S = 0.25$  and  $B = 0.1$ , you can represent the number  $V = 15.345$  with greater precision as:

$$Q = \text{round}((V - B)/S) = \text{round}((15.345 - 0.1)/0.25) = \text{round}(60.98) = 61$$

$$V_{approx} = SQ + B = 0.25 \square 61 + 0.1 = 15.35.$$

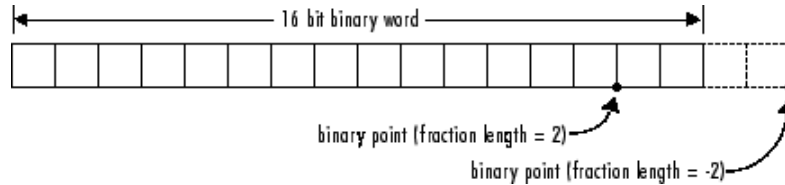
The difference between  $V_{approx}$  and  $V$  is always less than the slope  $S$ .

### Specify Fixed-Point Data

In the Model Explorer, you can specify the fixed-point encoding for a data object by using the Data Type Assistant, as described in “Fixed-Point Data Properties” on page 12-10. Set the **Mode** field to **Fixed point** and specify these properties:

- **Signedness:** Choose **Signed** or **Unsigned**.
- **Word length:** Specify the bit size of the word that holds the quantized integer  $Q$ .
- **Scaling:** Choose **Binary point** or **Slope and bias**.

- If you select **Binary point**, the Data Type Assistant displays the **Fraction length** field, which specifies the binary point location. Choosing a **Fraction length** of  $n$  defines a fixed-point encoding with a slope of  $S = 2^{-n}$  and a bias of  $B = 0$ .



- If you select **Slope and bias**, the Data Type Assistant displays fields for entering the **Slope**  $S$  and **Bias**  $B$  for the fixed-point encoding scheme.

Alternatively, you can specify the encoding for a fixed-point data object directly by using the `fixdt` function. In the Property Inspector or the Model Explorer, in the **Type** field, enter an expression in one of these formats:

```
fixdt(Signed, WordLength, FractionLength)
```

```
fixdt(Signed, WordLength, Slope, Bias)
```

---

**Tip:** Some encoding schemes are computationally expensive, particularly in multiplication and division operations. Selecting a slope that is an integer power of two and a zero bias avoids these computationally expensive instructions. Using binary point scaling is recommended.

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## Conversion Operations

Stateflow charts convert real numbers into fixed-point numbers during data initialization and as part of casting operations in the application. These conversions compute a quantized integer  $Q$  from a real number input. The type of conversion depends on the action language for the chart.

### Conversion in Charts That Use MATLAB as the Action Language

In a chart that uses MATLAB as the action language, you define the method for all conversions through the fixed-point properties for the chart. See “Fixed-Point Properties” on page 28-6.

For example, if you set the **MATLAB Chart fimath** property to **Same as MATLAB**, then the chart rounds the resulting quantized integer to its nearest integer value.

### Conversions in Charts That Use C as the Action Language

Charts that use C as the action language employ two methods for converting fixed-point data:

- Offline conversions initialize data during code generation. Offline conversions are designed to maximize accuracy. These conversions round the resulting quantized integer to its nearest integer value. Offline conversions are performed for initialization of data (variables and constants) in the Stateflow hierarchy and from the MATLAB workspace.
- Online conversions perform casting operations during run time. Online conversions are designed to maximize computational efficiency. They are faster and more efficient, but less precise than offline conversions. Instead of rounding  $Q$  to its nearest integer, online conversions round to the floor (except for division, which can round to 0, depending on the C compiler).

For example, this table illustrates the difference between offline and online conversions of real numbers to fixed-point numbers defined with a slope of  $S = 2^{-4}$  and a bias of  $B = 0$ . For each real-world value  $V$ , the chart computes a quantized integer  $Q$  by rounding  $(V-B)/S$  to the nearest integer (in offline conversion) or to the floor (in online conversion). For each conversion,  $V_{approx} = QS + B$  is the approximate real-world value resulting from  $Q$ .

Real-World Value		Offline Conversion		Online Conversion	
$V$	$(V-B)/S$	$Q$	$V_{approx}$	$Q$	$V_{approx}$
15.345	245.52	246	15.375	245	15.3125
3.45	55.2	55	3.4375	55	3.4375
1.0375	16.6	17	1.0625	16	1
2.06	32.96	33	2.0625	32	2

## Fixed-Point Context-Sensitive Constants

In charts that use C as the action language, you can avoid explicit type casts by using fixed-point context-sensitive constants. These constants infer their type from the context in which they occur. They are written like ordinary numbers with the suffix C or c. For example, 4.3C and 123.4c are valid fixed-point context-sensitive constants that you can use in action statements.

Although fixed-point context-sensitive constants can appear in expressions with any data types (including integers and floating-point data), their main use is with fixed-point numbers. The algorithm that interprets the context-sensitive constant computes a type that provides maximum accuracy without overflow. The algorithm depends on:

- The operations in the expression
- The other data types in the context
- The value of the constant

Fixed-point context-sensitive constants infer their type according to these rules:

- In a casting operation, the constant has the type to which it is being cast.
- In a simple assignment operation of the form  $a = b$ :
  - If  $b$  is a context-sensitive constant, it has the same type as  $a$ .
  - If  $b$  is an addition or subtraction operation, then the constant has the same type as the other operand.
  - If  $b$  is a multiplication or division operation with a fixed-point operand, then the constant has the type that provides the best possible precision for a fixed-point result, as determined by the `fixptbestexp` function.
  - If  $b$  is a multiplication or division operation with a floating-point operand of type `double` or `single`, then the constant has the same type as the floating-point operand.
- In a special assignment operation of the form  $a := b$ :
  - If  $b$  is a context-sensitive constant, it has the same type as  $a$ .
  - If  $b$  is an arithmetic operation with a floating-point operand of type `double` or `single`, or if  $a$  is a floating-point data object, then the constant has the same type as the floating-point number.

- If **b** is an addition or subtraction operation with a fixed-point operand and **a** is a fixed-point data object, then the constant has the same type as **a**.
- If **b** is a multiplication or division operation with a fixed-point operand and **a** is a fixed-point data object, then the constant has the type that provides the best possible precision for a fixed-point result.
- As an argument in a function call, the constant has the same type as the formal argument.

You cannot use context-sensitive constants as both operands of a binary operation or as the leftmost operand of an assignment operation.

## Tips for Using Fixed-Point Data

- Develop and test your application by using double- or single-precision floating-point numbers. Using double- or single-precision floating-point numbers does not limit the range or precision of your computations. Once your application works as designed, you can start substituting fixed-point data for double-precision data.
- In the Model Configuration Parameters dialog box, on the **Hardware Implementation** pane, set the integer word size for the simulation environment to the integer size of the intended target environment. Code generated by Stateflow uses this integer size to select result types for your fixed-point operations. See “Hardware Implementation Pane” (Simulink).
- When you simulate your model, use overflow detection to warn you when the result of a fixed-point operation exceeds the numeric capacity of its fixed-point type. In the Model Configuration Parameters dialog box, on the **Diagnostics > Data Validity** pane, set **Wrap on overflow** and **Saturate on overflow** to error or warning. If you encounter overflow errors in fixed-point data, increase the range of your data by:
  - Increasing the **Word length** value for the overflowing fixed-point data. For example, change the number of bits used to encode the fixed-point data from 16 to 32. This action changes the base integer type for *Q* from `int16` to `int32`.
  - Decreasing the **Fraction length** value (if using **Binary point scaling**) or increasing the **Slope** value (if using **Slope and bias scaling**). For example, decrease the **Fraction length** value from 4 to 1 (or, equivalently, increase the **Slope** value from  $S = 2^{-4} = 0.0625$  to  $S = 2^{-1} = 0.5$ ). This action increases the range of your fixed-point data but decreases the available precision.

For more information, see “Data Range Violations” on page 33-34.

- If you encounter issues with model behavior stemming from inadequate precision in your fixed-point data, increase the precision of your data by increasing the **Fraction length** value (if using **Binary point scaling**) or decreasing the **Slope** value (if using **Slope and bias scaling**). For example, increase the **Fraction length** value from 2 to 3 (or, equivalently, decrease the **Slope** value from  $S = 2^{-2} = 0.25$  to  $S = 2^{-3} = 0.125$ ). This action increases the precision of your fixed-point data but decreases the available range.
- In charts that use C as the action language, you can use a special assignment operation `:=` and context-sensitive constants to maintain as much precision as possible. See “Override Fixed-Point Promotion in C Charts” on page 26-15 and “Fixed-Point Context-Sensitive Constants” on page 26-4.

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**Note** If you do not use context-sensitive constants with fixed-point types, noninteger numeric constants (constants that have a decimal point) can force fixed-point operations to produce floating-point results.

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## Automatic Scaling of Fixed-Point Data

Automatic scaling tools can change the settings of Stateflow fixed-point data. You can prevent automatic scaling by selecting the **Lock data type setting against changes by the fixed-point tools** option for the fixed-point data object. See “Lock Data Type Against Fixed-Point Tools” on page 12-8. For methods on autoscaling fixed-point data, see “Choosing a Range Collection Method” (Fixed-Point Designer).

## Share Fixed-Point Data with Simulink Models

To share fixed-point data with Simulink models:

- Use the same property values to specify the data in the Stateflow chart and in the Simulink model. For an example of this method of sharing input data from a Simulink model, see “Model Bang-Bang Temperature Control System” on page 16-52.

For some Simulink blocks, you can specify the type of input or output data directly. For example, you can specify the fixed-point data type for a Constant block directly in the **Output data type** field by using the `fixdt` function.

- Define the data as **Input** or **Output** in the Stateflow chart and instruct the sending or receiving block in the Simulink model to inherit its type from the chart data. In many blocks, you can set data types through inheritance from the driving block, or through back propagation from the next block. You can set the data type of a Simulink block to match the data type of the Stateflow port to which it connects.

For example, you can set the Constant block to inherit its type from the Stateflow **Input to Simulink** port that it supplies. Set the **Output data type** block parameter to `Inherit via back propagation`.

## Implementation of Fixed-Point Data in Stateflow

Stateflow charts define fixed-point data types from the values that you specify for  $S$ ,  $B$ , and the base integer type for  $Q$ .

- For each fixed-point data, the chart defines an integer variable for  $Q$  in the generated code. This integer is the only part of a fixed-point number that changes in value. The available base types for  $Q$  are the unsigned integer types `uint8`, `uint16`, and `uint32`, and the signed integer types `int8`, `int16`, and `int32`. If a fixed-point number has a slope  $S = 1$  and a bias  $B = 0$ , it is equivalent to its quantized integer  $Q$  and behaves exactly as its base integer type.
- The slope  $S$  is factored into a coefficient  $F$  with  $1 \leq F < 2$  and an integer power of two with exponent  $E$ :

$$S = F \square 2^E.$$

If the fractional slope  $F$  is greater than 1, it is converted into a fixed-point number. Encoding schemes with  $F > 1$  can be computationally expensive, particularly in multiplication and division operations. Setting  $F = 1$  avoids these computationally expensive instructions. In this setting, scaling by a power of 2 is implemented as bit shifts, which are more efficient than multiply instructions. Therefore, using binary-point-only scaling, in which  $F = 1$  and  $B = 0$ , is recommended.

- Operations for fixed-point types are implemented with solutions for the quantized integer as described in “Arithmetic Operations for Fixed-Point Data” on page 26-19. To generate efficient code, the fixed-point promotion rules choose values for slope and bias that cancel difficult terms in the solutions. See “Promotion Rules for Fixed-Point Operations” on page 26-20.

**See Also**

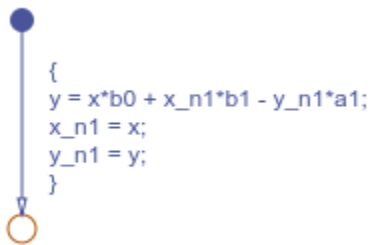
`fixdt` | `fixptbestexp`

**More About**

- “Fixed-Point Operations in Stateflow Charts” on page 26-19
- “Supported Operations for Fixed-Point Data” on page 26-12
- “Build a Low-Pass Filter by Using Fixed-Point Data” on page 26-8
- “Set Data Properties” on page 12-5

## Build a Low-Pass Filter by Using Fixed-Point Data

This example shows how to build a Stateflow® chart that uses fixed-point data to implement a low-pass Butterworth filter. By designing the filter with fixed-point data instead of floating-point data, you can simulate your model using less memory. For more information, see “Fixed-Point Data in Stateflow Charts” on page 26-2.



### Build the Fixed-Point Butterworth Filter

The Low-Pass Filter chart is a stateless flow chart that accepts one input and provides one output. The chart contains these data symbols:

- **x** — **Scope:** Input, **Type:** Inherit:Same as Simulink
- **y** — **Scope:** Output, **Type:** fixdt(1,16,10)
- **x\_n1** — **Scope:** Local, **Type:** fixdt(1,16,12)
- **y\_n1** — **Scope:** Local, **Type:** fixdt(1,16,10)
- **b0** — **Scope:** Parameter, **Type:** fixdt(1,16,15)
- **b1** — **Scope:** Parameter, **Type:** fixdt(1,16,15)
- **a1** — **Scope:** Parameter, **Type:** fixdt(1,16,15)

The values of **b0**, **b1**, and **a1** are the coefficients of the low-pass Butterworth filter.

To build the Low-Pass Filter chart:

- 1 Create a Simulink® model with an empty Stateflow chart by entering `sfnw` at the MATLAB® command prompt.
- 2 In the Stateflow chart, add a flow chart with a single branch that assigns values to **y**, **x\_n1**, and **y\_n1**.
- 3 Add input, output, local, and parameter data to the chart, as described in “Add Stateflow Data” on page 12-2.

### Define the Model Callback Function

Before loading the model, MATLAB calls the `butter` (Signal Processing Toolbox) function to compute the values for the parameters **b0**, **b1**, and **a1**. The function constructs a first-order low-pass Butterworth filter with a normalized cutoff frequency of  $(2*\pi*F_c/(F_s/2))$  radians per second, where:

- The sampling frequency is  $F_s = 1000$  Hz.
- The cutoff frequency is  $F_c = 50$  Hz.



The function output B contains the numerator coefficients of the filter in descending powers of z. The function output A contains the denominator coefficients of the filter in descending powers of z.

```

Fs = 1000;
Fc = 50;
[B,A] = butter(1,2*pi*Fc/(Fs/2));
b0 = B(1);
b1 = B(2);
a1 = A(2);

```

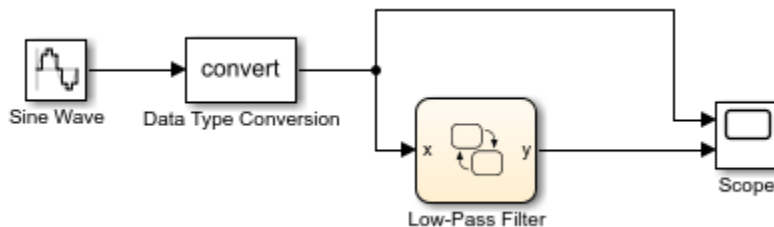
To define the preload callback for the model:

- 1 In the **Modeling** tab, under **Setup**, select **Model Settings > Model Properties**.
- 2 In the Model Properties dialog box, on the **Callbacks** tab, select **PreLoadFcn**.
- 3 Enter the MATLAB code for the preload function call.
- 4 Click **OK**.

To load the parameter values to the MATLAB workspace, save, close, and reopen the model.

### Add Other Blocks to the Model

To complete the model, add a Sine Wave (Simulink) block, a Data Type Conversion (Simulink) block, and a Scope (Simulink) block. Connect and label the blocks according to this diagram.



### Sine Wave block

The Sine Wave block outputs a floating-point signal. The block has these settings:

- **Sine type:** Time based
- **Time:** Use simulation time
- **Amplitude:** 1
- **Bias:** 0
- **Frequency:**  $2 \cdot \pi \cdot F_c$
- **Phase:** 0
- **Sample time:**  $1/F_s$
- **Interpret vector parameters as 1-D:** On

### Data Type Conversion block

The Data Type Conversion block converts the floating-point signal from the Sine Wave block to a fixed-point signal. By converting the signal to a fixed-point type, you can simulate your model using less memory. The block has these settings:

- **Output minimum:** []
- **Output maximum:** []
- **Output data type:** `fixdt(1,16,14)`
- **Lock output data type setting against changes by the fixed-point tools:** `Off`
- **Input and output to have equal:** Real World Value (RWV)
- **Integer rounding mode:** `Floor`
- **Saturate on integer overflow:** `Off`
- **Sample time:** `-1`

### Scope block

The Scope block has two input ports that connect to the input and output signals for the Low-Pass Filter chart. To display the two signals separately, select a scope layout with two rows and one column.

### Set Model Configuration Parameters

Because none of the blocks in the model have a continuous sample time, use a discrete solver with these configuration parameters:

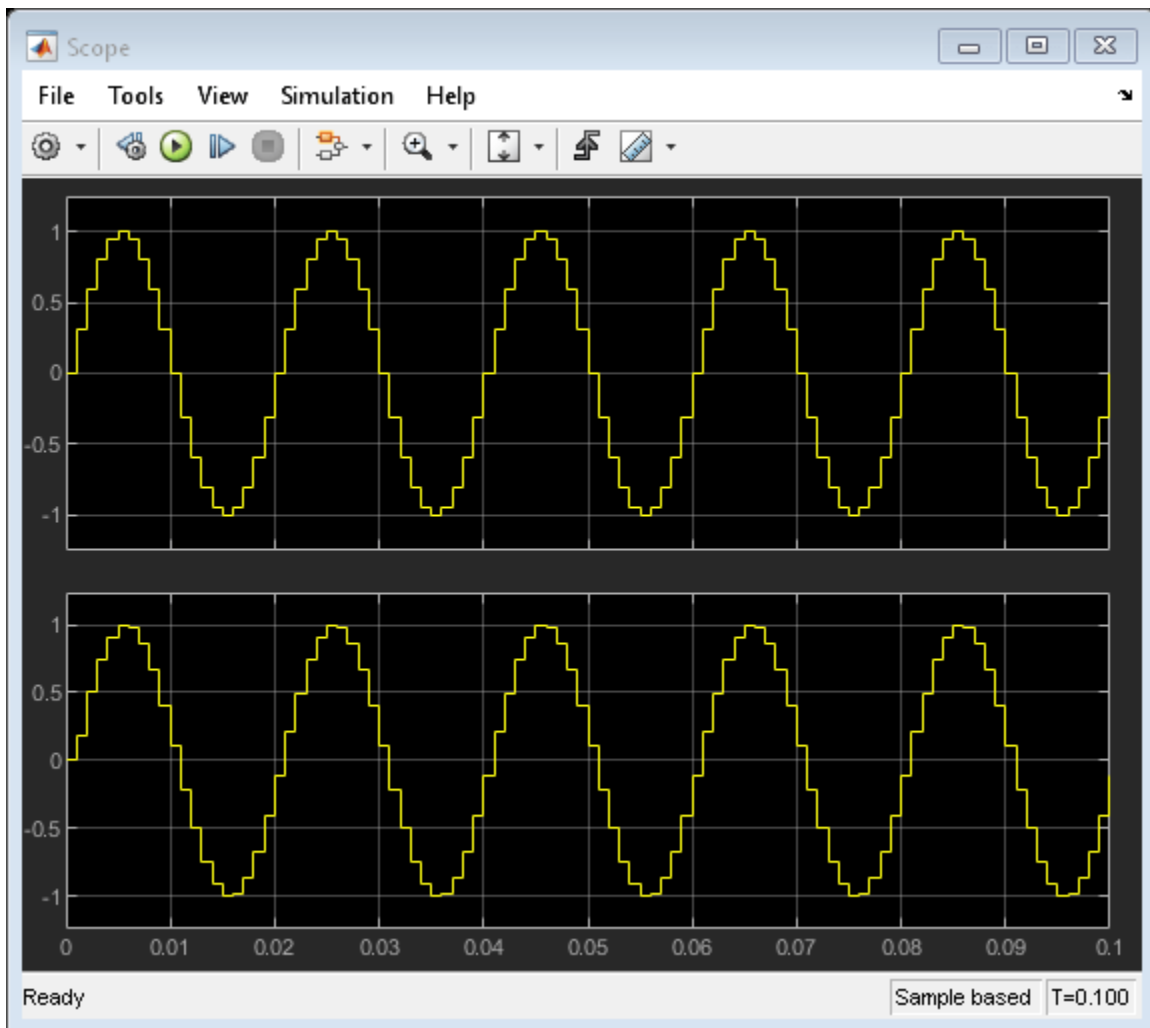
- **Stop time:** `0.1`
- **Type:** `Fixed-step`
- **Solver:** `discrete (no continuous states)`
- **Fixed-step size (fundamental sample time):** `1/Fs`

To configure the model:

- 1 In the **Modeling** tab, under **Setup**, select **Model Settings**.
- 2 In the **Solver** pane, set the discrete solver parameters.
- 3 Click **OK**.

### Run the Model

When you simulate the model, the Scope block displays two signals. The top signal shows the fixed-point version of the sine wave input to the chart. The bottom signal corresponds to the filtered output from the chart. The filter removes high-frequency values from the signal but allows low-frequency values to pass through the chart unchanged.



## See Also



[Data Type Conversion](#) | [Scope](#) | [Sine Wave](#) | [butter](#) | [sfnew](#)

## More About

- “Fixed-Point Data in Stateflow Charts” on page 26-2
- “Fixed-Point Operations in Stateflow Charts” on page 26-19
- “Supported Operations for Fixed-Point Data” on page 26-12

## Supported Operations for Fixed-Point Data

Stateflow charts in Simulink models have an action language property that defines the syntax that you use to compute with fixed-point data:

-  MATLAB as the action language.
-  C as the action language.

For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Binary Operations

This table summarizes the interpretation of all binary operations on fixed-point operands according to their order of precedence (0 = highest, 9 = lowest). Binary operations are left associative so that, in any expression, operators with the same precedence are evaluated from left to right.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a \wedge b$	0	Power. Not supported for fixed-point operands defined by using either a slope that is not an integer power of two or a nonzero bias. Exponent operand must be a constant whose value is a non-negative integer.	Power. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property. See “Enable C-bit operations” on page 28-4.
$a * b$	1	Multiplication. For fixed-point operands defined by using either a slope that is not an integer power of two or a nonzero bias, specify a chart <code>fimath</code> object with <code>ProductMode</code> set to <code>SpecifyPrecision</code> . See “Multiplication” on page 26-22.	Multiplication. Not supported for fixed-point operands defined by using a nonzero bias. See “Multiplication” on page 26-22.
$a / b$	1	Division. Not supported for fixed-point operands defined by using either a slope that is not an integer power of two or a nonzero bias. See “Division” on page 26-22.	Division. Not supported for fixed-point operands defined by using a nonzero bias. See “Division” on page 26-22.
$a + b$	2	Addition. For fixed-point operands defined by using either a slope that is not an integer power of two or a nonzero bias, specify a chart <code>fimath</code> object with <code>SumMode</code> set to <code>SpecifyPrecision</code> . See “Addition and Subtraction” on page 26-21.	Addition. See “Addition and Subtraction” on page 26-21.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a - b$	2	Subtraction. For fixed-point operands defined by using either a slope that is not an integer power of two or a nonzero bias, specify a chart <code>fimath</code> object with <code>SumMode</code> set to <code>SpecifyPrecision</code> . See "Addition and Subtraction" on page 26-21.	Subtraction. See "Addition and Subtraction" on page 26-21.
$a > b$	3	Comparison, greater than. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, greater than. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a < b$	3	Comparison, less than. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, less than. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a \geq b$	3	Comparison, greater than or equal to. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, greater than or equal to. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a \leq b$	3	Comparison, less than or equal to. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, less than or equal to. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a == b$	4	Comparison, equal to. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, equal to. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a \neq b$	4	Comparison, not equal to. See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, not equal to. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.
$a \neq b$	4	Not supported. Use the operation $a \neq b$ . See "Relational Operations for Fixed-Point Data" on page 26-19.	Comparison, not equal to. Not supported for fixed-point operands with mismatched biases. See "Relational Operations for Fixed-Point Data" on page 26-19.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
a <> b	4	Not supported. Use the operation a ~= b. See “Relational Operations for Fixed-Point Data” on page 26-19.	Comparison, not equal to. Not supported for fixed-point operands with mismatched biases. See “Relational Operations for Fixed-Point Data” on page 26-19.
a && b	8	Logical AND. See “Logical Operations for Fixed-Point Data” on page 26-20.	Logical AND. See “Logical Operations for Fixed-Point Data” on page 26-20.
a    b	9	Logical OR. See “Logical Operations for Fixed-Point Data” on page 26-20.	Logical OR. See “Logical Operations for Fixed-Point Data” on page 26-20.

## Unary Operations and Actions

This table summarizes the interpretation of all unary operations and actions on fixed-point operands. Unary operations:

- Have higher precedence than binary operators.
- Are right associative so that, in any expression, they are evaluated from right to left.

Operation	MATLAB as the Action Language	C as the Action Language
~a	Not supported. Use the expression a == cast(0, 'like', a). See “Logical Operations for Fixed-Point Data” on page 26-20.	Logical NOT. Enable this operation by clearing the <b>Enable C-bit operations</b> chart property. See “Logical Operations for Fixed-Point Data” on page 26-20 and “Enable C-bit operations” on page 28-4.
!a	Not supported. Use the expression a == cast(0, 'like', a). See “Logical Operations for Fixed-Point Data” on page 26-20.	Logical NOT. See “Logical Operations for Fixed-Point Data” on page 26-20.
-a	Negative. See “Unary Minus” on page 26-23.	Negative. See “Unary Minus” on page 26-23.
a++	Not supported. Use the expression a = a + 1.	Increment. Equivalent to a = a + 1.
a--	Not supported. Use the expression a = a - 1.	Decrement. Equivalent to a = a - 1.

## Assignment Operations

This table summarizes the interpretation of assignment operations on fixed-point operands.

Operation	MATLAB as the Action Language	C as the Action Language
a = b	Simple assignment.	Simple assignment.

Operation	MATLAB as the Action Language	C as the Action Language
$a := b$	Not supported. To override fixed-point promotion rules, use explicit type cast operations. See “Type Cast Operations” on page 16-8.	Special assignment that overrides fixed-point promotion rules. See “Override Fixed-Point Promotion in C Charts” on page 26-15.
$a += b$	Not supported. Use the expression $a = a + b$ .	Equivalent to $a = a + b$ .
$a -= b$	Not supported. Use the expression $a = a - b$ .	Equivalent to $a = a - b$ .
$a *= b$	Not supported. Use the expression $a = a * b$ .	Equivalent to $a = a * b$ .
$a /= b$	Not supported. Use the expression $a = a / b$ .	Equivalent to $a = a / b$ .

### Override Fixed-Point Promotion in C Charts

In charts that use C as the action language, a simple assignment of the form  $a = b$  calculates an intermediate value for  $b$  according to the fixed-point promotion rules. Then this intermediate value is cast to the type of  $a$  by using an online conversion. See “Promotion Rules for Fixed-Point Operations” on page 26-20 and “Conversion Operations” on page 26-3. Simple assignments are most efficient when both types have equal bias and slopes that either are equal or are both powers of two.

In contrast, a special assignment of the form  $a := b$  overrides this behavior by initially using the type of  $a$  as the result type for the value of  $b$ .

- Constants in  $b$  are converted to the type of  $a$  by using offline conversions.
- The expression  $b$  can contain at most one arithmetic operator (+, -, \*, or /). The result is determined by using an online conversion.
- If  $b$  contains anything other than an arithmetic operation or a constant, then the special assignment operation behaves like the simple assignment operation (=).

Use the special assignment operation  $:=$  when you want to:

- Avoid an overflow in an arithmetic operation. For example, see “Avoid Overflow in Fixed-Point Addition” on page 26-15.
- Retain precision in a multiplication or division operation. For example, see “Improve Precision in Fixed-Point Division” on page 26-16.

---

**Note** Using the special assignment operation  $:=$  can result in generated code that is less efficient than the code you generate by using the normal fixed-point promotion rules.

---

### Avoid Overflow in Fixed-Point Addition

You can use the special assignment operation  $:=$  to avoid overflow when performing an arithmetic operation on two fixed-point numbers. For example, consider a chart that computes the sum  $a+b$  where  $a = 2^{12}-1 = 4095$  and  $b = 1$ .

Suppose that:

- Both inputs are signed 16-bit fixed-point numbers with three fraction bits (type `fixdt(1,16,3)`).
- The output `c` is a signed 32-bit fixed-point number with three fraction bits (type `fixdt(1,32,3)`).
- The integer word size for production targets is 16 bits.

Because the target integer size is 16 bits, the simple assignment `c = a+b` adds the inputs in 16 bits before casting the sum to 32 bits. The intermediate result is 4096, which, as a type `fixdt(1,16,3)` value, results in an overflow.

In contrast, the special assignment `c := a+b` casts the inputs to 32 bits before computing the sum. The result of 4096 is safely computed as a type `fixdt(1,32,3)` value without an overflow.

### Improve Precision in Fixed-Point Division

You can use the special assignment operation `:=` to obtain a more precise result when multiplying or dividing two fixed-point numbers. For example, consider a chart that computes the ratio `a/b` where `a = 2` and `b = 3`.

Suppose that:

- The input `a` is a fixed-point number with four fraction bits (type `fixdt(1,16,4)`).
- The input `b` is a fixed-point number with three fraction bits (type `fixdt(1,16,3)`).
- The output `c` is a signed 16-bit fixed-point number with six fraction bits (type `fixdt(1,16,6)`).

The inputs correspond to these slopes and quantized integers:

$$S_a = 2^{-4}, Q_a = 32$$

$$S_b = 2^{-3}, Q_b = 24.$$

The simple assignment `c = a/b` first calculates an intermediate value for `a/b` according to the fixed-point promotion rules. The quantized integer is rounded to the floor:

$$S_{\text{int}} = S_a/S_b = 2^{-4}/2^{-3} = 2^{-1}$$

$$Q_{\text{int}} = Q_a/Q_b = 32/24 \approx 1.$$

The intermediate result is then cast as a signed 16-digit fixed-point number with six fraction bits:

$$S_c = 2^{-6} = 1/64$$

$$Q_c = S_{\text{int}}Q_{\text{int}}/S_c = 2^{-1}/2^{-6} = 2^5 = 32.$$

Therefore, the approximate real-world value for `c` is  $V_c \approx S_c Q_c = 32/64 = 0.5$ . This result is not a good approximation of the actual value of `2/3`.

In contrast, the special assignment `c := a/b` calculates `a/b` directly as a signed 16-digit fixed-point number with six fraction bits. Again, the quantized integer is rounded to the floor:

$$S_c = 2^{-6} = 1/64$$

$$Q_c = (S_a Q_a)/(S_c S_b Q_b) = 128/3 \approx 42.$$

Therefore, the approximate real-world value for `c` is  $V_c \approx S_c Q_c = 42/64 = 0.6563$ . This result is a better approximation to the actual value of `2/3`.

### Compare Results of Fixed-Point Arithmetic

This example shows the difference between various implementations of fixed-point arithmetic in Stateflow charts. The model contains three charts that calculate the ratio `a/b` where `a = 19` and `b = 24`. Both inputs are signed 16-digit fixed-point numbers with one fraction bit (type `fixdt(1,16,1)`). They correspond to these slopes and quantized integers:

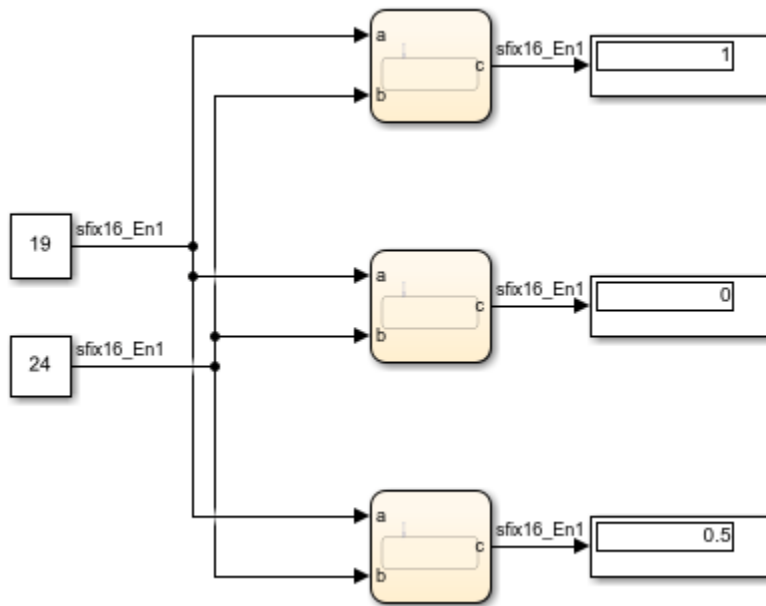
$$S_a = 2^{-1}, Q_a = 38$$



$$S_b = 2^{-1}, Q_b = 48$$

The model calculates the value of  $a/b$  as a floating-point number of type `fixdt(1, 16, 1)` in three different ways:

- A type casting operation in a chart that uses MATLAB as the action language.
- A simple assignment operation in a chart that uses C as the action language.
- A special assignment operation in a chart that uses C as the action language.



### Type Casting in Chart That Uses MATLAB as the Action Language

The chart at the top of the model computes an intermediate value for  $a/b$ . The quantized integer for the intermediate value is rounded to the nearest integer:

$$S_{\text{int}} = S_a/S_b = 1$$

$$Q_{\text{int}} = Q_a/Q_b = 38/48 \approx 1.$$

The intermediate value is then cast as a signed 16-digit fixed-point number  $c$  with one fraction bit:

$$S_c = 2^{-1}$$

$$Q_c = S_{\text{int}} \cdot Q_{\text{int}}/S_c = 2.$$

The output value from this chart is

$$\tilde{V}_c = S_c \cdot Q_c = 1.$$

### Simple Assignment in Chart That Uses C as the Action Language

The middle chart also computes an intermediate value for  $a/b$ . In this case, the quantized integer for the intermediate value is rounded to the floor:

$$S_{\text{int}} = S_a/S_b = 1$$

$$Q_{\text{int}} = Q_a/Q_b = 38/48 \approx 0.$$

The intermediate value is then cast as a signed 16-digit fixed-point number  $c$  with one fraction bit:

$$S_c = 2^{-1}$$

$$Q_c = S_{\text{int}} \cdot Q_{\text{int}}/S_c = 0.$$

The output value from this chart is

$$\tilde{V}_c = S_c \cdot Q_c = 0.$$

### Special Assignment in Chart That Uses C as the Action Language

The chart at the bottom of the model uses a special assignment of the form  $c := a/b$ . The value of the division is calculated directly as a signed 16-digit fixed-point number with one fraction bit. The quantized integer is rounded to the floor:

$$S_c = 2^{-1}$$

$$Q_c = (S_a \cdot Q_a)/(S_c \cdot S_b \cdot Q_b) = 19/12 \approx 1.$$

Therefore, the output value from this chart is

$$\tilde{V}_c = S_c \cdot Q_c = 0.5.$$

The three results exhibit loss of precision compared to the floating-point answer of  $19/24 = 0.7917$ . To minimize the loss of precision to an acceptable level in your application, adjust the encoding scheme in your fixed-point data.

## See Also

### More About

- “Fixed-Point Data in Stateflow Charts” on page 26-2
- “Fixed-Point Operations in Stateflow Charts” on page 26-19
- “Build a Low-Pass Filter by Using Fixed-Point Data” on page 26-8

## Fixed-Point Operations in Stateflow Charts

Fixed-point numbers use integers and integer arithmetic to approximate real numbers. They enable you to perform computations involving real numbers without requiring floating-point support in underlying system hardware. For more information, see “Fixed-Point Data in Stateflow Charts” on page 26-2.

### Arithmetic Operations for Fixed-Point Data

The general equation for a binary arithmetic operation between fixed-point operands is

$$c = a \text{ <op> } b$$

where  $a$  and  $b$  are fixed-point numbers and  $\text{<op>}$  refers to addition, subtraction, multiplication, or division. The result of the operation is a fixed-point number  $c$  of the form

$$V_c \approx S_c Q_c + B_c.$$

The fixed-point type for  $c$  determines the slope  $S_c$ , the bias  $B_c$ , and the number of bits used to store the quantized integer  $Q_c$ . For each arithmetic operation, this table lists the value of the quantized integer  $Q_c$  in terms of the values of the operands ( $a$  and  $b$ ) and the fixed-point type for  $c$ .

Operation		Slope and Bias Scaling	Binary-Point Scaling
Addition	$c = a+b$	$Q_c = \text{round}((S_a/S_c)Q_a + (S_b/S_c)Q_b + (B_a + B_b - B_c)/S_c)$	$Q_c = \text{round}((S_a/S_c)Q_a + (S_b/S_c)Q_b)$
Subtraction	$c = a-b$	$Q_c = \text{round}((S_a/S_c)Q_a - (S_b/S_c)Q_b - (B_a - B_b - B_c)/S_c)$	$Q_c = \text{round}((S_a/S_c)Q_a - (S_b/S_c)Q_b)$
Multiplication	$c = a*b$	$Q_c = \text{round}((S_a S_b/S_c)Q_a Q_b + (B_a S_b/S_c)Q_a + (B_b S_a/S_c)Q_b + (B_a B_b - B_c)/S_c)$	$Q_c = \text{round}((S_a S_b/S_c)Q_a Q_b)$
Division	$c = a/b$	$Q_c = \text{round}((S_a Q_a + B_a)/(S_c(S_b Q_b + B_b)) - (B_c/S_c))$	$Q_c = \text{round}((S_a/(S_b S_c))Q_a/Q_b)$

To simplify these expressions and avoid computationally expensive operations, use binary-point scaling to encode all your fixed-point data. With this setting, the slope is an integer power of two and the bias is zero. Then, all fixed-point operations consist of integer arithmetic and bit shifts on the quantized integers.

**Note** The result of an arithmetic operation depends on the rounding method that computes the value of the quantized integer  $Q_c$ . For more information, see “Conversion Operations” on page 26-3.

### Relational Operations for Fixed-Point Data

You can use relational operations to compare fixed-point data. Comparing fixed-point values of different types can yield unexpected results because each operand is converted to a common type for comparison. Because of rounding or overflow errors during the conversion, some values that appear to be equal are not equal as fixed-point numbers.

For example, suppose that  $a$  and  $b$  represent the real-world value  $V = 2.2$  in two different fixed-point encoding schemes:

- $a$  is a fixed-point number with slope  $S_a = 0.3$  and bias  $B_a = 0.1$ . The quantized integer for  $a$  is:

$$Q_a = (V - B_a)/S_a = (2.2 - 0.1)/0.3 = 7.$$

- **b** is a fixed-point number with slope  $S_b = 0.7$  and bias  $B_b = 0.1$ . The quantized integer for **b** is:  
 $Q_b = (V - B_b)/S_b = (2.2 - 0.1)/0.7 = 3.$

To compare these values, the chart first converts them to a common fixed-point type with slope  $S_{\text{comp}} = 1.06811 \cdot 10^{-5} \approx S_a/28087 \approx S_b \cdot 2^{-16}$  and bias  $B_{\text{comp}} = 0.1$ . (In this case, the slope  $S_{\text{comp}}$  arises from the approximate value of  $S_a/S_b = 0.3/0.7 \approx 28087 \cdot 2^{-16}$ .) In this common encoding scheme, **a** and **b** correspond to these quantized integers:

$$Q_{a'} = S_a Q_a / S_{\text{comp}} = Q_a (S_a / S_{\text{comp}}) \approx 7 \square 28087 = 196609$$

$$Q_{b'} = S_b Q_b / S_{\text{comp}} = Q_b (S_b / S_{\text{comp}}) \approx 3 \square 2^{16} = 196608.$$

After the conversion, the quantized integers are different. Although **a** and **b** represent the same real-world value, they are not equal as fixed-point numbers.

---

**Note** In charts that use C as the action language, comparisons of fixed-point operands with mismatched biases are not supported.

---

## Logical Operations for Fixed-Point Data

In a logical operation, a fixed-point operand **a** is interpreted as `false` if it corresponds to the real-world value for zero in the fixed-point type of **a**. Otherwise, **a** is interpreted as `true`.

- In charts that use MATLAB as the action language, using **a** in a logical operation is equivalent to the expression `a ~= cast(0, 'like', a)`.
- In charts that use C as the action language, using **a** in a logical operation is equivalent to the expression `a != 0c`, where `0c` is a fixed-point context-sensitive constant. See “Fixed-Point Context-Sensitive Constants” on page 26-4.

For example, suppose that **a** is a fixed-point number with a slope of  $S_a = 0.25$  and a bias of  $B_a = 5.1$ . Using **a** in a logical operation is equivalent to testing whether the quantized integer  $Q_a$  satisfies the condition

$$Q_a = \text{round}((0 - B_a)/S_a) = \text{round}(-5.1 / 0.25) = \text{round}(-20.4) = -20.$$

Therefore, **a** is equivalent to `false` when its real-world approximation is

$$V_a \approx S_a Q_a + B_a = 0.25 \square (-20) + 5.1 = 0.1.$$

## Promotion Rules for Fixed-Point Operations

The rules for selecting the numeric type used for the result of an operation on fixed-point numbers are called *fixed-point promotion rules*. These rules help to maintain computational efficiency and usability.

The fixed-point promotion rules determine a result type for an operation  $c = a \langle op \rangle b$  by selecting the slope  $S_c$ , the bias  $B_c$ , and the number of bits  $w_c$  used to store the quantized integer  $Q_c$ . These parameters depend on the fixed-point types of the operands **a** and **b**, the operation  $\langle op \rangle$  to be performed, and the action language property for the chart.

- In a chart that uses MATLAB as the action language, you control the fixed-point promotion rules through the fixed-point properties for the chart. See “Fixed-Point Properties” on page 28-6.
- If you set the **MATLAB Chart `fimath`** property to `Same` as MATLAB, then arithmetic operations follow the default fixed-point promotion rules for MATLAB. See “Performing Fixed-Point Arithmetic” (Fixed-Point Designer).

- If you specify a chart `fimath` object with `SumMode` and `ProductMode` set to `SpecifyPrecision`, then you can define the word length, slope, and bias for all sums and products explicitly. See “`fimath` Object Properties” (Fixed-Point Designer).
- In a chart that uses C as the action language, the fixed-point promotion rules determine the type for an intermediate value of the result. This intermediate value is then cast to the type that you specify for `c`.

For all arithmetic operations, the default number of bits  $w_c$  used to store the quantized integer is the larger value between:

- The maximum number of bits in the operand types ( $w_a$  and  $w_b$ ).
- The number of bits in the integer word size for the target machine ( $w_{int}$ ).

To set the value of  $w_{int}$ , open the **Model Configuration Parameters** dialog box. On the **Hardware Implementation** pane, select Custom Processor from the **Device vendor** drop-down list and enter the target integer word size in the **int** field. For more information, see “Hardware Implementation Pane” (Simulink).

You can avoid overflow and improve the precision in your floating-point operations by using the special assignment operation of the form `c := a <op> b`. The special assignment operation does not follow the fixed-point promotion rules. Instead, the chart determines the result of the operation by using the type that you specify for `c`. See “Override Fixed-Point Promotion in C Charts” on page 26-15.

### Addition and Subtraction

By default, charts that use MATLAB as the action language support addition and subtraction only on fixed-point data defined through binary-point scaling. If either operand is a signed fixed-point number, then the result is also signed. The choice of word length accommodates the integer and fraction parts of each operand in addition to a possible carry bit. The fraction length of the result is equal to the fraction length of the most precise operand. To perform addition and subtraction on fixed-point data defined by using either a slope that is not an integer power of two or a nonzero bias, specify a chart `fimath` object with `SumMode` set to `SpecifyPrecision`.

Charts that use C as the action language support addition and subtraction for operands of all fixed-point data types. The result is a signed fixed-point number only if both operands are signed. Mixing signed and unsigned operands can yield unexpected results and is not recommended. The slope of the result is equal to the slope of the least precise operand. To simplify calculations and yield efficient code, the biases of the two inputs are added for an addition operation and subtracted for a subtraction operation.

	<b>a</b>	<b>b</b>	<b>MATLAB as the Action Language</b>	<b>C as the Action Language</b>
Sign	$s_a$	$s_b$	$s_c = s_a \mid s_b$	$s_c = s_a \ \&\& \ s_b$
Word length	$w_a$	$w_b$	$w_c = \max(w_a - f_a, w_b - f_b) + \max(f_a, f_b) + 1$	$w_c = \max(w_a, w_b, w_{int})$
Fraction length	$f_a$	$f_b$	$f_c = \max(f_a, f_b)$	$f_c = \min(f_a, f_b)$

	a	b	MATLAB as the Action Language	C as the Action Language
Slope	$S_a$ ( $2^{-f_a}$ if using binary-point scaling)	$S_b$ ( $2^{-f_b}$ if using binary-point scaling)	$S_c = \min(S_a, S_b)$	$S_c = \max(S_a, S_b)$
Bias	$B_a$ (0 if using binary-point scaling)	$B_b$ (0 if using binary-point scaling)	$B_c = 0$	$B_c = B_a + B_b$ for addition or $B_c = B_a - B_b$ for subtraction

### Multiplication

By default, charts that use MATLAB as the action language support multiplication only on fixed-point data defined through binary-point scaling. If either operand is a signed fixed-point number, then the result is also signed. A full precision product requires a word length equal to the sum of the word lengths of the operands. The fraction length of a product is the sum of the fraction lengths of the operands. To perform multiplication on fixed-point data defined by using either a slope that is not an integer power of two or a nonzero bias, specify a chart `fimath` object with `ProductMode` set to `SpecifyPrecision`.

Charts that use C as the action language support multiplication only on fixed-point data operands defined by nonzero biases. The result is a signed fixed-point number only if both operands are signed. Mixing signed and unsigned operands can yield unexpected results and is not recommended. The slope of a product is the product of the slopes of the operands.

	a	b	MATLAB as the Action Language	C as the Action Language
Sign	$s_a$	$s_b$	$s_c = s_a \&\& s_b$	$s_c = s_a \&\& s_b$
Word length	$w_a$	$w_b$	$w_c = w_a + w_b$	$w_c = \max(w_a, w_b, w_{int})$
Fraction length	$f_a$	$f_b$	$f_c = f_a + f_b$	$f_c = f_a + f_b$
Slope	$S_a$ ( $2^{-f_a}$ if using binary-point scaling)	$S_b$ ( $2^{-f_b}$ if using binary-point scaling)	$S_c = S_a S_b$	$S_c = S_a S_b$
Bias	$B_a = 0$	$B_b = 0$	$B_c = 0$	$B_c = 0$

### Division

Charts that use MATLAB as the action language support division only on fixed-point data defined through binary-point scaling. If either operand is a signed fixed-point number, then the result is also signed. A full precision quotient requires a word length equal to the maximum number of bits in the operands. The fraction length of a quotient is the difference of the fraction lengths of the operands.

Charts that use C as the action language support division for fixed-point data operands defined by nonzero biases. The result is a signed fixed-point number only if both operands are signed. Mixing signed and unsigned operands can yield unexpected results and is not recommended. The slope of a quotient is the quotient of the slopes of the operands.

	<b>a</b>	<b>b</b>	<b>MATLAB as the Action Language</b>	<b>C as the Action Language</b>
Sign	$s_a$	$s_b$	$s_c = s_a \mid s_b$	$s_c = s_a \&\& s_b$
Word length	$w_a$	$w_b$	$w_c = \max(w_a, w_b)$	$w_c = \max(w_a, w_b, w_{int})$
Fraction length	$f_a$	$f_b$	$f_c = f_a - f_b$	$f_c = f_a - f_b$
Slope	$S_a$ ( $2^{f_a}$ if using binary-point scaling)	$S_b$ ( $2^{f_b}$ if using binary-point scaling)	$S_c = S_a/S_b$	$S_c = S_a/S_b$
Bias	$B_a = 0$	$B_b = 0$	$B_c = 0$	$B_c = 0$

### Unary Minus

The only unary operation that requires a promotion of its result type is the unary minus operation  $c = -a$ . Taking the negative of an unsigned fixed-point number can yield unexpected results and is not recommended. The word size of the result depends on the action language property of the chart. The slope of the result is equal to the slope of the operand. The bias of the result type is the negative of the bias of the operand.

	<b>a</b>	<b>MATLAB as the Action Language</b>	<b>C as the Action Language</b>
Sign	$s_a$	$s_c = s_a$	$s_c = s_a$
Word length	$w_a$	$w_c = w_a$	$w_c = \max(w_a, w_{int})$
Fraction length	$f_a$	$f_c = f_a$	$f_c = f_a$
Slope	$S_a$ ( $2^{f_a}$ if using binary-point scaling)	$S_c = S_a$	$S_c = S_a$
Bias	$B_a$ (0 if using binary-point scaling)	$B_c = -B_a$	$B_c = -B_a$

### Arithmetic with Mixed Numeric Types

This table summarizes the fixed-point promotion rules for a binary operation between a fixed-point number and an operand of a different numeric type.

Numeric Type of Second Operand	MATLAB as the Action Language	C as the Action Language
Floating-point numbers: <ul style="list-style-type: none"> <li>• single</li> <li>• double</li> </ul>	Before performing the operation, the chart casts the floating-point operand to a fixed-point number. The type used for the cast depends on the operation: <ul style="list-style-type: none"> <li>• Addition and subtraction operations use the same type as the fixed-point operand.</li> <li>• Multiplication operations use the same word length and signedness as the fixed-point operand, and the best precision fraction length for a fixed-point result.</li> </ul> The result of the operation is a fixed-point number.	Before performing the operation, the chart casts the fixed-point operand to a floating-point number. The casting operation uses the same type (single or double) as the floating-point operand. The result of the operation is a floating-point number.
Integers: <ul style="list-style-type: none"> <li>• int64</li> <li>• int32</li> <li>• int16</li> <li>• int8</li> <li>• uint64</li> <li>• uint32</li> <li>• uint16</li> <li>• uint8</li> </ul>	The integer operand is treated as a fixed-point number of the same word length and signedness with slope $S = 1$ and bias $B = 0$ . The result of the operation is a fixed-point number.	The integer operand is treated as a fixed-point number of the same word length and signedness with slope $S = 1$ and bias $B = 0$ . The result of the operation is a fixed-point number.

**See Also**

**More About**

- “Fixed-Point Data in Stateflow Charts” on page 26-2
- “Supported Operations for Fixed-Point Data” on page 26-12
- “Build a Low-Pass Filter by Using Fixed-Point Data” on page 26-8

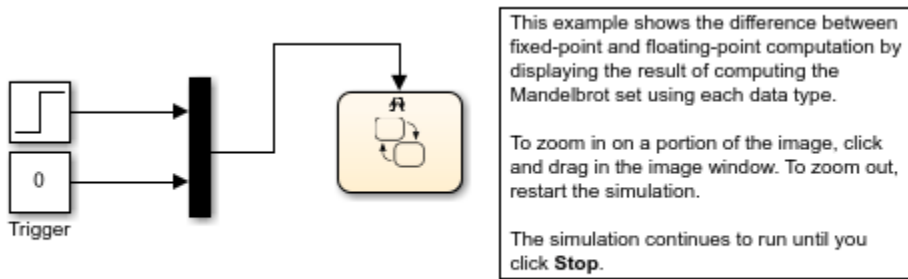


## Fixed-Point Mandelbrot Set

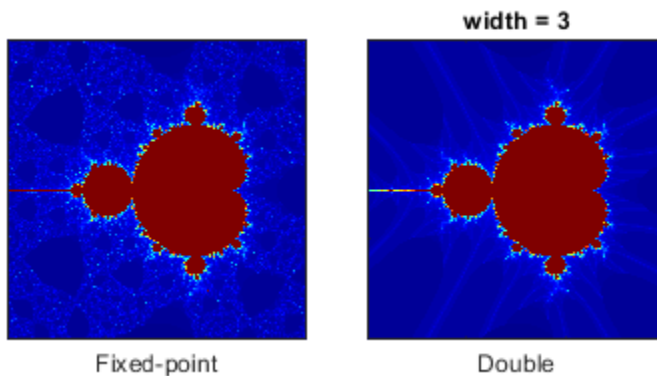
This example shows the difference between fixed-point and floating-point computation by displaying the result of computing the Mandelbrot set using each data type.

To zoom in on a portion of the image, click and drag in the image window. To zoom out, restart the simulation.

The simulation continues to run until you click **Stop**.



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### See Also

### More About

- “Fixed-Point Data”

## Using Multiword Fixed-Point Data

This example shows a simple use of multiword fixed-point data in Stateflow® charts. You can define multiword fixed-point data at the chart level, with one of the following scopes:

- Input
- Output
- Parameter
- Data Store Memory

You can also pass these data as inputs and outputs to and from MATLAB® functions, MATLAB truth tables, and Simulink® functions in Stateflow charts.



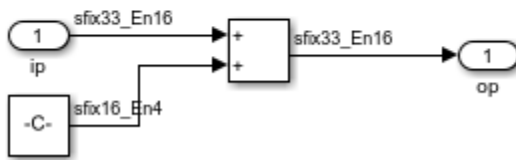
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Chart MultiwordFixptIO takes in an input, `data`, that is a multiword fixed-point type, and returns an output, `out`, that is also a multiword fixed-point data type.



The chart defines a Simulink function `foo` that declares both its input and output to be of multiword fixed-point type. `foo` returns the value of its input, incremented by a fixed-point constant value. At each time step, the chart MultiwordFixptIO passes its input to `foo`, and assigns the output from `foo` to `out`.

f()



## See Also

### More About

- “Fixed-Point Data”



# Complex Data

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- “Complex Data in Stateflow Charts” on page 27-2
- “Supported Operations for Complex Data” on page 27-4
- “Rules for Using Complex Data in C Charts” on page 27-7
- “Best Practices for Using Complex Data in C Charts” on page 27-9
- “Measure Frequency Response by Using Spectrum Analyzer” on page 27-12
- “Detect Valid Transmission Data by Using Frame Synchronization” on page 27-18

## Complex Data in Stateflow Charts

Complex data is data whose value is a complex number. For example, in a Stateflow chart in Simulink model, an input signal with the value  $3 + 5i$  is complex. See “Complex Signals” (Simulink).

### Define Complex Data

- 1 Add a data object to your chart, as described in “Add Stateflow Data” on page 12-2.
- 2 Set the **Complexity** property for the data object to `On`. For more information, see “Complexity” on page 12-7.
- 3 Specify the name, scope, size, base type, and other properties for the data object, as described in “Set Data Properties” on page 12-5.
  - Complex data does not support the scope `Constant`.
  - Complex data does not support the base types `ml`, `struct`, and `boolean`.

### When to Use Complex Data

Use complex data when you model applications in communication systems and digital signal processing. For example, you can use this design pattern to model a frame synchronization algorithm in a communication system:

- 1 Use Simulink blocks (such as filters) to process complex signals.
- 2 Use charts to implement mode logic for frame synchronization.
- 3 Let the charts access complex input and output data so that nested MATLAB functions can drive the mode logic.

For an example of modeling a frame synchronization algorithm, see “Detect Valid Transmission Data by Using Frame Synchronization” on page 27-18.

---

**Note** Continuous-time variables of complex type are *not* supported. For more information, see “Store Continuous State Information in Local Variables” on page 25-8.

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### Where You Can Use Complex Data

You can define complex data at these levels of the Stateflow hierarchy:

- Charts
- Subcharts
- States
- Functions

### How You Can Use Complex Data

You can use complex data to define:

- Complex vectors

- Complex matrices

You can also use complex data as arguments for:

- State actions
- Transition actions
- MATLAB functions (see “Reuse MATLAB Code by Defining MATLAB Functions” on page 9-2)
- Truth table functions (see “Use Truth Tables to Model Combinatorial Logic” on page 10-2)
- Graphical functions (see “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18)
- Change detection operators (see “Detect Changes in Data Values” on page 16-64)

---

**Note** Exported functions do not support complex data as arguments.

---



## See Also

### More About

- “Supported Operations for Complex Data” on page 27-4
- “Rules for Using Complex Data in C Charts” on page 27-7
- “Best Practices for Using Complex Data in C Charts” on page 27-9

## Supported Operations for Complex Data

Stateflow charts in Simulink models have an action language property that defines the syntax that you use to compute with complex data. The action language properties are:

-  MATLAB as the action language.
-  C as the action language.

For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

### Notation for Complex Data

In charts that use MATLAB as the action language, you can define complex data by using complex number notation  $a + bi$ , where  $a$  and  $b$  are real numbers. For example, this statement assigns a value of  $3+4i$  to  $x$ :

```
x = 3 + 4i;
```

Alternatively, you can define complex data by using the `complex` operator:

```
complex(<real_part>,<imag_part>)
```

`<real_part>` and `<imag_part>` are arguments that define the real and imaginary parts of the complex number, respectively. The two arguments must be real values or expressions that evaluate to real values. As in the preceding example, this statement assigns a value of  $3+4i$  to  $x$ :

```
x = complex(3,4);
```

Charts that use C as the action language do not support complex number notation  $a + bi$ . To define a complex number based on two real values, use the `complex` operator.

### Binary Operations

This table summarizes the interpretation of all binary operations on complex operands according to their order of precedence (1 = highest, 3 = lowest). Binary operations are left associative so that, in any expression, operators with the same precedence are evaluated from left to right.

Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a * b$	1	Multiplication.	Multiplication.
$a / b$	1	Division.	Not supported. Use the <code>\</code> operation in a MATLAB function. See “Perform Complex Division with a MATLAB Function” on page 27-10.
$a + b$	2	Addition.	Addition.
$a - b$	2	Subtraction.	Subtraction.
$a == b$	3	Comparison, equal to.	Comparison, equal to.



Operation	Precedence	MATLAB as the Action Language	C as the Action Language
$a \sim= b$	3	Comparison, not equal to.	Comparison, not equal to.
$a != b$	3	Not supported. Use the operation $a \sim= b$ .	Comparison, not equal to.
$a <> b$	3	Not supported. Use the operation $a \sim= b$ .	Comparison, not equal to.

## Unary Operations and Actions

This table summarizes the interpretation of all unary operations and actions on complex data. Unary operations:

- Have higher precedence than the binary operators.
- Are right associative so that, in any expression, they are evaluated from right to left.

Operation	MATLAB as the Action Language	C as the Action Language
$-a$	Negative.	Negative.
$a++$	Not supported. Use the expression $a = a + 1$ .	Increment. Equivalent to $a = a + 1$ .
$a--$	Not supported. Use the expression $a = a - 1$ .	Decrement. Equivalent to $a = a - 1$ .

## Assignment Operations

This table summarizes the interpretation of assignment operations in Stateflow charts.

Operation	MATLAB as the Action Language	C as the Action Language
$a = b$	Simple assignment.	Simple assignment.
$a += b$	Not supported. Use the expression $a = a + b$ .	Equivalent to $a = a + b$ .
$a -= b$	Not supported. Use the expression $a = a - b$ .	Equivalent to $a = a - b$ .
$a *= b$	Not supported. Use the expression $a = a * b$ .	Equivalent to $a = a * b$ .

## Access Real and Imaginary Parts of a Complex Number

To access the real and imaginary parts of a complex number, use the `real` and `imag` operators.

### real Operator

The `real` operator returns the value of the real part of a complex number:

```
real(<complex_expr>)
```

`<complex_expr>` is an expression that evaluates to a complex number. For example, if `frame(200)` evaluates to the complex number  $8.23 + 4.56i$ , this expression returns a value of `8.2300`:

```
real(frame(200))
```

### **imag Operator**

The `imag` operator returns the value of the imaginary part of a complex number:

```
imag(<complex_expr>)
```

`<complex_expr>` is an expression that evaluates to a complex number. For example, if `frame(200)` evaluates to the complex number  $8.23 + 4.56i$ , this expression returns a value of  $4.5600$ :

```
imag(frame(200))
```

### **See Also**

`complex` | `i` | `imag` | `real`

### **More About**

- “Complex Data in Stateflow Charts” on page 27-2
- “Rules for Using Complex Data in C Charts” on page 27-7
- “Best Practices for Using Complex Data in C Charts” on page 27-9

## Rules for Using Complex Data in C Charts

Complex data is data whose value is a complex number. For example, in a Stateflow chart in Simulink model, an input signal with the value  $3 + 5i$  is complex. See “Complex Data in Stateflow Charts” on page 27-2.

These rules apply when you use complex data in Stateflow charts that use C as the action language.

### Do not use complex number notation in actions

C charts do not support complex number notation ( $a + bi$ ), where  $a$  and  $b$  are real numbers. Therefore, you cannot use complex number notation in state actions, transition conditions and actions, or any statements in C charts.

To define a complex number, use the `complex` operator as described in “Notation for Complex Data” on page 27-4.

### Do not perform math function operations on complex data in C charts

Math operations such as `sin`, `cos`, `min`, `max`, and `abs` do not work with complex data in C charts. However, you can use MATLAB functions for these operations.

For more information, see “Perform Math Function Operations with a MATLAB Function” on page 27-9.

### Mix complex and real operands only for addition, subtraction, and multiplication

If you mix operands for any other math operations in C charts, an error appears when you try to simulate your model.

To mix complex and real operands for division, you can use a MATLAB function as described in “Perform Complex Division with a MATLAB Function” on page 27-10.

---

**Tip** Another way to mix operands for division is to use the `complex`, `real`, and `imag` operators in C charts.

Suppose that you want to calculate  $y = x1/x2$ , where  $x1$  is complex and  $x2$  is real. You can rewrite this calculation as:

```
y = complex(real(x1)/x2, imag(x1)/x2)
```

For more information, see “Access Real and Imaginary Parts of a Complex Number” on page 27-5.

---

### Do not define complex data with constant scope

If you define complex data with Constant scope, an error appears when you try to simulate your model.

### Do not define complex data with `ml`, `struct`, or `boolean` base type

If you define complex data with `ml`, `struct`, or `boolean` base type, an error appears when you try to simulate your model.

**Use only real values to set initial values of complex data**

When you define the initial value for data that is complex, use only a real value. See “Additional Properties” on page 12-16 for instructions on setting an initial value in the Data properties dialog box.

**Do not enter minimum or maximum values for complex data**

In the Data properties dialog box, do not enter any values in the **Minimum** or **Maximum** field when you define complex data. If you enter a value in either field, an error message appears when you try to simulate your model.

**Assign complex values only to data of complex type**

If you assign complex values to real data types, an error appears when you try to simulate your model.

---

**Note** You can assign both real and complex values to complex data types.

---

**Do not pass real values to function inputs of complex type**

This restriction applies to the following types of chart functions:

- Graphical functions
- Truth table functions
- MATLAB functions
- Simulink functions

If your C chart passes real values to function inputs of complex type, an error appears when you try to simulate your model.

**Do not use complex data with temporal logic operators**

You cannot use complex data as an argument for temporal logic operators, because you cannot define time as a complex number.

**See Also****More About**

- “Complex Data in Stateflow Charts” on page 27-2
- “Supported Operations for Complex Data” on page 27-4
- “Best Practices for Using Complex Data in C Charts” on page 27-9

## Best Practices for Using Complex Data in C Charts

Complex data is data whose value is a complex number. For example, in a Stateflow chart in Simulink model, an input signal with the value  $3 + 5i$  is complex. See “Complex Data in Stateflow Charts” on page 27-2.

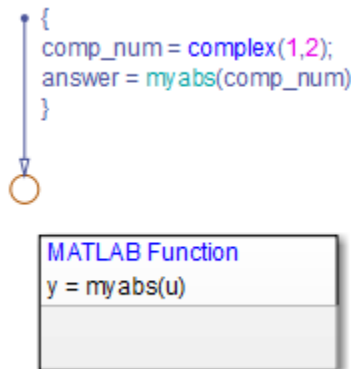
When you use complex data in Stateflow charts that use C as the action language, follow these best practices.

### Perform Math Function Operations with a MATLAB Function

Math functions such as `sin`, `cos`, `min`, `max`, and `abs` do not work with complex data in C charts. However, you can use a MATLAB function in your chart to perform math function operations on complex data.

#### A Simple Example

In the following chart, a MATLAB function calculates the absolute value of a complex number:



The value of `comp_num` is  $1+2i$ . Calculating the absolute value gives an answer of 2.2361.

#### How to Calculate Absolute Value

Suppose that you want to find the absolute value of a complex number. Follow these steps:

- 1 Add a MATLAB function to your chart with this signature:

```
y = myabs(u)
```

- 2 Double-click the function box to open the editor.
- 3 In the editor, enter the code below:

```
function y = myabs(u)
%#codegen
y = abs(u);
```

The function `myabs` takes a complex input `u` and returns the absolute value as an output `y`.

- 4 Configure the input argument `u` to accept complex values.
  - a Open the Model Explorer.

- b** In the **Model Hierarchy** pane of the Model Explorer, navigate to the MATLAB function `myabs`.
- c** In the **Contents** pane of the Model Explorer, right-click the input argument `u` and select **Properties** from the context menu.
- d** In the Data properties dialog box, select `On` in the **Complexity** field and click **OK**.

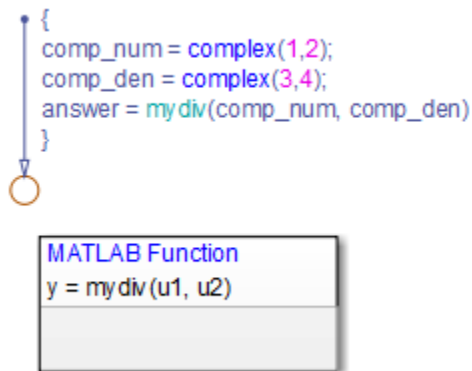
You cannot pass real values to function inputs of complex type. For details, see “Rules for Using Complex Data in C Charts” on page 27-7.

## Perform Complex Division with a MATLAB Function

Division with complex operands is not available as a binary or assignment operation in C charts. However, you can use a MATLAB function in your chart to perform division on complex data.

### A Simple Example

In the following chart, a MATLAB function performs division on two complex operands:



The values of `comp_num` and `comp_den` are  $1+2i$  and  $3+4i$ , respectively. Dividing these values gives an answer of  $0.44+0.08i$ .

### How to Perform Complex Division

To divide two complex numbers:

- 1** Add a MATLAB function to your chart with this function signature:

```
y = mydiv(u1, u2)
```

- 2** Double-click the function box to open the editor.
- 3** In the editor, enter the code below:

```
function y = mydiv(u1, u2)
%#codegen
y = u1 / u2;
```

The function `mydiv` takes two complex inputs, `u1` and `u2`, and returns the complex quotient of the two numbers as an output `y`.

- 4** Configure the input and output arguments to accept complex values.

- a** Open the Model Explorer.
- b** In the **Model Hierarchy** pane of the Model Explorer, navigate to the MATLAB function `mydiv`.
- c** For each input and output argument, follow these steps:
  - i** In the **Contents** pane of the Model Explorer, right-click the argument and select **Properties** from the context menu.
  - ii** In the Data properties dialog box, select **On** in the **Complexity** field and click **OK**.

You cannot pass real values to function inputs of complex type. For details, see “Rules for Using Complex Data in C Charts” on page 27-7.

## See Also

### More About

- “Complex Data in Stateflow Charts” on page 27-2
- “Supported Operations for Complex Data” on page 27-4
- “Rules for Using Complex Data in C Charts” on page 27-7

## Measure Frequency Response by Using Spectrum Analyzer

This example shows how to emulate a spectrum analyzer that measures the frequency response of a continuous-time system driven by a complex sinusoidal signal. In this Simulink® model, the Plant block describes a second-order resonant system of the form

$$\frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$$

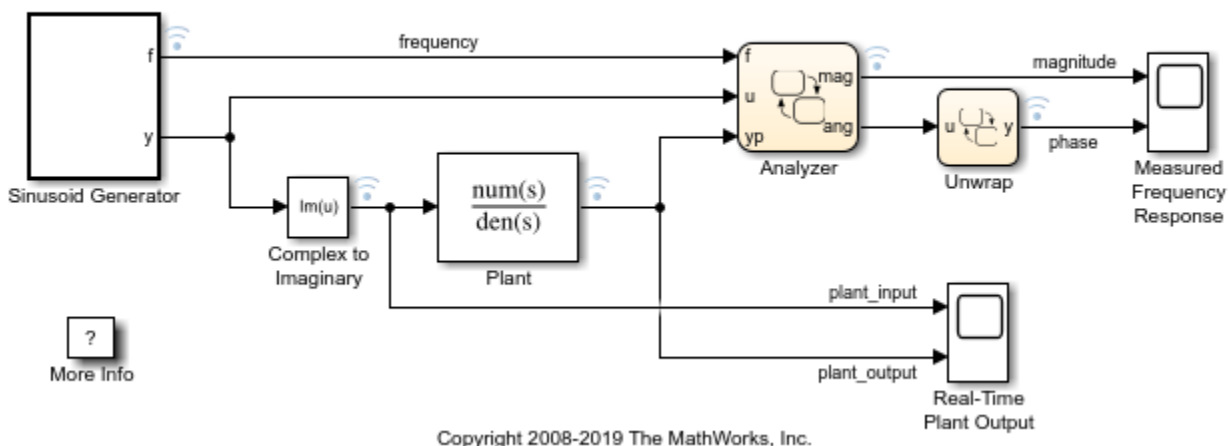
with a natural frequency of  $\omega = 2\pi \cdot 150$  (or 150 Hz) and a damping ratio of  $\zeta = 0.3$ . Because the system is underdamped ( $\zeta < 1$ ), the system has two complex conjugate poles. In a real-world application, replace this block with a subsystem composed of xPC D/A and A/D blocks that measure the response of a device under test (DUT).

The spectrum analyzer consists of these components:

- The Sinusoidal Generator block, which produces a complex sinusoidal signal of increasing frequency. Inside the block, a Stateflow® chart uses temporal logic to iterate over a range of frequencies.
- The Stateflow chart Analyzer, which calculates the frequency response (magnitude and phase angle) of the system at a specified frequency. The chart registers changes in the frequency by using change detection logic.
- The Stateflow chart Unwrap, which processes the measured phase angle and unwraps the result so that there are no sharp jumps between  $\pi$  and  $-\pi$ .

The spectrum analyzer displays the measured frequency response as a pair of discrete Bode plots.

### Measure Frequency Response by Using Spectrum Analyzer



#### Generate Sinusoid Signal

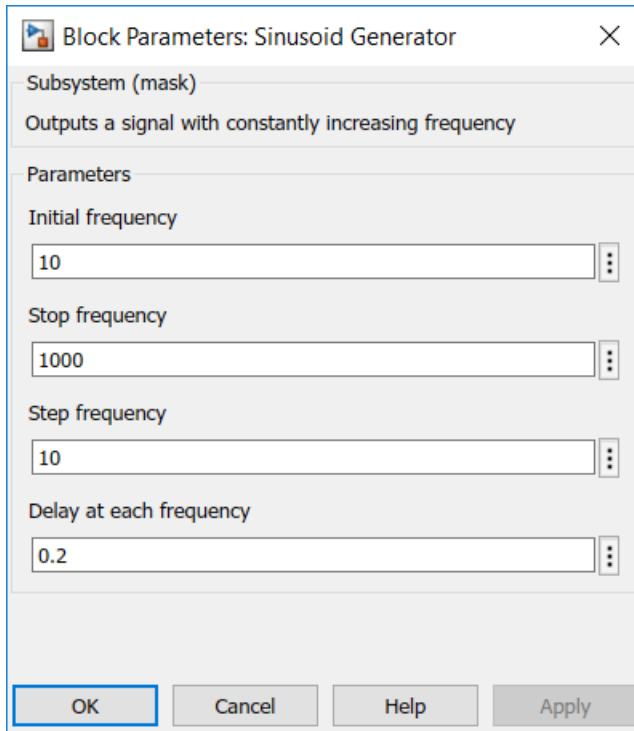
The Sinusoid Generator block has two outputs:

- A scalar  $f$  that represents the current frequency.

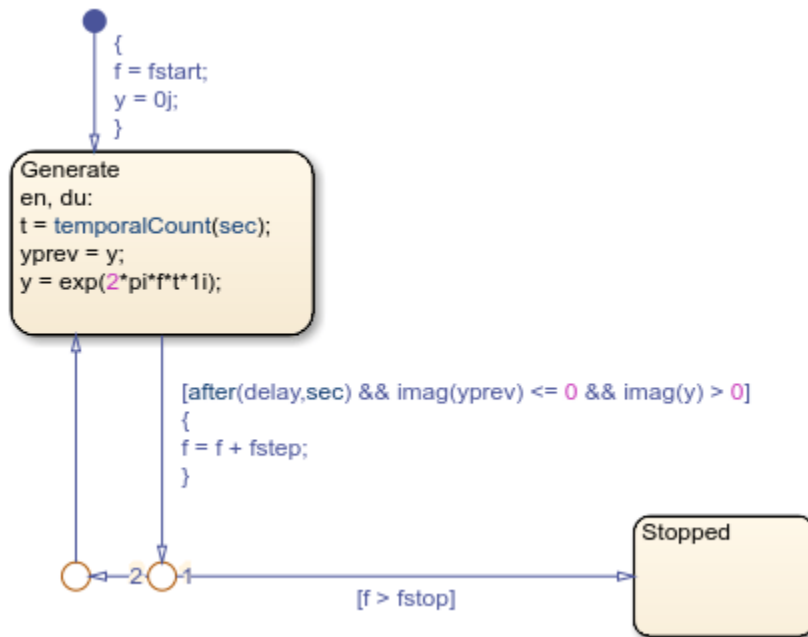


- A complex signal  $y$  that has a frequency of  $f$ .

You can control the behavior of the block by modifying its mask dialog box parameters. For example, the default values specify a sinusoidal signal with frequencies between 10Hz and 1000Hz. The block holds each frequency value for 0.2 seconds, and then increments the frequency by a step of 10Hz.



To control the timing of the signal generator, the block contains a Stateflow chart that applies absolute-time temporal logic.

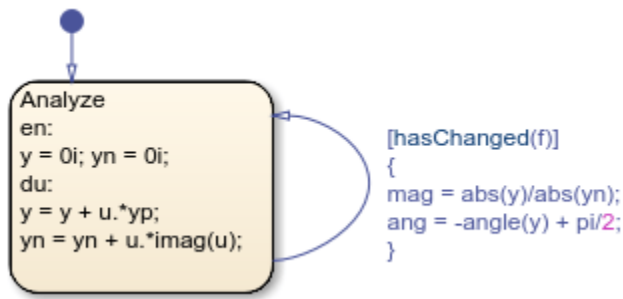


During simulation, the chart goes through these stages:

- **Initialize Frequency:** The default transition sets the signal frequency  $f$  to the value of the parameter  $f_{start}$ . Specify the value of  $f_{start}$  in the Sinusoid Generator mask dialog box.
- **Generate Signal:** While the Generate state is active, the chart produces the complex signal  $y = \exp(2\pi i f t)$  based on the frequency  $f$  and the time  $t$  since the last change in frequency. To determine the elapsed time (in seconds) since the state became active, the chart calls the temporal logic operator `temporalCount`.
- **Update Frequency:** After the Generate state is active for `delay` seconds, the chart transitions out of the state, increases the frequency  $f$  by `fstep`, and returns to the Generate state. To determine the timing of the frequency updates, the chart calls the temporal logic operator `after` and checks the sign of the imaginary part of the signal before and after the current time step. The sign checks ensure that the output signal completes a full cycle before the frequency is updated, preventing large changes in the output signal. Specify the values of `fstep` and `delay` in the Sinusoid Generator mask dialog box.
- **Stop Simulation:** When the frequency  $f$  reaches the value of the parameter  $f_{stop}$ , the chart transitions to the Stopped state. The active state output `Stopped` triggers a Stop Simulation (Simulink) block and the simulation ends. Specify the value of  $f_{stop}$  in the Sinusoid Generator mask dialog box.

### Calculate Frequency Response

The Analyzer chart takes the complex signal  $u$  and the output  $y_p$  from the Plant block and computes the magnitude and phase of the plant output.



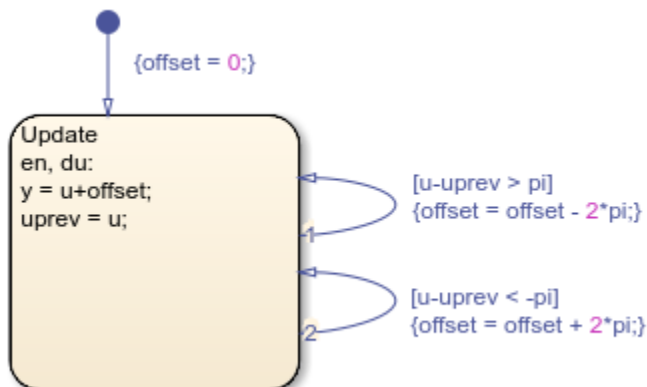
For each frequency value, the chart maintains two running sums:

- The sum  $y$  approximates the integral of the product of the plant output  $yp$  (a real number) and the complex signal  $u$ .
- The sum  $yn$  approximates the integral of the product of the plant input  $\text{imag}(u)$  and the complex signal  $u$ . This integral represents the accumulation of a hypothetical plant with a unit transfer function.

To detect a change in frequency, the chart uses the operator `hasChanged` to guard the self-transition on the state `Analyze`. When the frequency changes, the actions on this transition compute the magnitude and phase of the plant output by normalizing  $y$  with respect to  $yn$ .

### Unwrap Measured Phase Angle

The Unwrap chart prevents the measured phase angle from changing by more than  $\pi$  radians in a single time step.



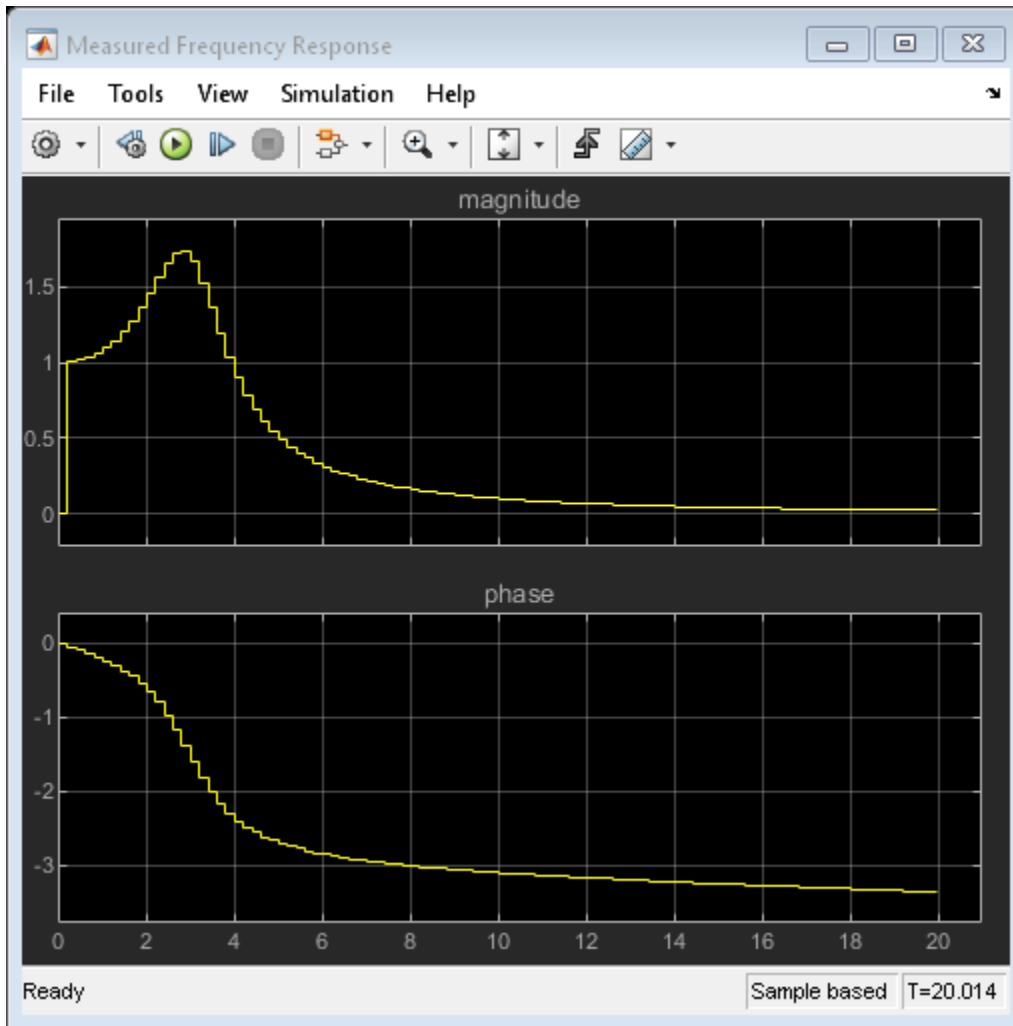
In this chart, the transitions test the change in the input  $u$  before computing the new output value  $y$ .

- If the input increases by more than  $\pi$  radians, the chart offsets the output by  $-2\pi$  radians.
- If the input decreases by more than  $-\pi$  radians, the chart offsets the output by  $+2\pi$  radians.

### Examine Simulation Results

When you simulate the model, the scope block shows the frequency response of the system (magnitude and phase) as a function of simulation time.

- In the magnitude plot, the maximum value at  $t \approx 3$  indicates the response of the Plant block to a resonant frequency. The peak amplitude is approximately 1.7.
- In the phase plot, the angle changes from 0 to  $-\pi$  radians. Each complex pole of the system adds  $-\pi/2$  radians to the phase angle.



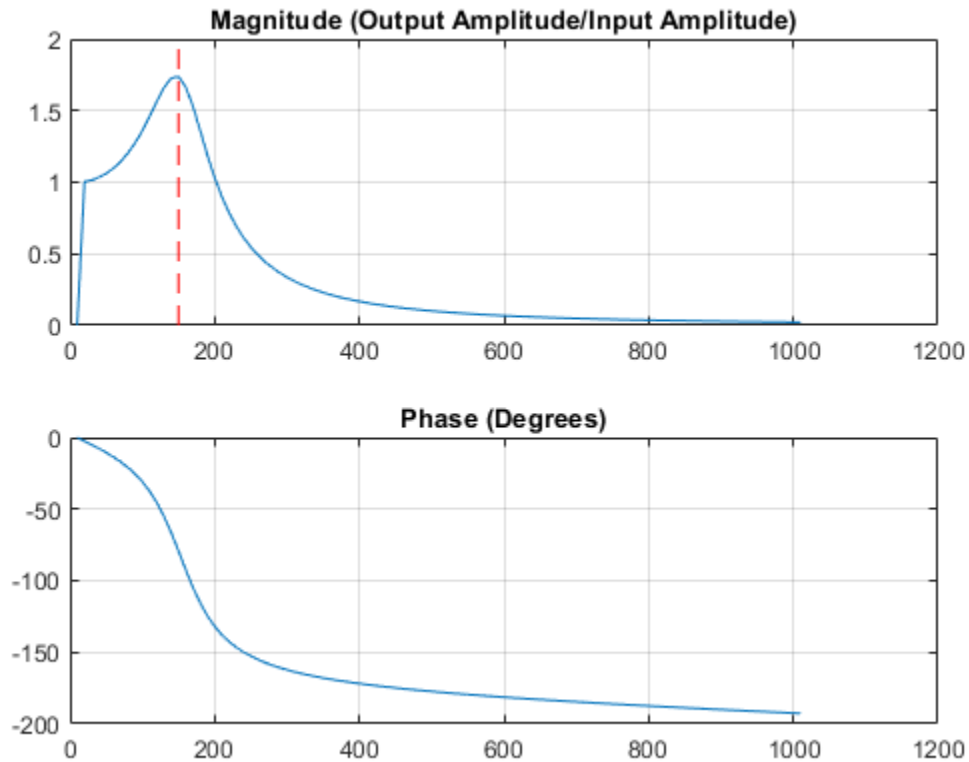
To determine the measured resonant frequency, plot the measured magnitude and phase against the plant input frequency. During simulation, the model saves these values in a signal logging object `logout` in the MATLAB workspace. You can access the logged values by using the `get` (Simulink) method. For example, to create the Bode plot for the measured frequency response of the system and draw a red cursor at 150Hz, enter:

```
figure;
subplot(211);
plot(logout.get('frequency').Values.Data, logout.get('magnitude').Values.Data);
line([150 150],[0 2], 'Color', 'red', 'LineStyle', '--');
grid on;
title('Magnitude (Output Amplitude/Input Amplitude)');

subplot(212);
plot(logout.get('frequency').Values.Data, logout.get('phase').Values.Data*180/pi)
```

```
grid on;  
title('Phase (Degrees)');  
close_system mdl, 0;
```

The Bode plot shows that the measured resonant frequency is approximately 150Hz, matching the value predicted by the plant dynamics.



## See Also

Stop Simulation | after | get | hasChanged | temporalCount

## More About

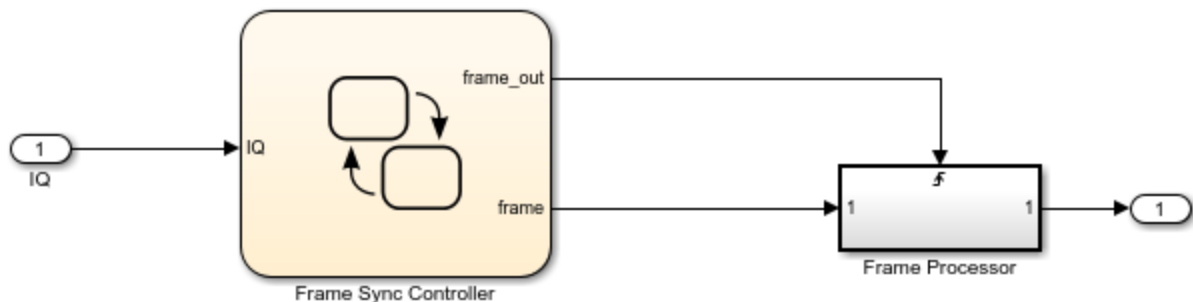
- "Complex Data in Stateflow Charts" on page 27-2
- "Control Chart Execution by Using Temporal Logic" on page 16-36
- "Detect Changes in Data Values" on page 16-64
- "Access Signal Logging Data" on page 33-46

## Detect Valid Transmission Data by Using Frame Synchronization

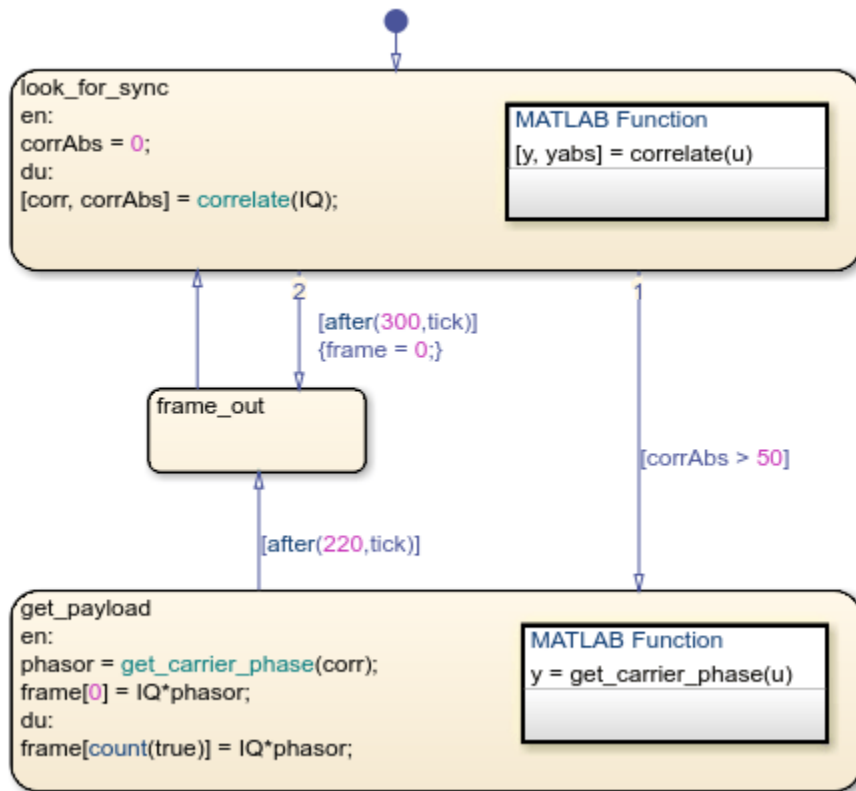
This example shows how to process complex data in a Stateflow® chart. The model uses vectors of complex data to find a fixed pattern in a signal from a communication system.

### Frame Synchronization

In communication systems, frame synchronization is a method of finding valid data in a transmission that consists of *data frames*. To aid frame synchronization, the transmitter inserts a fixed data pattern at the start of each data frame to mark the start of valid data. The receiver searches for the fixed pattern and achieves frame synchronization when the correlation between the input data and the fixed pattern is high.



In this example, the Stateflow chart *Frame Sync Controller* accepts a complex input signal *IQ* and searches for the fixed data pattern *trainSig*. After recognizing the start of a data frame, the chart stores the valid data in a complex output signal *frame*. This output signal is a vector of complex products between each valid data point and the phase angle of the carrier wave. The chart then passes the valid data to the *Frame Processor* subsystem.



Note that this model does not contain the rest of the communication system.

### Synchronize Data Frame

In the Frame Sync Controller chart, the `look_for_sync` state starts the frame synchronization algorithm. At each time step, the MATLAB® function `correlate` calculates the correlation between the input signal `IQ` and the fixed data pattern `trainSig`. The function stores the complex correlation as `corr` and its absolute value as `corrAbs`. The value of `corrAbs` is the correlation percentage, which can range from 0 to 100 percent. At 0 percent, there is no correlation. At 100 percent, there is perfect correlation.

- If `corrAbs` exceeds 50 percent, the correlation is high and the chart registers the start of a data frame. The chart takes the transition to the `get_payload` state and stores 220 valid data points in the complex vector `frame`.
- If `corrAbs` stays below 50 percent for 300 consecutive data points, the frame synchronization algorithm resets. The chart takes the transition to the `frame_out` state and triggers the Frame Processor subsystem. The chart then returns to the `look_for_sync` state.

### Store Scalar Data in a Vector

When the Frame Sync Controller chart recognizes the start of a data frame, the `get_payload` state calls the MATLAB function `get_carrier_phase` to compute the phase angle of the carrier wave. The state stores this phase angle as the local data object `phasor`. Then the state collects the scalar values of the product of `IQ*phasor` in the vector `frame`. To avoid using an extra variable as an index counter, this state indexes into this vector by using the `count` operator:

- When the state becomes active, the `entry` action stores the initial value of the product in the first element of `frame`.
- In later time steps, the `during` action stores the next values of this product in successive elements of `frame`. The indexing expression `count(true)` returns the number of time steps since the state became active.

After 220 time steps, the transition condition `[after(220,tick)]` becomes `true` and the chart exits from the state. When the chart enters the `frame_out` state, the vector `frame` contains the values of 220 products. The chart passes this data to the Frame Processor subsystem and then returns to the `look_for_sync` state.

## See Also

`after` | `count`

## More About

- “Complex Data in Stateflow Charts” on page 27-2
- “Vectors and Matrices in Stateflow Charts” on page 21-2
- “Control Chart Execution by Using Temporal Logic” on page 16-36



# Define Interfaces to Simulink Models and the MATLAB Workspace

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- “Specify Properties for Stateflow Charts” on page 28-2
- “Implement Interfaces to Simulink Models” on page 28-9
- “Reuse Charts in Models with Chart Libraries” on page 28-12
- “Create a Mask to Share Parameters with Simulink” on page 28-14
- “Specify Units for Stateflow Data” on page 28-17

## Specify Properties for Stateflow Charts

Chart properties enable you to specify how your Stateflow chart interfaces with a Simulink model. You can specify chart properties in the Property Inspector, the Model Explorer, or the Chart properties dialog box.

- To use the Property Inspector:
  - 1 To open the Property Inspector, in the **Modeling** tab, select **Property Inspector**.
  - 2 Click in the chart.
  - 3 In the Property Inspector, edit the chart properties.
- To use the Model Explorer:
  - 1 To open the Model Explorer, in the **Modeling** tab, select **Model Explorer**.
  - 2 In the **Model Hierarchy** pane, select the chart.
  - 3 In the **Chart** pane, edit the chart properties.
- To use the Chart properties dialog box:
  - 1 Right-click in the chart.
  - 2 Select **Properties**.
  - 3 Edit the chart properties.

You can also specify chart properties programmatically by using `Stateflow.Chart` objects. For more information about the Stateflow programmatic interface, see “Overview of the Stateflow API”.

### Stateflow Chart Properties

You can set the following chart properties in:

- The main and **Advanced** sections of the Property Inspector.
- The **General** tab of the Model Explorer or the Chart properties dialog box.

#### Name

Name of the chart (read-only). When you click the chart name hyperlink, the chart opens in the Stateflow Editor.

#### Machine

Name of the Simulink subsystem (read-only). When you click the machine name hyperlink, the Machine properties dialog box opens. This property is not available in the Property Inspector.

#### Action Language

Action language that defines the syntax for state and transition actions in the chart. Options include:

- MATLAB
- C

The default value is MATLAB. For more information, see “Differences Between MATLAB and C as Action Language Syntax” on page 17-5.

## State Machine Type

Type of state machine semantics to implement. Options include:

- Classic
- Mealy
- Moore

Classic charts provide the full set of Stateflow semantics. Mealy and Moore charts use a subset of these semantics. The default value is **Classic**. For more information, see “Overview of Mealy and Moore Machines” on page 7-2.

## Update Method

Method by which a simulation updates or wakes up a chart in a Simulink model.

Setting	Description
Inherited	<p>Input from the Simulink model determines when the chart wakes up during a simulation (default).</p> <p>If you define input events for the chart, the Stateflow chart is explicitly triggered by a signal on its trigger port originating from a connected Simulink block. You can set this trigger input event to occur in response to a Simulink signal. The Simulink signal can be <b>Rising</b>, <b>Falling</b>, or <b>Either</b> (rising and falling), or in response to a <b>Function Call</b>. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7.</p> <p>If you do not define input events, the Stateflow chart implicitly inherits triggers from the Stateflow model. These implicit events are the discrete or continuous sample times of the Stateflow signals providing inputs to the chart. If you define data inputs, the chart awakens at the rate of the fastest data input. If you do not define any data input for the chart, the chart wakes up as defined by the execution behavior of its parent subsystem.</p>
Discrete	<p>The Simulink model generates an implicit event at regular time intervals to awaken the Stateflow chart at the rate that you specify in the <b>Sample Time</b> chart property. Other blocks in the Simulink model can have different sample times.</p>
Continuous	<p>The Stateflow chart updates its state during major time steps only, although it computes outputs and local continuous variables during major and minor time steps. The chart can register zero crossings, which allows Simulink models to sample Stateflow charts whenever state changes occur. The Stateflow chart computes derivatives for local continuous variables. For more information, see “Continuous-Time Modeling in Stateflow” on page 25-2.</p>

## Sample Time

The time interval at which the Stateflow chart wakes up during simulation. The sample time can be any nonzero number. The sample time is in the same units as the Simulink simulation time. Other blocks in the Simulink model can have different sample times. This option is available only when you set the chart property **Update method** to **Discrete**.

**Enable zero-crossing detection**

Specifies that zero-crossing detection is enabled (default). This option is available only when you set the chart property **Update method** to Continuous. See “Disable Zero-Crossing Detection” on page 25-4.

**Enable C-bit operations**

Specifies that the operators  $\&$ ,  $\wedge$ ,  $|$ , and  $\sim$  perform bitwise operations in action statements (default). If you clear this check box:

- $\&$ ,  $|$ , and  $\sim$  perform logical operations.
- $\wedge$  performs the power operation.

This option is available only in charts that use C as the action language. For more information, see “Supported Operations for Chart Data” on page 16-5.

**User-specified state/transition execution order**

Specifies that the chart uses explicit ordering of parallel states and transitions (default). You determine the order in which the chart executes parallel states and tests transitions originating from a source. This option is available only in charts that use C as the action language. For more information, see “Execution Order for Parallel States” on page 3-60 and “Evaluate Transitions” on page 3-37.

**Export chart level functions**

Extends the scope of functions defined at the root level of the chart to other parts of the model. This option enables Simulink Caller blocks to call Stateflow functions in the local hierarchy by using qualified notation *chartName.functionName*. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

**Treat exported functions as globally visible**

Enables Stateflow and Simulink Caller blocks throughout the model to call functions exported from Stateflow without using qualified notation. This option is available only when you select the chart property **Export chart level functions**. For more information, see “Export Stateflow Functions for Reuse” on page 8-23.

**Use strong data typing with Simulink I/O**

Enables charts to interface directly with signals from Simulink models (default). The chart accepts only input signals whose data type matches the type of the corresponding Stateflow data object. Otherwise, a type mismatch error occurs. This option is available only in charts that use C as the action language. For more information, see “Strong Data Typing with Simulink Inputs and Outputs” on page 12-31.

---

**Note** The **Use strong data typing with Simulink I/O** chart property is provided for backward compatibility. Clearing this check box can produce unpredictable results and is not recommended.

---

**Execute (enter) chart at initialization**

Specifies that the chart initializes its state configuration at time 0 instead of at the first occurrence of an input event. For more information, see “Execution of a Chart at Initialization” on page 3-21.

**Initialize outputs every time chart wakes up**

Specifies that the chart resets its output values every time that the chart wakes up, not only at time 0. Output values are reset whenever a chart is triggered by function call, edge trigger, or clock tick. If you set an initial value for an output data object, the output resets to that value. Otherwise, the output resets to zero. Select this option to:

- Ensure that all outputs are defined in every chart execution.
- Prevent latching of outputs (carrying over values of outputs computed in previous executions).
- Provide all chart outputs with a meaningful initial value.

For more information, see “Initial Value” on page 12-8.

**Enable super step semantics**

Specifies that the chart can take multiple transitions in each time step until it reaches a stable state. This option is not available when you set the chart property **Update method** to Continuous. For more information, see “Super Step Semantics” on page 3-45.

**Maximum iterations in each super step**

Specifies the maximum number of transitions that the chart can take in each time step. The chart always takes one transition during a super step, so the value  $N$  that you specify represents the maximum number of *additional* transitions (for a total of  $N+1$ ). This option is available only when you select the chart property **Enable super step semantics**. For more information, see “Maximum Number of Iterations” on page 3-45.

**Behavior after too many iterations**

Specifies how the chart behaves after it reaches the maximum number of transitions in a time step.

Setting	Description
Proceed	Chart execution continues to the next time step.
Throw Error	Simulation stops and an error message appears. This setting is valid only for simulation. In generated code, chart execution always proceeds.

This option is available only when you select the chart property **Enable super step semantics**.

**Support variable-size arrays**

Specifies that chart supports input and output data that varies in dimension during simulation. See “Declare Variable-Size Inputs and Outputs” on page 22-2.

**Saturate on integer overflow**

Specifies that integer overflows saturate in the generated code. See “Handle Integer Overflow for Chart Data” on page 12-36.

**Generate preprocessor conditionals**

Generates a preprocessor conditional in the generated code. See “Code Generation Using Variant Transitions” on page 32-8.

**States when enabling**

Specifies how states behave when function-call input events reenable the chart. Options include:

- Held
- Reset

See “Control States in Charts Enabled by Function-Call Input Events” on page 14-11.

**Create output for monitoring**

Specifies that the chart produces active state output. When you enable this option, you can select one of these activity types to output:

- Child activity
- Leaf state activity

See “Monitor State Activity Through Active State Data” on page 13-2.

**Fixed-Point Properties**

You can set fixed-point properties for the chart in:

- The **Fixed Point Properties** section of the Property Inspector.
- The **Fixed Point Properties** tab of the Model Explorer or the Chart properties dialog box.

Fixed-point properties are available only in charts that use MATLAB as the action language.

**Treat These Inherited Simulink Signal Types as fi Objects**

Specifies whether the chart treats inherited fixed-point and integer signals as Fixed-Point Designer `fi` objects.

Setting	Description
Fixed-point	The chart treats all fixed-point inputs as <code>fi</code> objects (default).
Fixed-point & Integer	The chart treats all fixed-point and integer inputs as <code>fi</code> objects.

**MATLAB Chart `fimath`**

Specifies default properties for the chart.

Setting	Description
Same as MATLAB	Use the same <code>fimath</code> properties as the current default <code>fimath</code> object in MATLAB.

Setting	Description
Specify Other	Use your own default <code>fimath</code> object. You can: <ul style="list-style-type: none"> <li>• Construct a <code>fimath</code> object inside the edit box.</li> <li>• Create a <code>fimath</code> object in the MATLAB or model workspace and enter its variable name in the edit box.</li> </ul>

For more information, see “`fimath` Properties Usage for Fixed-Point Arithmetic” (Fixed-Point Designer).

## Additional Properties

You can set additional properties for the chart in:

- The **Info** tab of the Property Inspector.
- The **Documentation** tab of the Model Explorer or the Chart properties dialog box.

### Description

Description of the chart. You can enter a brief description and comments.

### Document Link

Link to online documentation for the chart. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow evaluates the link and displays the documentation.

## Machine Properties

The Stateflow machine represents all of the Stateflow blocks in a model (including all charts, state transition tables, and truth tables). You can specify machine properties in the Machine properties dialog box.

- 1 Open the Model Explorer or the Chart properties dialog box for any chart in the model.
- 2 In the **Machine** chart property field, click the machine name link.
- 3 In the Machine properties dialog box, edit the properties for the Stateflow machine.

### Simulink Model

Name of the Simulink model that defines this Stateflow machine (read-only). You change the model name when you save the model.

### Creation Date

Date on which this Stateflow machine was created (read-only).

### Creator

Name of the person who created this Stateflow machine.

**Modified**

Comment text for recording modifications to the Simulink model that defines this Stateflow machine.

**Version**

Comment text for recording the version of the Simulink model that defines this Stateflow machine.

**Description**

Description of the Stateflow machine. You can enter a brief description and comments.

**Document Link**

Link to online documentation for the Stateflow machine. You can enter a web URL address or a MATLAB command that displays documentation in a suitable online format, such as an HTML file or text in the MATLAB Command Window. When you click the **Document link** hyperlink, Stateflow evaluates the link and displays the documentation.

**See Also****More About**

- “Differences Between MATLAB and C as Action Language Syntax” on page 17-5
- “Overview of Mealy and Moore Machines” on page 7-2
- “Continuous-Time Modeling in Stateflow” on page 25-2
- “Supported Operations for Chart Data” on page 16-5



## Implement Interfaces to Simulink Models

### In this section...

- “Define a Triggered Stateflow Block” on page 28-9
- “Define a Sampled Stateflow Block” on page 28-9
- “Define an Inherited Stateflow Block” on page 28-10
- “Define a Continuous Stateflow Block” on page 28-11
- “Define Function-Call Output Events” on page 28-11
- “Define Edge-Triggered Output Events” on page 28-11

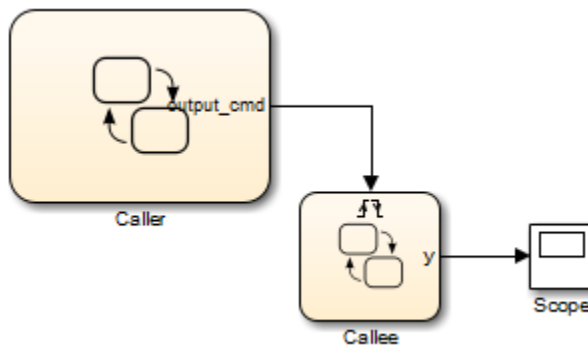
### Define a Triggered Stateflow Block

Essential conditions that define an edge-triggered Stateflow block are:

- The chart property **Update method** is **Discrete** or **Inherited**. See “Update Method” on page 28-3.
- The chart has an **Input** event defined and an edge-trigger type specified. See “Activate a Stateflow Chart by Sending Input Events” on page 14-7.

#### Triggered Stateflow Block Example

The following model shows an edge-triggered Stateflow block named Callee:



The **Input** event has an **Either** edge-trigger type. If you define more than one **Input** event, the Simulink model determines the sample times to be consistent with various rates of all the incoming signals. The outputs of a triggered Stateflow block are held after the execution of the block.

### Define a Sampled Stateflow Block

There are two ways you can define a sampled Stateflow block.

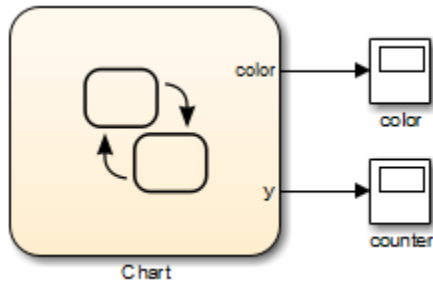
- Set the chart property **Update method** to **Discrete** and enter a **Sample Time** value. See “Update Method” on page 28-3.
- In the Stateflow Editor, in the **Modeling** tab, under **Design Data**, select **Data Input**. See “Share Input and Output Data with Simulink” on page 12-19.

Simulink determines the chart sample time to be consistent with the rate of the incoming data signal.

The **Sample Time** you set in the Chart properties dialog box takes precedence over the sample time of any input data.

### Sampled Stateflow Block Example

You specify a discrete sample rate to have Simulink trigger a Stateflow block that does use an explicit trigger port. You can specify a sample time for the chart in the Chart properties dialog box. Simulink then calls the Stateflow block at a defined, regular sample time.



The outputs of a sampled Stateflow block are held after the execution of the block.

### Define an Inherited Stateflow Block

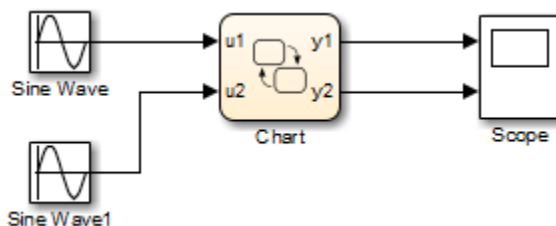
Essential conditions that define an inherited trigger Stateflow block are:

- The chart property **Update method** is **Discrete** or **Inherited**. See “Update Method” on page 28-3.
- The chart has an **Input from Simulink** data object defined using the Stateflow Editor **Add** menu or the Model Explorer. See “Share Input and Output Data with Simulink” on page 12-19. Simulink determines the chart sample time to be consistent with the rate of the incoming data signal.

### Inherited Stateflow Block Example

Simulink can trigger a Stateflow block that does not use an explicit trigger port or a specified discrete sample time. In this case, the Simulink calls the Stateflow block at a sample time determined by the model.

In this example, the chart contains two **Input from Simulink** data objects. Simulink determines the sample times to be consistent with the rates of both incoming signals.



The outputs of an inherited trigger Stateflow block are held after the execution of the block.

## Define a Continuous Stateflow Block

To define a continuous Stateflow block, set the chart **Update method** in the Chart properties dialog box to **Continuous**.

## Define Function-Call Output Events

This topic shows you how to trigger a function-call subsystem in a Simulink model with a function-call output event in a Stateflow chart. The procedure assumes that you have a programmed function-call subsystem and a Stateflow block in the model. Use the following steps to connect the Stateflow block to the function-call subsystem and trigger it during simulation.

- 1 In the **Modeling** tab, select under **Design Data**, click **Event Output**.

The Event properties dialog box appears with a default name of event and a **Scope of Output** to Simulink.

- 2 Set **Trigger** to Function Call.
- 3 Name the event appropriately and click **OK** to close the dialog box.

An output port with the name of the event you add appears on the right side of the Stateflow block.

- 4 Connect the output port on the Stateflow block for the function-call output event to the input trigger port of the subsystem.

Avoid placing any other blocks in the connection lines between the Stateflow block and the function-call subsystem.

---

**Note** You cannot connect a function-call output event from a chart to a Demux block to trigger multiple subsystems.

---

- 5 To execute the function-call subsystem, include an event broadcast of the function-call output event in the actions of the chart.

For examples of using function-call output events, see “Activate a Simulink Block by Using Function Calls” on page 14-17.

## Define Edge-Triggered Output Events

Simulink controls the execution of edge-triggered subsystems with output events. Essential conditions that define this use of triggered output events are:

- The chart has an **Output to Simulink** event with the trigger type set to **Either**. See “Activate a Simulink Block by Sending Output Events” on page 14-14.
- The Simulink block connected to the edge-triggered **Output** event has its own trigger type set to the equivalent edge trigger.

For examples of using edge-triggered output events, see “Activate a Simulink Block by Using Edge Triggers” on page 14-14.

## Reuse Charts in Models with Chart Libraries

In Simulink, you can create your own block libraries as a way to reuse the functionality of blocks or subsystems in one or more models. Similarly, you can reuse a set of Stateflow algorithms by encapsulating the functionality in a chart library.

As with other Simulink block libraries, you can specialize each instance of chart library blocks in your model to use different data types, sample times, and other properties. Library instances that inherit the same properties can reuse generated code.

For more information about Simulink block libraries, see “Custom Libraries” (Simulink).

### Create Specialized Chart Libraries for Large-Scale Modeling

- 1 Add Stateflow charts with polymorphic logic to a Simulink model.

Polymorphic logic is logic that can process data with different properties, such as type, size, and complexity.

- 2 Configure the charts to inherit the properties you want to specialize.

For a list, see “Customize Properties of Library Blocks” on page 28-12.

- 3 Optionally, customize your charts using masking.
- 4 Simulate and debug your charts.
- 5 In Simulink, create a library model. In the **Simulation** tab, select **New > Library**
- 6 Copy or drag the charts into a library model.

For an example using MATLAB Function blocks, see “Create Custom Block Libraries” (Simulink).

### Customize Properties of Library Blocks

You can customize instances of Stateflow library blocks by allowing them to inherit any of the following properties from Simulink.

Property	Inherits by Default?	How to Specify Inheritance
Type	Yes	Set the data type property to <b>Inherit: Same as Simulink</b> .
Size	Yes	Set the data size property to <b>-1</b> .
Complexity	Yes	Set the data complexity property to <b>Inherited</b> .
Limit range	No	Specify minimum and maximum values as Simulink parameters. For example, if minimum value = <code>aParam</code> and maximum value = <code>aParam + 3</code> , different instances of a Stateflow library block can resolve to different <code>aParam</code> parameters defined in their parent mask subsystems.

Property	Inherits by Default?	How to Specify Inheritance
Initial value	Depends on scope	For local data, temporary data, and outputs, specify initial values as Simulink parameters. Other data always inherits the initial value: <ul style="list-style-type: none"> <li>Parameters inherit the initial value from the associated parameter in the parent mask subsystem.</li> <li>Inputs inherit the initial value from the Simulink input signal.</li> <li>Data store memory inherits the initial value from the Simulink data store to which it is bound.</li> </ul>
Sampling mode (input)	Yes	Stateflow chart input ports always inherit sampling mode.
Data type override mode for fixed-point data	Yes	Different library instances inherit different data type override modes from their ancestors in the model hierarchy.
Sample time (block)	Yes	Set the block sample time property to <b>-1</b> .

## Limitations of Library Charts

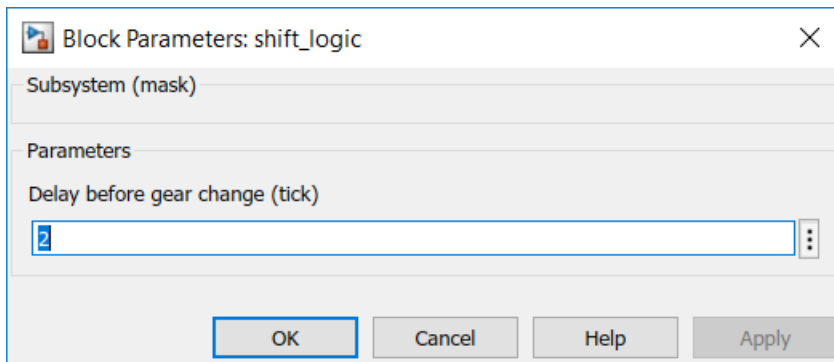
- 1 Events parented by a library Stateflow machine are invalid. The Stateflow parser flags such events as errors.
- 2 To include a linked library chart within another library chart, the two library charts must be in separate libraries.
- 3 To include a linked library chart within a Simulink subsystem, first save the library chart within a subsystem and place that library subsystem in the Simulink subsystem.

## Create a Mask to Share Parameters with Simulink

Creating masks for Stateflow charts, state transition tables, and truth tables simplifies how you use and share blocks in a Simulink model. The mask encapsulates the block by hiding the underlying logic and creates a user interface for the block. You can customize the block by:

- Changing the appearance with meaningful icons and ports.
- Creating a user interface for parameters.
- Adding customized documentation.

You decide which parameters to change through the mask user interface. You can provide meaningful descriptions of these parameters. For example, in the model `sf_car`, the `shift_logic` chart has a mask through which you can adjust the parameter `TWAIT`. To open the Mask Parameters dialog box, double-click the Stateflow chart. This dialog box contains a parameter description "Delay before gear change (tick)" and a box to edit the value. This value is tied to the parameter `TWAIT` inside the mask. When you edit the value in this box, Stateflow assigns the new value to `TWAIT` during simulation.



You can create other types of user interfaces for the mask parameters, such as check boxes, context menus, and option buttons.

You can create masks on Stateflow blocks accessible from the Simulink library: charts, state transition tables, and truth tables. You cannot mask atomic subcharts, states, or any other objects within a chart.

For more information, see "Create Block Masks" (Simulink).

### Create a Mask for a Stateflow Chart

To create a mask for the Stateflow chart in the model `old_sf_car`:

- 1 Open the model `old_sf_car`.
- 2 In the Simulink Editor, select the chart `shift_logic`.
- 3 Open the Mask Editor. In the **State Chart** tab, click **Create Mask**.

### Add an Icon to the Mask

To customize the appearance of the block icon, use drawing commands or load an image. For more information, see "Draw Mask Icon" (Simulink).

- 1 In the Mask Editor, select the **Icon & Ports** pane.
- 2 In the edit box under **Icon Drawing commands**, enter:


```
image('shift_logic.svg')
```

- 3 Click **Apply**.

## Add Parameters to the Mask

When you create a mask for a Stateflow block, you can define a custom interface for the block parameters. You provide access to the block parameters by defining corresponding parameters with the same name in the Mask Editor. A user interface to these parameters is then provided through a Mask Parameters dialog box. The mask parameters appear as editable fields in the Mask Parameters dialog box. Stateflow applies these values to the corresponding block parameters during simulation.

For example, the chart `shift_logic` has a parameter `TWAIT`. To add `TWAIT` as a parameter to the mask:

- 1 In the Mask Editor, select the **Parameters & Dialog** pane.
- 2 Double-click the **Edit parameter** icon .
- 3 Next to **edit**, under **Prompt**, enter the prompt for the new mask parameter in the Mask Parameters dialog box:

```
Delay before gear change(tick)
```

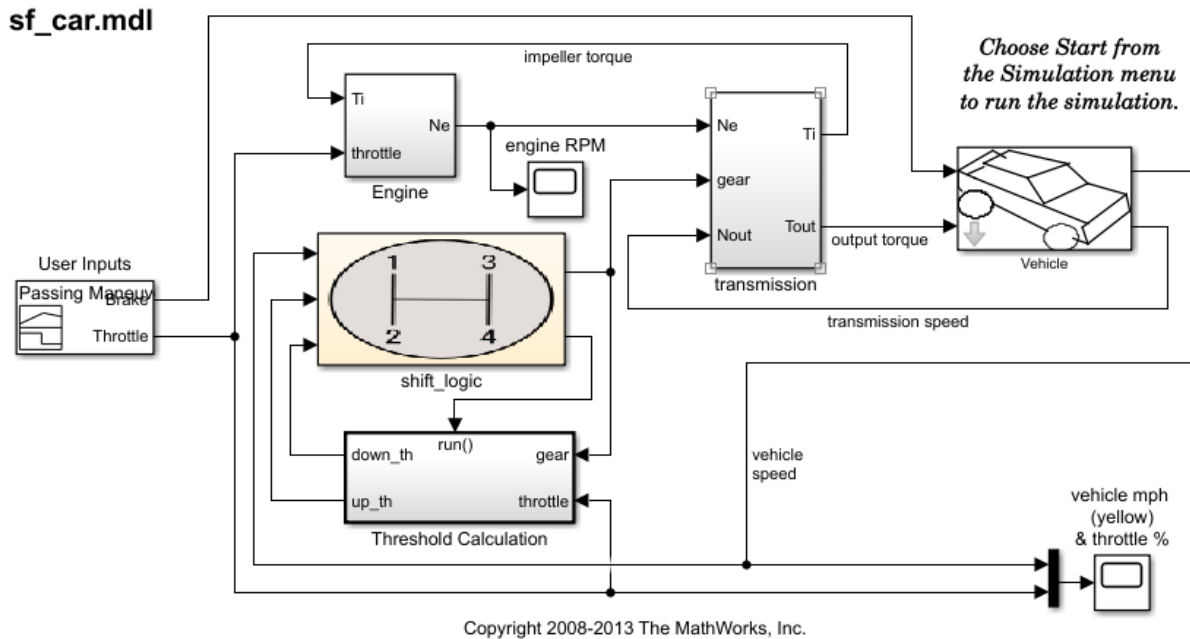
- 4 Under **Name**, enter the name of the parameter in the mask:

```
TWAIT
```

- 5 Click **Apply**.
- 6 Click **OK**.

## View the New Mask

After creating a mask, the new icon for the `shift_logic` chart appears in the Simulink canvas. If you double-click the icon, the Mask Parameters dialog box opens. This dialog box has the prompt for the parameter `TWAIT`. The value in the edit box is assigned to the parameter `TWAIT` during simulation.



## Look Under the Mask

You can view and edit the contents of a masked block by clicking the **Look inside mask** badge on the chart. The badge is a downward facing arrow in the lower-left corner of the chart. Alternatively, in the **State Chart** tab, click **Look Under Mask**. Looking under a mask does not unmask the block.

## Edit the Mask

To edit a mask, in the **State Chart** tab, click **Edit Mask**. In the Mask Editor, you can modify the mask icon, change the parameters, or add documentation. To remove the mask, click **Unmask** in the lower corner of the Mask Editor. After you change a mask, click **Apply** to save the changes.

## See Also

### More About

- “Share Parameters with Simulink and the MATLAB Workspace” on page 12-21
- “Masking Fundamentals” (Simulink)
- “Mask Editor Overview” (Simulink)
- “Draw Mask Icon” (Simulink)



## Specify Units for Stateflow Data

### Units for Input and Output Data

Stateflow charts in Simulink models support the specification of physical units as properties for data inputs and outputs. Specify units by using the **Unit (e.g., m, m/s<sup>2</sup>, N\*m)** parameter for input or output data on charts, state transition tables, or truth tables. When you start typing in the field, this parameter provides matching suggestions for units that Simulink supports. By default, the property is set to inherit the unit from the Simulink signal on the corresponding input or output port. If you select the **Data must resolve to signal object** property for output data, you cannot specify units. In this case, output data is assigned the same unit type as the Simulink signal connected to the output port.

To display the units on the Simulink lines in the model, in the **Debug** tab, select **Information Overlays > Port Units**.

### Consistency Checking

Stateflow checks the consistency of the signal line unit from Simulink with the unit setting for the corresponding input or output data in the Stateflow block. If the units do not match, Stateflow displays a warning during model update.

### Units for Stateflow Limitations

The unit property settings do not affect the execution of the Stateflow block. Stateflow checks only consistency with the corresponding Simulink signal line connected to the input or output. It does not check consistency of assignments inside the Stateflow blocks. For example, Stateflow does not warn against an assignment of an input with unit set to `ft` to an output with unit set to `m`. Stateflow does not perform unit conversions.

### See Also

#### More About

- “Unit Specification in Simulink Models” (Simulink)



# Structures and Bus Signals in Stateflow Charts

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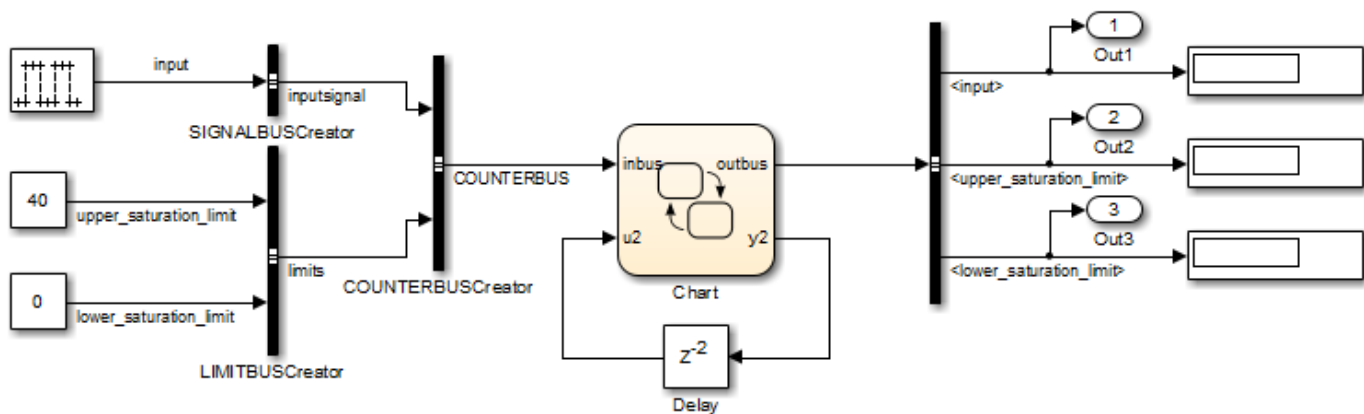
- “Access Bus Signals Through Stateflow Structures” on page 29-2
- “Index and Assign Values to Stateflow Structures” on page 29-7
- “Integrate Custom Structures in Stateflow Charts” on page 29-11

## Access Bus Signals Through Stateflow Structures

A Stateflow structure is a data type that you define from a `Simulink.Bus` object. Using Stateflow structures, you can bundle data of different size and type to create:

- Inputs and outputs that access Simulink bus signals from Stateflow charts, Truth Table blocks, and MATLAB Function blocks.
- Local data in Stateflow charts, truth tables, graphical functions, MATLAB functions, and boxes.
- Temporary data in Stateflow graphical functions, truth tables, and MATLAB functions.

For example, in the model `sf_bus_demo`, a Stateflow chart receives a bus input signal by using the structure `inbus` and outputs a bus signal from the structure `outbus`. The input signal comes from the Simulink Bus Creator block `COUNTERBUSCreator`, which bundles signals from two other Bus Creator blocks. The output structure `outbus` connects to a Simulink Bus Selector block. Both `inbus` and `outbus` derive their type from the `Simulink.Bus` object `COUNTERBUS`.



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The elements of a Stateflow structure data type are called *fields*. Fields can be any combination of individual signals, muxed signals, vectors, and other structures (also called substructures). Each field has its own data type. The data type does not have to match the type of any other field in the structure. For example, in the model `sf_bus_demo`, each of the structures `inbus` and `outbus` has two fields:

- `inputsignal` is a substructure with one field, `input`.
- `limits` is a substructure with two fields, `upper_saturation_limit` and `lower_saturation_limit`.

## Define Stateflow Structures

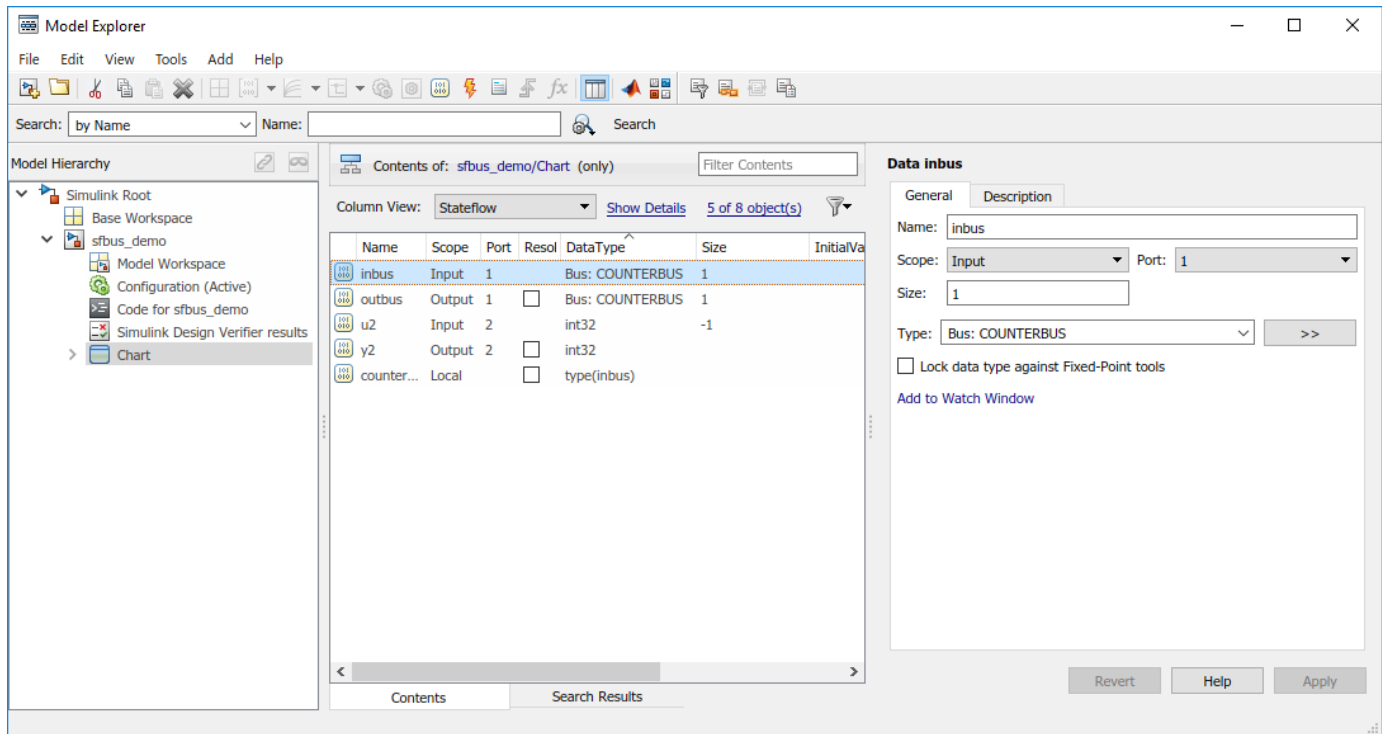
- 1 To define the structure data type, create a Simulink bus object in the base workspace, as described in “Create and Specify Simulink.Bus Objects” (Simulink).
- 2 Add a data object to the chart, as described in “Add Stateflow Data” on page 12-2.

To define temporary structures in truth tables, graphical functions, and MATLAB functions, add a data object *to your function*. For more information, see “Add Data Through the Model Explorer” on page 12-3.

- 3 Set the **Scope** property for the structure. Your choices are:
  - Input
  - Output
  - Local
  - Parameter
  - Temporary
- 4 Set the **Type** property for the structure. Depending on its scope, a Stateflow structure can have one of these data types.

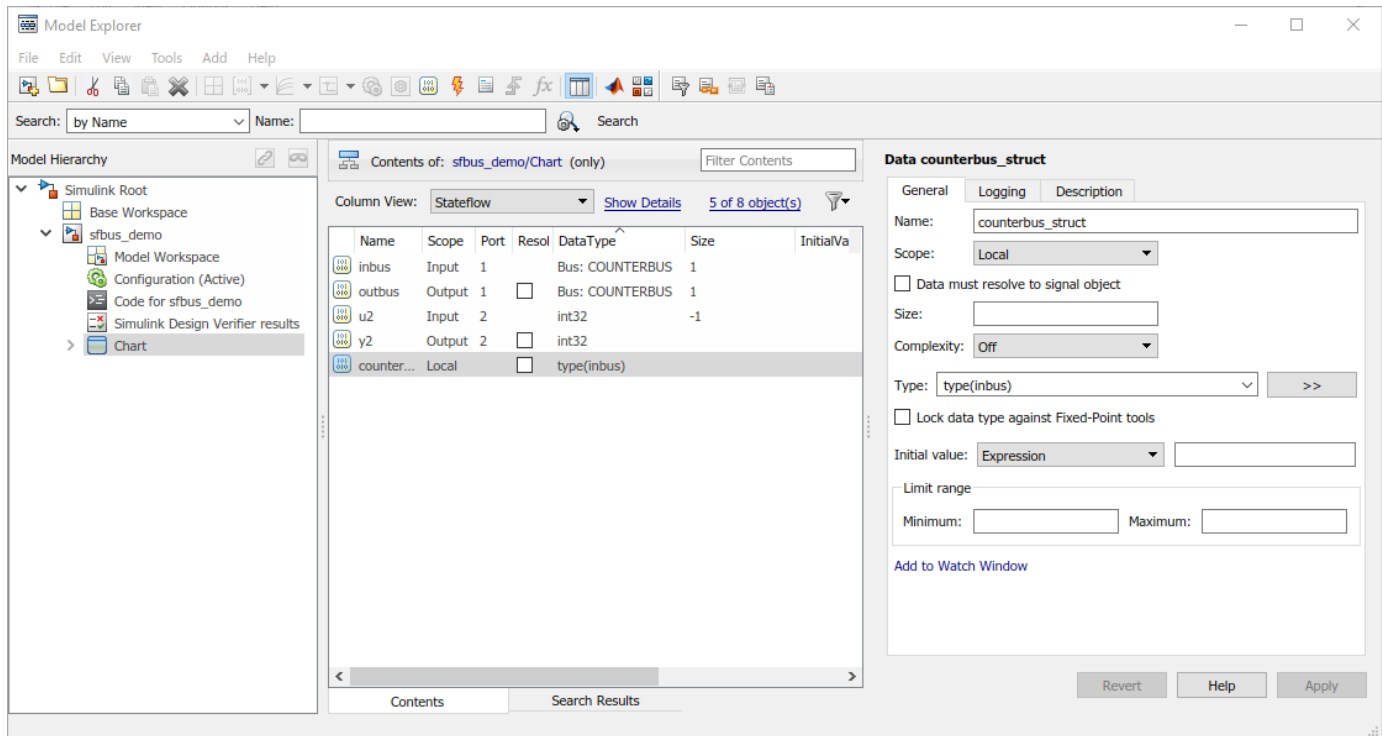
Type	Description
Inherit: Same as Simulink	<p>This option is available for input structures only. The input structure inherits its data type from the Simulink bus signal in your model that connects to it. The Simulink bus signal must be a nonvirtual bus. For more information, see “Virtual and Nonvirtual Buses” on page 29-5.</p> <p>In the base workspace, specify a <code>Simulink.Bus</code> object with the same properties as the bus signal that connects to the Stateflow input structure. These properties must match:</p> <ul style="list-style-type: none"> <li>• Number, name, and type of inputs</li> <li>• Dimension</li> <li>• Sample Time</li> <li>• Complexity</li> <li>• Sampling Mode</li> </ul> <p>If the input signal comes from a Bus Creator block, in the Bus Creator dialog box, specify an appropriate bus object for <b>Output data type</b> field. When you specify the bus object, Simulink verifies that the properties of the <code>Simulink.Bus</code> object in the base workspace match the properties of the Simulink bus signal.</p>
Bus: <object name>	<p>In the <b>Type</b> field, replace &lt;<i>object name</i>&gt; with the name of the <code>Simulink.Bus</code> object that defines the Stateflow structure.</p> <p>For input or output structures, you are not required to specify the bus signal in your Simulink model that connects to the Stateflow structure. If you do specify a bus signal, its properties must match the <code>Simulink.Bus</code> object that defines the Stateflow structure.</p>
<data type expression>	<p>In the <b>Type</b> field, replace &lt;<i>data type expression</i>&gt; with an expression that evaluates to a data type. For example:</p> <ul style="list-style-type: none"> <li>• Enter the name of the <code>Simulink.Bus</code> object that defines the Stateflow structure.</li> <li>• For structures with scopes other than Output, use the Stateflow type operator to copy the type of another structure. For more information, see “Specify Structure Types by Calling the type Operator” on page 29-4.</li> </ul>

For example, in the `sf_bus_demo` model, the input structure `inbus` and the output structure `outbus` derive their type through a type specification of the form `Bus: COUNTERBUS`.



## Specify Structure Types by Calling the type Operator

To specify structure types, you can use expressions that call the Stateflow type operator. This operator sets the type of one structure to the type of another structure in the Stateflow chart. For example, in the `sf_bus_demo` model, a type operator expression specifies the type of the local structure `counterbus_struct` in terms of the input structure `inbus`. Both structures are defined from the Simulink.Bus object COUNTERBUS. For more information, see “Derive Data Types from Other Data Objects” on page 12-30.



## Virtual and Nonvirtual Buses

Simulink models support virtual and nonvirtual buses. Nonvirtual buses read their inputs from data structures stored in contiguous memory. Virtual buses read their inputs from noncontiguous memory. For more information, see “Types of Composite Signals” (Simulink).

Stateflow charts support only nonvirtual buses. Stateflow input structures can accept virtual bus signals and convert them to nonvirtual bus signals. Stateflow input structures cannot inherit properties from virtual bus signals. If the input to a chart is a virtual bus, set the **Type** property of the input structure through a type specification of the form Bus: *<object name>*.

## Debug Structures

To debug a Stateflow structure, open the Stateflow Breakpoints and Watch window and examine the values of structure fields during simulation. To view the values of structure fields at the command line, use dot notation to index into the structure. For more information, see “Inspect and Modify Data and Messages While Debugging” on page 33-9.

## Guidelines for Structure Data Types

- Define each structure from a Simulink.Bus object in the base workspace.
- Structures cannot have a constant scope.
- Structures of parameter scope must be tunable.
- Data array objects cannot contain structures.
- You cannot define structures for Stateflow machines. For more information, see “Overview of Stateflow Objects” on page 2-2.

## **See Also**

Simulink.Bus

## **More About**

- “Index and Assign Values to Stateflow Structures” on page 29-7
- “Integrate Custom Structures in Stateflow Charts” on page 29-11
- “Add Stateflow Data” on page 12-2
- “Derive Data Types from Other Data Objects” on page 12-30
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Create and Specify Simulink.Bus Objects” (Simulink)
- “Types of Composite Signals” (Simulink)



## Index and Assign Values to Stateflow Structures

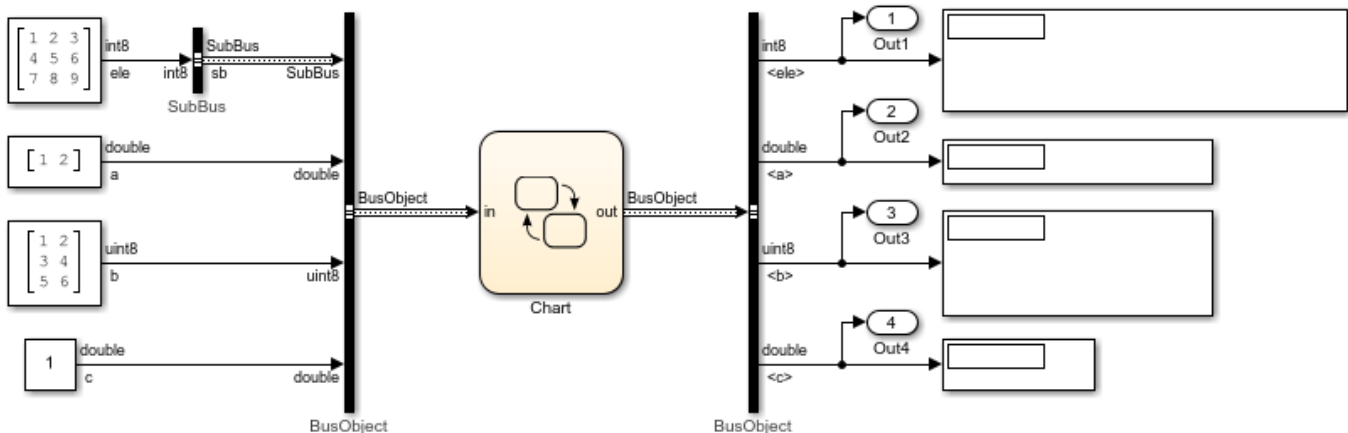
This example shows how to access and modify the contents of a Stateflow® structure. Stateflow structures enable you to bundle data of different sizes and types together into a single `Simulink.Bus` (Simulink) object. Using dot notation and numeric indices, you can access and modify the contents of a Stateflow structure. For more information, see “Access Bus Signals Through Stateflow Structures” on page 29-2

### Index Substructures and Fields

To index substructures and fields of Stateflow structures, use dot notation. The first part of a name identifies the parent object. Subsequent parts identify the children along a hierarchical path. When the parent is a structure, its children are individual fields or fields that contain other structures (also called substructures). The names of the fields of a Stateflow structure match the names of the elements of the `Simulink.Bus` object that defines the structure.

For example, the chart in this model contains an input structure (`in`), an output structure (`out`), and two local structures (`localbus` and `subbus`).

- The chart defines the input structure `in`, the output structure `out`, and the local structure `localbus` by using the `Simulink.Bus` object `BusObject`. These structures have four fields: `sb`, `a`, `b`, and `c`. The field `sb` is a substructure defined from the `Simulink.Bus` object `SubBus`.
- The chart defines the local structure `subbus` by using the `Simulink.Bus` object `SubBus`. This structure has one field called `ele`.



This list illustrates how the Stateflow chart resolves symbols in dot notation for indexing the fields of these structures:

- `in.c` — Field `c` of input structure `in`.
- `out.sb` — Substructure `sb` of output structure `out`.
- `in.a(1)` — First value of the vector field `a` of input structure `in`.
- `subbus.ele(2,2)` — Value in the second row, second column of field `ele` of local structure `subbus`.
- `in.sb.ele(3,4)` — Value in the third row, fourth column of field `ele` of substructure `in.sb`.

## Assign Values to Structures and Fields

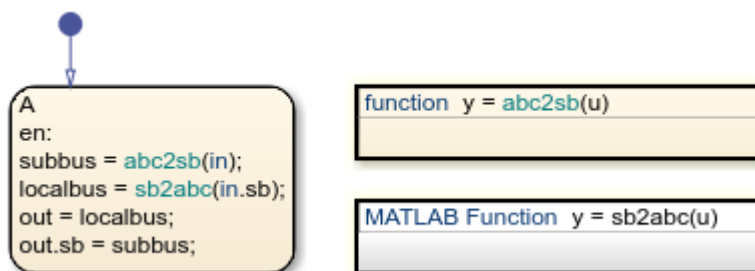
You can assign values to any Stateflow structure, substructure, or a field of a structure with a scope different from `Input`.

- To assign one structure to another structure, define both structures from the same `Simulink.Bus` object in the base workspace.
- To assign one structure to a substructure of a different structure (or the other way around), define the structure and substructure from the same `Simulink.Bus` object.
- To assign a field of one structure to a field of another structure, the fields must have the same type and size. You can define the Stateflow structures from different `Simulink.Bus` objects.

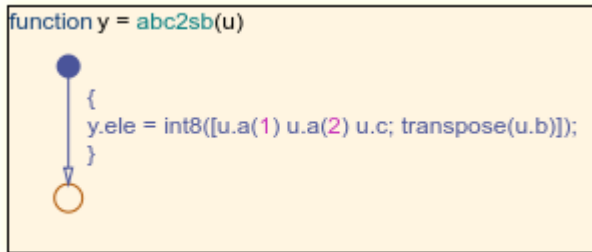
This list presents valid and invalid structure assignments based on the structure specifications for this example:

- `in = localbus;` — Invalid. You cannot write to input structures.
- `out = localbus;` — Valid. Both `out` and `localbus` are defined from the same `Simulink.Bus` object `BusObject`.
- `subbus = in;` — Invalid. The structures `subbus` and `in` are defined from different `Simulink.Bus` objects.
- `subbus = in.sb;` — Valid. The structure `subbus` and the substructure `in.sb` are defined from the same `Simulink.Bus` object `SubBus`.
- `in.sb = subbus;` — Invalid. You cannot write to substructures of input structures.
- `out.sb = subbus;` — Valid. The substructure `out.sb` and the structure `subbus` are defined from the same `Simulink.Bus` object `SubBus`.
- `in.c = out.c;` — Invalid. You cannot write to fields of input structures.
- `out.sb.ele = subbus.ele;` — Valid. The field `out.sb.ele` has the same type and size as the field `subbus.ele` (3-by-3 matrices of type `int8`).
- `localbus.a(1) = in.c;` — Valid. The value `localbus.a(1)` has the same type and size as the field `in.c` (scalars of type `double`).

For instance, in the entry action for state `A`, the chart calls the functions `abc2sb` and `sb2abc` and stores the results in the local structures `localbus` and `subbus`. Then, the chart writes to the output structure `out` by combining the values of the local structures `localbus` and `subbus`.



The graphical function `abc2sb` takes a structure of type `BusObject` and returns a structure of type `SubBus`. The function combines the values of the fields `a`, `b`, and `c` from its input and rearranges them in a 3-by-3 matrix of type `int8`. Then, the function stores this matrix as the field `ele` of the output structure.

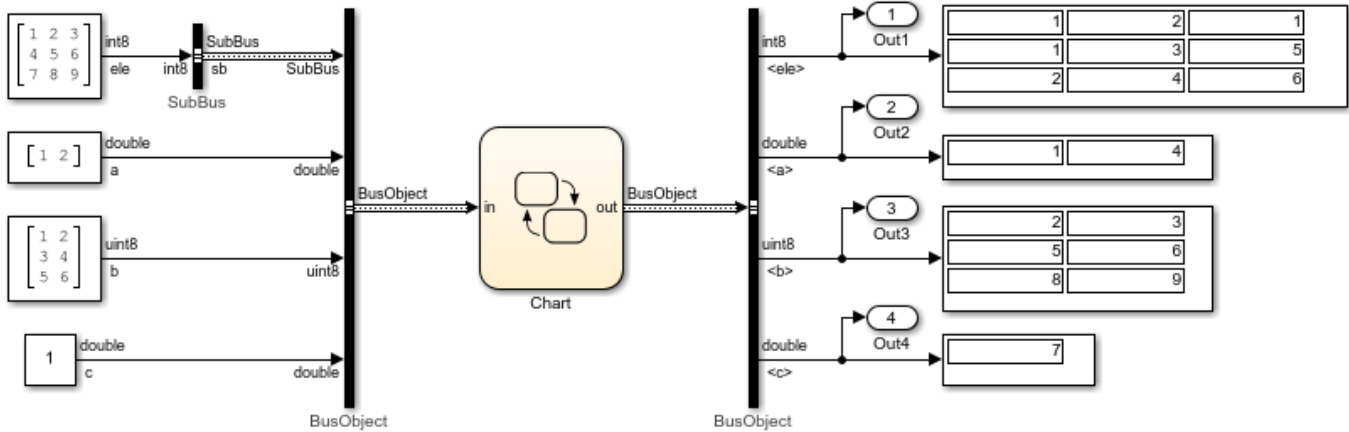


The MATLAB® function `sb2abc` takes a structure of type `SubBus` and returns a structure of type `BusObject`. The function decomposes the value of the field `ele` from its input into three components: a vector, a 3-by-2 matrix, and a scalar. The function stores these components in a local MATLAB struct `Y` that has the same structure as the Simulink `Bus` object `BusObject`. Then, the function assigns the value of the MATLAB struct `Y` to the output structure `y`.

```
function y = sb2abc(u)
% extract data from input structure
E = int8(magic(3));
A = double(u.ele(1:2,1));
B = uint8(u.ele(:,2:3));
C = double(u.ele(3,1));
% create local structure
X = struct('ele',E);
Y = struct('sb',X,'a',A,'b',B,'c',C);
% assign value to output structure
y = Y;
end
```

### Run the Simulation

When you simulate the example, the chart uses the values of the field `sb` of the input bus to populate the fields `a`, `b`, `c` of the output bus. The chart also uses the values of the fields `a`, `b`, `c` of the input bus to populate the field `sb` of the output bus.



**See Also**

Simulink.Bus | struct

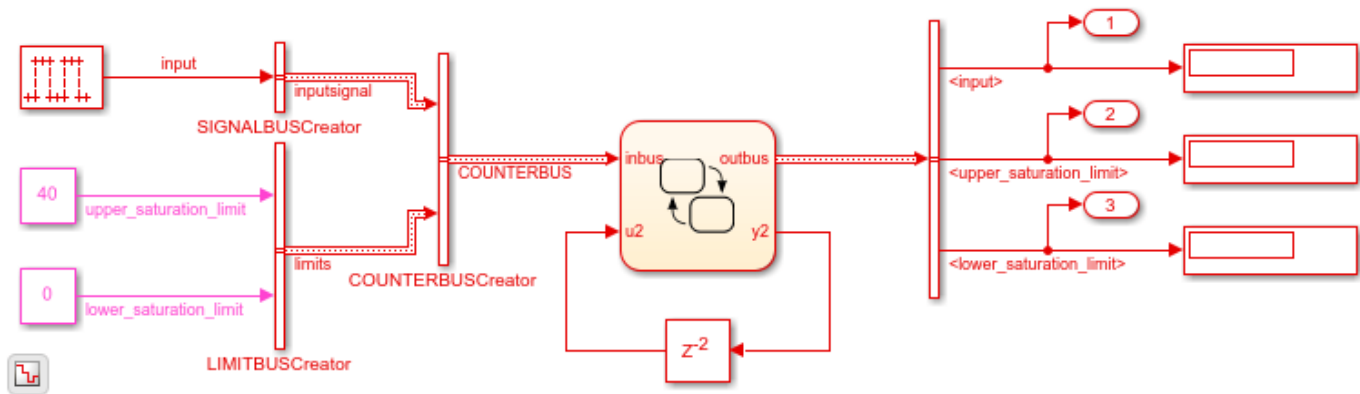
**More About**

- “Access Bus Signals Through Stateflow Structures” on page 29-2
- “Identify Data by Using Dot Notation” on page 12-39
- “Connect Structures in MATLAB Functions to Simulink Bus Signals” on page 9-12

## Integrate Custom Structures in Stateflow Charts

This example shows how to use structures from custom code in a Stateflow® chart. You can define structure typed data in C code and integrate it with Stateflow structures and Simulink® bus signals. By sharing data with custom code, you can augment the capabilities supported by Stateflow and take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

In this example, a Stateflow chart processes data from one Simulink bus signal and outputs the result to another Simulink bus signal. Both the input and output bus signals are defined by the Simulink.Bus (Simulink) object COUNTERBUS. In the chart, the Simulink bus signals interface with the Stateflow structures `inbus` and `outbus`. The chart calls a custom C function to write to the output structure `outbus`.



### Define Custom Structures in C Code

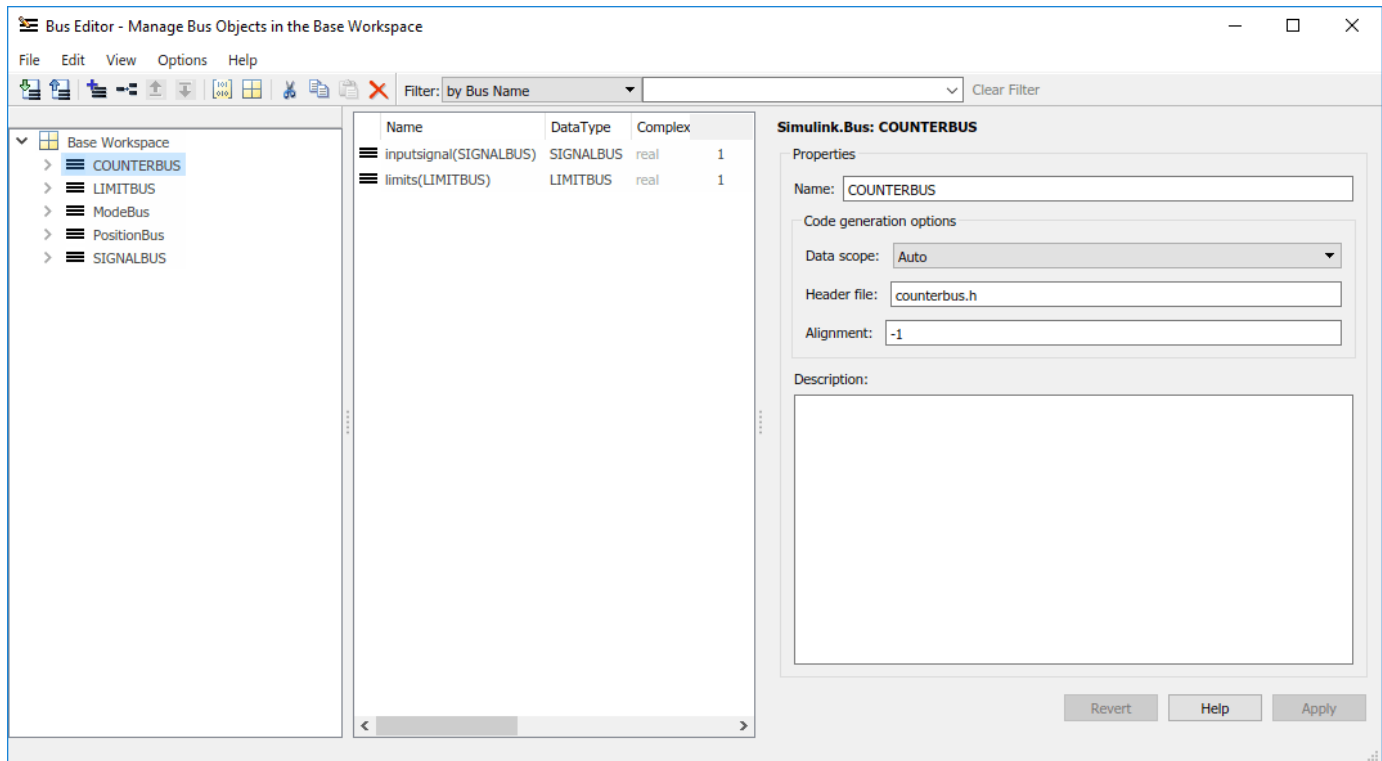
1. In your C code, define a structure by creating a custom header file. The header file contains typedef declarations that define the properties of the custom structure. For example, in this model, the header file `counterbus.h` declares three custom structures:

```
...
typedef struct {
    int input;
} SIGNALBUS;

typedef struct {
    int upper_saturation_limit;
    int lower_saturation_limit;
} LIMITBUS;

typedef struct {
    SIGNALBUS inputsignal;
    LIMITBUS limits;
} COUNTERBUS;
...
```

2. In the Bus Editor, define a Simulink.Bus object that matches each custom structure typedef declaration. In the **Header file** field of each Simulink.Bus object, enter the name of the header file that contains the matching typedef declaration.



3. Configure the Stateflow chart to include custom C code.

- To include custom code for simulation, see “Access Custom C Code in Nonlibrary Charts” on page 31-4.
- To include custom code for code generation, see “Integrate External Code by Using Model Configuration Parameters” (Simulink Coder).

4. Build and run your model.

### Pass Stateflow Structures to Custom Code

When you call custom code functions that take structure pointers as arguments, pass the Stateflow structures by address. To pass the address of a Stateflow structure or one of its fields to a custom function, use the `&` operator and dot notation:

- `&outbus` provides the address of the Stateflow structure `outbus`.
- `&outbus.inputsignal` provides the address of the substructure `inputsignal` of the structure `outbus`.
- `&outbus.inputsignal.input` provides the address of the field `input` of the substructure `outbus.inputsignal`.

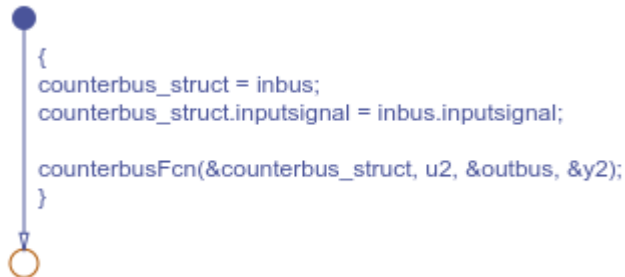
For more information, see “Index and Assign Values to Stateflow Structures” on page 29-7.

For instance, this example contains a custom C function `counterbusFcn` that takes structure pointers as arguments. The custom header file `counterbus.h` contains this function declaration:

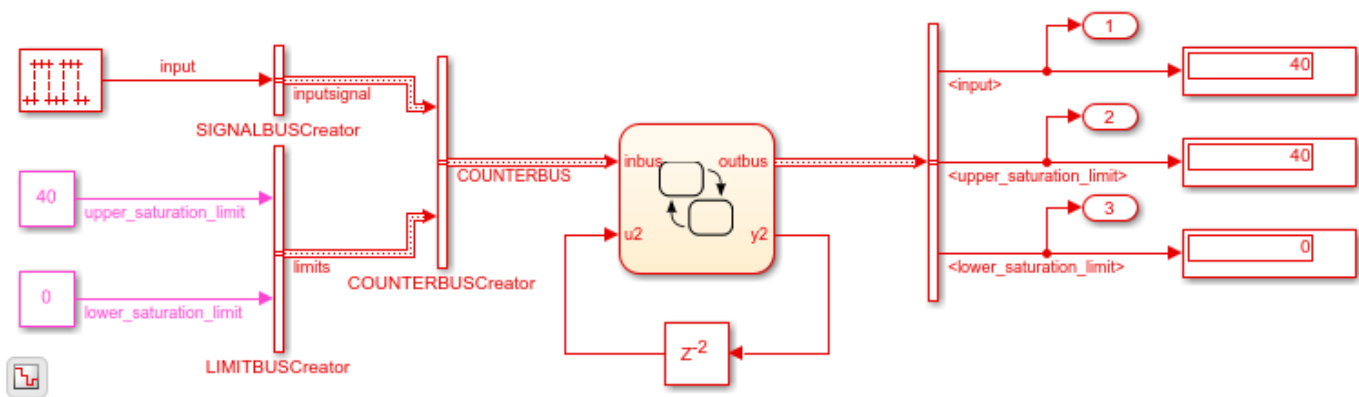
```
extern void counterbusFcn(COUNTERBUS *u1, int u2, COUNTERBUS *y1, int *y2);
```

The chart passes the addresses to the Stateflow structures `counterbus_struct` and `outbus` by using this function call:

```
counterbusFcn(&counterbus_struct, u2, &outbus, &y2);
```



The function reads the value of the chart input `u2` and the local structure `counterbus_struct`. It writes to the chart output `y2` and the output structure `outbus`.



## See Also

Simulink.Bus

## More About

- “Access Bus Signals Through Stateflow Structures” on page 29-2
- “Index and Assign Values to Stateflow Structures” on page 29-7
- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “Access Custom Code Variables and Functions in Stateflow Charts” on page 31-11
- “Integrate External Code by Using Model Configuration Parameters” (Simulink Coder)

## See Also





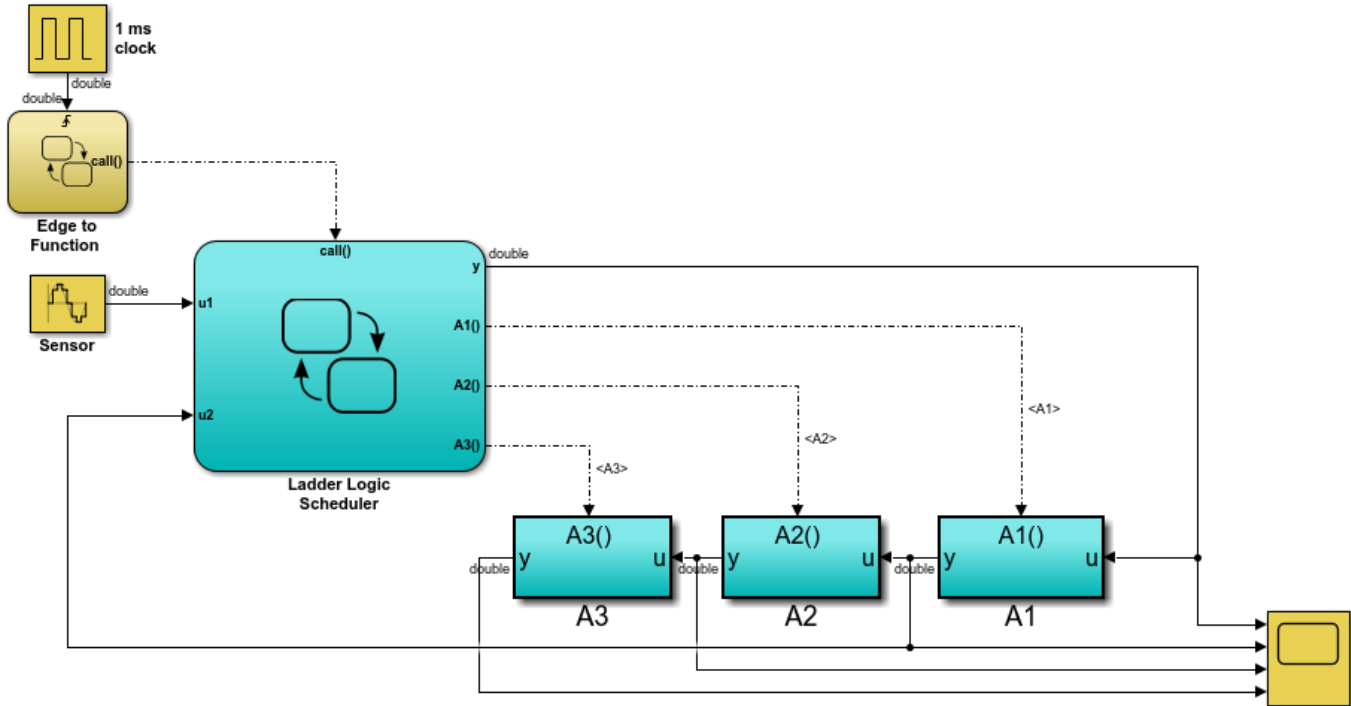
# Stateflow Design Patterns

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- “Schedule Multiple Subsystems in a Single Step” on page 30-2
- “Schedule a Subsystem Multiple Times in a Single Step” on page 30-6
- “Schedule Subsystems to Execute at Specific Times” on page 30-9
- “Reduce Transient Signals by Using Debouncing Logic” on page 30-12
- “Detect Faults in Aircraft Elevator Control System” on page 30-19
- “Map Fault Conditions to Actions by Using Truth Tables” on page 30-24
- “Design for Isolation and Recovery in a Chart” on page 30-27
- “Model a Launch Abort System” on page 30-31
- “Modeling a Fault-Tolerant Fuel Control System” on page 30-35
- “Model a Power Window Controller” on page 30-50
- “Model a Fitness Tracker” on page 30-57

## Schedule Multiple Subsystems in a Single Step

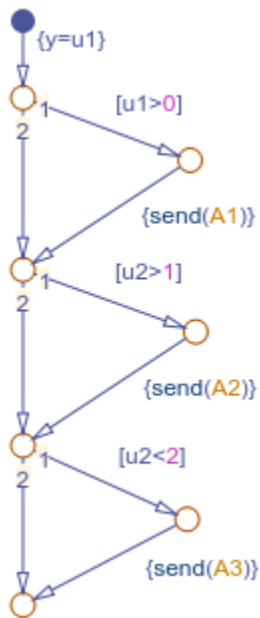
This example shows how to design a *ladder logic scheduler* in Stateflow®. The ladder logic scheduler design pattern allows you to specify the order in which multiple Simulink® subsystems execute in a single time step. Stateflow schedulers extend control of subsystem execution in a Simulink model, which determines order of execution implicitly based on block connectivity and sample time propagation.



### Key Behavior of the Ladder Logic Scheduler

In this example, the Ladder Logic Scheduler chart broadcasts a series of function-call output events to execute three function-call subsystems (A1, A2, and A3). During each time step:

- 1 The Simulink model activates the Edge to Function chart at the rising edge of the 1-millisecond pulse generator.
- 2 The Edge to Function chart broadcasts the function-call output event `call` to activate Ladder Logic Scheduler chart.
- 3 The Ladder Logic Scheduler chart uses sequencing ladder logic to broadcast function-call output events based on the values of the input signals `u1` and `u2`.

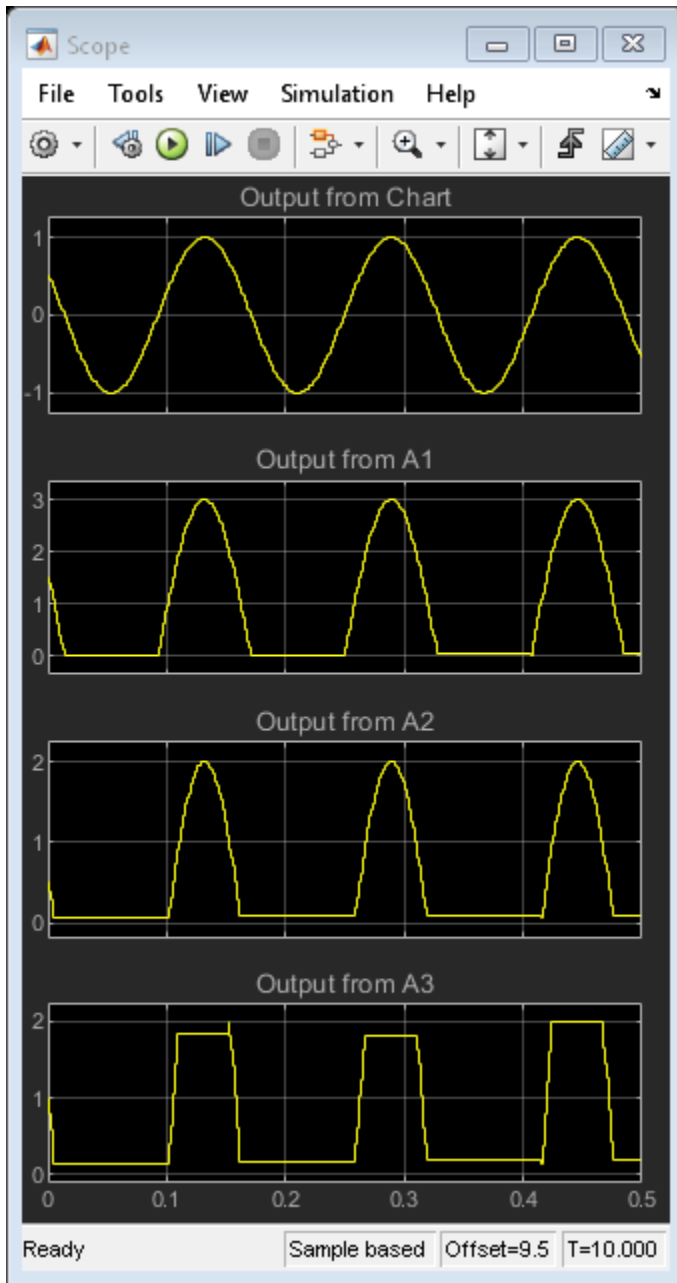


## Sequencing Ladder Logic

The chart evaluates each condition sequentially. When a condition is valid, the chart calls the `send` operator to broadcast an output event. The corresponding subsystem computes its output and returns control back to the Ladder Logic Scheduler chart.

### Run the Ladder Logic Scheduler

When you simulate the model, the scope shows the input and output of each function-call subsystem.



During each time step, the Ladder Logic Scheduler chart executes the subsystems depending on the values of the input signals  $u1$  and  $u2$ :

- 1 If  $u1$  is positive, the chart sends a function-call output event to execute subsystem A1. This subsystem multiplies the value of  $u1$  by a gain of 3 and passes this value back to the Ladder Logic Scheduler chart as input  $u2$ . Control returns to the next condition in the Ladder Logic Scheduler chart.
- 2 If  $u2$  is greater than 1, the chart sends a function-call output event to execute subsystem A2. This subsystem decreases the value of  $u2$  by 1. Control returns to the final condition in the Ladder Logic Scheduler chart.

- 3 If  $u_2$  is less than 2, the chart sends a function-call output event to execute subsystem A3. This subsystem multiplies its input by a gain of 2.

In the scope, horizontal segments indicate time steps when a subsystem does not execute.

## See Also

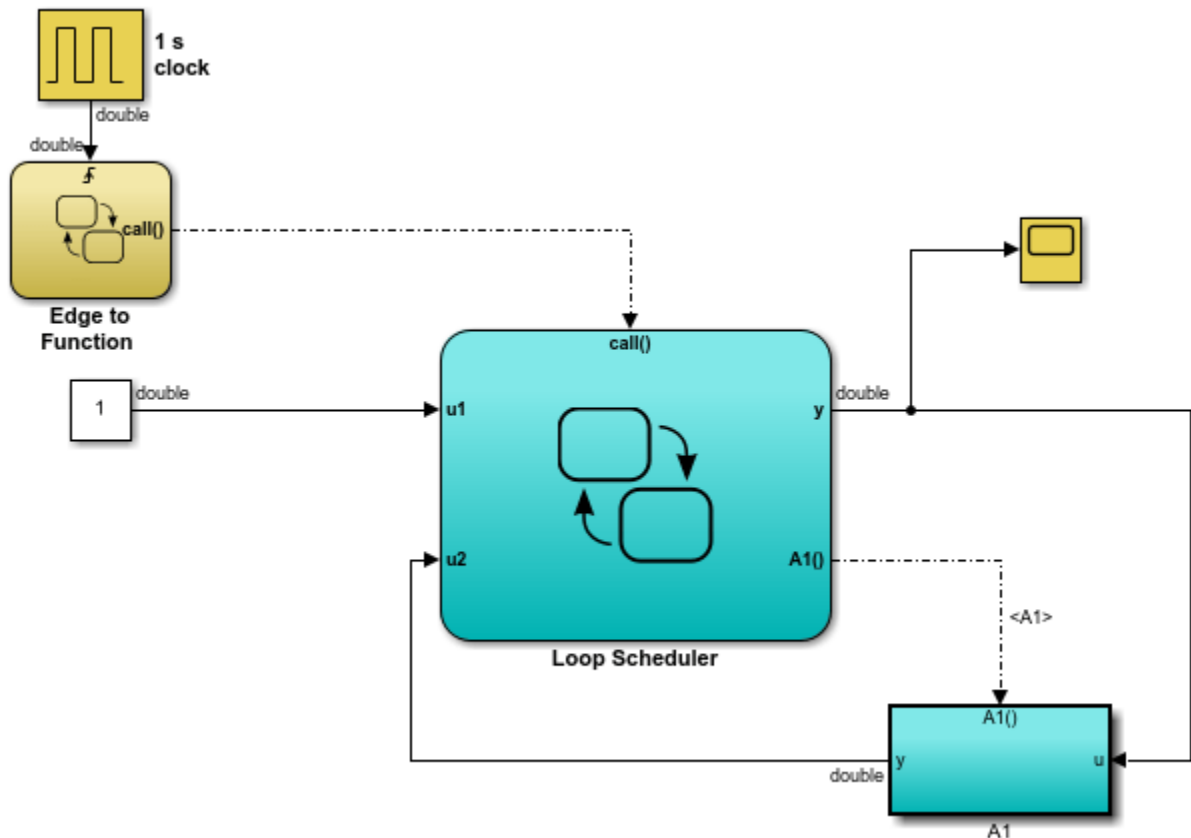
send

## More About

- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Activate a Simulink Block by Sending Output Events” on page 14-14

## Schedule a Subsystem Multiple Times in a Single Step

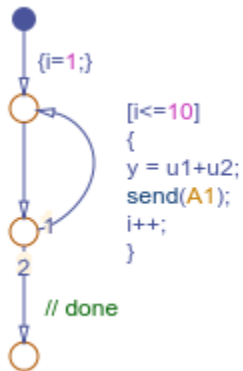
This example shows how to design a *loop scheduler* in Stateflow®. The loop scheduler design pattern enables you to execute a Simulink® subsystem multiple times in a single time step. Stateflow schedulers extend control of subsystem execution in a Simulink model, which determines order of execution implicitly based on block connectivity and sample time propagation.



### Key Behavior of the Loop Scheduler

In this example, the Loop Scheduler chart broadcasts a function-call output event to execute the function-call subsystem A1 multiple times every time step. During each time step:

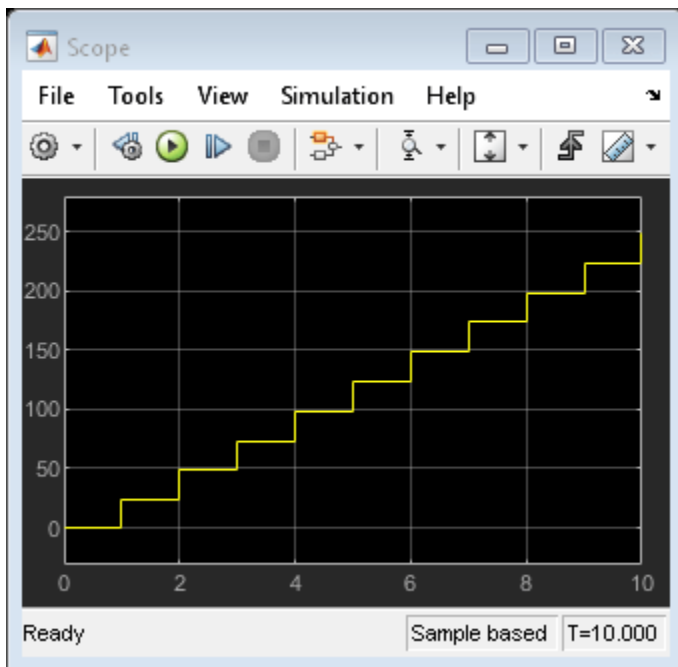
- 1 The Simulink model activates the Edge to Function chart at the rising edge of the 1-millisecond pulse generator.
- 2 The Edge to Function chart broadcasts the function-call output event `call` to activate the Loop Scheduler chart.
- 3 The Loop Scheduler chart calls the `send` operator to broadcast the function-call output event `A1` multiple times.



Each broadcast of the event A1 executes the subsystem A1. The subsystem computes its output and returns control back to the Loop Scheduler chart.

### Run the Loop Scheduler

When you simulate the model, the scope displays the value of  $y$  at each time step.



During each time step, the value of  $y$  increases by 25 because:

- The flow chart in the Loop Scheduler implements a `for` loop that iterates 10 times.
- In each iteration of the `for` loop, the chart increments  $y$  by 1 (the constant value of input  $u1$ ).
- Each time that the chart broadcasts the output event to subsystem A1, the subsystem increments  $y$  by 1.5.

### See Also

`send`

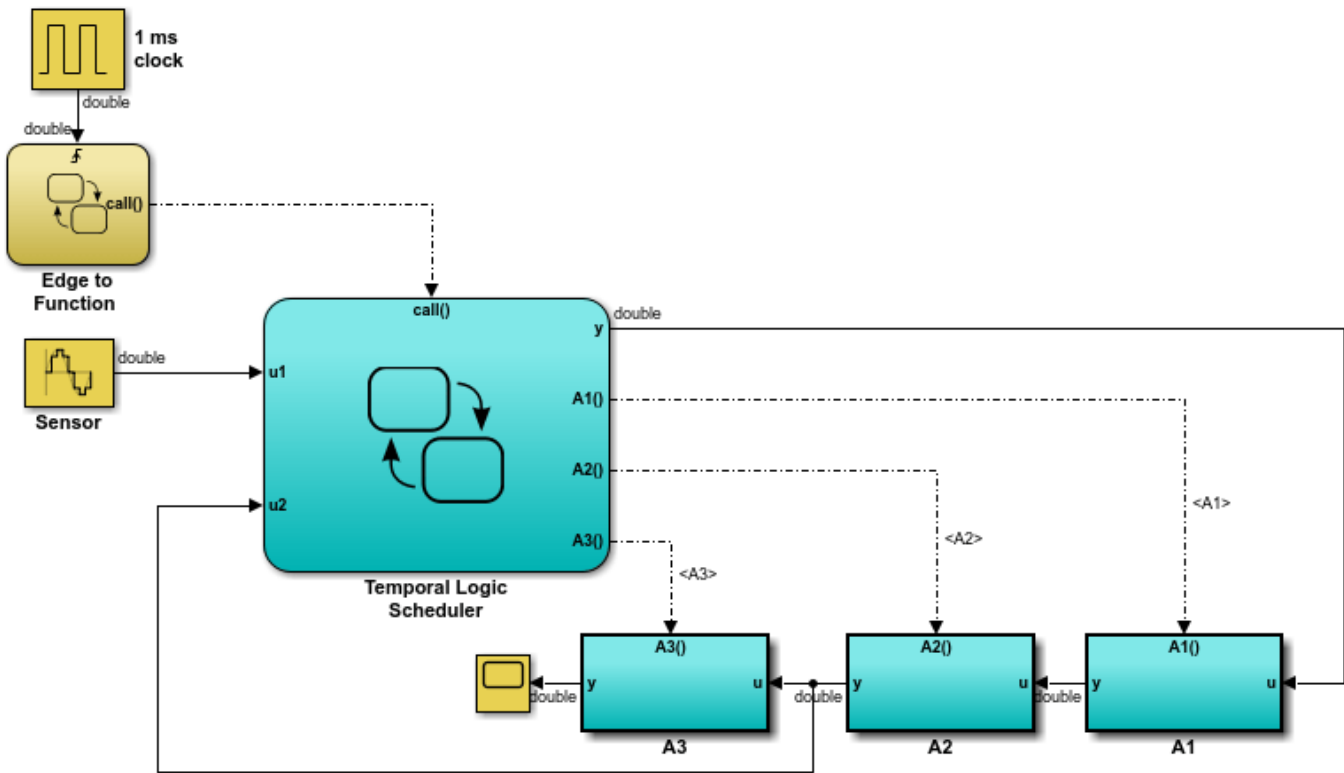
### **More About**

- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Activate a Simulink Block by Sending Output Events” on page 14-14



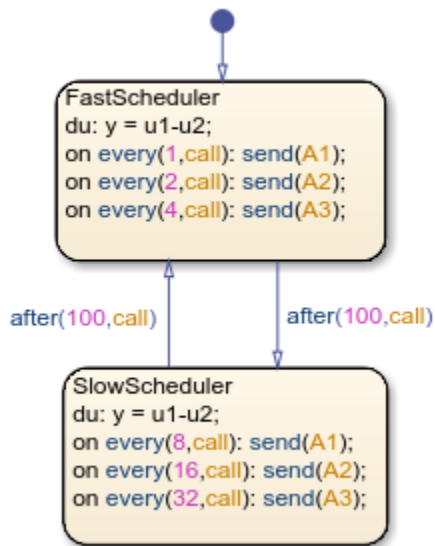
## Schedule Subsystems to Execute at Specific Times

This example shows how to design a *temporal logic scheduler* in Stateflow®. The temporal logic scheduler design pattern allows you to schedule Simulink® subsystems to execute at specified times. Stateflow schedulers extend control of subsystem execution in a Simulink model, which determines order of execution implicitly based on block connectivity and sample time propagation.



### Key Behavior of the Temporal Logic Scheduler

In this example, the Temporal Logic Scheduler chart contains two states that schedule the execution of three function-call subsystems (A1, A2, and A3) at different rates, as determined by the temporal logic operator every.



When the `FastScheduler` state is active, the chart schedules function calls to different Simulink subsystems at a fraction of the base rate at which the input event `call` wakes up the chart.

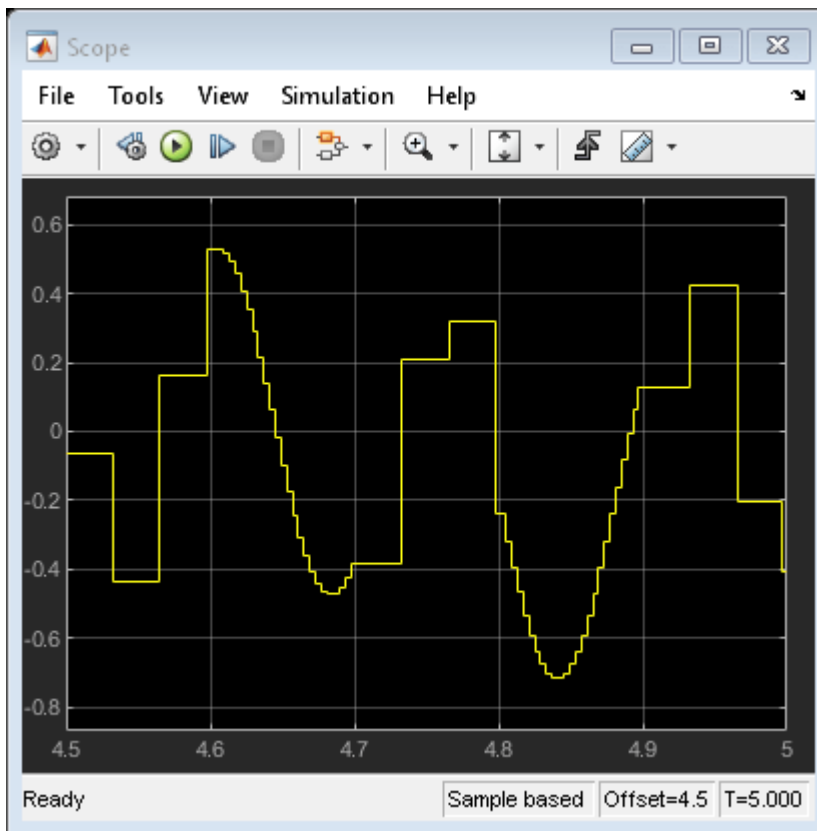
- The chart sends an event to execute subsystem A1 at the base rate.
- The chart sends an event to execute subsystem A2 at half the base rate.
- The chart sends an event to execute subsystem A3 at one quarter the base rate.

When the `SlowScheduler` state is active, the chart schedules function calls for A1, A2, and A3 at  $1/8$ ,  $1/16$ , and  $1/32$  times the base rate.

The chart switches between the fast and slow execution modes after every 100 invocations of the `call` event.

### Run the Temporal Logic Scheduler

When you simulate the model, the scope displays the value of `y` at each time step.



The changes in value illustrate the different rates of execution.

- When the chart executes the subsystems at a slow rate (for example, from  $t = 4.5$  to  $t = 4.6$ , from  $t = 4.7$  to  $t = 4.8$ , and from  $t = 4.9$  to  $t = 5.0$ ), the values change slowly.
- When the chart executes the subsystems at a fast rate (for example, from  $t = 4.6$  to  $t = 4.7$  and from  $t = 4.8$  to  $t = 4.9$ ), the values change rapidly.

## See Also

every | send

## More About

- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Activate a Simulink Block by Sending Output Events” on page 14-14

## Reduce Transient Signals by Using Debouncing Logic

When a switch opens and closes, the switch contacts can bounce off each other before the switch completely transitions to an on or off state. The bouncing action can produce transient signals that do not represent a true change of state. Therefore, when modeling switch logic, it is important to filter out transient signals by using *debouncing* algorithms.

If you model a controller in a Stateflow chart, you do not want your switch logic to overwork the controller by turning it on and off in response to every transient signal it receives. To avoid this, design a Stateflow controller that uses temporal logic to debounce your input signals and determine whether a switch is actually on or off.

### How to Debounce a Signal

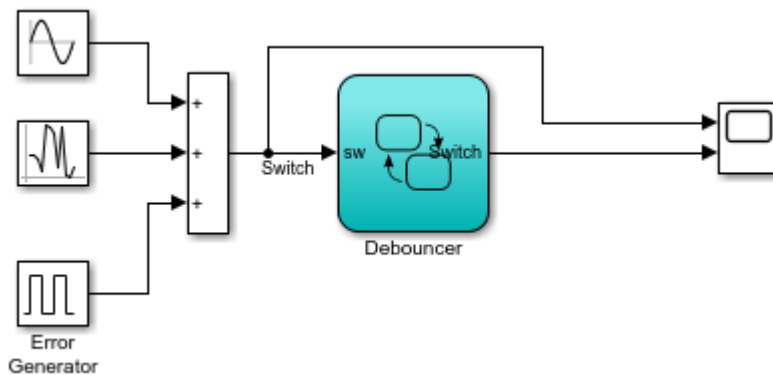
There are two ways to debounce a signal by using Stateflow:

- 1 Filter out transient signals by using the `duration` temporal operator.
- 2 Filter out transient signals by using an intermediate graphical state. Use intermediate graphical state for advanced filtering techniques, such as fault detection.

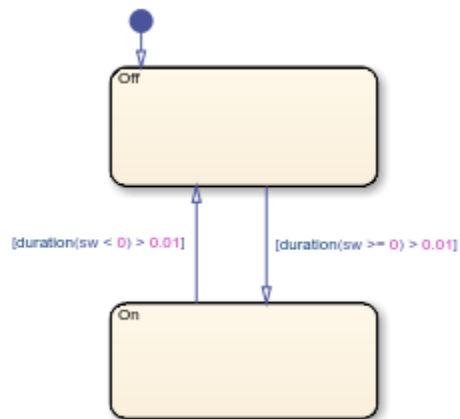
The `duration` operator is supported only in Stateflow charts in a Simulink model.

### Debounce Signals with the `duration` Operator

This example illustrates a design pattern that uses the `duration` operator to filter out transient signals.



The Debouncer chart contains this logic.



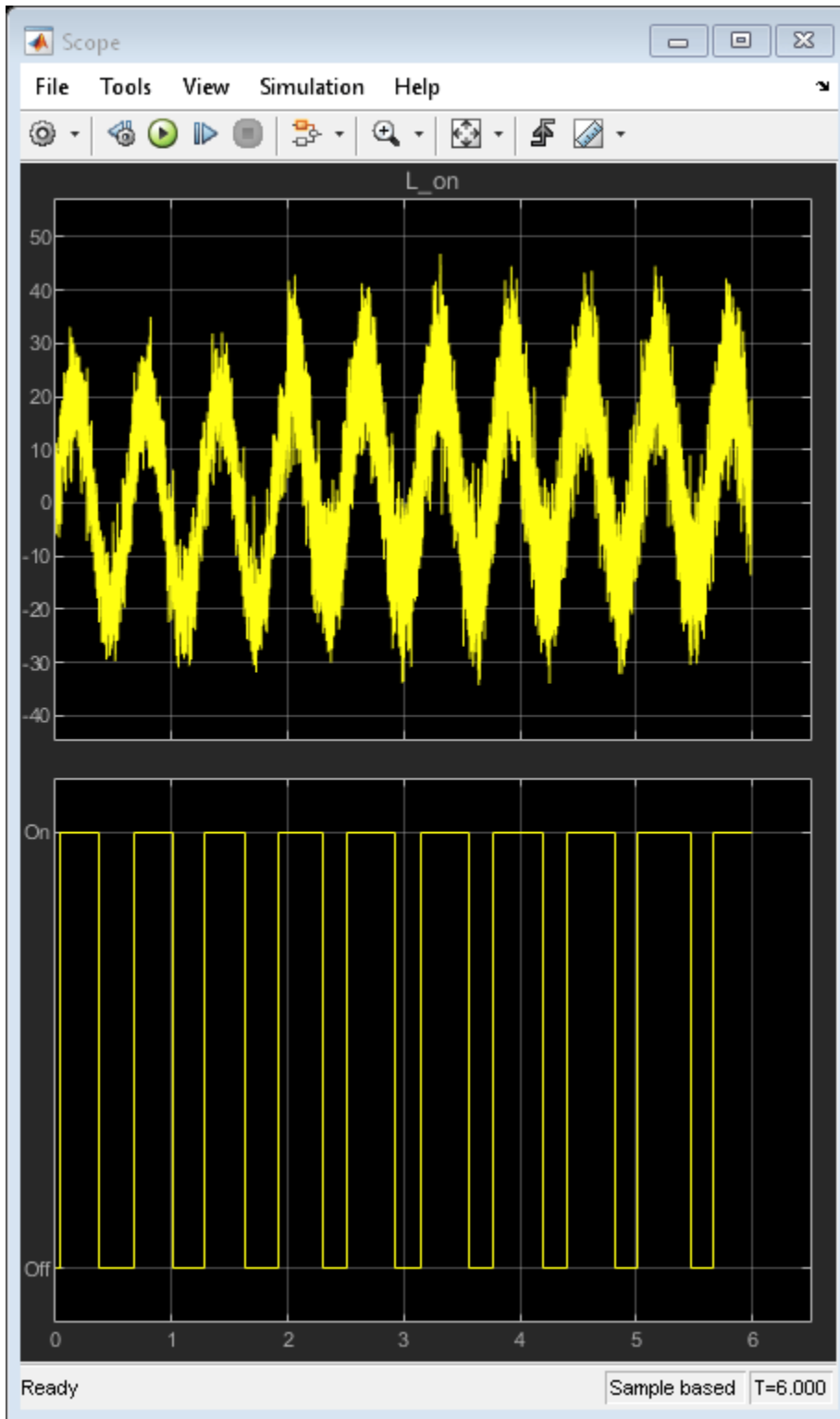
### State Logic

The initial state for this model is *Off*. By using the `duration` operator, you can control which state is active based on how long the switch signal, `sw`, has been negative or nonnegative.

- When `sw` has been nonnegative for longer than 0.01 seconds, the switch moves from state *Off* to state *On*.
- When `sw` has been negative for longer than 0.01 seconds, the switch moves from state *On* to state *Off*.

### Run the Debouncer

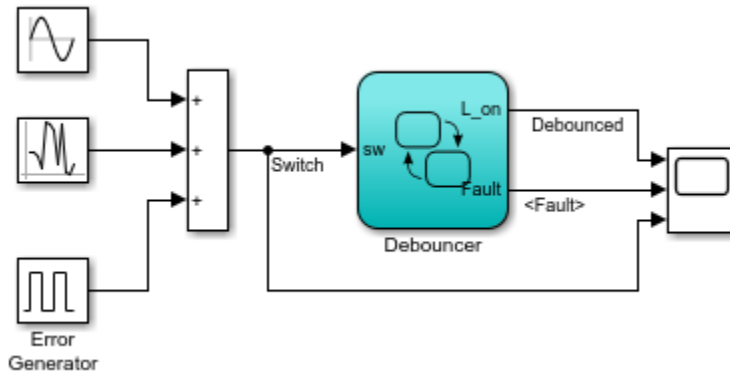
- 1 Open the model.
- 2 Open the Scope block.
- 3 Open the Stateflow chart Debouncer.
- 4 Simulate the model. The scope shows how the debouncer isolates transient signals from the noisy input signal.



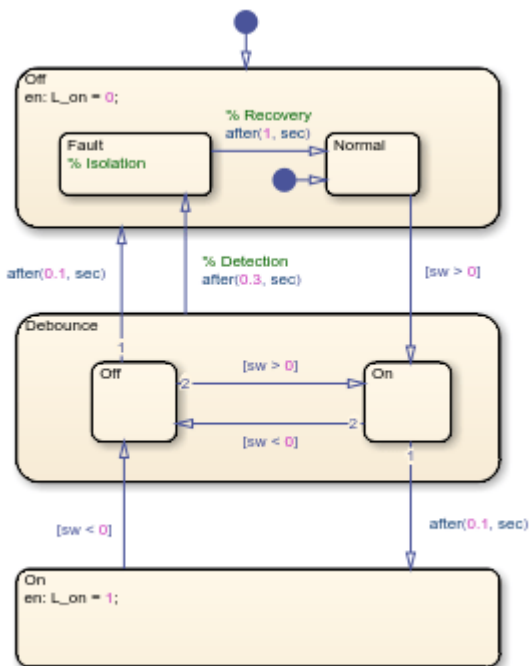
### Debounce Signals with Fault Detection

This example illustrates a design pattern that uses an intermediate state to isolate transient signals.

The debouncer design uses the `after` operator to implement absolute-time temporal logic. With this design pattern, you can also detect faults and allow your system time to recover.



The Debouncer chart contains this logic.



### State Logic

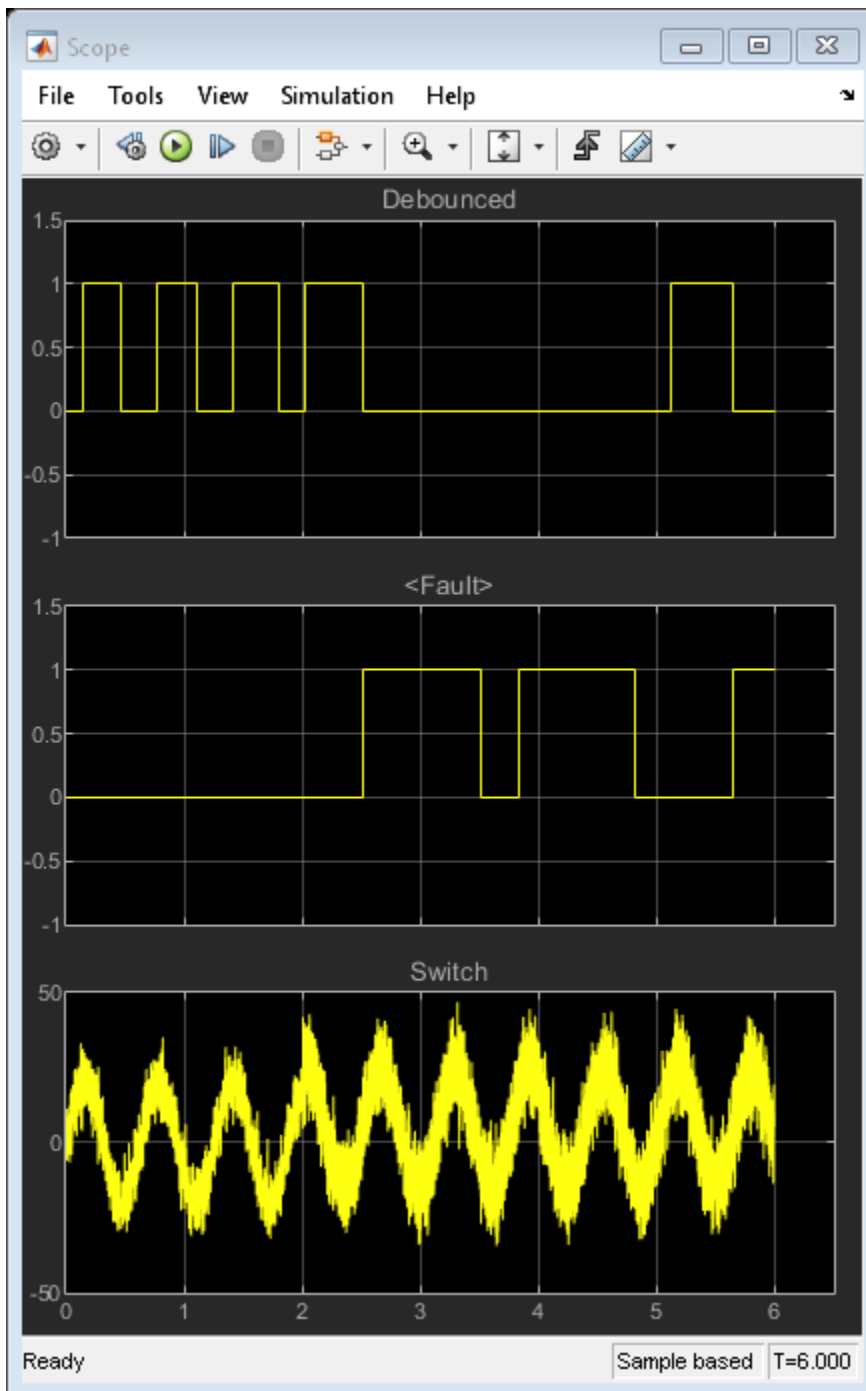
The Debouncer chart contains an intermediate state called `Debounce`. This state isolates transient inputs by checking if the signal `sw` remains positive or negative, or if it fluctuates between zero crossings over a prescribed period.

- When `sw` has been positive for longer than 0.1 seconds, the switch moves to state `On`.
- When `sw` has been negative for longer than 0.1 seconds, the switch moves to state `Off`.
- When `sw` fluctuates between zero crossings for longer than 0.3 seconds, the switch moves to state `Off`. `Fault`, isolating `sw` as a transient signal and giving it time to recover.

**Run the Debouncer**

- 1** Open the model.
- 2** Open the Scope block.
- 3** Open the Stateflow chart Debouncer.
- 4** Simulate the model. The scope shows how the debouncer isolates transient signals from the noisy input signal.





## Use Event-Based Temporal Logic

As an alternative to absolute-time temporal logic, you can apply event-based temporal logic to determine true state in the Debouncer chart by using the `after` operator. The keyword `tick` specifies and implicitly generates a local event when the chart awakens.

The Error Generator block in the `sf_debouncer` model generates a pulse signal every 0.001 second. Therefore, to convert the absolute-time temporal logic specified in the Debouncer chart to event-based logic, multiply the argument of the `after` operator by 1000, as indicated by this table.

Absolute Time-Based Logic	Event-Based Logic
<code>after(0.1, sec)</code>	<code>after(100, tick)</code>
<code>after(0.3, sec)</code>	<code>after(300, tick)</code>
<code>after(1, sec)</code>	<code>after(1000, tick)</code>

### See Also

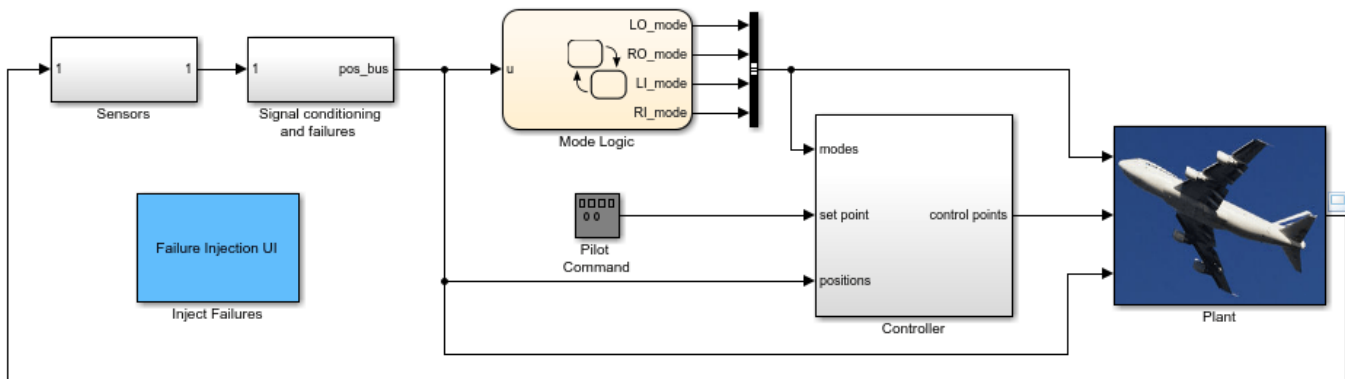
`after` | duration

### More About

- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Control Chart Behavior by Using Implicit Events” on page 14-26

## Detect Faults in Aircraft Elevator Control System

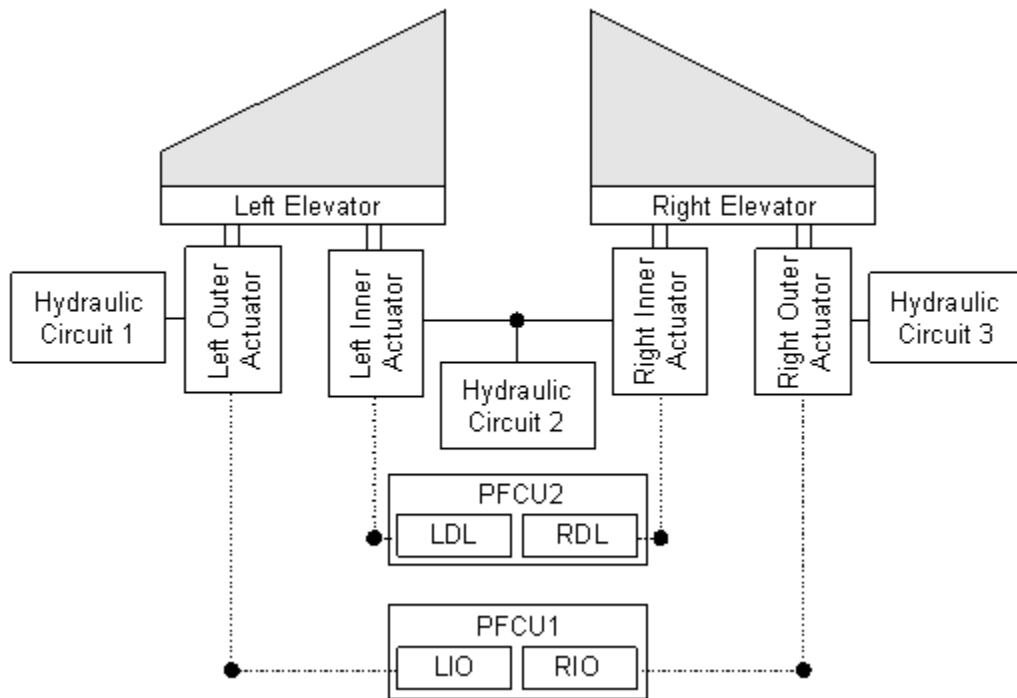
This example shows how to design a fault detection, isolation, and recovery (FDIR) application for a pair of aircraft elevators controlled by redundant actuators. This model uses the same fault detection control logic as the Avionics subsystem of the Aerospace Blockset™ example “HL-20 Project with Optional FlightGear Interface” (Aerospace Blockset).



### Elevator Control System

A typical aircraft has two elevators, one on each side of the fuselage, attached on the horizontal tails. To enhance the safety of the aircraft, the elevator control system contains these redundant parts:

- Four independent hydraulic actuators (two actuators per elevator).
- Three hydraulic circuits that drive the actuators. Each outer actuator has a dedicated hydraulic circuit. The inner actuators share a hydraulic circuit.
- Two primary flight control units (PFCU).
- Two control modules per actuator: full range control law and limited/reduced range control law.



If the aircraft is flying perfectly level, then the actuator position should maintain a constant value. The fault detection system registers a failure in an actuator if:

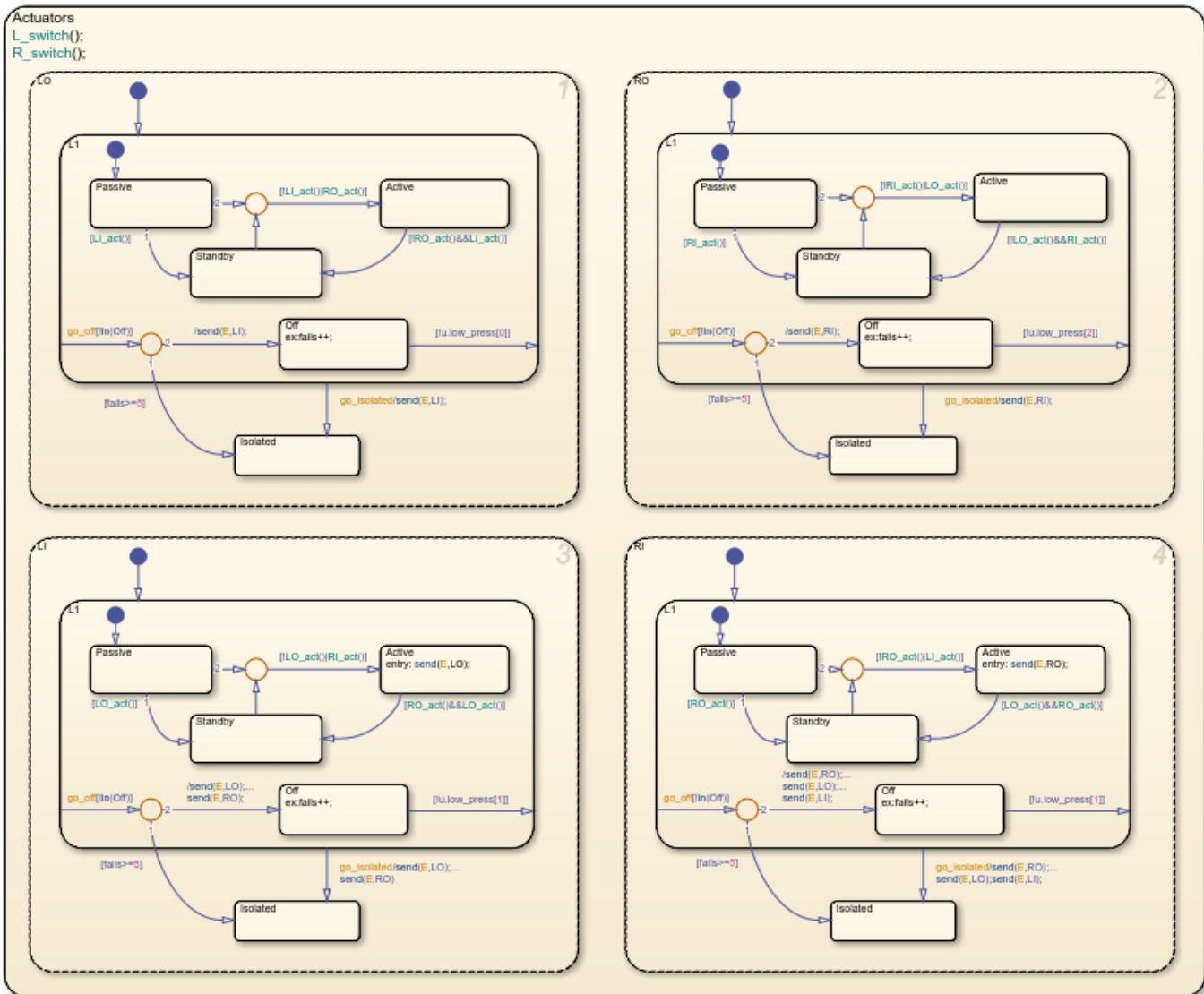
- The position of the actuator increases or decreases by 10 cm from this zero point.
- The actuator changes position rapidly (for instance, if the position changes at least 20 cm in 0.01 seconds).

The fault detection system also registers a fault in one of the hydraulic circuits if the pressure is out of bounds or if the pressure changes rapidly. In this example, the fault detection system checks that:

- The pressure in the hydraulic circuit is between 500 kPa and 2 MPa.
- The pressure changes no more than 100 kPa in 0.01 seconds.

### Fault Detection Control Logic

The Stateflow® chart Mode Logic defines the fault detection logic for the elevator control system. The chart contains a parallel substate for each actuator in the system. Each actuator can be in one of five modes: *Passive*, *Standby*, *Active*, *Off*, and *Isolated*. These operating modes are represented as substates of the parallel states.



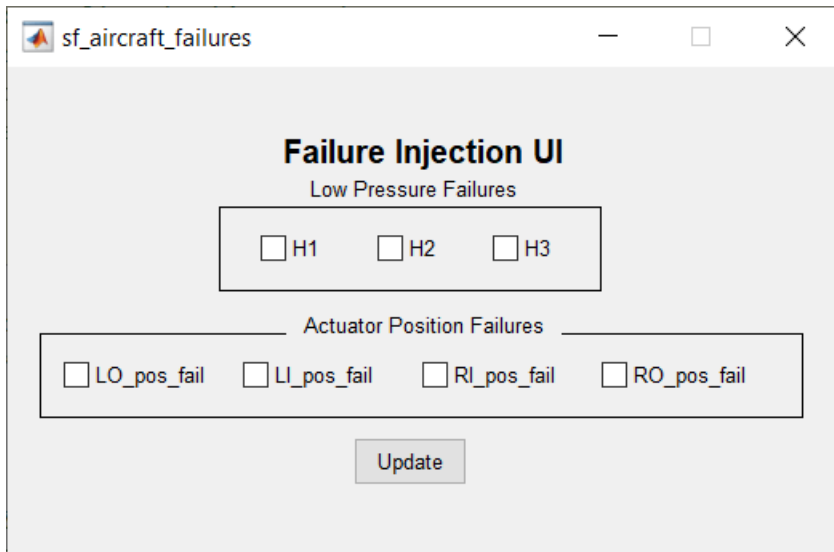
truthable L_switch	truthable R_switch	function y_act = LO_act	function y_act = LI_act	function y_act = RO_act	function y_act = RI_act
-----------------------	-----------------------	----------------------------	----------------------------	----------------------------	----------------------------

*This mode logic assumes that there are 3 hydraulic lines, one that is connected to the 2 redundant actuators (Left Inner and Right Inner actuators). The other two are connected to the primary actuators Left Outer and Right Outer (1 per actuator).*

By default, the outer actuators start in Active mode and the inner actuators start in Standby mode. If a failure is detected in the outer actuators or in the hydraulic circuits that are connected to them, the fault detection system responds by disabling the outer actuators and activating the inner actuators.

### Inject Failures Into Fault Detection System

To experiment with the model, during simulation, you can introduce hydraulic circuit and actuator position failures into the fault detection system through the Failure Injection UI.

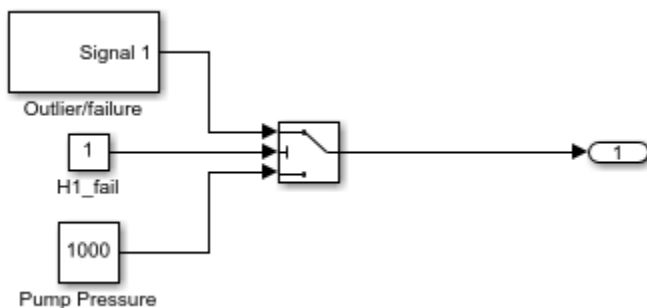


For example, to inject a failure in Hydraulic Circuit 1, select the H1 check box and click **Update**. The UI runs this MATLAB® code to communicate with the Simulink® model:

```
blockname=[mname '/Signal conditioning '...
'and failures /Hydraulic Pressures/Measured ',char(10),...
'Hydraulic system 1 ',...
'pressures/Hydraulic pressure/H1_fail'];
val=get(handles.H1,'Value');

if val
    set_param(blockname,'value','1');
else
    set_param(blockname,'value','0');
end
```

This code turns on a switch in the Signal conditioning subsystem that causes the fault detection system to register a fault in the hydraulic circuit.



The chart Mode Logic responds to failures in the hydraulic circuits and actuators by using truth table functions and event broadcasting. For example, if the fault detection system registers an isolated failure in Hydraulic Circuit 1, then:

- The truth table function `L_switch` broadcasts the event `go_off` to the substate `L0`.

- The substate L0 enters the Off mode and sends the event E to the substate LI.
- Because the substate L0 is no longer in the Active mode, LI enters the Active mode.
- Because the substate LI is now in the active mode, RI enters the Active mode and sends a second event E to the substate R0.
- The substate R0 enters the Standby mode.

After the fault detection systems registers a failure in Hydraulic Circuit 1, the left outer actuator is turned off, the right outer actuator is placed on standby, and the inner actuators are activated.

### Recover from Hydraulic Failures

The fault detection control logic enables the system to recover from a hydraulic circuit failure. For example, to bring the Hydraulic Circuit 1 back online, in the Failure Injection UI, clear the H1 check box and click **Update**. In the chart, the condition `!u.low_press[0]` becomes true, so the substate L0 transitions from the Off mode to the Standby mode. As a result, the left outer actuator can then be activated in the event that the fault detection system registers another failure later in the simulation.

### Isolate Actuators After Failures

When the fault detection system registers a failure in one of the actuators, that actuator can no longer be activated. In the chart Mode Logic, the failure of an actuator is represented by the substate Isolated. This substate has no outgoing transitions so once an actuator enters the Isolated state, it remains in that state for the rest of the simulation.

### References

Pieter J. Mosterman and Jason Ghidella, "Model Reuse for the Training of Fault Scenarios in Aerospace," in *Proceedings of the AIAA® Modeling and Simulation Technologies Conference*, CD-ROM, paper 2004-4931, August 16 - 19, 2004, Rhode Island Convention Center, Providence, RI.

Jason R. Ghidella and Pieter J. Mosterman, "Applying Model-Based Design to a Fault Detection, Isolation, and Recovery System," in *Military Embedded Systems*, Summer, 2006.

### See Also

#### More About

- "Synchronize Model Components by Broadcasting Events" on page 14-2
- "Use Truth Tables to Model Combinatorial Logic" on page 10-2
- "Reuse Logic Patterns by Defining Graphical Functions" on page 8-18
- "HL-20 Project with Optional FlightGear Interface" (Aerospace Blockset)

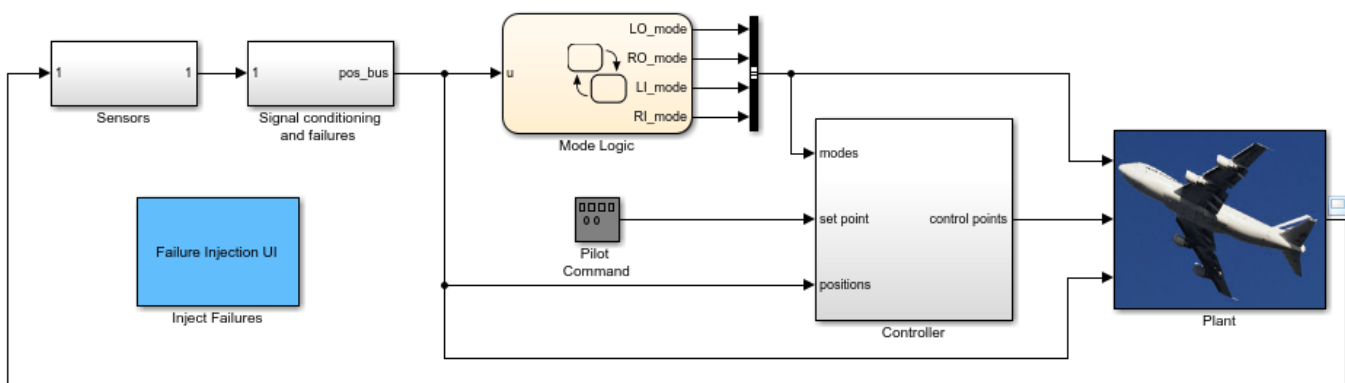
## Map Fault Conditions to Actions by Using Truth Tables

This example shows how to use truth tables to map fault conditions of a system directly to their consequent actions.

Truth tables are only supported in Simulink®. For more information, see “Use Truth Tables to Model Combinatorial Logic” on page 10-2.

### Detect Faults in a System

This model maps the fault conditions and actions of an aircraft elevator control system by using truth tables.



This list describes the requirements for the fault detection system in the model.

- Hydraulic pressure 1 failure — While there are no other failures, turn off the left outer actuator.
- Hydraulic pressure 2 failure — While there are no other failures, turn off the left inner actuator and the right inner actuator.
- Hydraulic pressure 3 failure — While there are no other failures, turn off the right outer actuator.
- Actuator position failure — While there are no other failures, isolate that specific actuator.
- Hydraulic pressure 1 and left outer actuator failures — While there are no other failures, turn off the left outer actuator.
- Hydraulic pressure 2 and left inner actuator failures — While there are no other failures, turn off the left inner actuator.
- Hydraulic pressure 3 and right outer actuator failures — While there are no other failures, turn off the right outer actuator.
- Multiple failures on left hydraulics and actuators — Isolate the left outer actuator and the left inner actuator.
- Multiple failures on right hydraulics and actuators — Isolate the right outer actuator and the right inner actuator.
- Intermittent actuator failures — If an actuator has been switched on and off five times during operation, isolate that specific actuator.

In the Mode Logic chart, a pair of truth table functions define the logic to satisfy these requirements. `L_switch` controls the left elevator and `R_switch` controls the right elevator. This truth table is for the left elevator.



sf\_aircraft ▶ Mode Logic ▶ L\_switch

### Condition Table

	DESCRIPTION	CONDITION	D1	D2	D3	D4	D5	D6	D7
1	Hydraulic system 1 Low pressure (Left Outer line)	u.low_press[0]	T	T	F	F	-	-	-
2	Left Outer actuator position failed	u.L_pos_fail[0]	-	-	T	T	-	-	-
3	Hydraulic system 2 Low pressure (Inner line)	u.low_press[1]	F	-	F	-	T	-	-
4	Left Inner actuator position failed	u.L_pos_fail[1]	F	-	F	-	-	T	-
		<b>ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE</b>	<b>2</b>	<b>3,5</b>	<b>3</b>	<b>3,5</b>	<b>4</b>	<b>5</b>	<b>Default</b>

### Action Table

	DESCRIPTION	ACTION
1	Default - All ok, do nothing.	Default:
2	Hydraulic System 1 Failure. Turn off Left Outer Actuator	<code>send(go_off,Actuators.LO);</code>
3	Left Outer Actuator Failure. Isolate Left Outer Actuator	<code>send(go_isolated,Actuators.LO);</code>
4	Hydraulic System 2 Failure. Turn off Left Inner Actuator	<code>send(go_off,Actuators.LI);</code>
5	Left Inner Actuator Failure. Isolate Left Inner Actuator	<code>send(go_isolated,Actuators.LI);</code>

The first requirement indicates that if a failure is only detected in the hydraulic pressure 1 system, turn off the left outer actuator. In the truth table, this requirement is represented by the decision **D1**. If there is low pressure in the hydraulic system 1, then **D1** specifies that action 2 is performed. Action 2 sends an event `go_off` to the left actuator, `Actuators.LO`.

Similarly, the other requirements are mapped to the appropriate actions in the truth table. For example, if the left outer actuator fails, **D3** causes action 3. Action 3 sends the event `go_isolated` to `Actuators.LO` to isolate the left actuator.

The truth table functions are called at entry and during actions for the chart so that fault checks execute at each time step.

## **See Also**

### **More About**

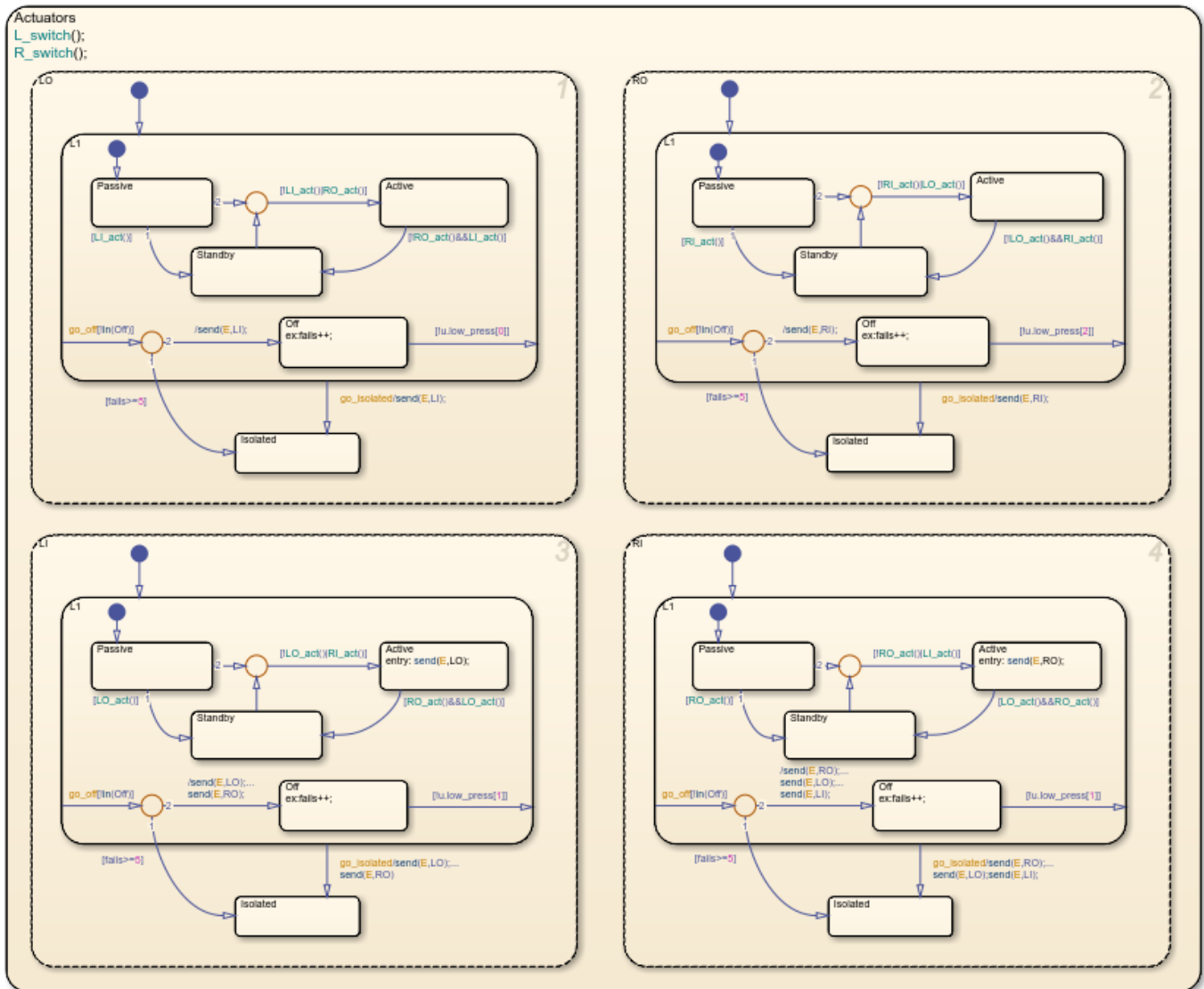
- “Use Truth Tables to Model Combinatorial Logic” on page 10-2
- “Program a Truth Table” on page 10-8

## Design for Isolation and Recovery in a Chart

### Mode Logic for the Elevator Actuators

This example shows how the model `sf_aircraft` uses the chart `Mode Logic` to detect system faults and recover from failure modes for an aircraft elevator control system. For more information on this model, see “Detect Faults in Aircraft Elevator Control System” on page 30-19.

There are two elevators in the system, each with an outer and inner actuator. The `Actuators` state has a corresponding substate for each of the four actuators. An actuator has five modes: `Passive`, `Active`, `Standby`, `Off`, and `Isolated`. By default, the outer actuators are on, and the inner actuators are on standby. If a fault is detected in the outer actuators, the system responds to maintain stability by turning the outer actuators off and activating the inner actuators.



truthtable L_switch	truthtable R_switch	function y_act = LO_act	function y_act = LI_act	function y_act = RO_act	function y_act = RI_act
------------------------	------------------------	----------------------------	----------------------------	----------------------------	----------------------------

*This mode logic assumes that there are 3 hydraulic lines, one that is connected to the 2 redundant actuators (Left Inner and Right Inner actuators). The other two are connected to the primary actuators Left Outer and Right Outer (1 per actuator).*

### States for Failure and Isolation

Each actuator contains an Off state and an Isolated state. When the fault detection logic in one of the truth tables detects a failure, it broadcasts the event go\_off or go\_isolated to the failing actuator. For more information, see “Map Fault Conditions to Actions by Using Truth Tables” on page 30-24.

The go\_off event instructs the failing actuator to transition to the Off state until the condition is resolved. The event go\_isolated causes the failing actuator to transition to Isolated. Transitions

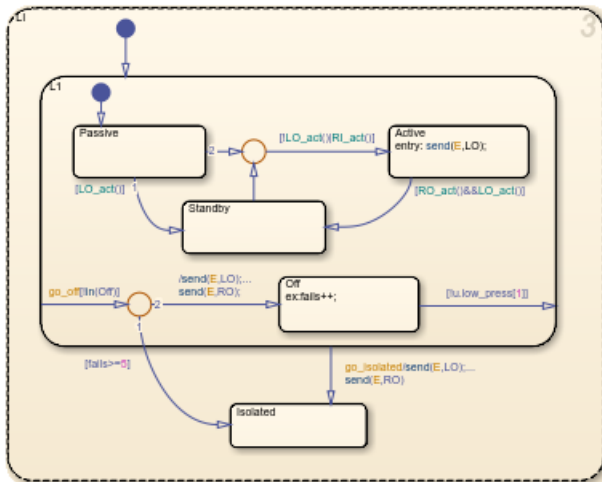
to the `Isolated` state are from the superstate `L1`, which contains all the other operating modes. This state has no outgoing transitions, so that once an actuator has entered `Isolated` it remains there. Intermittent failures that cause an actuator to fail 5 or more times, also cause a transition to `Isolated`. The variable `fails` logs the number of failures for an actuator by incrementing each time a transition occurs out of `Off`.

## Transitions for Recovery

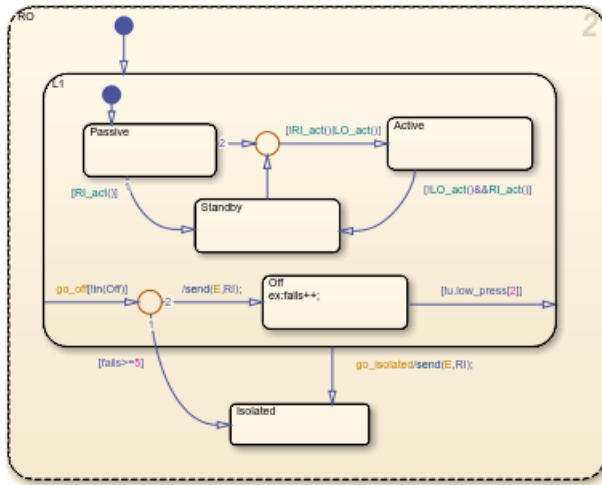
Transitions in the substates for each actuator account for recovery requirements of the elevator system. These requirements derive from rules for symmetry and safety of the elevators such as:

- Only one actuator for an elevator must be active at one time.
- Outer actuators have priority over the inner actuators.
- Actuator activity should be symmetric if possible.
- Switching between actuators must be kept to a minimum.

For example, one requirement of the system is if one outer actuator fails, then the other outer actuator must move to standby and the inner actuators take over. Consequently, there is a transition from each `Active` state to `Standby`, and vice versa.



For the inner left actuator (`LI`), the transition to `Active` inside the `L1` superstate is conditionally based on `[!LO_act() | RI_act()]`. This causes the left inner actuator to turn on if the outer actuator (`LO`) has failed, or the right inner actuator (`RI`) has turned on.



Another consequence if LO fails and moves out of Active is a transition that occurs in the right outer actuator (RO). The RO state transitions inside the L1 superstate from Active to Standby. This satisfies the requirement of the outer actuators and inner actuators to work in symmetry.

## Model a Launch Abort System

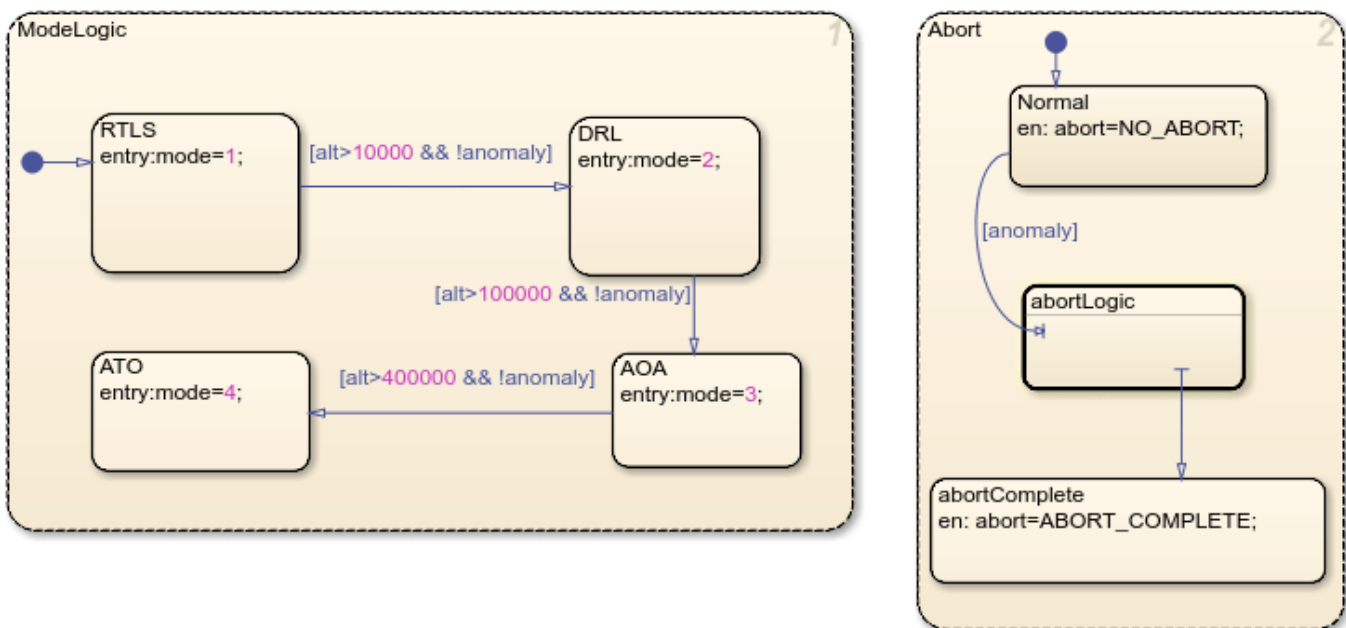
This example shows how to model a launch abort system. An aircraft is launched into outer space. If an anomaly or fault occurs during the launch, the operation is aborted, and the aircraft is sent back down to Earth.

### Description

The LaunchAbortController chart is used to control the mode logic and launch abort behavior. The state chart consists of two parallel states: `ModeLogic` and `Abort`. Within the `ModeLogic` state, the aircraft can be in one of four states:

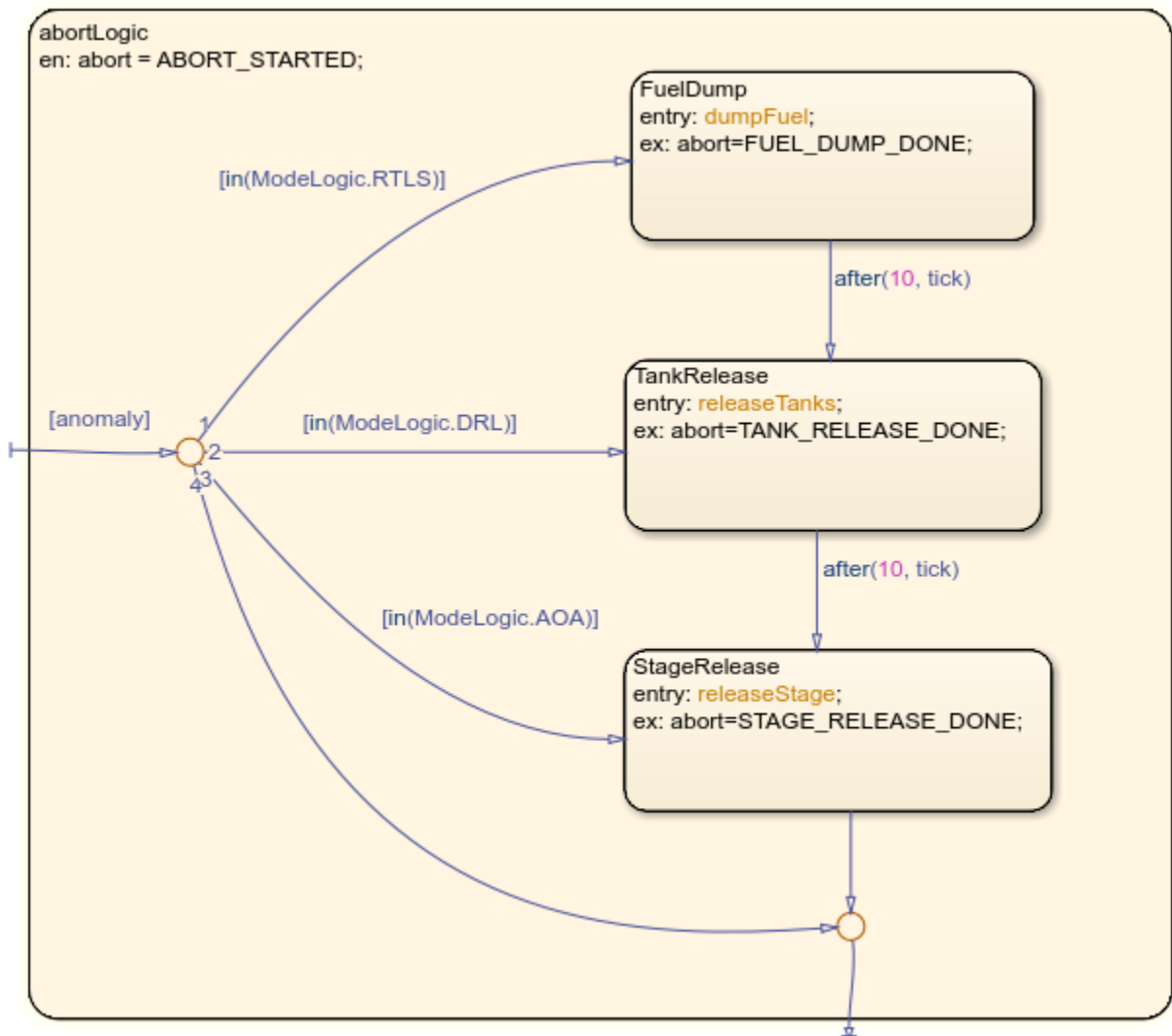
- `RTLS`: Return to Launch Site
- `DRL`: Downrange Landing
- `AOA`: Abort Once Around
- `ATO`: Abort to Orbit

The aircraft transitions from one mode to the next based on the altitude of the aircraft (a simplification).



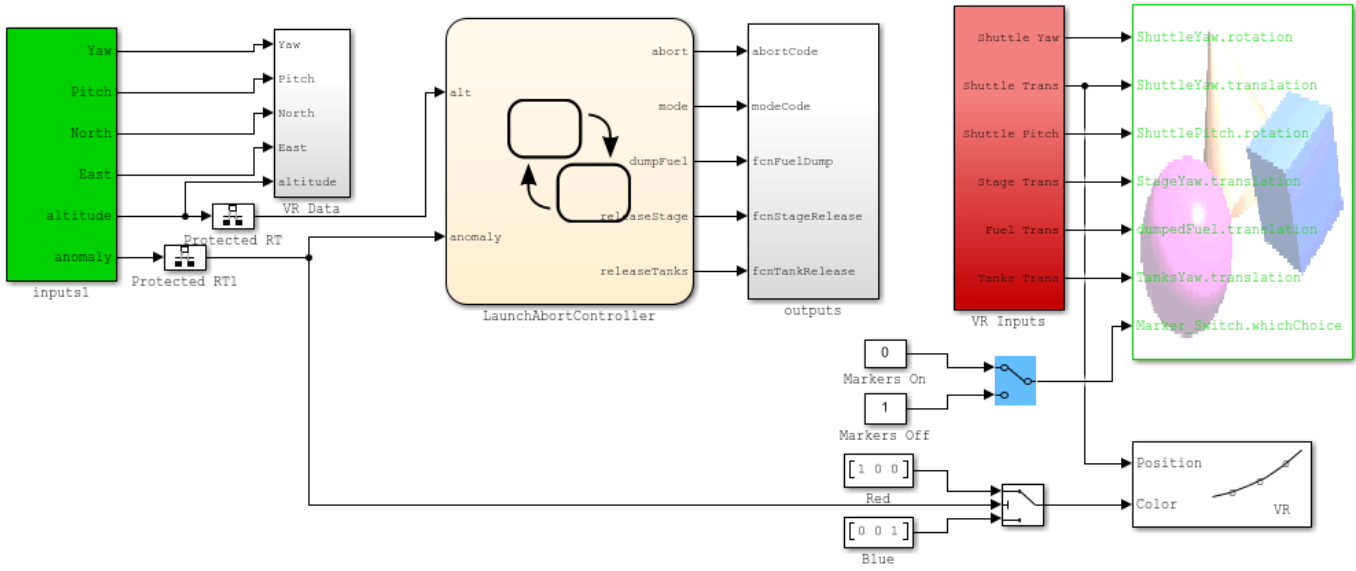
The second parallel state controls the behavior of the aircraft if an anomaly is detected. If an anomaly occurs, the system transitions to the `abortLogic` substate and one of these actions can occur, depending on the current state of the system:

- Dump the fuel
- Release the tanks
- Release the stage

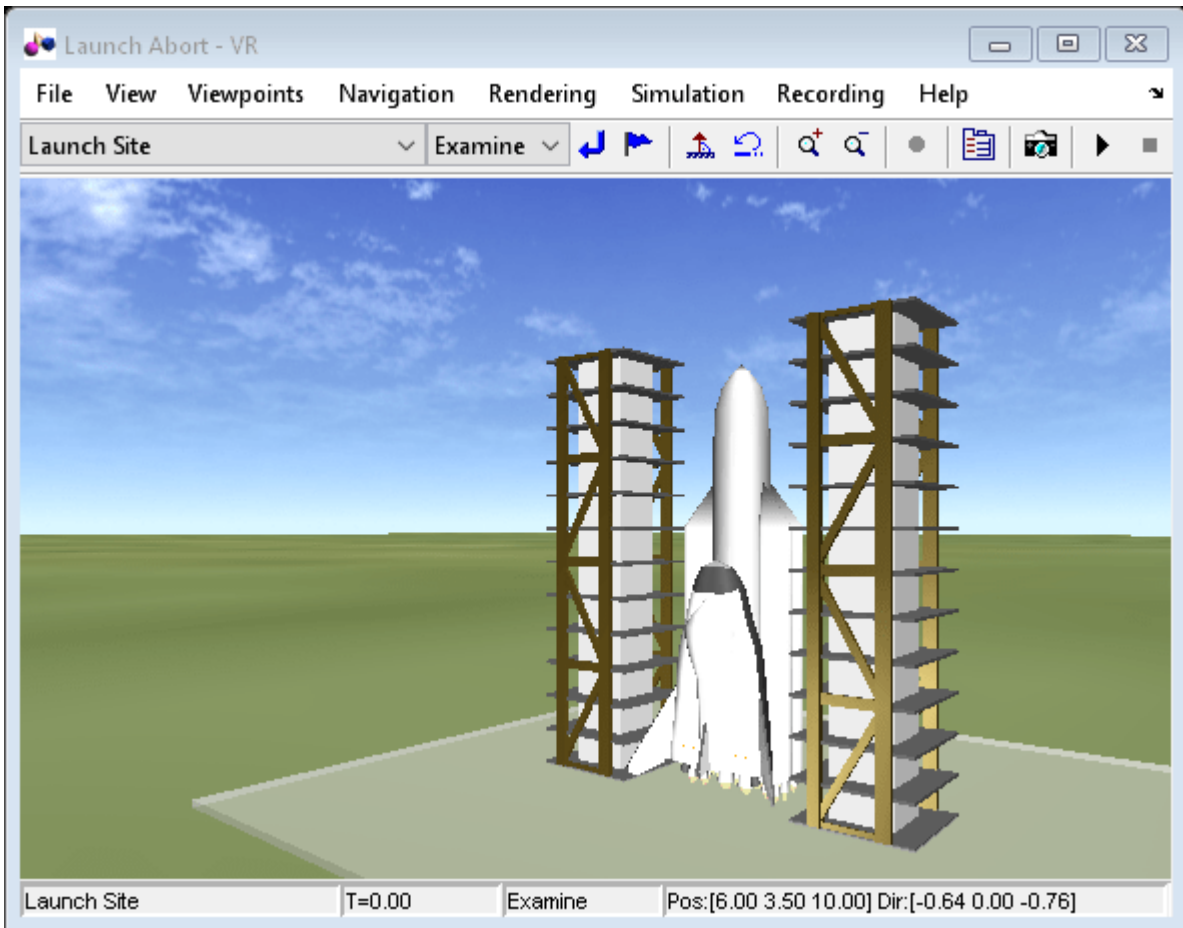


Although Stateflow® is used to schedule when these events occur, the fuel, tank, and stage subsystems are modeled in Simulink®. Since this is a simplified example, the dynamics of the subsystems are not modeled here. However, a visualization of the fuel dump, tank release, and stage release can be seen through the use of Simulink 3D Animation™.





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**Reference**

Nelson, D. K., Bradford, J. E., Olds, J. R., "Abortability Metrics: Quantifying Intact Abort Mode Availability for Reusable Launch Vehicles," AIAA-2006-7293, Space 2006, San Jose, California, September 19-21, 2006.

**See Also****More About**

- "Check State Activity by Using the in Operator" on page 13-17
- "Control Chart Execution by Using Temporal Logic" on page 16-36
- "Simulink 3D Animation"

## Modeling a Fault-Tolerant Fuel Control System

This example shows how to combine Stateflow® with Simulink® to efficiently model hybrid systems. This type of modeling is particularly useful for systems that have numerous possible operational modes based on discrete events. Traditional signal flow is handled in Simulink while changes in control configuration are implemented in Stateflow. The model described below represents a fuel control system for a gasoline engine. The system is highly robust in that individual sensor failures are detected and the control system is dynamically reconfigured for uninterrupted operation.

### Analysis and Physics

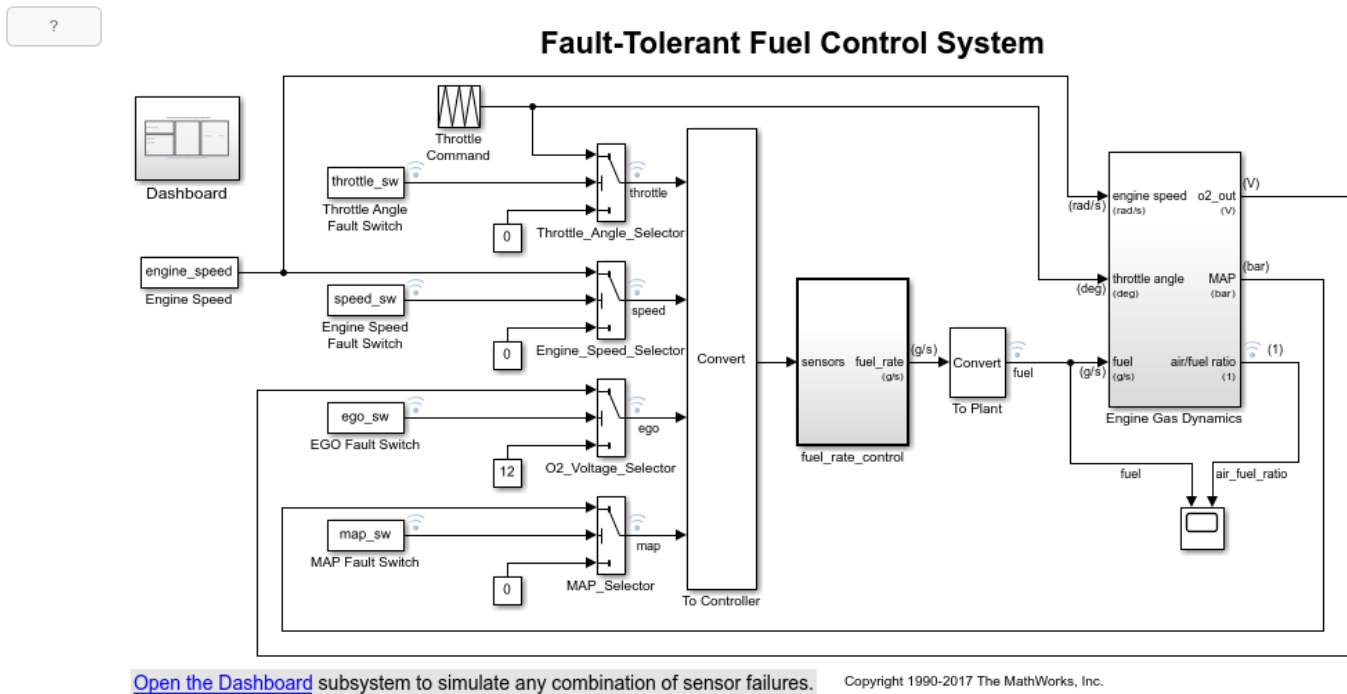
Physical and empirical relationships form the basis for the throttle and intake manifold dynamics of this model. The air-fuel ratio is computed by dividing the air mass flow rate (pumped from the intake manifold) by the fuel mass flow rate (injected at the valves). The ideal (i.e. stoichiometric) mixture ratio provides a good compromise between power, fuel economy, and emissions. The target air-fuel ratio for this system is 14.6. Typically, a sensor determines the amount of residual oxygen present in the exhaust gas (EGO). This gives a good indication of the mixture ratio and provides a feedback measurement for closed-loop control. If the sensor indicates a high oxygen level, the control law increases the fuel rate. When the sensor detects a fuel-rich mixture, corresponding to a very low level of residual oxygen, the controller decreases the fuel rate.

### Modeling

Figure 1 shows the top level of the Simulink model. To open the model, click **Open Model**. Press the Play button in the model window toolbar to run the simulation. The model loads necessary data into the model workspace from `sldemo_fuelsys_data.m`. The model logs relevant data to MATLAB workspace in a data structure called `sldemo_fuelsys_output` and streams the data to the Simulation Data Inspector. Logged signals are marked with a blue indicator while streaming signals are marked with the light blue badge (see Figure 1).

Note that loading initial conditions into the model workspace keeps simulation data isolated from data in other open models that you may have open. This also helps avoid MATLAB workspace cluttering. To view the contents of the model workspace select Modeling > Model Explorer, and click on Model Workspace from the Model Hierarchy list.

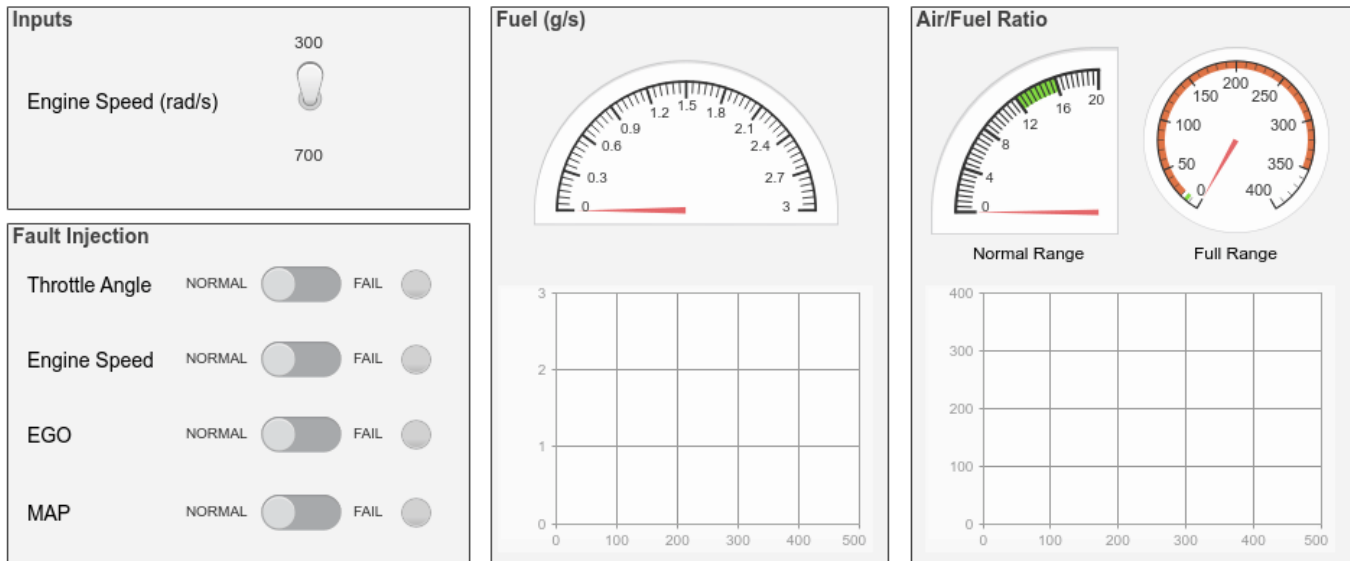
Notice that units are visible on the model and subsystem icons and signal lines. Units are specified on the ports and on the bus object.



**Figure 1:** Top-level diagram for the fuel control system model

The Dashboard subsystem (shown in Figure 2) allows you to interact with the model during simulation. The Fault Injection switches can be moved from the Normal to Fail position to simulate sensor failures, while the Engine Speed selector switch can be toggled to change the engine speed. The fuel and air/fuel ratio signals are visualized using the dashboard gauges and scopes to provide visual feedback during a simulation run.

## Fault-Tolerant Fuel Control System Dashboard



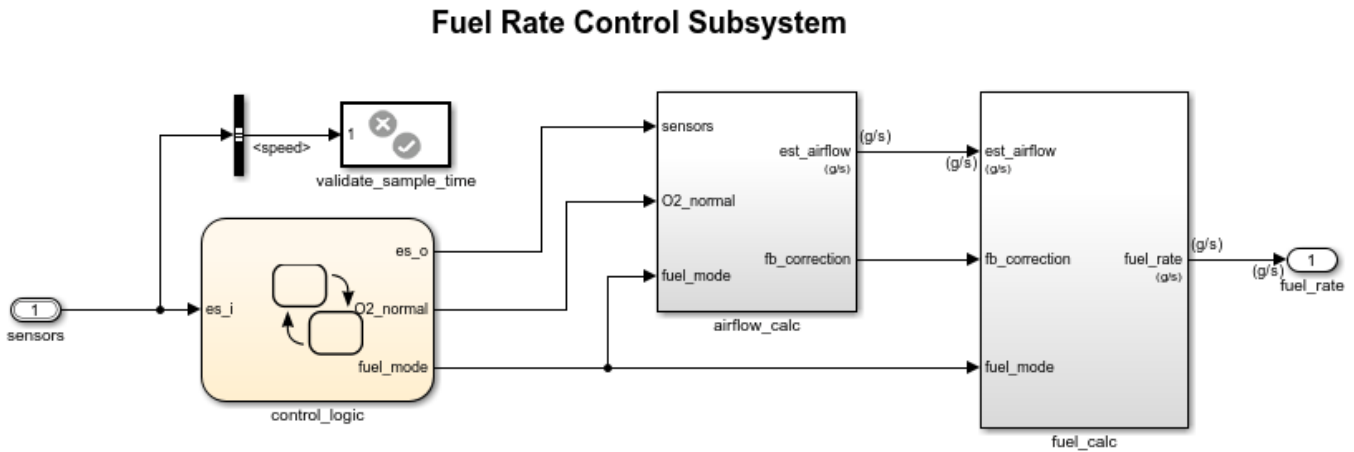
[Update Diagram](#) (Ctrl+D) to bind switches to model workspace variables.

**Figure 2:** Dashboard subsystem for the fuel control system model

The `fuel_rate_control` uses signals from the system's sensors to determine the fuel rate which gives a stoichiometric mixture. The fuel rate combines with the actual air flow in the engine gas dynamics model to determine the resulting mixture ratio as sensed at the exhaust.

You can selectively disable each of the four sensors (throttle angle, speed, EGO and manifold absolute pressure [MAP]) by using the slider switches in the dashboard subsystem, to simulate failures. Simulink accomplishes this by binding slider switches to the value parameter of the constant block. Double-click on the dashboard subsystem to open the control dashboard to change the position of the switch. Similarly, you can induce the failure condition of a high engine speed by toggling the engine speed switch on the dashboard subsystem. A Repeating Table block provides the throttle angle input and periodically repeats the sequence of data specified in the mask.

The `fuel_rate_control` block, shown in Figure 3, uses the sensor input and feedback signals to adjust the fuel rate to give a stoichiometric ratio. The model uses three subsystems to implement this strategy: control logic, airflow calculation, and fuel calculation. Under normal operation, the model estimates the airflow rate and multiplies the estimate by the reciprocal of the desired ratio to give the fuel rate. Feedback from the oxygen sensor provides a closed-loop adjustment of the rate estimation in order to maintain the ideal mixture ratio.

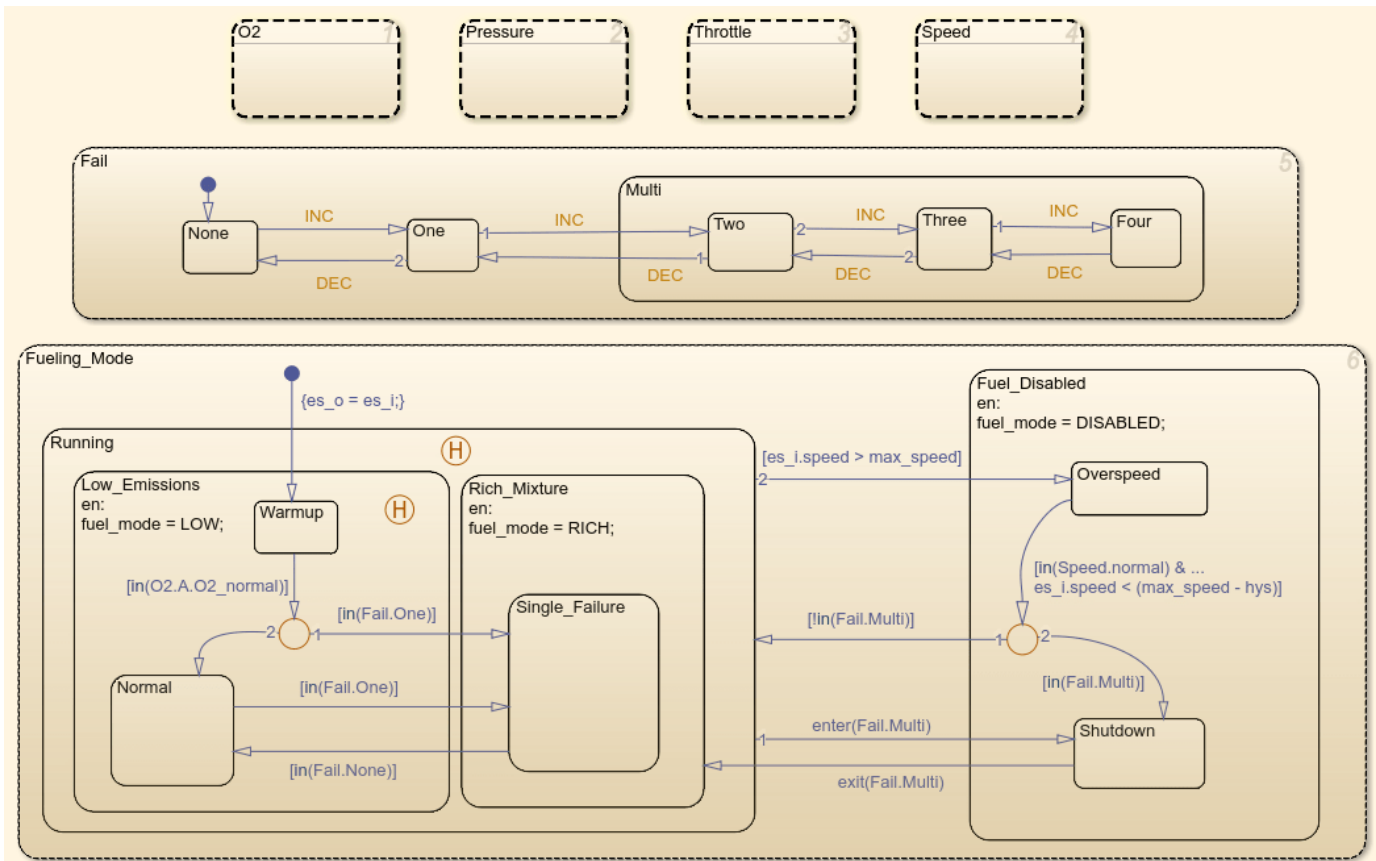


**Figure 3:** Fuel rate controller subsystem

### Control Logic

A single Stateflow chart, consisting of a set of six parallel states, implements the control logic in its entirety. The four parallel states shown at the top of Figure 4 correspond to the four individual sensors. The remaining two parallel states at the bottom consider the status of the four sensors simultaneously and determine the overall system operating mode. The model synchronously calls the entire Stateflow diagram at a regular sample time interval of 0.01 sec. This permits the conditions for transitions to the correct mode to be tested on a timely basis.

To open the `control_logic` Stateflow chart, double-click on it in the `fuel_rate_control` subsystem.



**Figure 4:** The control logic chart

When execution begins, all of the states start in their **normal** mode with the exception of the oxygen sensor (EGO). The `O2_warmup` state is entered initially until the warmup period is complete. The system detects throttle and pressure sensor failures when their measured values fall outside their nominal ranges. A manifold vacuum in the absence of a speed signal indicates a speed sensor failure. The oxygen sensor also has a nominal range for failure conditions but, because zero is both the minimum signal level and the bottom of the range, failure can be detected only when it exceeds the upper limit.

Regardless of which sensor fails, the model always generates the directed event broadcast `Fail.INC`. In this way the triggering of the universal sensor failure logic is independent of the sensor. The model also uses a corresponding sensor recovery event, `Fail.DEC`. The `Fail` state keeps track of the number of failed sensors. The counter increments on each `Fail.INC` event and decrements on each `Fail.DEC` event. The model uses a superstate, `Multi`, to group all cases where more than one sensor has failed.

The bottom parallel state represents the fueling mode of the engine. If a single sensor fails, operation continues but the air/fuel mixture is richer to allow smoother running at the cost of higher emissions. If more than one sensor has failed, the engine shuts down as a safety measure, since the air/fuel ratio cannot be controlled reliably.

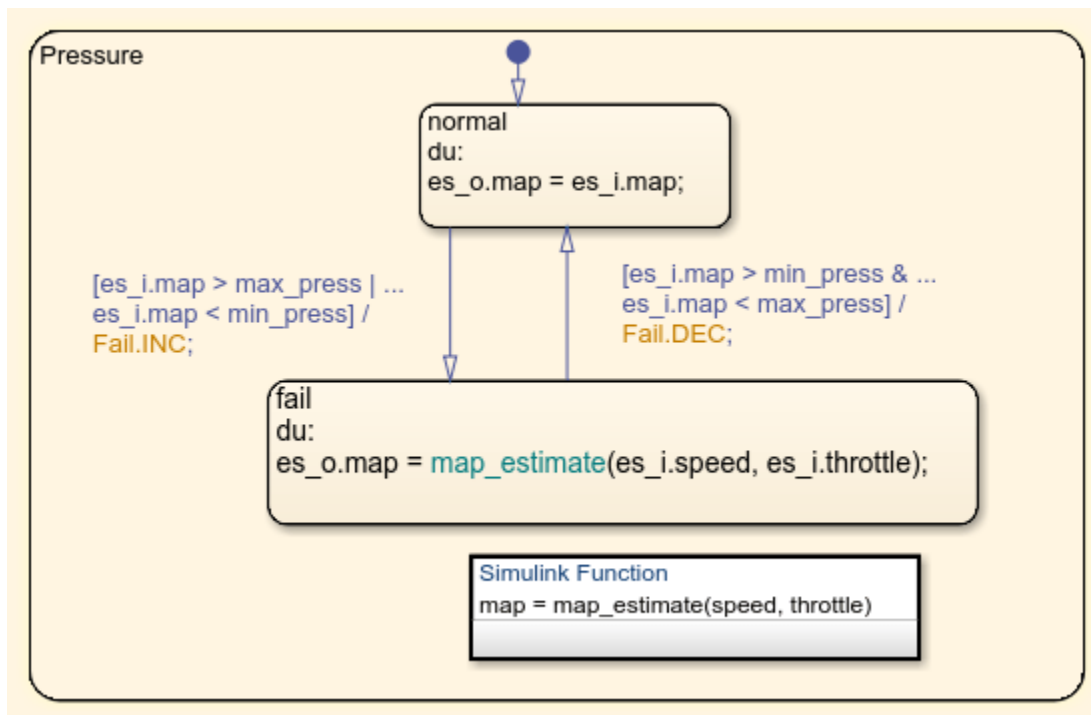
During the oxygen sensor warm-up, the model maintains the mixture at normal levels. If this is unsatisfactory, you can change the design by moving the warm-up state to within the `Rich_Mixture`

superstate. If a sensor failure occurs during the warm-up period, the `Single_Failure` state is entered after the warm-up time elapses. Otherwise, the `Normal` state is activated at this time.

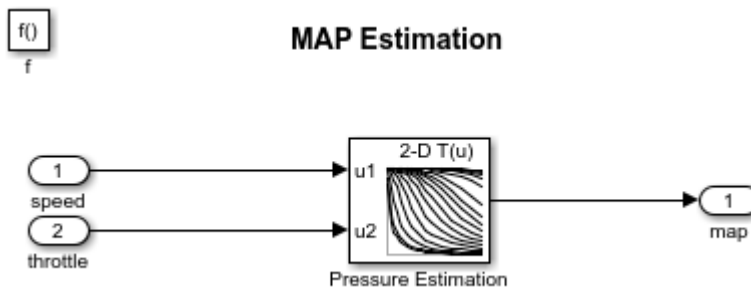
A protective overspeed feature has been added to the model by creating a new state in the `Fuel_Disabled` superstate. Through the use of history junctions, we assured that the chart returns to the appropriate state when the model exits the overspeed state. As the safety requirements for the engine become better specified, we can add additional shutdown states to the `Fuel_Disabled` superstate.

### Sensor Correction

When a sensor fails, the model computes an estimate of the sensor. For example, open the pressure sensor calculation. Under normal sensor operation, the model uses the value of the pressure sensor. Otherwise, the model estimates the value.



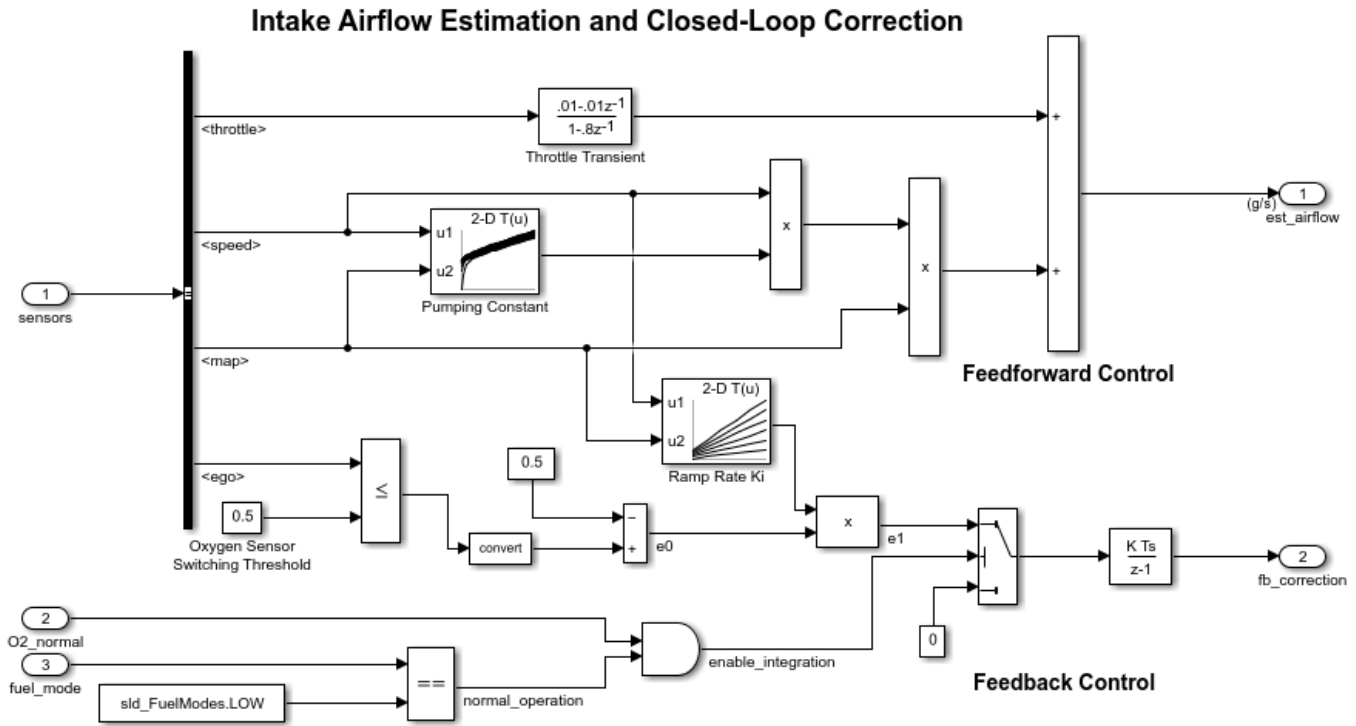
The model computes an estimate of manifold pressure as a function of the engine speed and throttle position. To compute the value, the model uses a Simulink function inside Stateflow.





## Airflow Calculation

The Airflow Calculation block (shown in Figure 6) is the location for the central control laws. This block is found inside the fuel\_rate\_control subsystem (open this block). The block estimates the intake air flow to determine the fuel rate which gives the appropriate air/fuel ratio. Closed-loop control adjusts the estimation according to the residual oxygen feedback in order to maintain the mixture ratio precisely. Even when a sensor failure mandates open-loop operation, the most recent closed-loop adjustment is retained to best meet the control objectives.



**Figure 6:** Airflow estimation and correction

### Equation 1

The engine's intake air flow can be formulated as the product of the engine speed, the manifold pressure and a time-varying scale factor.

$$q = \frac{N}{4\pi} V_{cd} \nu \frac{P_m}{RT} = C_{pump}(N, P_m) N P_m = \text{intake mass flow}$$

$N$  = engine angular speed (Rad/sec)

$V_{cd}$  = engine cylinder displacement volume

$\nu$  = volumetric efficiency

$P_m$  = manifold pressure

$R, T$  = specific gas constant, gas temperature

$C_{pump}$  is computed by a lookup table and multiplied by the speed and pressure to form the initial flow estimate. During transients, the throttle rate, with the derivative approximated by a high-pass filter, corrects the air flow for filling dynamics. The control algorithm provides additional correction according to Equation 2.

**Equation 2**

$$e_0 = 0.5 \text{ for } EGO \leq 0.5$$

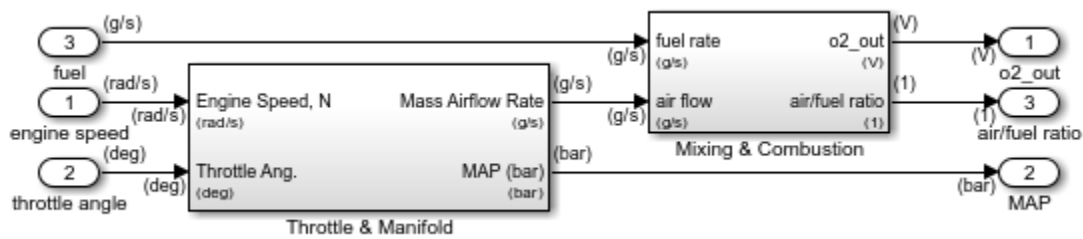
$$e_0 = -0.5 \text{ for } EGO > 0.5$$

$$e_1 = K_i(N, P_m)e_0 \text{ for } EGO \leq 0.5$$

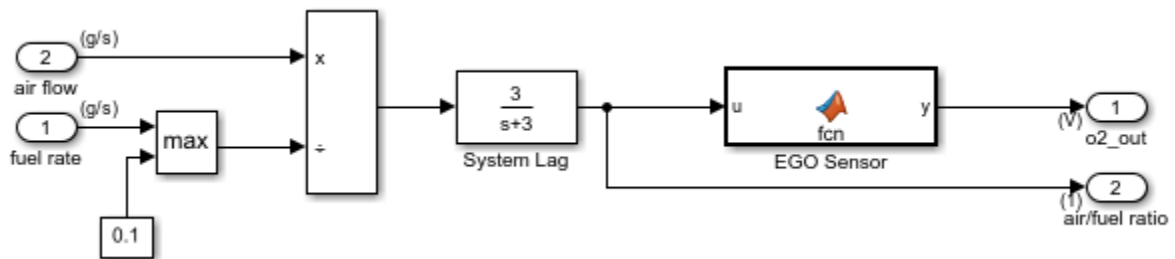
$$\dot{e}_2 = e_1 \text{ for LOW mode with valid EGO signal}$$

$$\dot{e}_2 = 0 \text{ for RICH, DISABLE or EGO warmup}$$

$e_0, e_1, e_2 =$  intermediate error signals



**Figure 7:** Engine Gas Dynamics subsystem



**Figure 8:** Mixing & Combustion block within the Engine Gas Dynamics subsystem

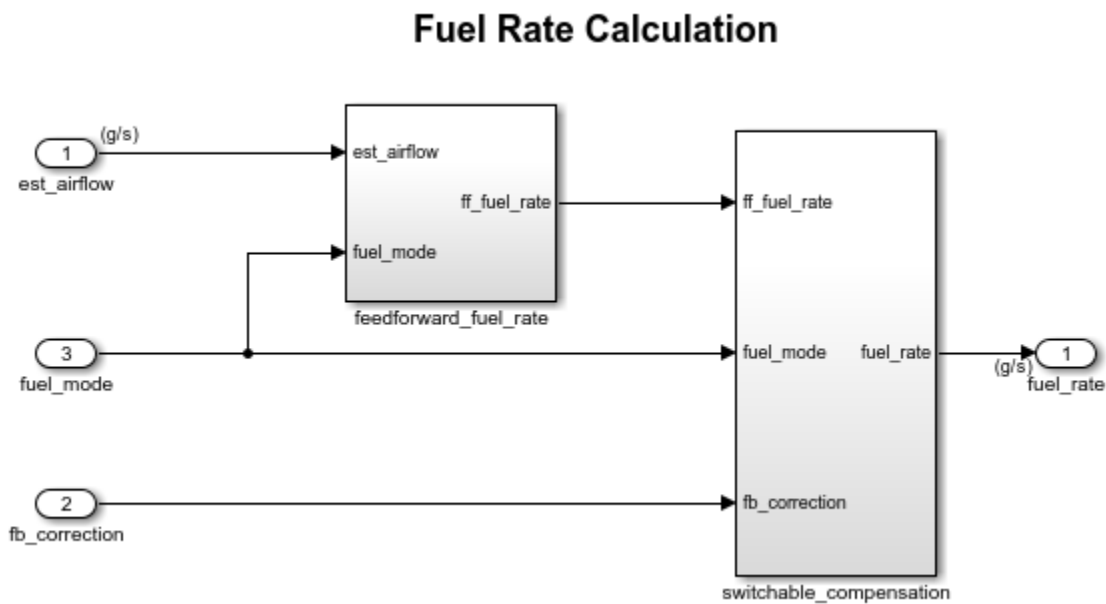
The nonlinear oxygen sensor (EGO Sensor block) is found inside the Mixing & Combustion block (see Figure 8) within the Engine Gas Dynamics subsystem (see Figure 7). EGO Sensor is modeled as a hyperbolic tangent function, and it provides a meaningful signal when in the vicinity of 0.5 volt. The raw error in the feedback loop is thus detected with a switching threshold, as indicated in Equation 2. If the air-fuel ratio is low (the mixture is lean), the original air estimate is too small and needs to be increased. Conversely, when the oxygen sensor output is high, the air estimate is too large and needs to be decreased. Integral control is utilized so that the correction term achieves a level that brings about zero steady-state error in the mixture ratio.

The normal closed-loop operation mode, LOW, adjusts the integrator dynamically to minimize the error. The integration is performed in discrete time, with updates every 10 milliseconds. When

operating open-loop however, in the RICH or O2 failure modes, the feedback error is ignored and the integrator is held. This gives the best correction based on the most recent valid feedback.

### Fuel Calculation

The fuel\_calc subsystem (within the fuel\_rate\_control subsystem, see Figure 9) sets the injector signal to match the given airflow calculation and fault status. The first input is the computed airflow estimation. This is multiplied with the target fuel/air ratio to get the commanded fuel rate. Normally the target is stoichiometric, i.e. equals the optimal air to fuel ratio of 14.6. When a sensor fault occurs, the Stateflow control logic sets the mode input to a value of 2 or 3 (RICH or DISABLED) so that the mixture is either slightly rich of stoichiometric or is shut down completely.



**Figure 9:** fuel\_calc subsystem

The fuel\_calc subsystem (Figure 9) employs adjustable compensation (Figure 10) in order to achieve different purposes in different modes. In normal operation, phase lead compensation of the feedback correction signal adds to the closed-loop stability margin. In RICH mode and during EGO sensor failure (open loop), however, the composite fuel signal is low-pass filtered to attenuate noise introduced in the estimation process. The end result is a signal representing the fuel flow rate which, in an actual system, would be translated to injector pulse times.

### Loop Compensation and Filtering

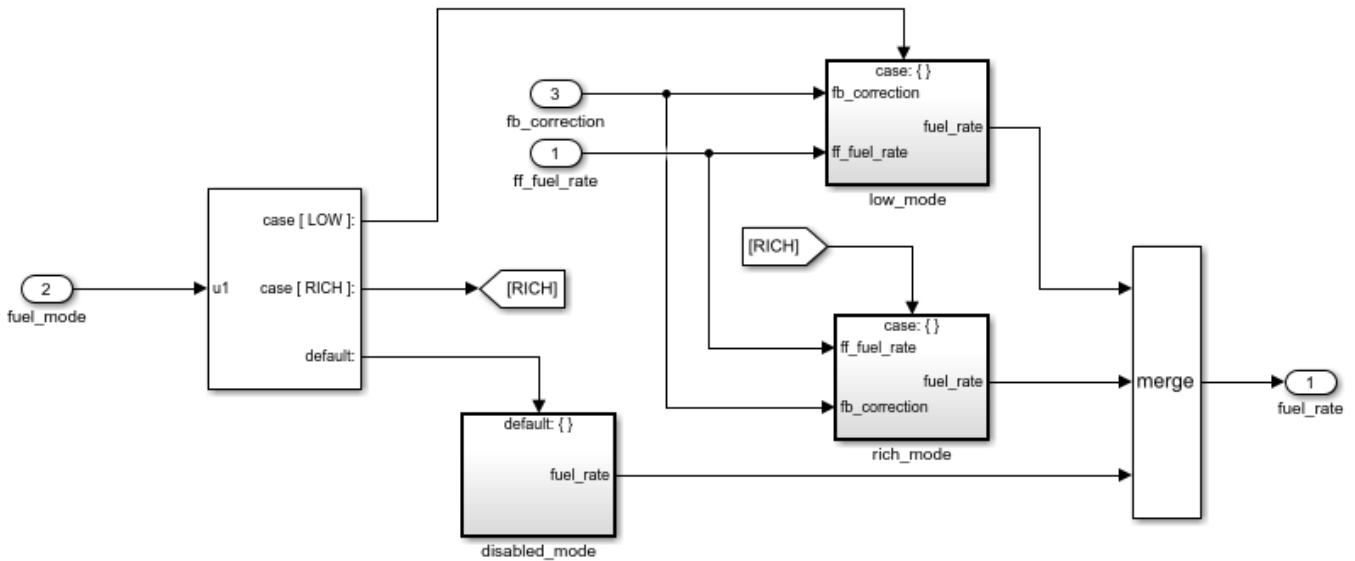
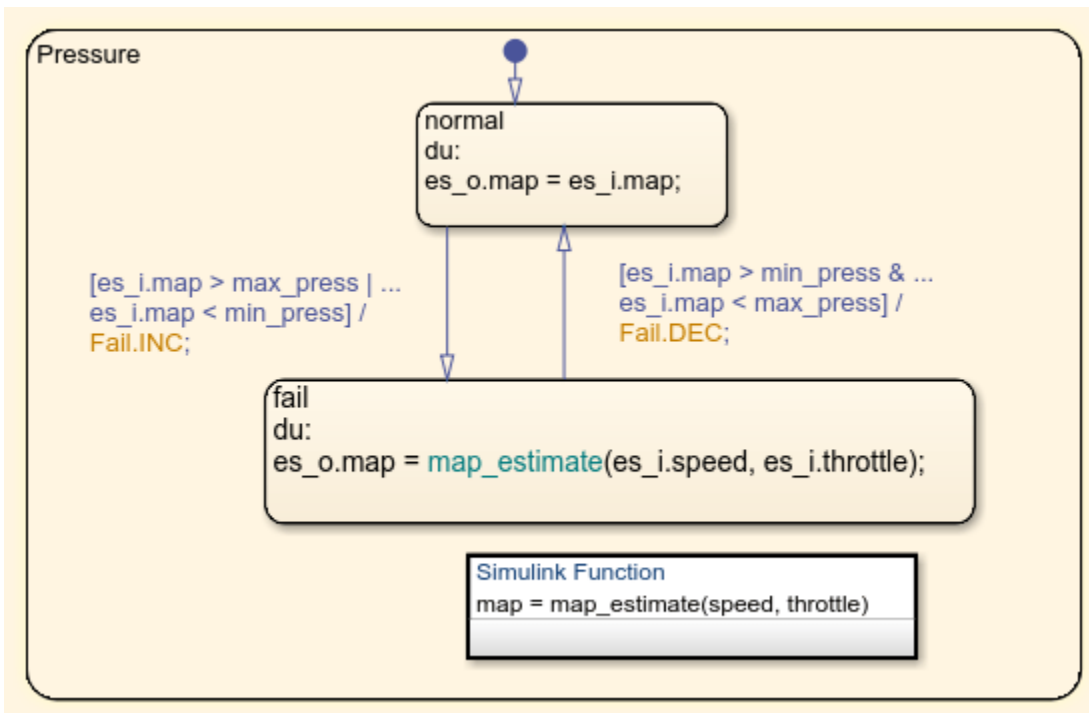


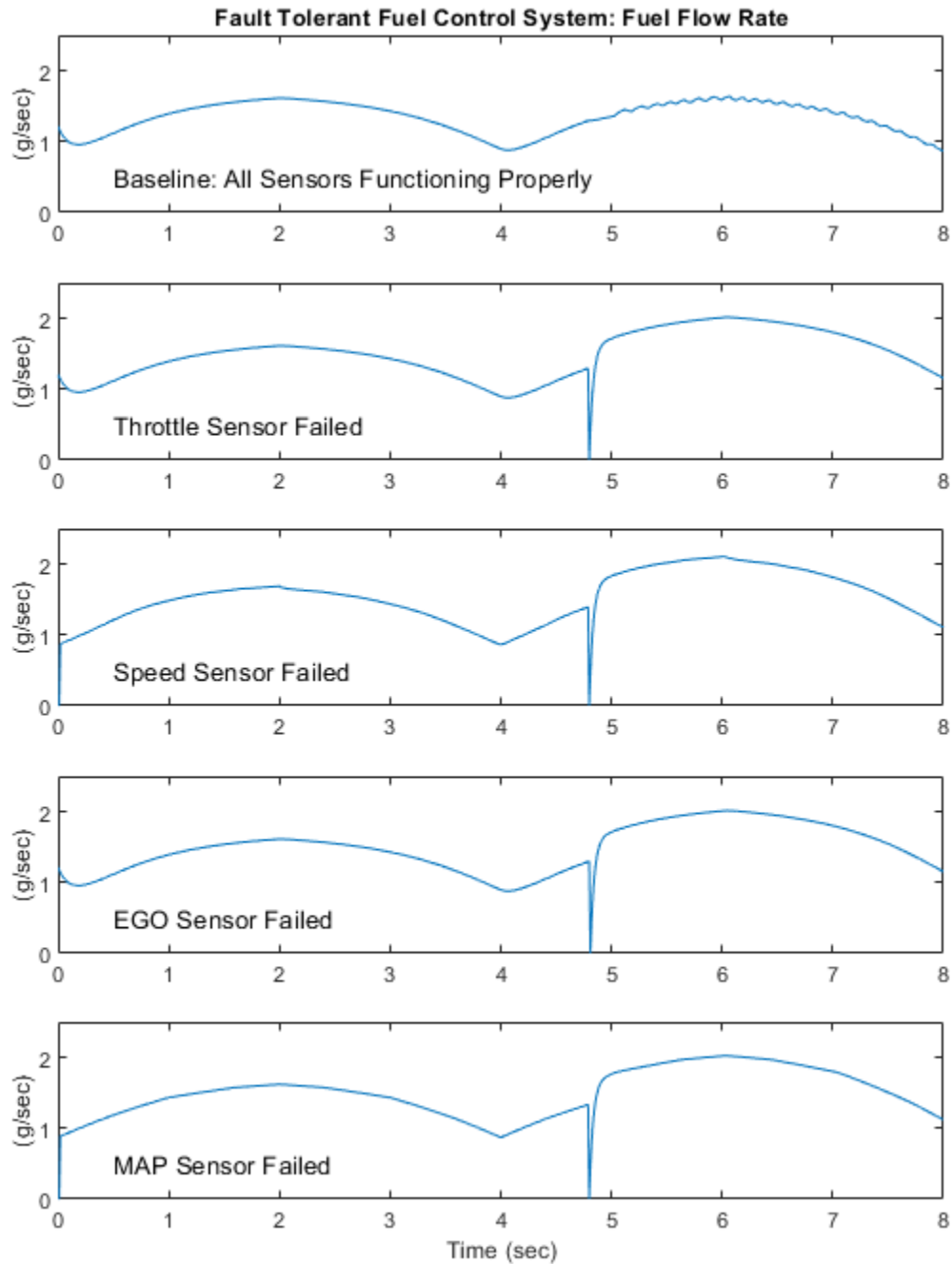
Figure 10: Switchable compensation subsystem



### Results and Conclusions

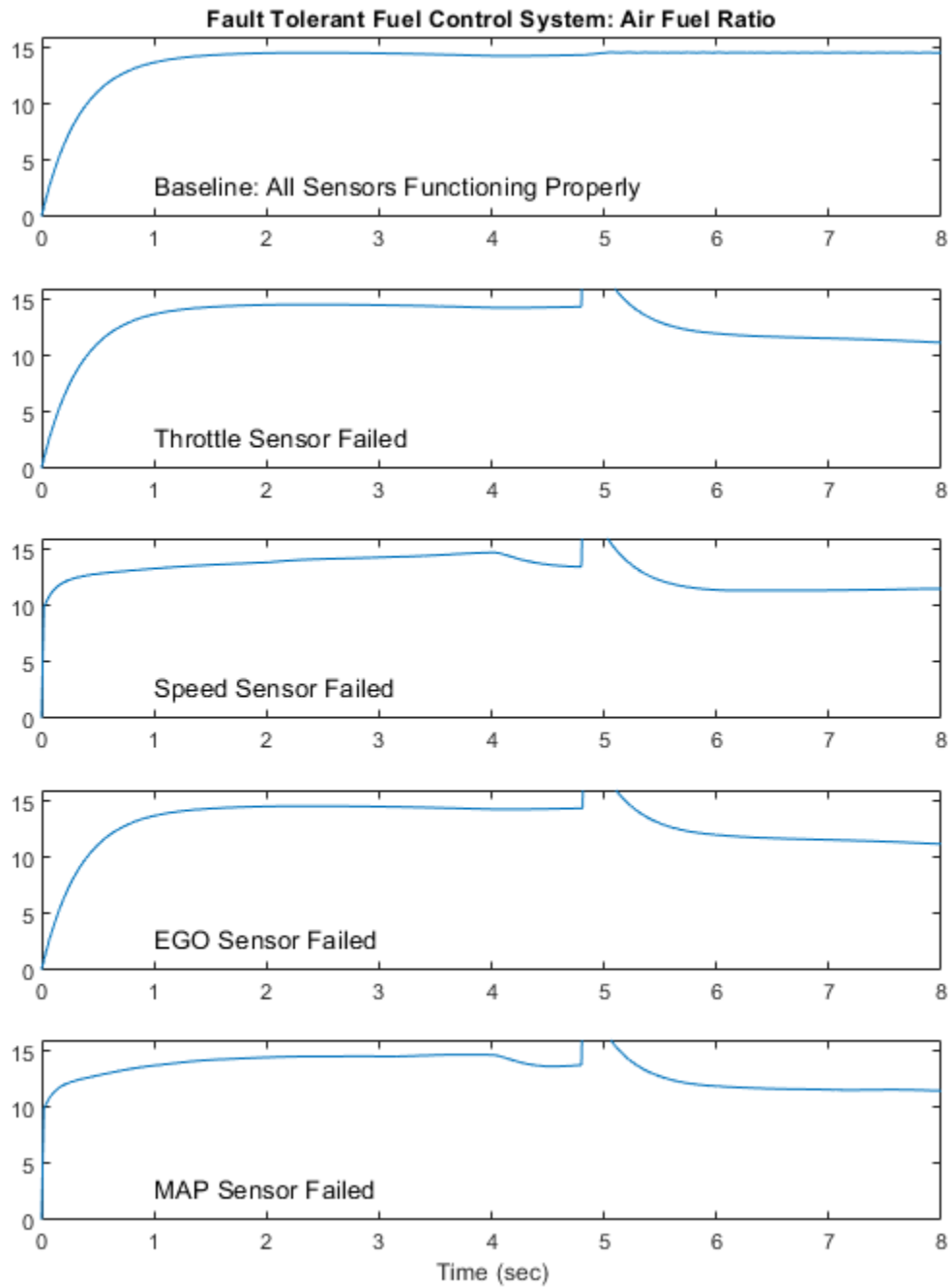
Simulation results are shown in Figure 11 and Figure 12. The simulation is run with a throttle input that ramps from 10 to 20 degrees over a period of two seconds, then goes back to 10 degrees over the next two seconds. This cycle repeats continuously while the engine is held at a constant speed so

that the user can experiment with different fault conditions and failure modes. Click on a sensor fault switch in the dashboard subsystem to simulate the failure of the associated sensor. Repeat this operation to slide the switch back for normal operation.



**Figure 11:** Comparing the fuel flow rate for different sensor failures

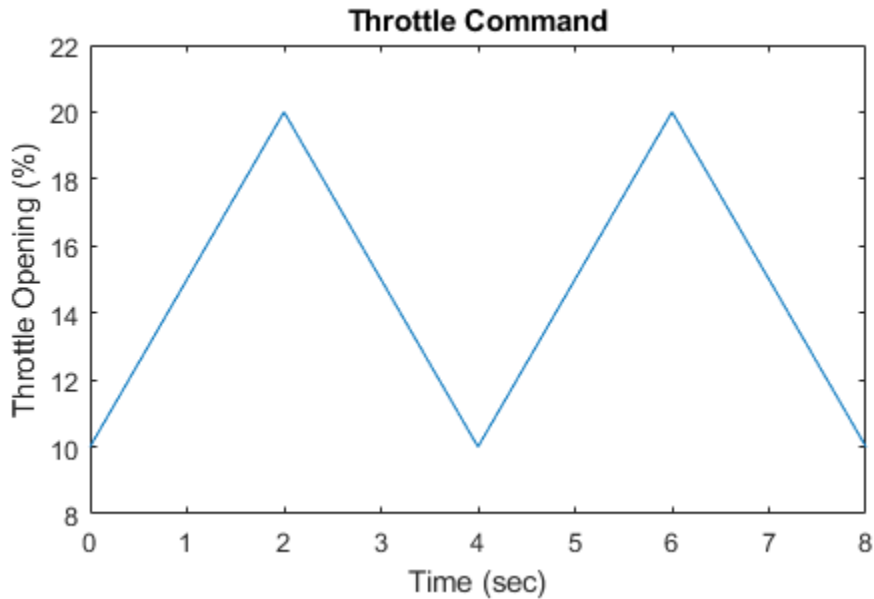
Figure 11 compares the fuel flow rate under fault-free conditions (baseline) with the rate applied in the presence of a single failure in each sensor individually. In each case note the nonlinear relationship between fuel flow and the triangular throttle command (shown in Figure 13). In the baseline case, the fuel rate is regulated tightly, exhibiting a small ripple due to the switching nature of the EGO sensor's input circuitry. In the other four cases the system operates open loop. The control strategy is proven effective in maintaining the correct fuel profile in the single-failure mode. In each of the fault conditions, the fuel rate is essentially 125% of the baseline flow, fulfilling the design objective of 80% rich.



**Figure 12:** Comparing the air-fuel ratio for different sensor failures

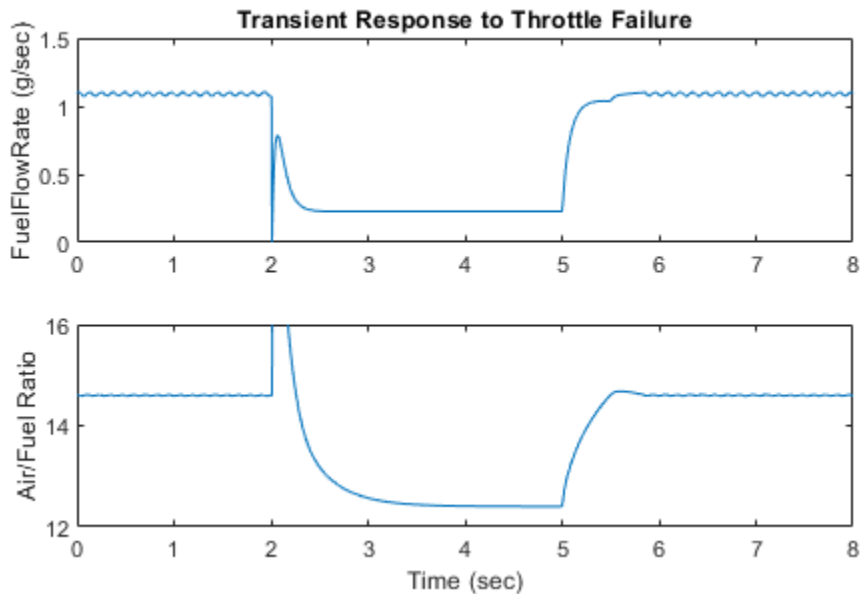
Figure 12 plots the corresponding air/fuel ratio for each case. The baseline plot shows the effects of closed-loop operation. The mixture ratio is regulated very tightly to the stoichiometric objective of

14.6. The rich mixture ratio is shown in the bottom four plots of Figure 12. Although they are not tightly regulated, as in the closed-loop case, they approximate the objective of air/fuel ( $0.8 \times 14.6 = 11.7$ ).



**Figure 13:** Throttle command

The transient behavior of the system is shown in Figure 14. With a constant 12 degree throttle angle and the system in steady-state, a throttle failure is introduced at  $t = 2$  and corrected at  $t = 5$ . At the onset of the failure, the fuel rate increases immediately. The effects are seen at the exhaust as the rich ratio propagates through the system. The steady-state condition is then quickly recovered when closed-loop operation is restored.



**Figure 14:** Transient response to fault detection



**Remarks**

If you enable animation in the Stateflow debugger, the state transitions are highlighted in the Stateflow diagram (see Figure 4) as the various states are activated. The sequence of activation is indicated by changing colors. This closely coupled synergy between Stateflow and Simulink fosters the modeling and development of complete control systems.

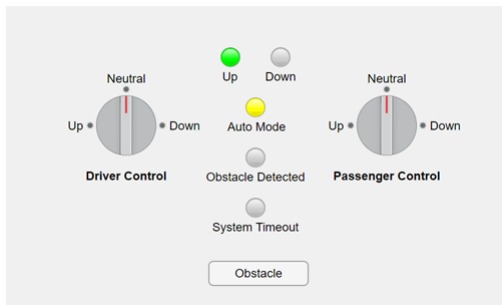
**See Also****More About**

- “Fixed-Point Fuel Rate Control System” (Fixed-Point Designer)
- “Air-Fuel Ratio Control System with Fixed-Point Data” (Embedded Coder)
- “Air-Fuel Ratio Control System with Stateflow Charts” (Embedded Coder)

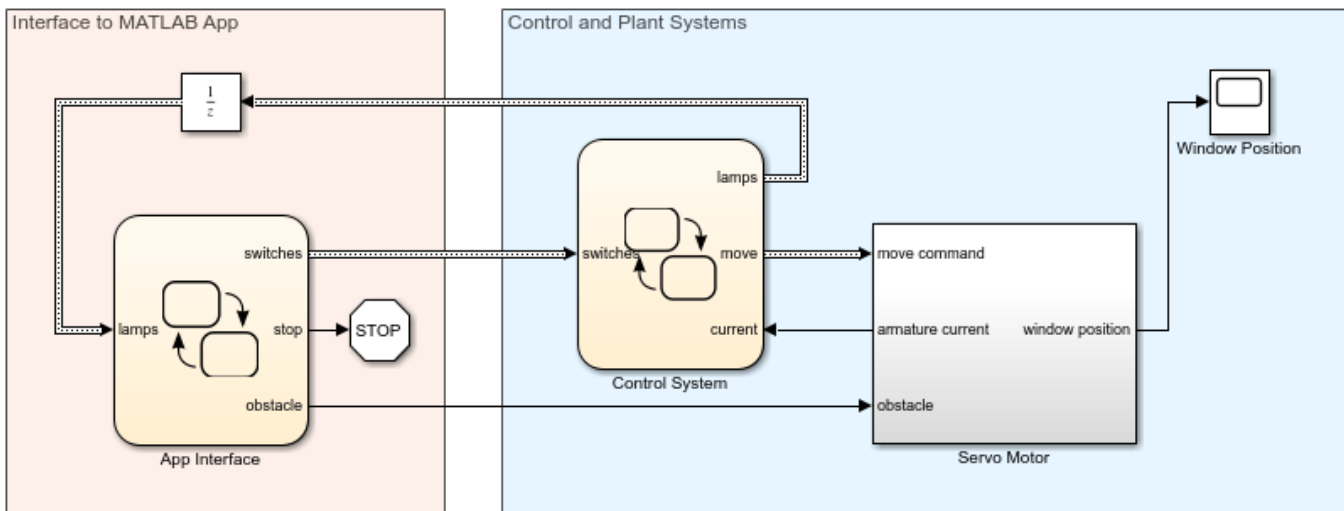
## Model a Power Window Controller

This example shows how to create an interface between a Stateflow® chart that uses MATLAB® as the action language and a MATLAB app created in App Designer. For more information on connecting a Stateflow chart that uses C as the action language to a MATLAB app, see “Simulate a Media Player” on page 24-17.

In this example, an automotive power window system raises and lowers the passenger-side window in response to a pair of window control switches. The switches in the MATLAB app represent the controls on the driver and passenger doors. The app also contains several indicator lamps that monitor the status of the power window system and a button for introducing an obstacle in the path of the window.



The Stateflow chart `App Interface` provides a bidirectional connection between the MATLAB app and the control and plant systems in the Simulink® model. When you point a switch in the app to a new position, the chart sends a corresponding "Up," "Down," or "Neutral" command to the power window control system. Conversely, when the control system changes state, the chart enables or disables the corresponding status lamps in the app.



To run the example, open the Simulink model and click **Run**. The chart `App Interface` opens the app and initializes the control and plant systems in the power window system. To stop the simulation, click **Stop** or close the app.

## Connect Chart to MATLAB App

The chart App Interface is already configured to communicate with the MATLAB app `sf_power_window_app`. To create a bidirectional connection between your MATLAB app and a Stateflow chart that uses MATLAB as the action language, follow these steps. In the MATLAB app:

- 1 Create a custom property to interface with the chart during simulation. The app uses this property to access chart inputs, chart outputs, and local data. For more information, see “Share Data Within App Designer Apps”.
- 2 Modify the `startupFcn` callback for the app by adding a new input argument and storing its value as the property that you created in the previous step. For more information, see “Write Callbacks in App Designer”.

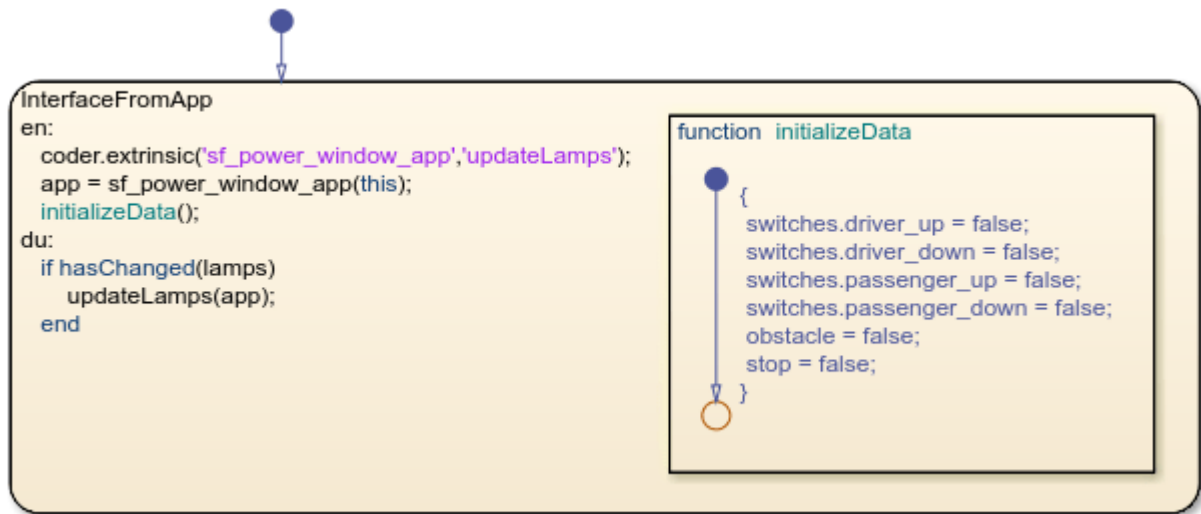
In the Stateflow chart:

- 1 Create a local data object to interface with the app. The chart uses this local data object as an argument when it calls helper functions in the app.
- 2 Set the type of the local data object you created in the previous step to `Inherit: From definition in chart`. For more information, see “Specify Type of Stateflow Data” on page 12-27.
- 3 Call the `coder.extrinsic` function to declare the app and any helper functions as extrinsic MATLAB code. For more information, see “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40.
- 4 Run the app using the keyword `this` as an argument to give the app access to the chart during simulation. Store the value returned by the function call to the app as the local data object that you created to interface with the app.

In this example, the power window app uses a property called `chart` to interface with the chart App Interface. The app callbacks use this property to write to the chart outputs:

- When you move the driver-side control switch to a new position, the `DriverControlValueChanged` callback sets the values of `switches.driver_up` and `switches.driver_down`.
- When you move the passenger-side control switch to a new position, the `PassengerControlValueChanged` callback sets the values of `switches.passenger_up` and `switches.passenger_down`.
- When you click the **Obstacle** button, the `ObstacleButtonPushed` callback sets the value of `obstacle` to `true`.
- When you close the app, the `UIFigureCloseRequest` callback sets the value of `stop` to `true`.

Conversely, in the chart, the entry actions in the `InterfaceWithApp` state run the app `sf_power_window_app` and store the returned value as the local data object `app`. The chart uses this local data object when it calls the helper function `updateLamps`. In the app, this helper function turns the lamps on and off based on the value of the chart input `lamps`.



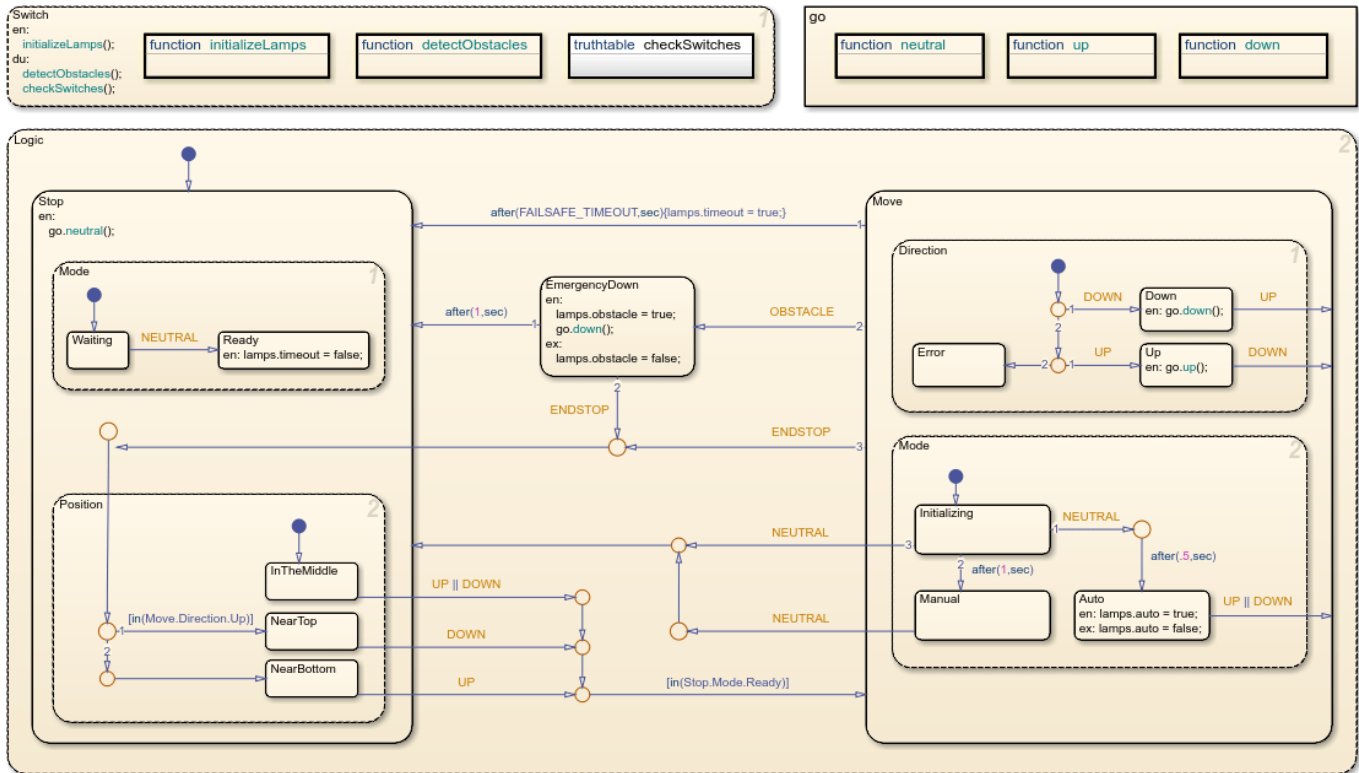
### Control System Design

The power window control system uses mode logic to determine when the window should move and outputs a unified motion command to a servo motor. To lower production costs, the control system does not keep track of the window position. Instead, it relies on a signal from the servo motor to determine when the window is fully open or fully closed, or when it encounters an obstacle.

The control system meets these performance requirements:

- 1 The window must open or close completely in 5 seconds.
- 2 The motor must stop when the window reaches a fully opened or fully closed position.
- 3 The motor must be able to detect an obstacle when the window is moving up. When the motor detects an obstacle in the path of the window, the window must be lowered for one second or until the window is fully open.
- 4 The motor must stop after 10 seconds of continuous movement in any direction. This requirement provides a fail-safe protection for the window mechanism, motor, and drive.
- 5 If a control switch is pressed for less than half a second, or if it is pressed for longer than one second, the window must stop when the switch is released.
- 6 If a control switch is pressed for longer than half a second and released before one second, the window must open or close completely unless it is interrupted by a new command or by an obstacle. This requirement represents the automatic mode capability of the power window.
- 7 The driver-side control has priority over the passenger-side control.
- 8 Obstacle detection has priority over both driver-side and passenger-side controls.

The Stateflow chart `Control System` models an event-driven controller that satisfies these requirements. The chart consists of two states (`Switch` and `Logic`) in parallel decomposition. These states react to changes in the chart inputs, determine the operating mode of the power window system, and manage the output signals that activate the servo motor.



### Monitor Controller Input

The state `Switch` reads the values of the chart inputs and broadcasts local events to change the operating mode of the power window system. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

At every time step of the simulation, the state calls the truth table function `checkSwitches` to determine the positions of the driver-side and passenger-side control switches. Depending on the value of the input structure `switches`, this function broadcasts the `UP`, `DOWN`, and `NEUTRAL` events. Because the function ignores any input from the passenger-side control when the driver-side control is not in the "Neutral" position, the driver-side control has priority over the passenger-side control, as specified by requirement 7.

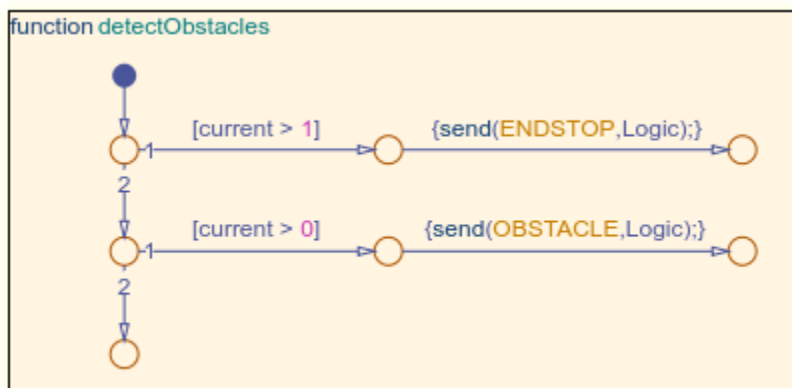
Condition Table

DESCRIPTION	CONDITION	D1	D2	D3	D4	D5
1	switches.driver_up	T	F	F	F	-
2	switches.driver_down	F	T	F	F	-
3	switches.passenger_up	-	-	T	F	-
4	switches.passenger_down	-	-	F	T	-
	ACTIONS: SPECIFY A ROW FROM THE ACTION TABLE	1	2	1	2	3

Action Table

DESCRIPTION	ACTION
1 Move Up	<code>send(UP,Logic);</code>
2 Move Down	<code>send(DOWN,Logic);</code>
3 Stay Neutral	<code>send(NEUTRAL,Logic);</code>

In a similar way, the state calls the graphical function `detectObstacles` to determine the strength of the armature current in the servo motor. If the value of `current` is small and nonzero, an obstacle is present so the function broadcasts the event `OBSTACLE`. In contrast, if the value of `current` is large, the window has reached a fully open or fully closed position so the function broadcasts the event `ENDSTOP`. Because the chart calls `detectObstacles` before `checkSwitches`, obstacle detection has priority over both driver-side and passenger-side controls, as specified by requirement 8.



### Determine Operating Mode

The state `Logic` incorporates fault detection algorithms to protect the window hardware and any obstacles in the path of the window. The state contains three substates, `Stop`, `Move`, and `EmergencyDown`, that represent the operating modes of the power window system.

Initially, the state `Stop` is active. This state contains two parallel substates named `Mode` and `Position`.

- `Mode` determines when the power system is ready to accept new commands from the control switches. The system is ready for new commands when both control switches are in the "Neutral" position.
- `Position` records whether the window is fully open, fully closed, or somewhere in the middle. The chart makes this determination by noting the direction in which the window is moving when the servo motor reaches the end of its range.

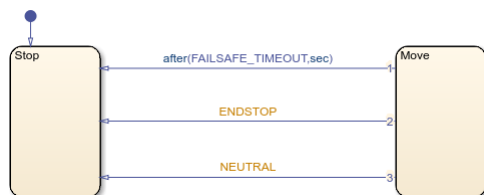
**Stop** remains active until a broadcast of the events **UP** or **DOWN** indicates a command from one of the control switches. As long as the window is not fully open or fully closed, these events trigger the transition to the state **Move**. However, the event **UP** is considered invalid when the window is already fully open. Likewise, the event **DOWN** is invalid when the window is fully open.



The state **Move** is active whenever the window is in motion. This state implements several of the power window requirements related to automatic window movement and fault detection. The state has two parallel substates named **Direction** and **Mode**.

- **Direction** determines the direction in which the window should move and calls the functions `go.up` and `go.down`, as appropriate. These functions set the values of the output signals that control the servo motor and the "Up" and "Down" status lamps in the app.
- **Mode** implements the automatic and manual modes of the power window specified by requirements 5 and 6. This state has three exclusive substates (**Initializing**, **Auto**, and **Manual**). Initially, the substate **Initializing** is active. The substate waits for a broadcast of the **NEUTRAL** event, which indicates that the control switches have returned to the "Neutral" position. If the broadcast occurs within half a second of **Initializing** becoming active, the event triggers a transition to the **Stop** state, indicating that the window must stop moving. If the broadcast occurs after half a second but before one second of **Initializing** becoming active, the event triggers a transition to the substate **Auto**, indicating that the power window system is operating in its automatic mode. This substate remains active until it is interrupted by a broadcast of the events **ENDSTOP** (when the window is fully open or fully closed), **OBSTACLE** (when the window encounters an obstacle), or **UP** or **DOWN** (when the system receives a new command from one of the control switches). Finally, if the broadcast does not occur before one second of **Initializing** becoming active, the temporal logic expression `after(1, sec)` triggers the transition to the substate **Manual**. This substate remains active until a broadcast of the event **NEUTRAL** triggers the transition back to the **Stop** state.

Independent of whether the system is in automatic or manual mode, the chart transitions directly from **Move** to **Stop** on the broadcast of the event **ENDSTOP** or when **Move** is active for longer than **FAILSAFE\_TIMEOUT** seconds, as specified by requirements 2 and 4. By default, the value of this constant is set to 10.

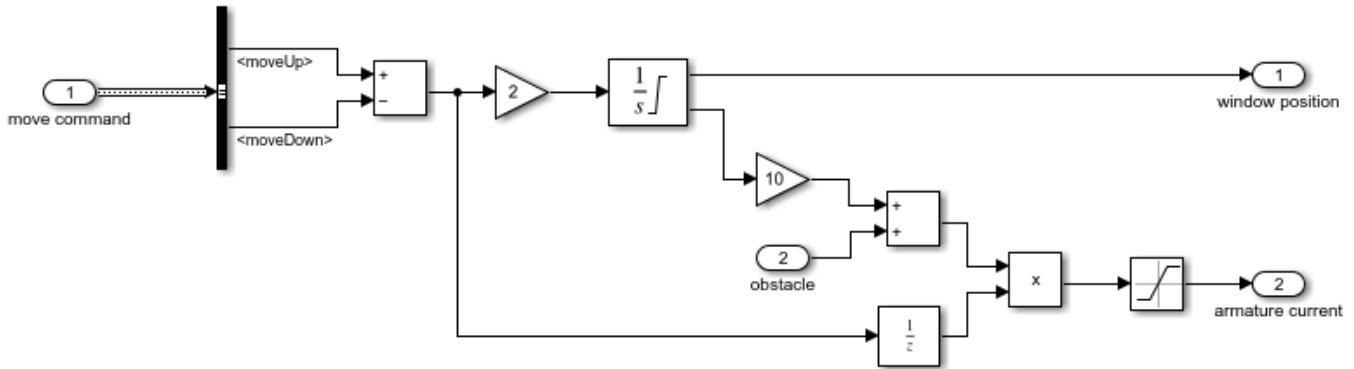


## Detect Obstacles

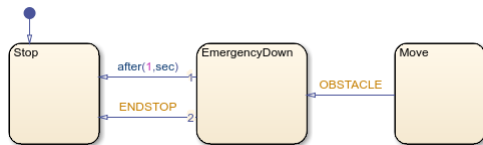
When the window encounters an obstacle, the applied force on the window increases the load on the servo motor and causes a rise in the armature current. By monitoring for sharp increases in the armature current, the system detects obstacles in the path of the window.

In this example, a Simulink subsystem simulates the servo motor. The position of the window is computed by an Integrator (Simulink) block with saturation limits of 0 (fully open) and 10 (fully

closed). Because the input to this block has a gain of 2, the window opens and closes completely in 5 seconds, as specified by requirement 1. When the Integrator block reaches a saturation point, the system output `armature current` increases to 10. This value indicates that the window is fully open or fully closed.



To introduce an obstacle in the path of the window, click the **Obstacle** button in the app while the window is moving up. The App Interface chart responds by sending a positive signal to the servo motor, which in turn produces a small rise in the armature current. In the Control System chart, the function `detectObstacles` registers this change in current and broadcasts the event `OBSTACLE`. In the Logic state, this event triggers the transition from the substate `Move` to the substate `EmergencyDown`. While this substate is active, the system moves the window down for one second or until the window is fully open. Then, the chart transitions back to the substate `Stop`, indicating that the window must stop moving, as specified by requirement 3.



## See Also

Integrator | after | `coder.extrinsic` | `hasChanged` | `send` | `this`

## More About

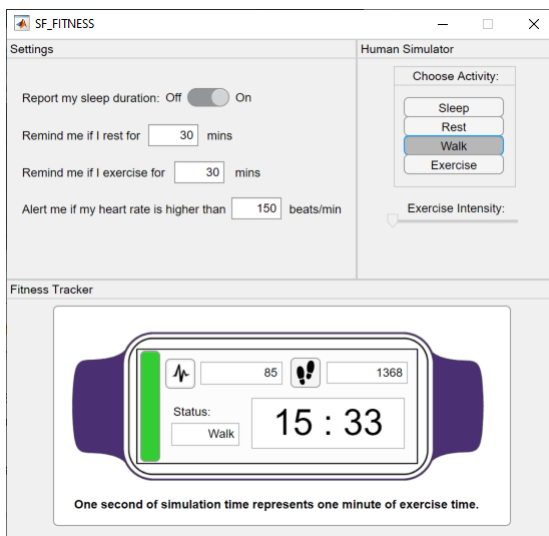
- “Simulate a Media Player” on page 24-17
- “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40
- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Develop Apps Using App Designer”



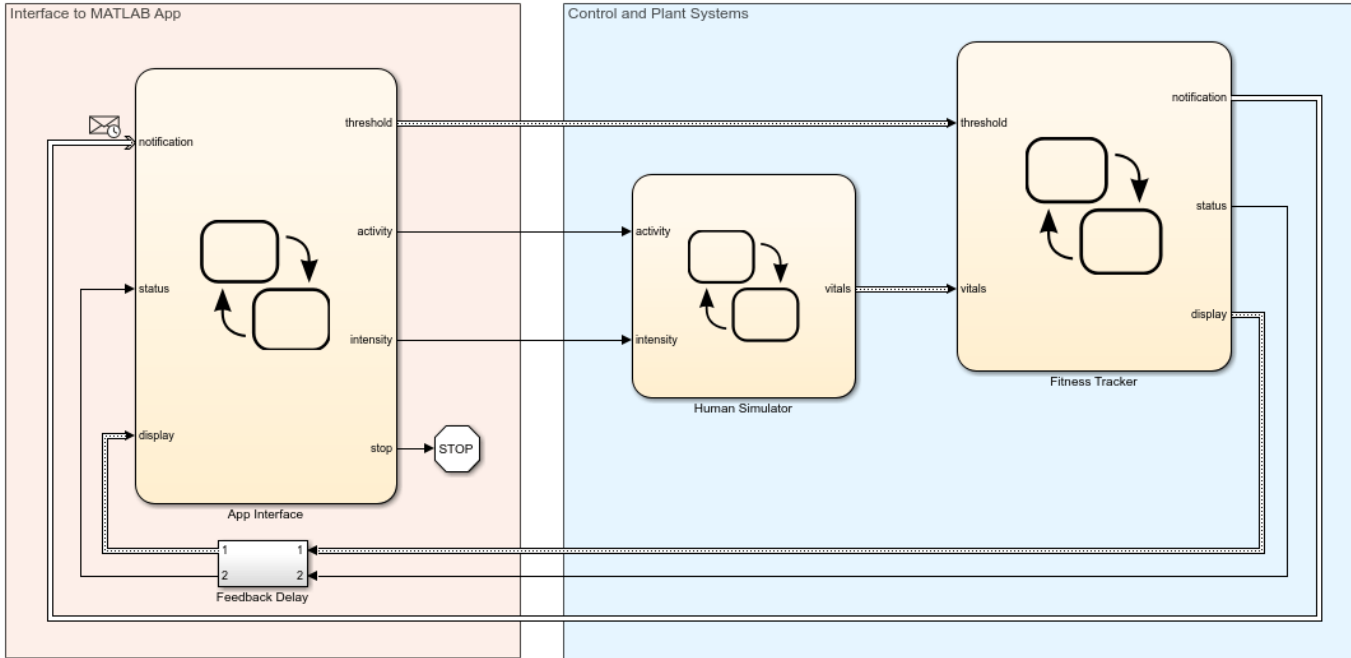
## Model a Fitness Tracker

This example shows how to create an interface between a Stateflow® chart and a MATLAB® app created in App Designer. For other examples that show how to connect a Stateflow chart to a MATLAB app, see “Model a Power Window Controller” on page 30-50 and “Simulate a Media Player” on page 24-17. For a version of this example that uses standalone charts in MATLAB, see “Model a Fitness App by Using Standalone Charts” on page 35-35.

In this example, a MATLAB app models a fitness tracker. During simulation, you can adjust the settings for the tracker and select an activity (**Sleep**, **Rest**, **Walk**, or **Exercise**). When you choose **Exercise**, you can also set the intensity of your workout.



The Stateflow chart `App Interface` provides a bidirectional connection between the MATLAB app and the control and plant systems in the Simulink® model. When you interact with the widgets in the app, the chart communicates your selections to the other charts in the model. Conversely, the chart uses the output of the fitness tracker to update the numeric and text fields in the app. For example, when you click the **Rest** button on the app, the `App Interface` chart sets the value of the output `activity` to the enumerated value `Activity.Rest`. The `Human Simulator` chart responds by producing vital sign values that model a person at rest. The `Fitness Tracker` chart analyses these values and sets the output signal `status` to `Activity.Rest`. The `App Interface` chart monitors this signal and updates the contents of the **Status** field in the app to **Rest**.



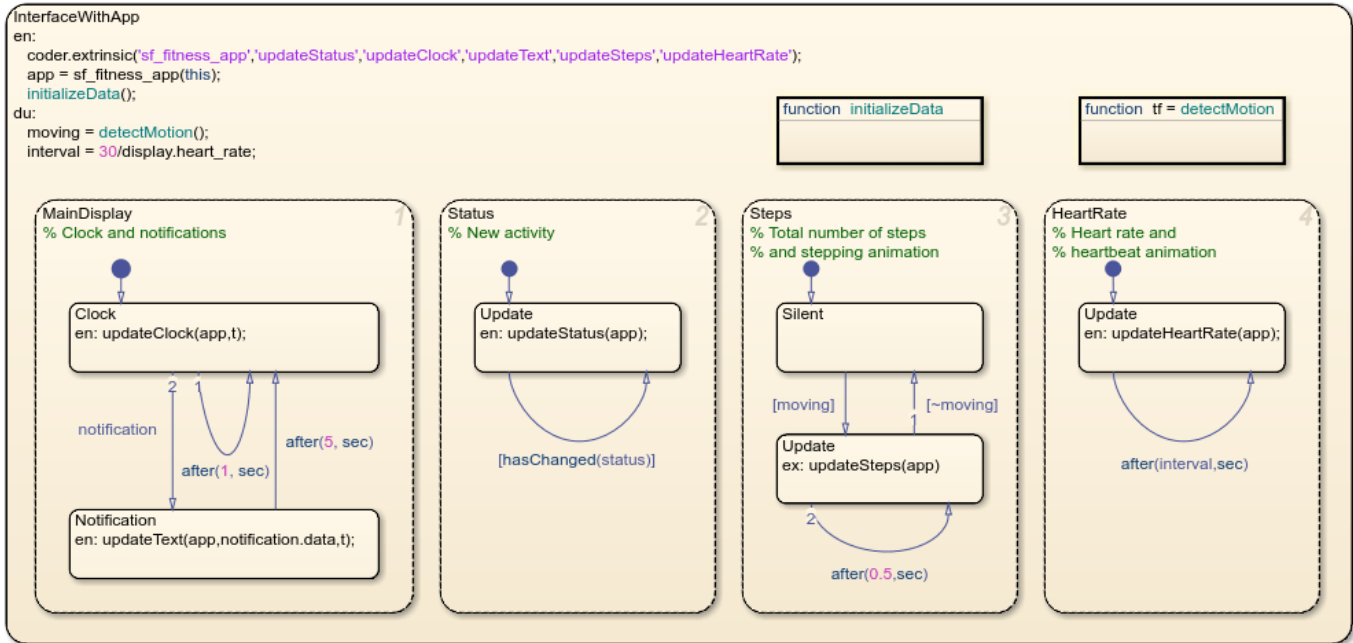
To run the example, open the Simulink model and click **Run**. The chart `App Interface` opens the app and initializes the `Human Simulator` and `Fitness Tracker` charts. While the example is running, one second of simulation represents one minute of exercise time. To stop the simulation, click **Stop** or close the app.

### Connect Chart to MATLAB App

The chart `App Interface` is configured to communicate with the MATLAB app `sf_fitness_app`.

- The app uses a property called `chart` to interface with the chart `App Interface`. The app callbacks use this property to read the chart inputs and write to the chart outputs. For example, when you change the value of one of the fields in the **Settings** pane, a callback updates the value of the corresponding field of the output structure `threshold`. Similarly, when you select a new activity or change the intensity of your workout in the **Human Simulator** pane, a callback sets the value of the chart outputs `activity` and `intensity`. Finally, when you close the app, the `UIFigureCloseRequest` callback sets the value of the chart output `stop` to `true`.
- In the chart, the entry actions in the `InterfaceWithApp` state run the app `sf_fitness_app` and store the returned value as the local data object `app`. The chart uses this local data object when it calls the helper functions `updateStatus`, `updateClock`, `updateText`, `updateSteps`, and `updateHeartRate`. In the app, these helper functions change the contents of the activity status, clock, and step counter fields, and create the animation effects in the heartbeat and footstep displays. For example, when the chart receives a `notification` message, the substate `MainDisplay` calls the helper function `updateText`. This function replaces the contents of the clock display with a customized notification. After five seconds, the substate calls the helper function `updateClock` to restore the clock display.

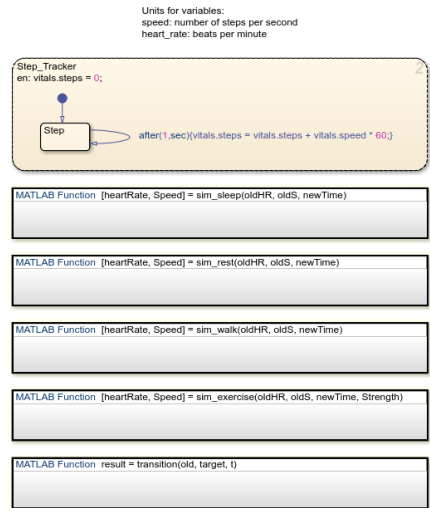
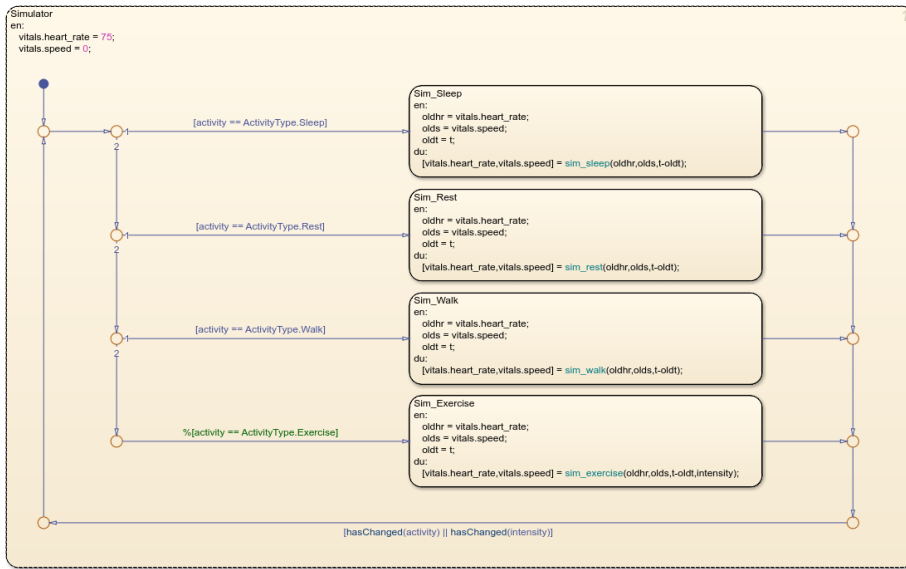
For more information on how to create a bidirectional connection between your MATLAB app and a Stateflow chart, see “Model a Power Window Controller” on page 30-50 and “Simulate a Media Player” on page 24-17.



The functions used to interact with the app are not supported for code generation, so the `InterfaceWithApp` state first calls the `coder.extrinsic` function to declare them as extrinsic MATLAB code. For more information, see “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40.

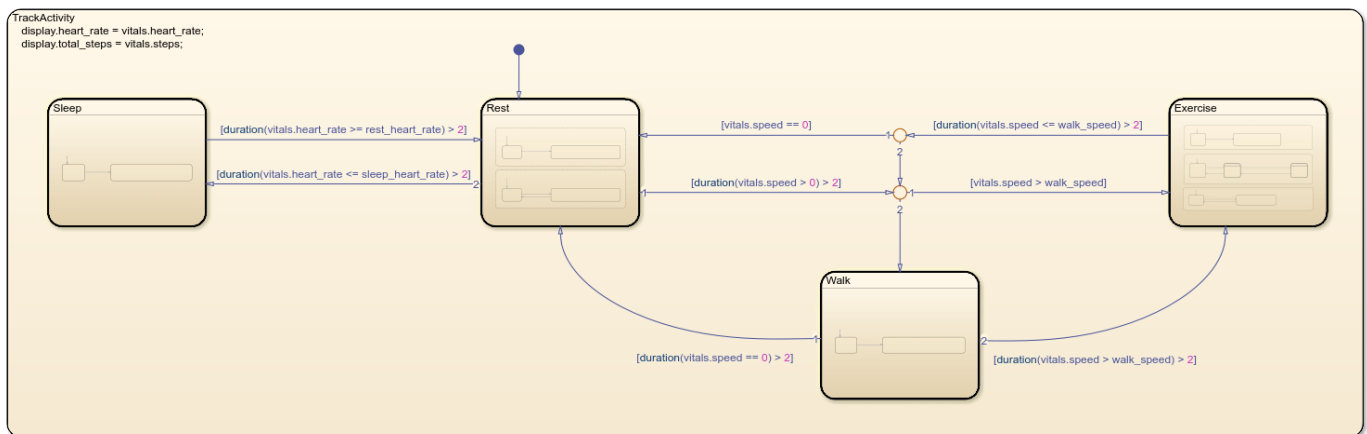
### Simulate Vital Signs Based on Activity

The `Human Simulator` chart models the vital signs of a human engaged in the activity you select in the app. The chart uses the output structure `vitals` to relay these vital signs to the fitness tracker. The fields of the structure represent your heart rate, speed, and the number of steps that you have taken. When you select a new activity or adjust the intensity of your workout, the chart calls the function transition to ensure that these vital signs change gradually over time. To detect changes in activity or exercise intensity, the chart calls the `hasChanged` operator. For more information, see “Detect Changes in Data Values” on page 16-64.



### Determine Fitness Tracker Output

The chart **Fitness Tracker** models the core logic of the fitness tracker. The chart consists of four subcharts that correspond to the possible activities. The chart registers your activity status based on the heart rate and speed produced by the **Human Simulator** chart and transitions between these subcharts. To filter out signal noise, the chart uses the `duration` operator to implement simple debouncing logic. For instance, when you are at rest, you can make some quick and sudden movements that do not correspond to exercise. The chart determines that you are walking or exercising only if your motion lasts longer than two minutes (or two seconds of simulation time). The chart monitors the active child state and passes this information to the **App Interface** chart through the output data `status`. For more information, see “Monitor State Activity Through Active State Data” on page 13-2.



The chart uses other temporal logic operators to track the amount of time you spend in each activity and determine when to send notifications to the app:

- The exit actions in each subchart call the `elapsed` operator to determine how long the subchart was active. The chart communicates this value, along with other information such as your heart

rate and your total number of steps, to the App Interface chart through the output structure `display`.

- The chart uses the `after` operator to determine when you sleep or walk for longer than five minutes, rest or exercise for longer than the threshold you specify in the app, or exercise at a high intensity (taking more than 4 steps a second) for longer than 15 minutes. In each of these cases, the chart sends a `Notification` message. The App Interface chart receives this message and causes a notification to appear in the main display of the app. Depending on the type of notification, the notification button changes color.

## See Also

Stop Simulation | `after` | `coder.extrinsic` | `duration` | `elapsed` | `hasChanged`

## More About

- “Model a Fitness App by Using Standalone Charts” on page 35-35
- “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Communicate with Stateflow Charts by Sending Messages” on page 15-2
- “Monitor State Activity Through Active State Data” on page 13-2
- “Develop Apps Using App Designer”



# Build Targets

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- “Access Custom C++ Code in Stateflow Charts” on page 31-2
- “Access Custom C Code in Nonlibrary Charts” on page 31-4
- “Access Custom C Code in Library Models” on page 31-7
- “Access Custom C Code in All Charts in Model” on page 31-9
- “Access Custom Code Variables and Functions in Stateflow Charts” on page 31-11
- “Include Custom C Code Functions and Structures” on page 31-13
- “C++ Code Generation and Integration in Stateflow” on page 31-15
- “Speed Up Simulation” on page 31-17
- “Command-Line API to Set Simulation and Code Generation Parameters” on page 31-19
- “Specify Relative Paths to Your Custom Code” on page 31-22
- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “Model Battery Management with Custom Code” on page 31-28
- “Resolve Undefined Symbols in Your Chart” on page 31-37
- “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40

## Access Custom C++ Code in Stateflow Charts

You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### Task 1: Prepare Code Files

Prepare your custom C++ code for simulation as follows:

- 1 Add a C function wrapper to your custom code. This wrapper function executes the C++ code that you are including.

The C function wrapper should have this form:

```
int my_c_function_wrapper()
{
    .
    .
    .
    //C++ code
    .
    .
    .
    return result;
}
```

- 2 Create a header file that prototypes the C function wrapper in the previous step.

The header file should have this form:

```
int my_c_function_wrapper();
```

The value `_cplusplus` exists if your compiler supports C++ code. The `extern "C"` wrapper specifies C linkage with no name mangling.

### Task 2: Include Custom C++ Source and Header Files for Simulation

To include custom C++ code for simulation, you must configure your simulation target and select C++ as the custom code language:

- 1 Open the Model Configuration Parameters dialog box.
- 2 In the Model Configuration Parameters dialog box, select the **Simulation Target** pane.
- 3 Add your custom header file in the **Header file** subpane. Click **Apply**.
- 4 Add your custom C++ files in the **Source files** subpane. Click **Apply**.
- 5 In the Model Configuration Parameters dialog box, select the **Code Generation** pane.
- 6 Select C++ from the **Language** menu.
- 7 Click **OK**.



### **Task 3: Choose a C++ Compiler**

You can change the default compiler by calling the `mex -setup` command, and following the instructions. For a list of supported compilers, see [www.mathworks.com/support/compilers/current\\_release/](http://www.mathworks.com/support/compilers/current_release/).

### **Task 4: Simulate the Model**

Simulate your model by clicking the play button in the toolbar of the editor.

For information on setting simulation options using the command-line API, see “Command-Line API to Set Simulation and Code Generation Parameters” on page 31-19.

### **See Also**

#### **More About**

- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “C++ Code Generation and Integration in Stateflow” on page 31-15

## Access Custom C Code in Nonlibrary Charts

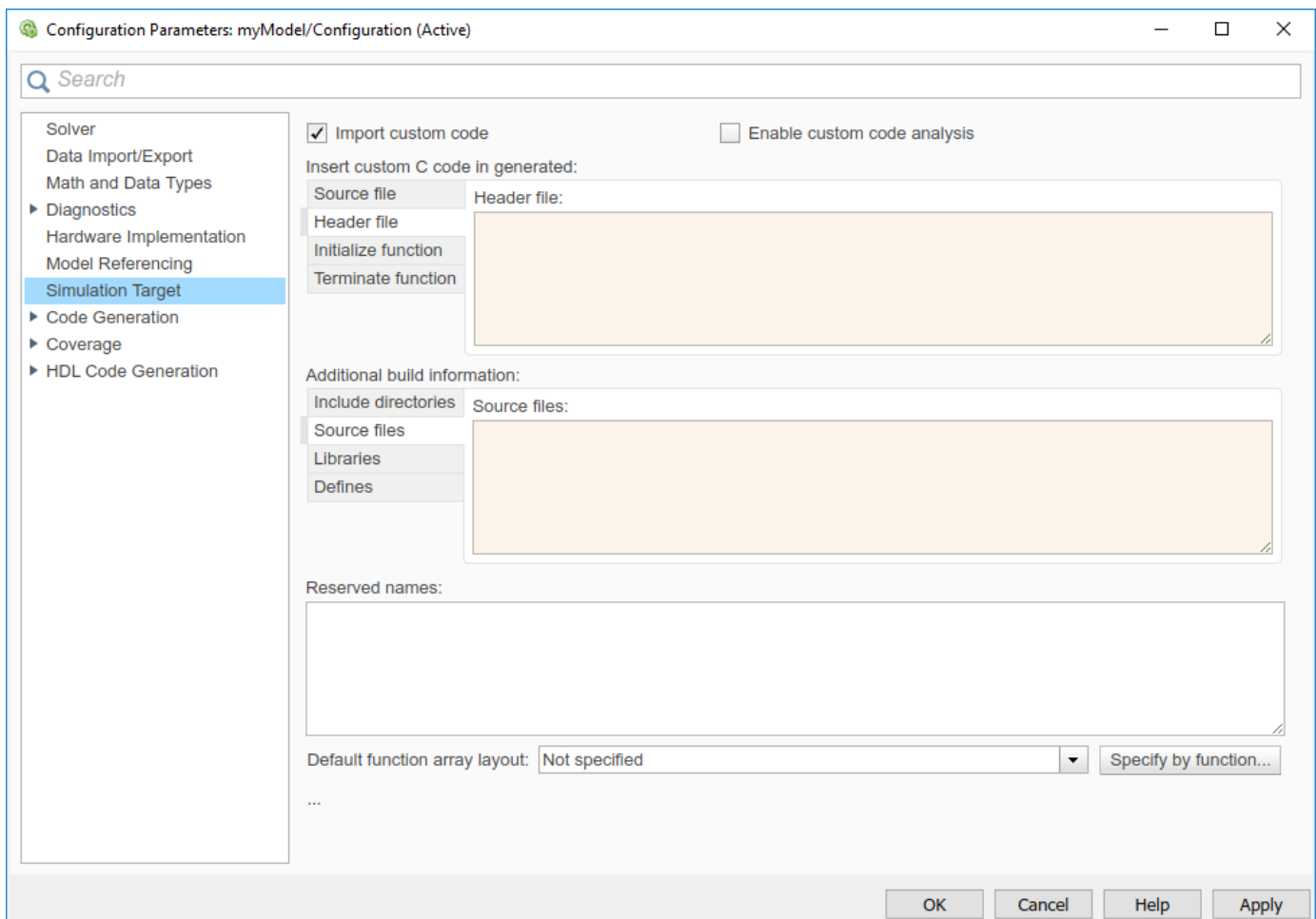
You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### Task 1: Include Custom C Code in the Simulation Target

Specify custom code options in the simulation target for your model:

- 1 Open the Model Configuration Parameters dialog box.
- 2 In the Model Configuration Parameters dialog box, select the **Simulation Target** pane.

The custom code options appear.



- 3 Specify your custom code in the subpanes.

Follow the guidelines in “Specify Relative Paths to Your Custom Code” on page 31-22.

- **Source file** — Enter code lines to include at the top of a generated source code file. These code lines appear at the top of the generated `model.c` source file, outside of any function.

For example, you can include `extern int` declarations for global variables.

- **Header file** — Enter code lines to include at the top of the generated `model.h` header file that declares custom functions and data in the generated code. These code lines appear at the top of all generated source code files and are visible to all generated code.

---

**Note** When you include a custom header file, you must enclose the file name in double quotes. For example, `#include "sample_header.h"` is a valid declaration for a custom header file.

---

Since the code you specify in this option appears in multiple source files that link into a single binary, limitations exist on what you can include. For example, do not include a global variable definition such as `int x;` or a function body such as

```
void myfun(void)
{
...
}
```

These code lines cause linking errors because their symbol definitions appear multiple times in the source files of the generated code. You can, however, include `extern` declarations of variables or functions such as `extern int x;` or `extern void myfun(void);`.

- **Initialize function** — Enter code statements that execute once at the start of simulation. Use this code to invoke functions that allocate memory or perform other initializations of your custom code.
- **Terminate function** — Enter code statements that execute at the end of simulation. Use this code to invoke functions that free memory allocated by the custom code or perform other cleanup tasks.
- **Include directories** — Enter a space-separated list of the folder paths that contain custom header files that you include either directly (see **Header file** option) or indirectly in the compiled target.
- **Source files** — Enter a list of source files to compile and link into the target. You can separate source files with a comma, a space, or a new line.
- **Libraries** — Enter a space-separated list of static libraries that contain custom object code to link into the target.

4 Click **OK**.

## Task 2: Simulate the Model

Simulate your model by clicking the play button in the toolbar of the editor.

For information on setting simulation options using the command-line API, see “Command-Line API to Set Simulation and Code Generation Parameters” on page 31-19.

## See Also

### More About

- “Reuse Custom Code in Stateflow Charts” on page 31-23

- “Include Custom C Code Functions and Structures” on page 31-13
- “Share String Data with Custom C Code” on page 24-13
- “Integrate Custom Structures in Stateflow Charts” on page 29-11

## Access Custom C Code in Library Models

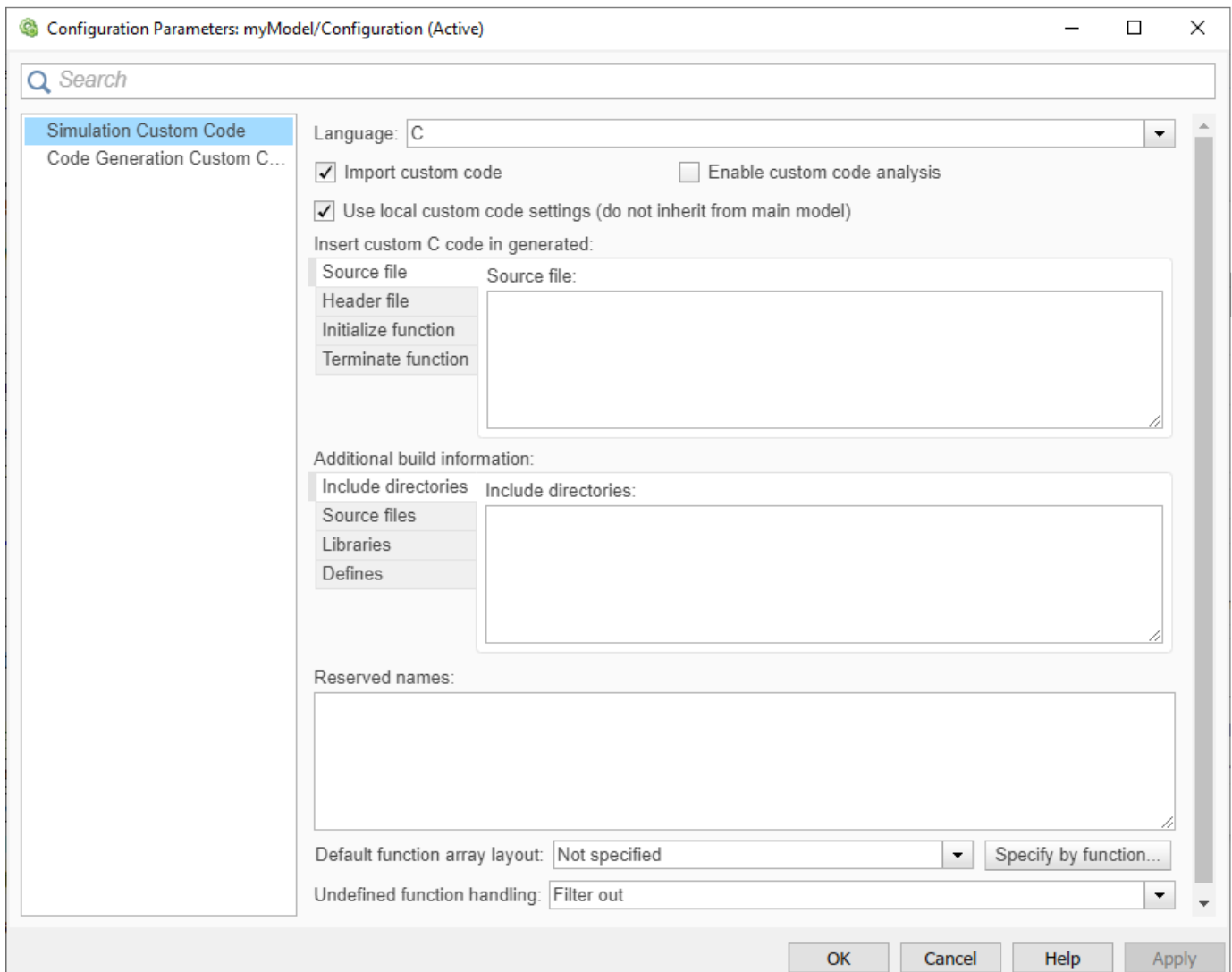
You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### Task 1: Include Custom C Code in Simulation Targets for Library Models

Specify custom code options in the simulation target for each library model that contributes a chart to the main model:

- 1 In the **Modeling** tab, under **Design**, select **Simulation Custom Code**.

The Configuration Parameters dialog box appears. Open the **Simulation Custom Code** pane.



- 2 Select **Use local custom code settings (do not inherit from main model)**.

This step ensures that each library model retains its own custom code settings during simulation.

- 3 Specify your custom code in the subpanes.

Follow the guidelines in “Specify Relative Paths to Your Custom Code” on page 31-22.

---

**Note** See “Task 1: Include Custom C Code in the Simulation Target” on page 31-4 for descriptions of the custom code options.

---

- 4 Click **OK**.

## Task 2: Simulate the Model

Simulate your model by clicking the play button in the toolbar of the editor.

For information on setting simulation options using the command-line API, see “Command-Line API to Set Simulation and Code Generation Parameters” on page 31-19.

---

**Note** You cannot simulate only the Stateflow blocks in a library model. You must first create a link to the library block in your main model and then simulate the main model.

---

## See Also

### More About

- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “Include Custom C Code Functions and Structures” on page 31-13
- “Share String Data with Custom C Code” on page 24-13
- “Integrate Custom Structures in Stateflow Charts” on page 29-11

## Access Custom C Code in All Charts in Model

You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

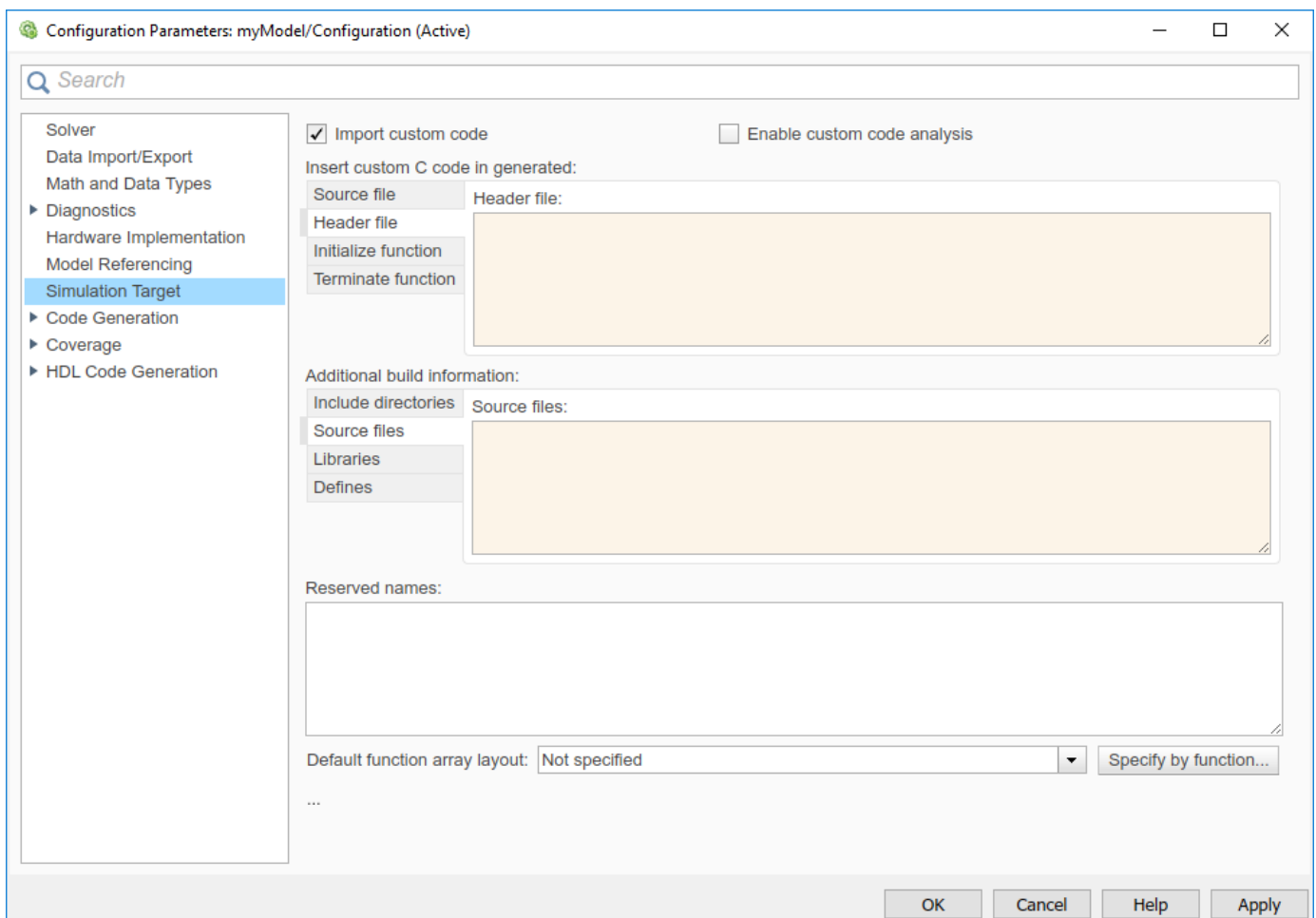
To integrate custom C code that applies to all charts for simulation, perform the tasks that follow.

### Task 1: Include Custom C Code in the Simulation Target for the Main Model

Specify custom code options in the simulation target for your main model:

- 1 Open the Model Configuration Parameters dialog box.
- 2 In the Model Configuration Parameters dialog box, select the **Simulation Target** pane.

The custom code options appear.



- 3 Specify your custom code in the subpanes.

Follow the guidelines in “Specify Relative Paths to Your Custom Code” on page 31-22.

---

**Note** See “Task 1: Include Custom C Code in the Simulation Target” on page 31-4 for descriptions of the custom code options.

---

- 4 Click **OK**.

By default, settings in the **Simulation Target** pane for the main model apply to all charts contributed by library models.

---

**Tip** If you want to rebuild the target to include custom code changes, in the **Apps** tab, select **Simulink Coder**. The **C Code** tab appears. Click **Build**.

---

## Task 2: Ensure That Custom C Code for the Main Model Applies to Library Charts

Configure the simulation target for each library model that contributes a chart to your main model:

- 1 In the **Modeling** tab, select **Model Settings**. Open the **Simulation Target** pane.
- 2 Clear the **Use local custom code settings (do not inherit from main model)** check box.

This step ensures that library charts inherit the custom code settings of your main model.

- 3 Click **OK**.

## Task 3: Simulate the Model

Simulate your model by clicking the play button in the toolbar of the editor.

For information on setting simulation options using the command-line API, see “Command-Line API to Set Simulation and Code Generation Parameters” on page 31-19.

## See Also

### More About

- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “Include Custom C Code Functions and Structures” on page 31-13
- “Share String Data with Custom C Code” on page 24-13
- “Integrate Custom Structures in Stateflow Charts” on page 29-11



## Access Custom Code Variables and Functions in Stateflow Charts

You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### Custom Code Variables in Charts That Use MATLAB as the Action Language

You can read and write the following C code variables directly in your charts that use MATLAB as the action language.

Custom C Code Type	Description
double	Double-precision floating point
single	Single-precision floating point
int8	Signed 8-bit integer
uint8	Unsigned 8-bit integer
int16	Signed 16-bit integer
uint16	Unsigned 16-bit integer
int32	Signed 32-bit integer
uint32	Unsigned 32-bit integer

By right clicking on the Stateflow object that uses your custom code, you can access your custom code variable. After right clicking on the object, hover over **Explore**. Your custom code variable appears, denoted by (C variable). Clicking the C variable allows you to access the custom code from MATLAB.

### Custom Code Functions in Charts That Use MATLAB as the Action Language

You can use the following C function argument types directly in your charts that use MATLAB as the action language without using `coder.ceval`. For information on calling external code from MATLAB code by using `coder.ceval`, see “Call C/C++ Code from MATLAB Code” (MATLAB Coder).

Custom C Function Argument Type	Description
double	Double-precision floating point
single	Single-precision floating point
int8	Signed 8-bit integer
uint8	Unsigned 8-bit integer
int16	Signed 16-bit integer
uint16	Unsigned 16-bit integer

<b>Custom C Function Argument Type</b>	<b>Description</b>
int32	Signed 32-bit integer
uint32	Unsigned 32-bit integer

By right clicking on the Stateflow object that uses your custom code, you can access your custom code function. After right clicking on the object, hover over **Explore**. Your custom code function appears, denoted by (C function). Clicking the C function allows you to access the custom code from MATLAB.

## Accessing Enumerations in Custom Code

In charts that use C as the action language, to include enumerations in your custom code, select **Import custom code** in the **Simulation Target** pane of the **Configuration Parameters**. After this option is selected, define your enumerations in a header file, and include your header file in the **Insert custom C code in generated** section of the **Simulation Target** pane.

## See Also

### More About

- “Reuse Custom Code in Stateflow Charts” on page 31-23
- “Specify Relative Paths to Your Custom Code” on page 31-22

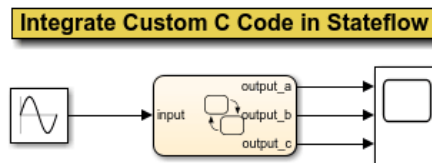
# Include Custom C Code Functions and Structures

This model shows how Stateflow® allows you to incorporate and to call your custom-written C code functions.

In this particular example, a C function defined in `my_function.c` and a structure that is defined in `my_header.h` are included in the chart. `MY_FUNCTION` multiplies its input by two. The structure in `my_header.h` is defined as follows:

```
typedef struct { real_T a; int8_T b[10]; } MyStruct;
```

The model accesses the structure member using the dot notation `MyStruct.a` and also with the use of the pointer `gMyStructPointerVar ->b[1]`.



Integrating C code into model	Calling C code from Stateflow	Calling C++ code from Stateflow
<p>Custom written C-files can be integrated easily into Stateflow models. Custom code can be used to augment the capabilities of your Stateflow chart and to take advantage of legacy code.</p> <p>To add custom C-files open the Model Configuration Parameters dialog box, select the <b>Simulation Target</b> pane, and enter:</p> <p><b>Header file:</b> Header that defines functions, structures, and data to be accessible by Stateflow.</p> <p><b>Include directories:</b> Path to folders that contain your custom code.</p> <p><b>Source files:</b> C-files that define the functions and data accessible by Stateflow.</p> <p>▶ <a href="#">Open Simulation Target Settings</a></p> <p>If you are generating code through Simulink Coder, add the same settings to the <b>Code Generation &gt; Custom Code</b> pane.</p> <p>▶ <a href="#">Open Custom Code Settings</a></p> <p>▶ <a href="#">Build Model Using Simulink Coder</a></p>	<p><b>Functions:</b> Stateflow charts call custom C-code functions by using the same syntax as graphical, truth table, MATLAB, and Simulink function calls:</p> <pre>result = my_custom_function(in_args);</pre> <p><b>Structures:</b> Stateflow charts can access variables of structure type by using dot notation:</p> <pre>result = my_var.my_field;</pre> <p>▶ <a href="#">Open my_header.h</a></p> <p>▶ <a href="#">Open my_function.c</a></p>	<p>Custom C++ code can also be integrated into Stateflow and Simulink Coder. Double-click this link for a demonstration.</p> <p>▶ <a href="#">Open sf_cpp</a></p> <p><b>Additional documentation</b></p> <p>For additional documentation on how to integrate C and C++ code in your model, double-click these links.</p> <p>▶ <a href="#">C Code integration</a></p> <p>▶ <a href="#">C++ Code integration</a></p>

## Integrate C Code into Model

Custom written C-files can be integrated easily into Stateflow models. Custom code can be used to augment the capabilities of your Stateflow chart and to take advantage of legacy code.

To add custom C-files open the Model Configuration Parameters dialog box, select the **Simulation Target** pane, and enter:

- **Header file:** Header that defines functions, structures, and data to be accessible by Stateflow.

- **Include directories:** Path to folders that contain your custom code.
- **Source files:** C-files that define the functions and data accessible by Stateflow.

If you are generating code through Simulink Coder, add the same settings to the **Code Generation > Custom Code** pane.

### Calling C Code from Stateflow

**Functions:** Stateflow charts call custom C-code functions by using the same syntax as graphical, truth table, MATLAB®, and Simulink® function calls:

```
result = my_custom_function(in_args);
```

**Structures:** Stateflow charts can access variables of structure type by using dot notation:

```
result = my_var.my_field;
```

### Calling C Code from Stateflow

Custom C++ code can also be integrated into Stateflow and Simulink Coder. For more information, see “C++ Code Generation and Integration in Stateflow” on page 31-15.

## See Also

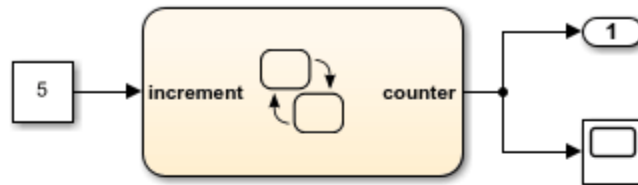
### More About

- “Access Custom Code Variables and Functions in Stateflow Charts” on page 31-11

## C++ Code Generation and Integration in Stateflow

This example shows how custom C++ files can be used in a Stateflow® model.

### C++ Code Generation and Integration in Stateflow



For this demo to run you must select a C++ compiler.  
At the MATLAB command prompt enter: `mex -setup c++`

#### C++ Code Integration

You can integrate C++ code into a model by using Stateflow. These steps illustrate the workflow:

- 1) Create a C-style wrapper function or create access macros for each method called within the C chart.

▶ [Open adder\\_cpp.cpp](#)

▶ [Open adder\\_cpp.h](#)

- 2) Open the Model Configuration Parameters dialog box. In the **Simulation Target** pane, add the custom header file, source files, and any include directories.

▶ [Open Simulation Target Settings](#)

- 3) In the **Code Generation > Custom Code** pane, enter the same information.

▶ [Open Custom Code Settings](#)

#### C++ Code Generation

Open the Model Configuration Parameters dialog box. In the **Code Generation** pane, change the **Language** setting to C++.

▶ [Open Code Generation Settings](#)

#### Additional documentation

For additional documentation on using *Simulink Coder* to generate and integrate C++ code, double-click these links.

▶ [Select and Configure C++ Compiler](#)

▶ [C++ Language Support Limitations](#)

#### C++ Code Integration

You can integrate C++ code into a model by using Stateflow. These steps illustrate the workflow:

- 1 Create a C-style wrapper function or create access macros for each method called within the C chart.
- 2 Open the Model Configuration Parameters dialog box. In the **Simulation Target** pane, add the custom header file, source files, and any include directories.
- 3 In the **Code Generation > Custom Code** pane, enter the same information.

### **C++ Code Generation**

Open the Model Configuration Parameters dialog box. In the **Code Generation** pane, change the **Language** setting to C++.

### **See Also**

### **More About**

- “Access Custom Code Variables and Functions in Stateflow Charts” on page 31-11

# Speed Up Simulation

## Improve Model Update Performance

Stateflow uses Just-In-Time (JIT) compilation mode to improve model update performance for most charts in Simulink models. Stateflow applies JIT mode to charts that qualify. For a chart in JIT mode, Stateflow generates an execution engine in memory for simulation. For these charts, Stateflow does not generate C code or a MEX file to simulate the chart. JIT mode provides the best performance during the compilation of a model.

Some charts do not qualify for JIT mode, such as charts with signal logging.

Stateflow models include debugging support for simulation. To gain optimal performance, turn off debugging by using this command:

```
sfc('coder_options', 'forceDebugOff', 1);
```

When you run this command, your Stateflow charts do not have debugging support or run-time error checking.

---

**Note** When you turn off debugging, animation is also turned off.

---

## Disable Simulation Target Options That Impact Execution Speed

To simulate your model more quickly, in the Model Configuration Parameters dialog box, on the **Simulation Target** pane, clear the check boxes for these parameters:

- **Echo expressions without semicolons** — To disable run-time output in the MATLAB Command Window, such as actions that do not terminate with a semicolon, clear this check box.
- **Ensure responsiveness**— To disable ability to break out of long-running execution using Ctrl+C, clear this check box.

Click **OK**.

## Speed Up Simulation

Use these tips to further speed up simulation:

### Keep Charts Closed

During model simulation, any open charts with animation enabled take longer to simulate. If you keep all charts closed, the simulation runs faster.

### Disable Content Preview

During model simulation, any open charts with content preview enabled take longer to simulate. If you disable content preview, the simulation runs faster. To disable content preview, select the chart that has content preview enabled. On the **State Chart** tab, click **Content Preview**.

**Keep Scope Blocks**

During model simulation, any open Scope blocks continuously update their display. If you keep all Scope blocks closed, you can speed up the simulation. After the simulation ends, you can open the Scope blocks to view the results.

**Use Library Charts in Your Model**

If your model contains multiple charts that do not use JIT mode and contain the same elements, you might generate multiple copies of identical simulation code. By using library charts, you can minimize the number of copies of identical simulation code. For example, using five library charts reduces the number of identical copies from five to one.

For more information, see “Create Specialized Chart Libraries for Large-Scale Modeling” on page 28-12.

**See Also****More About**

- “Reduce the Compilation Time of a Chart” on page 19-29



## Command-Line API to Set Simulation and Code Generation Parameters

In Stateflow charts in Simulink models, you can use the command-line API to set options in the Model Configuration Parameters dialog box for simulation and embeddable code generation, .

### Set Parameters at the Command Line

- 1 At the MATLAB command prompt, type:

```
object_name = getActiveConfigSet(gcs)
```

This command returns an object handle to the model settings in the Model Configuration Parameters dialog box for the current model.

- 2 To set a parameter for that dialog box, type:

```
object_name.set_param('parameter_name', value)
```

This command sets a configuration parameter to the value that you specify.

For example, you can set the **Reserved names** parameter for simulation by typing:

```
cp = getActiveConfigSet(gcs)
cp.set_param('SimReservedNameArray', {'abc','xyz'})
```

---

**Note** You can also get the current value of a configuration parameter by typing:

```
object_name.get_param('parameter_name')
```

---

For more information about using `get_param` and `set_param`, see the Simulink documentation.

### Simulation Parameters for Nonlibrary Models

The following table summarizes the parameters and values that you can set for simulation of nonlibrary models using the command-line API.

Parameter and Values	Dialog Box Equivalent	Description
SimIntegrity - 'off', 'on'	<b>Ensure memory integrity</b>	Detect violations of memory integrity in code generated for MATLAB Function blocks and stop execution with a diagnostic.
SFSimEcho - 'off', 'on'	<b>Echo expressions without semicolons</b>	Enable run-time output to appear in the MATLAB Command Window during simulation.
SimCtrlC - 'off', 'on'	<b>Ensure responsiveness</b>	Enable responsiveness checks in code generated for MATLAB Function blocks.

Parameter and Values	Dialog Box Equivalent	Description
SimBuildMode - 'sf_incremental_build', 'sf_nonincremental_build', 'sf_make', 'sf_make_clean', 'sf_make_clean_objects'	<b>Simulation target build mode</b>	Specify how you build the simulation target for a model.
SimReservedNameArray <i>string array</i> - {}	<b>Symbols &gt; Reserved names</b>	Enter the names of variables or functions in the generated code that match the names of variables or functions specified in custom code to avoid naming conflicts.
SimParseCustomCode - 'off', 'on'	<b>Import custom code</b>	Specify whether or not to parse the custom code and report unresolved symbols for the C charts in a model.
SimCustomSourceCode <i>string</i> - ''	<b>Source file</b>	Enter code lines to appear near the top of a generated source code file.
SimCustomHeaderCode <i>string</i> - ''	<b>Header file</b>	Enter code lines to appear near the top of a generated header file.
SimCustomInitializer <i>string</i> - ''	<b>Initialize function</b>	Enter code statements that execute once at the start of simulation.
SimCustomTerminator <i>string</i> - ''	<b>Terminate function</b>	Enter code statements that execute at the end of simulation.
SimUserIncludeDirs <i>string</i> - ''	<b>Include directories</b>	Enter a space-separated list of folder paths that contain files you include in the compiled target.  <b>Note</b> If your list includes any Windows® paths that contain spaces, each instance must be enclosed in double quotes within the argument, for example,  'C:\Project "C:\Custom Files"'
SimUserSources <i>string</i> - ''	<b>Source files</b>	Enter a space-separated list of source files to compile and link into the target.
SimUserLibraries <i>string</i> - ''	<b>Libraries</b>	Enter a space-separated list of static libraries that contain custom object code to link into the target.

## Simulation Parameters for Library Models

The following table summarizes the simulation parameters that apply to library models.

Parameter and Values	Dialog Box Equivalent	Description
SimUseLocalCustomCode - 'off', 'on'	<b>Use local custom code settings (do not inherit from main model)</b>	Specify whether a library model can use custom code settings that are unique from the main model to which the library is linked.
SimCustomSourceCode <i>string</i> - ''	<b>Source file</b>	Enter code lines to appear near the top of a generated source code file.
SimCustomHeaderCode <i>string</i> - ''	<b>Header file</b>	Enter code lines to appear near the top of a generated header file.
SimCustomInitializer <i>string</i> - ''	<b>Initialize function</b>	Enter code statements that execute once at the start of simulation.
SimCustomTerminator <i>string</i> - ''	<b>Terminate function</b>	Enter code statements that execute at the end of simulation.
SimUserIncludeDirs <i>string</i> - ''	<b>Include directories</b>	Enter a space-separated list of folder paths that contain files you include in the compiled target.  <b>Note</b> If your list includes any Windows paths that contain spaces, each instance must be enclosed in double quotes within the argument, for example,  'C:\Project "C:\Custom Files"'
SimUserSources <i>string</i> - ''	<b>Source files</b>	Enter a space-separated list of source files to compile and link into the target.
SimUserLibraries <i>string</i> - ''	<b>Libraries</b>	Enter a space-separated list of static libraries that contain custom object code to link into the target.

## See Also

### More About

- “Recommended Settings Summary for Model Configuration Parameters” (Simulink Coder)

## Specify Relative Paths to Your Custom Code

You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code. For more information, see “Reuse Custom Code in Stateflow Charts” on page 31-23.

### Why Use Relative Paths?

If you specify paths and files with absolute paths and later move them, you must change these paths to point to new locations. To avoid this problem, use relative paths for custom code options that specify paths or files.

### Search Relative Paths

Search paths exist relative to these folders:

- The current folder
- The model folder (if different from the current folder)
- The custom list of folders that you specify
- All the folders on the MATLAB search path, excluding the toolbox folders

### Path Syntax Rules

When you construct relative paths for custom code, follow these syntax rules:

- You can use the forward slash (/) or backward slash (\) as a file separator, regardless of whether you are on a UNIX® or PC platform. The makefile generator returns the path names with the correct platform-specific file separators.
- You can use tokens that evaluate in the MATLAB workspace, if you enclose them with dollar signs (\$...\$). For example, consider this path:

```
$mydir1$dir1
```

In this example, `mydir1` is a variable that you define in the MATLAB workspace as `'d:\work\source\module1'`. In the generated code, this custom include path appears as:

```
d:\work\source\module1\dir1
```

- You must enclose paths in double quotes if they contain spaces or other nonstandard path characters, such as hyphens (-).

### See Also

#### More About

- “Reuse Custom Code in Stateflow Charts” on page 31-23

## Reuse Custom Code in Stateflow Charts

You can integrate custom code written in C or C++ with Stateflow charts in Simulink models. By sharing data and functions between your custom code and your Stateflow chart, you can augment the capabilities of Stateflow and leverage the software to take advantage of your preexisting code.

Stateflow charts call custom code functions by using the same syntax as other reusable functions:

```
return_val = function_name(arg1,arg2,...)
```

---

**Note** Do not share fixed-point data between your custom code and your Stateflow chart.

---

### Choose the Appropriate Procedure for Simulation

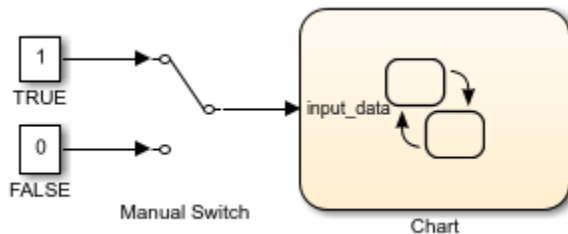
To choose the right procedure for simulation, click the highlighted block that best describes your goal.



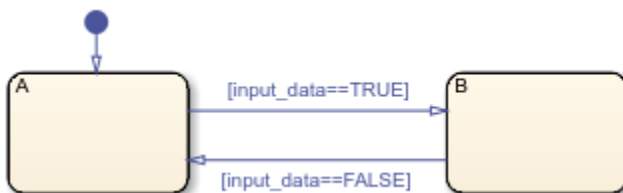
### Use Custom Code to Define Global Constants

This example shows how to use custom C code to define constants that apply to all charts in your model.

The model contains a Stateflow® chart with an input, which you can set to 0 or 1 by toggling the manual switch in the model during simulation.



The chart contains two states A and B. In this example, you define two constants named TRUE and FALSE to guard the transitions between the states in the chart, instead of using the values 1 and 0. These custom definitions improve the readability of your chart actions. TRUE and FALSE are not Stateflow data objects.

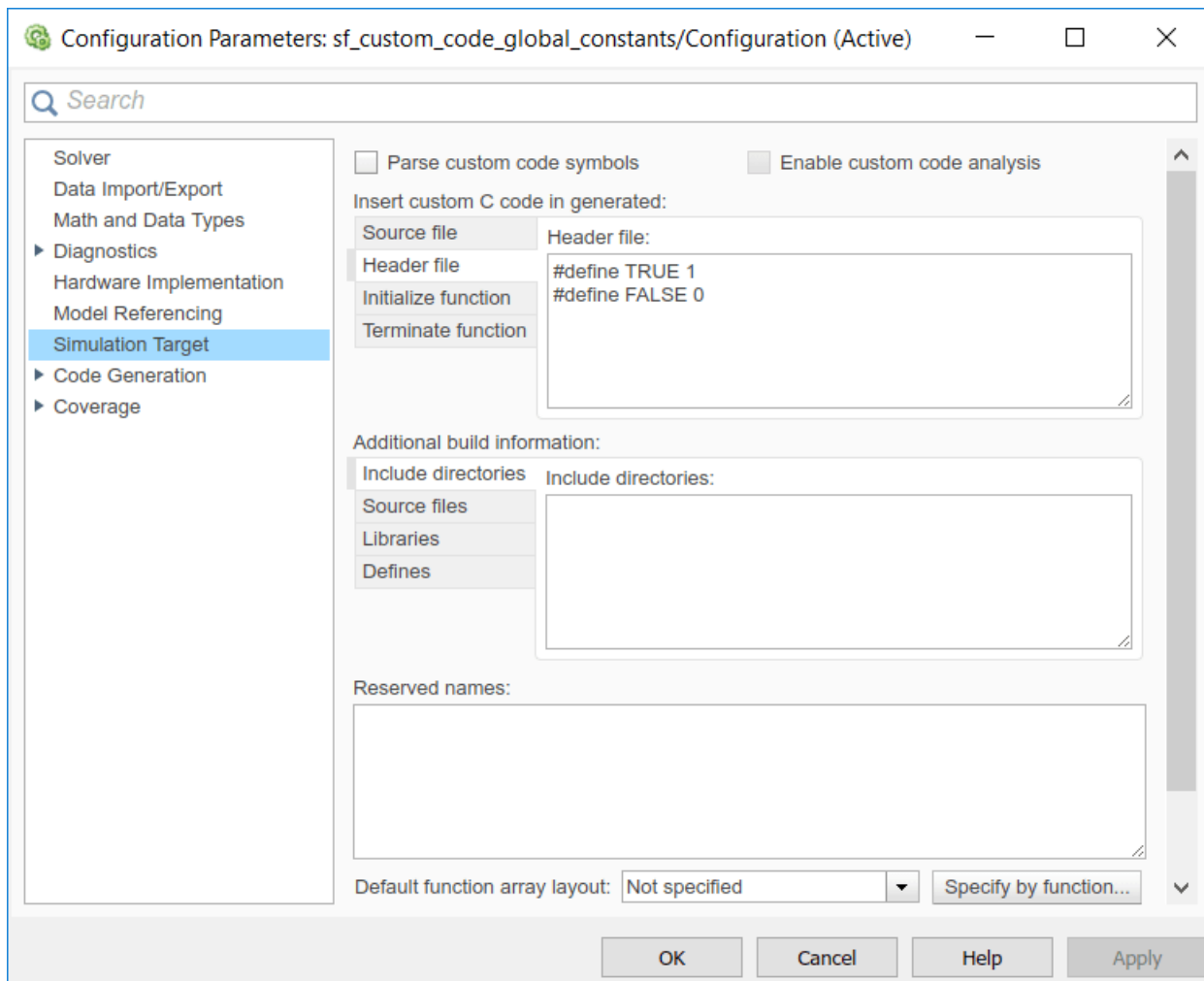


To enter the custom code that defines the two constants:

- 1 Open the Model Configuration Parameters dialog box.
- 2 Select the **Simulation Target** pane.
- 3 In the **Header file** subpane, enter `#define` and `#include` statements. For instance, in this example, you define the global constants with this code:

```
#define TRUE 1
#define FALSE 0
```

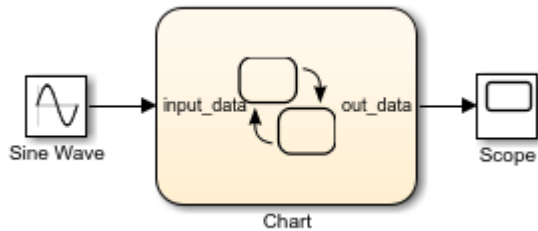
Because the two custom definitions appear at the top of the generated machine header file `sf_custom_code_global_constants_sf.h`, you can use `TRUE` and `FALSE` in all charts that belong to this model.



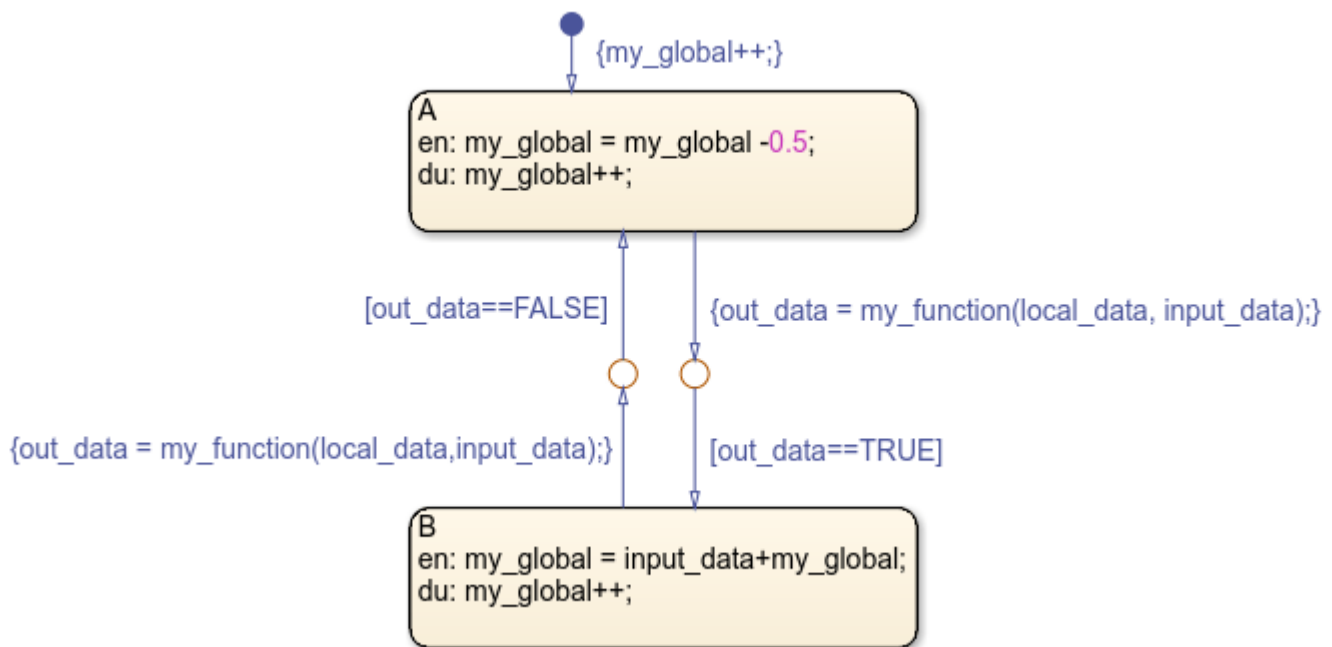
## Use Custom Code to Define Constants, Variables, and Functions

This example shows how to use custom C code to define constants, variables, and functions that apply to all charts in your model.

The model contains a Stateflow chart with an input signal from a Sine Wave block.



The chart contains two states A and B, and three data objects: `input_data`, `local_data`, and `out_data`. The chart accesses a custom variable named `my_global` and calls a custom function named `my_function`.

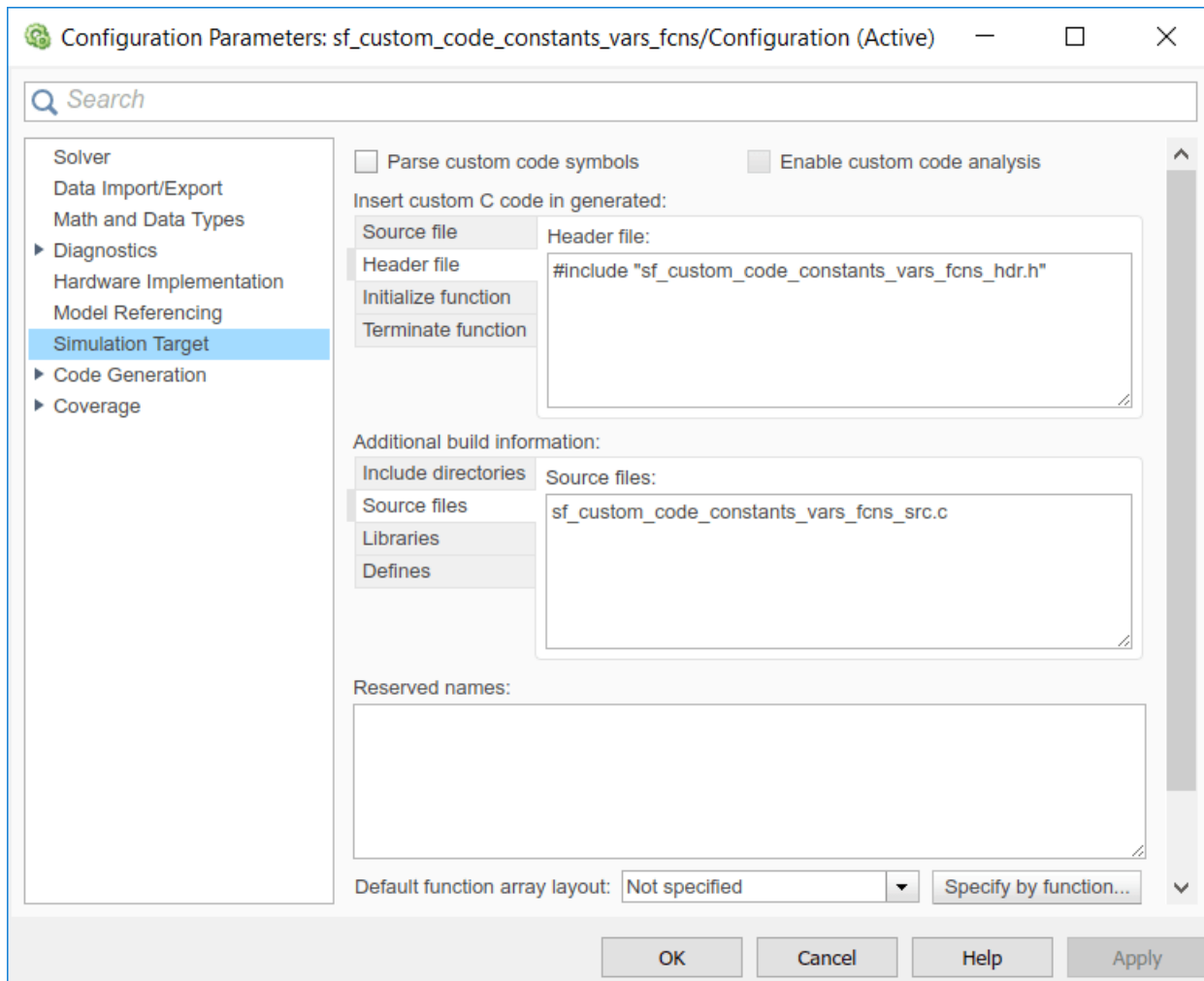


To configure the model to access the custom code:

- 1 Open the Model Configuration Parameters dialog box.
- 2 Select the **Simulation Target** pane.
- 3 In the **Header file** subpane, enter `#define` and `#include` statements. When you include a custom header file, you must enclose the file name in double quotes.
- 4 In the **Include directories** subpane, enter the name of the folder that contains your custom code files. To access custom code files in a subfolder of the model folder, use a relative path name of the form `.\subfolder_name`.
- 5 In the **Source files** subpane, enter the name of the source file that contains your custom code. To access a source file that resides in a subfolder of the model folder, use a relative path name of the form `.\subfolder_name\source_file.c`.

In this example, the custom code defines three constants, a variable, and a function by using these configurations:

- The **Header file** subpane contains this statement: `#include "sf_custom_code_constants_vars_fcns_hdr.h"`
- The **Include directories** subpane contains a single period (.) to indicate that all of the custom code files reside in the same folder as the model.
- The **Source file** subpane contains this file name: `sf_custom_code_constants_vars_fcns_src.c`



The custom header file `sf_custom_code_constants_vars_fcns_hdr.h` contains the definitions of three constants:

```
#define TRUE 1
#define FALSE 0
#define MAYBE 2
```

The header file also contains declarations for the variable `my_global` and the function `my_function`:

```
extern int myglobal;
extern int my_function(int var1, double var2);
```



The custom source file `sf_custom_code_constants_vars_fcns_src.c` is compiled in conjunction with the Stateflow generated code into a single S-function MEX file.

Because the custom definitions appear at the top of the generated machine header file `sf_custom_code_constants_vars_fcns_sfun.h`, you can access them in all charts that belong to this model.

## See Also

### More About

- “Access Custom C Code in Nonlibrary Charts” on page 31-4
- “Access Custom C Code in Library Models” on page 31-7
- “Access Custom C Code in All Charts in Model” on page 31-9
- “Access Custom C++ Code in Stateflow Charts” on page 31-2

## Model Battery Management with Custom Code

With Stateflow you can integrate your custom C code into charts. Using custom C code in a Stateflow chart allows you to:

- Reuse existing algorithms that you have already coded.
- Use C code for low-level hardware operations, which may be difficult to implement with Stateflow.

This example shows how to use custom C code with Stateflow to model a system that manages battery percentage, also known as the state of charge (SOC).

### Battery Management

To open the model, in the command prompt type:

```
openExample('stateflow/BatteryManagementExample')
sf_battery_management
```

This model represents several components of a battery management system. This system is designed to be implemented on a controller for battery powered devices, such as battery powered vehicle or a cell phone. The purpose of the battery management system is to limit the power demands on the battery and to ensure that the SOC does not get too high or too low. An SOC that is too high or too low would be detrimental to the health of the battery. Additionally, the model is designed to limit the discharge of the battery when the charge is low in a trade-off of performance for battery lifetime.

The battery management model achieves these goals with three different charts.

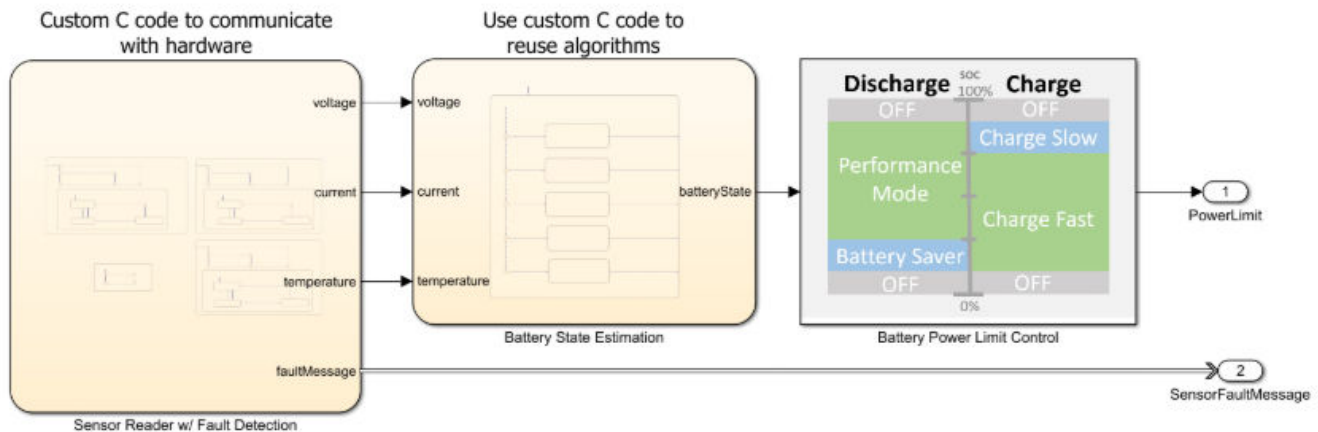
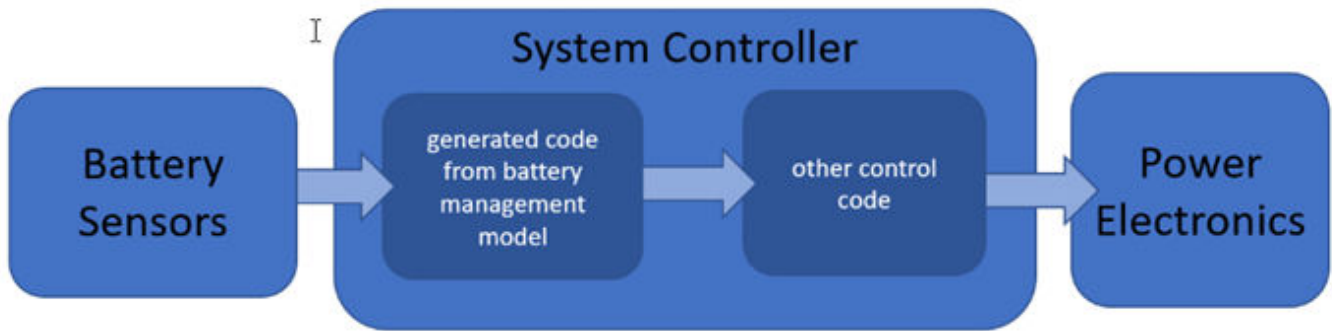


Chart `Sensor Reader w/ Fault Detection` reads the sensor values from the battery pack and reports out when the sensors is in a faulted state. Chart `Battery State Estimation` uses the sensor reading to estimate the SOC of the battery. Chart `Battery Power Limit Control` conserves the battery, protects the battery health, and keeps the SOC away from either extreme. The chart accomplishes these tasks by setting power limits for the controller.

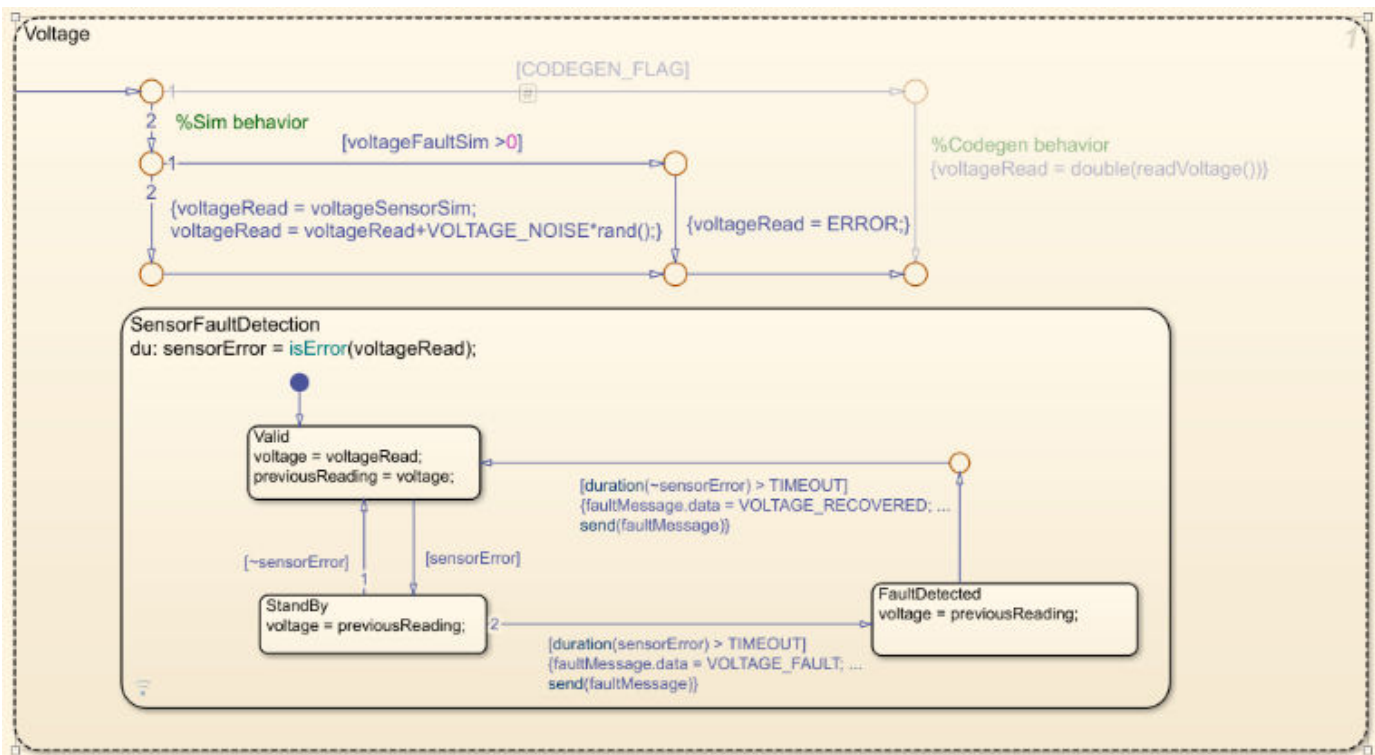
With this model you can generate code and deploy that code to an embedded controller along with other control code that your system may need.



### Simulate Communication with Hardware

When using the model for simulation, the Dashboard panel allows you to control the sensor readings for the system inputs. If the calls to the battery monitor timeout, an error code of -9999 is returned from the function.

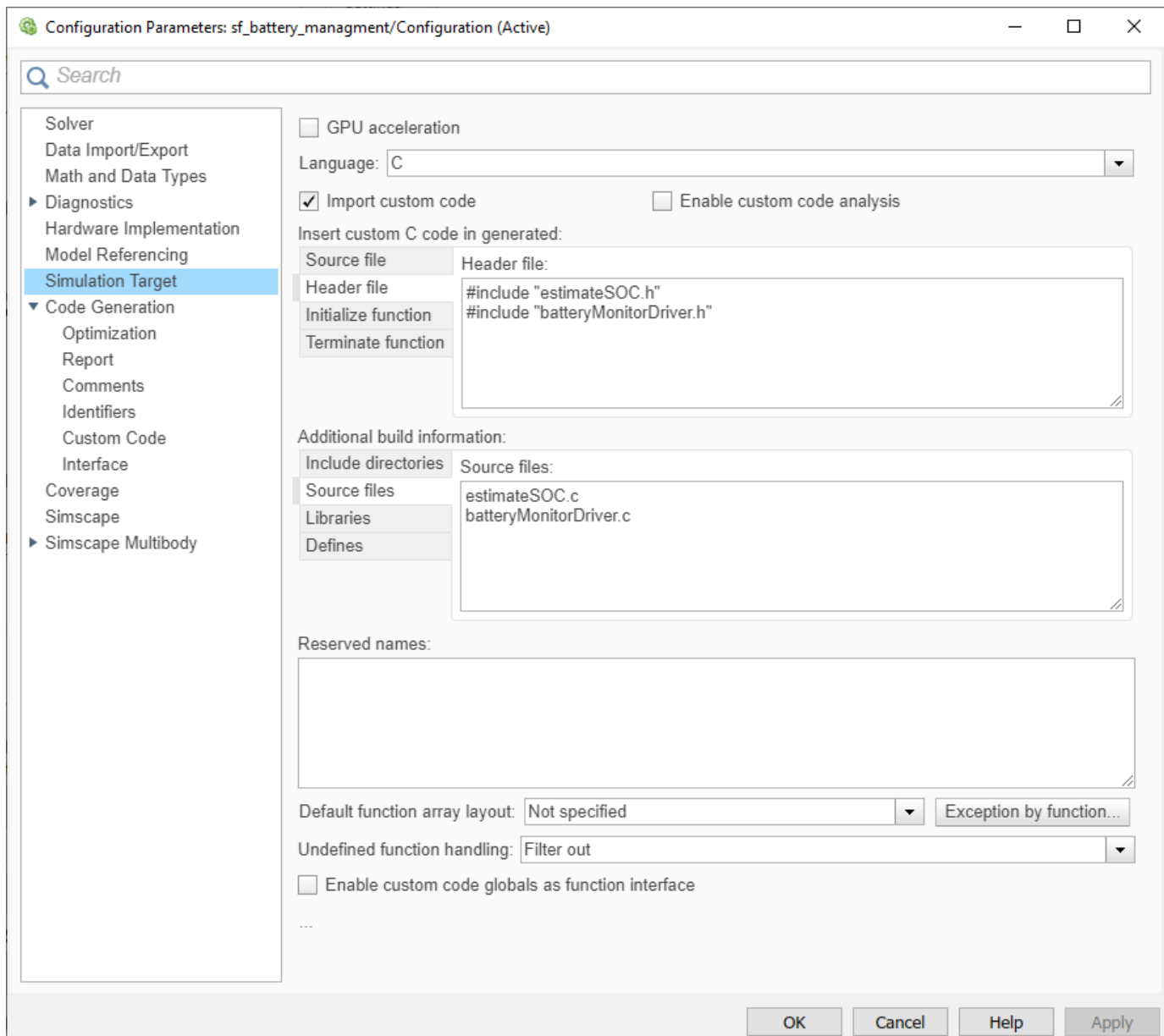
Two C code files are included with Sensor Reader w/ Fault Detection: `batteryMonitorDriver.h` and `batteryMonitorDriver.c`. These two files represent the device driver code that would be used to get sensor data from the system, including battery voltage, current, and temperature and are used for code generation. See "Code Generation" on page 31-34.



The Stateflow chart can also handle the error signals returned by the sensors. In the event of a sensor error, the `SensorFaultDetection` subchart holds the last known valid sensor reading until the error code has been received for a certain amount of time. After this threshold is met,

SensorFaultDetection sends a fault message and assumes it will be handled by the other control components of the controller.

In order to simulate the model with the driver code, you must include the header file and specify the source file in the **Simulation Target** pane of the Configuration Parameters, and the **Import custom code** option must be selected. For information on the **Import custom code** option, see “Import custom code” (Simulink).



## Estimate Battery State of Charge by Reusing Custom Code

To estimate the battery state of charge, the model utilizes a custom C code algorithm. The included file estimateSOC.c contains the following code:

```
double estimateSOC(double V, double I, double T)
{
    double SOC;
    double r_int;
    double V_emf;

    r_int = batteryResistance(T); //internal resistance

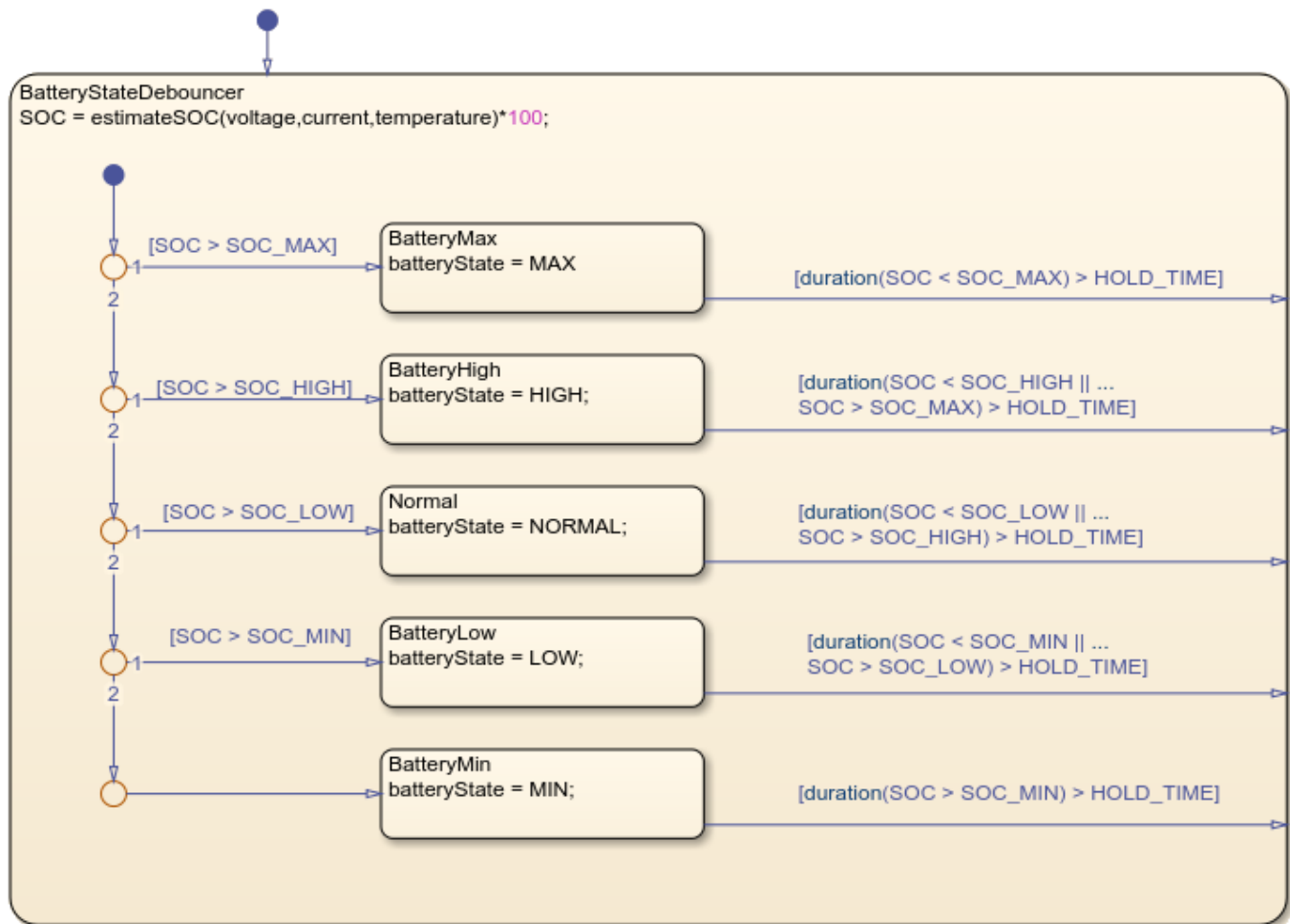
    V_emf = voltage_EMF(V,I,r_int); //volage emf of battery

    SOC = calculateSOC(V,T);

    return SOC;
}
```

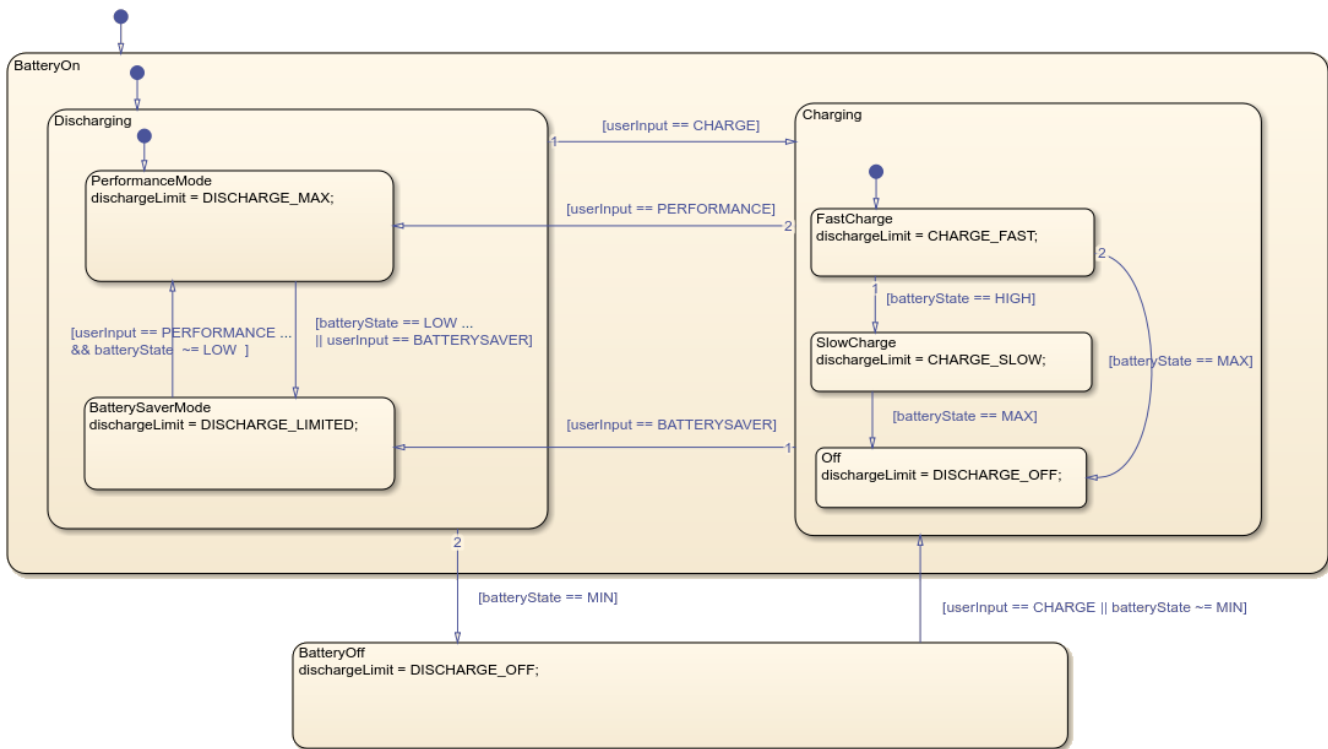
With this algorithm, you can easily call the C code function, rather than reimplementing it with Stateflow charts.

In order to account for the sensitivity of noise and change of current in the estimateSOC algorithm, Stateflow logic is used to implement a debouncing algorithm. This logic simplifies the SOC percentage into 5 ranges: MAX, HIGH, NORMAL, LOW, and MIN. These ranges prevent rapid fluctuation between different control states. The exit transitions from the child states go to the edge of the parent state. When these transitions are taken, Stateflow returns to the default transition of the parent state.



## Logic to Control Device State of Charge

It is easier to design this control logic with a Stateflow chart, rather than implementing the logic control through custom code. This chart implements power limit on the battery based on the estimated battery state.

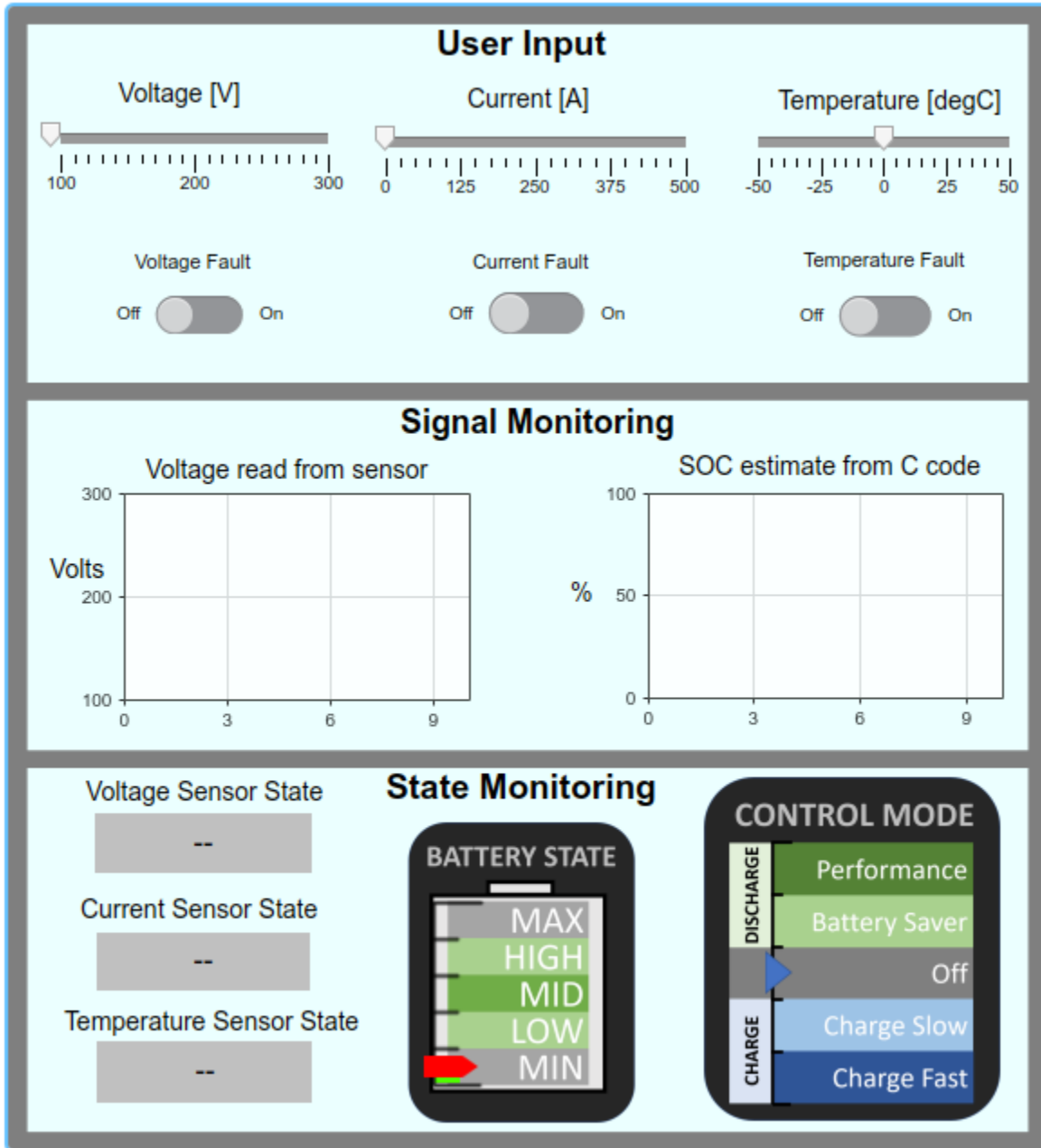


The chart represents 5 possible modes for power limits on the battery.

- 1 Performance Mode: Allow high power draw when battery charge is high.
- 2 Battery Saver Mode: Limit power draw on the battery for efficiency when charge is low.
- 3 Off: Do not allow Power Draw when battery is at state of charge limits.
- 4 Fast Charge: Quickly charge the battery when charge is low.
- 5 Slow Charge: Slowly charge the battery when charge is high for battery health benefits.

## Simulate Using the Dashboard Panel

To test that the model behaves as expected, you can use the dashboard panel to simulate the voltage, current, and temperature readings. The switches allow you to simulate a sensor error to test the fault detection logic. The gauge and plot dashboard blocks are bound to the activity of stateflow charts to visualize internal states and data. You can move and minimize the dashboard panel while navigating the model. For more information on dashboard blocks, see “Control Simulations with Interactive Displays” (Simulink).



## Code Generation

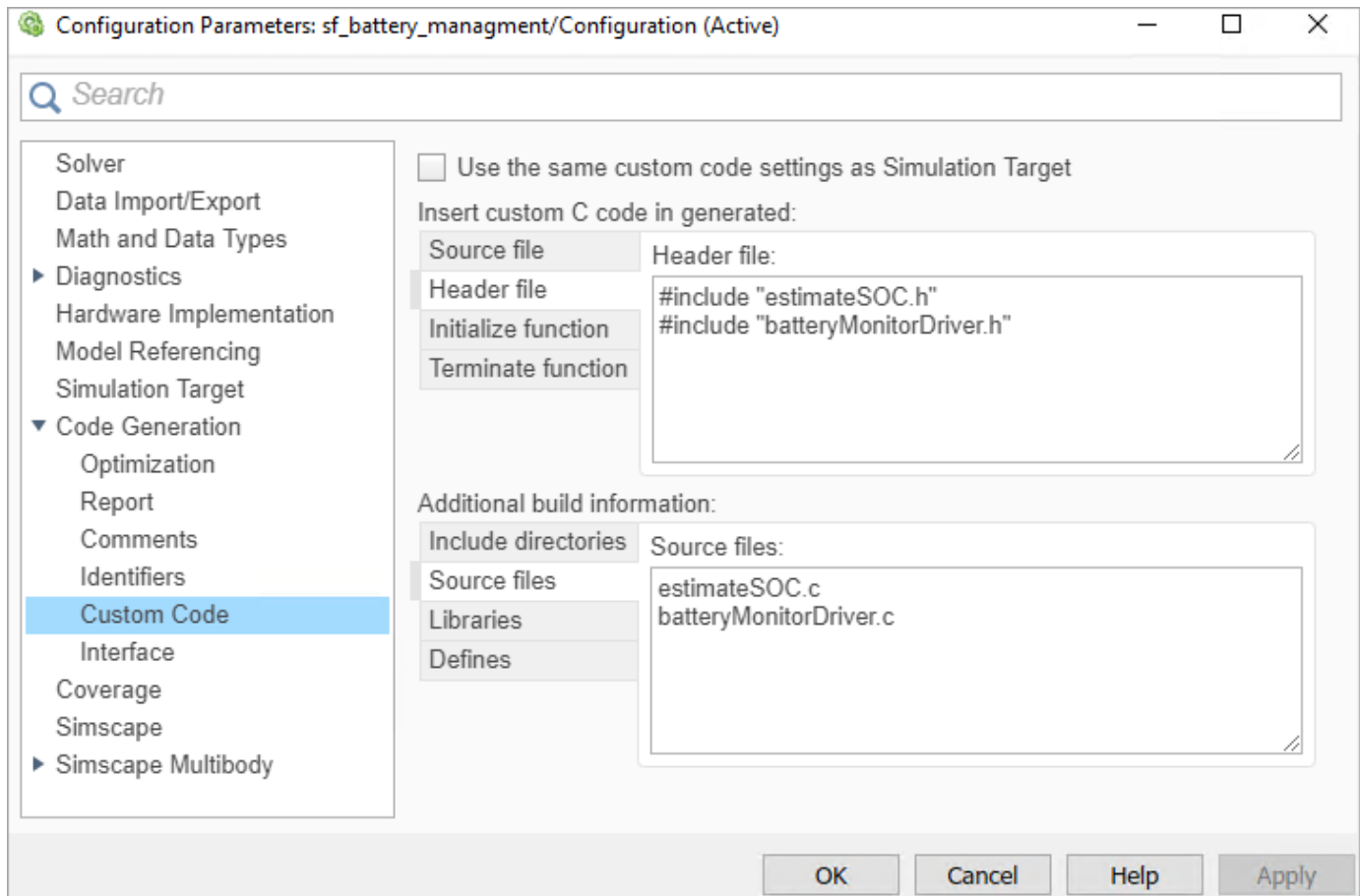
inputs into the state Sensor Reader w/ Fault Detection are provided with two C code files: `batteryMonitorDriver.h` and `batteryMonitorDriver.c`. These two files represent the device driver code that would be used to get sensor data from the system, including battery voltage, current, and temperature.

To use this model for code generation, the driver code must communicate with the external hardware. To enable this functionality, a variant transition using the control variable `CODEGEN_FLAG` allows the Stateflow chart to call the C code directly when generating code and simulate the sensor value with



noise. In the Model Explorer, open the Base Workspace and set the value of **CODEGEN\_FLAG** to **true**. For more information on Stateflow Variants and variant transitions, see “Code Generation Using Variant Transitions” on page 32-8.

In order to compile the generated code with the driver code, you must include the header file and specify the source file in the **Custom Code** pane of the Configuration Parameters.



## References

- [1] Ramadass, P., B. Haran, R. E. White, and B. N. Popov. “Mathematical modeling of the capacity fade of Li-ion cells.” *Journal of Power Sources*. 123 (2003), pp. 230-240.
- [2] Ning, G., B. Haran, and B. N. Popov. “Capacity fade study of lithium-ion batteries cycled at high discharge rates.” *Journal of Power Sources*. 117 (2003), pp. 160-169.

## See Also

### More About

- “Code Generation by Using Simulink Coder” (Simulink Coder)
- “Code Generation Workflows with Embedded Coder” (Embedded Coder)


- “Tune and Experiment with Block Parameter Values” (Simulink)
- “Create a Variant Configuration” on page 32-8


## Resolve Undefined Symbols in Your Chart

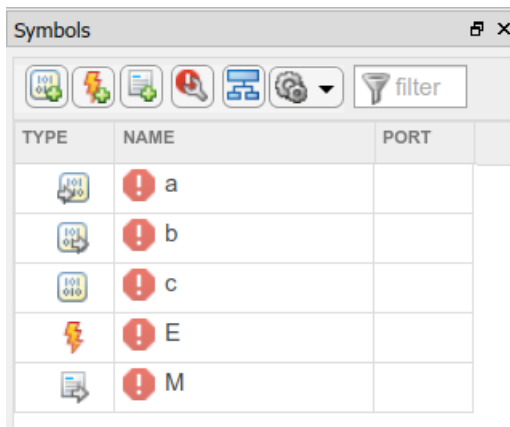
Symbols that appear in your chart but that you have not added as data, events, or messages are undefined or unresolved. You can resolve undefined symbols by using the Symbols pane or the Symbol Wizard. For each undefined symbol, based on the symbol usage in the chart, Stateflow infers these properties:

- Class (data, event, or message)
- Scope
- Size
- Type
- Complexity

### Resolve Symbols Through the Symbols Pane

As you edit your chart, Stateflow detects undefined symbols and marks them in the Symbols pane with a red error icon . For each undefined symbol, the **TYPE** column displays the class and scope inferred from the usage in the chart. You can resolve undefined symbols individually or collectively.

- To define a symbol with the inferred class and scope, click the error icon and select **Fix**.
- To define a symbol with a different class or scope, select another combination of class and scope from the **TYPE** drop-down list.
- To resolve all of the undefined symbols with their inferred classes and scopes, click the **Resolve undefined symbols** button .



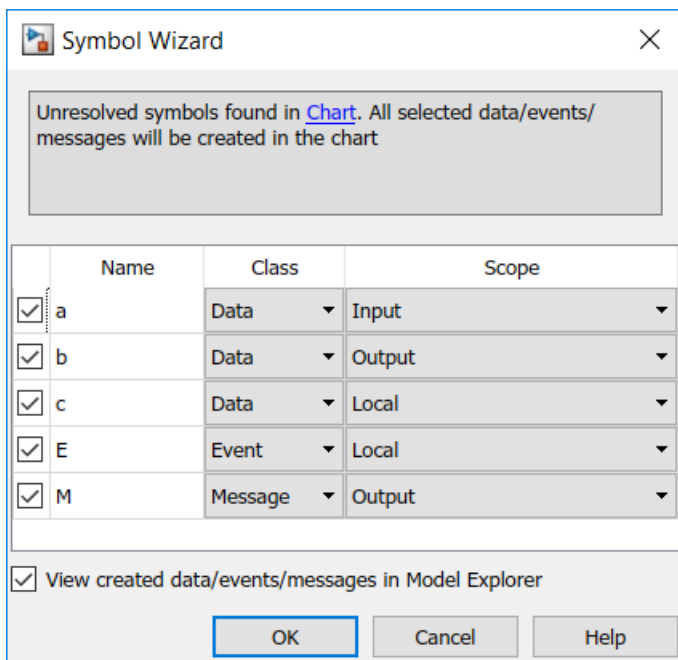
### Resolve Symbols Through the Symbol Wizard

If your chart contains any undefined symbols when you update the chart, update the model, or simulate the model, the Symbol Wizard opens and lists the undefined symbols. For each undefined symbol, the **Class** and **Scope** columns display the class and scope inferred from the usage in the chart. You can accept, modify, or reject each symbol definition that the Symbol Wizard suggests.

- To accept a definition with the inferred class and scope, select the check box in front of the symbol.

- To modify a definition, select a different class or scope from the **Class** or **Scope** drop-down lists.
- To reject a definition, clear the check box in front of the symbol.

After you edit the symbol definitions, add the symbols to the Stateflow hierarchy by clicking **OK**.



## Detect Symbol Definitions in Custom Code

Detection of symbols defined in custom code depends on the model configuration parameter **Import custom code**.

- If you select **Import custom code**, the Stateflow parser tries to find unresolved chart symbols in the custom code. If the custom code does not define these symbols, they appear in the Symbol Wizard.
- If you do not select **Import custom code**, the Stateflow parser considers unresolved data symbols in the chart as defined in the custom code. If the custom code does not define these symbols, simulating and generating code from the model results in an error.

The **Import custom code** option is not available for charts that use MATLAB as the action language. For more information, see “Import custom code” (Simulink).

## See Also



### More About

- “Add Stateflow Data” on page 12-2
- “Set Data Properties” on page 12-5
- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2
- “Detect Unused Data in the Symbols Pane” on page 34-3

- “Import custom code” (Simulink)

## Call Extrinsic MATLAB Functions in Stateflow Charts

Stateflow charts in Simulink models have an action language property that defines the syntax for state and transition actions. An icon in the lower-left corner of the chart canvas indicates the action language for the chart.

-  MATLAB as the action language.
-  C as the action language.

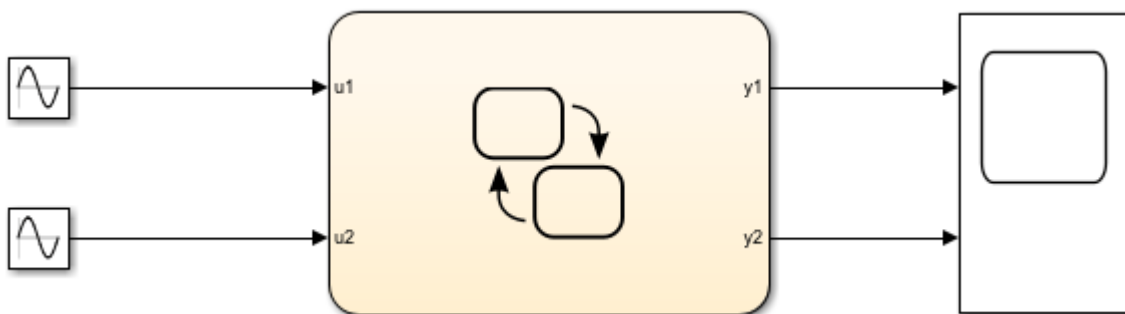
In charts that use C as the action language, you can call built-in MATLAB functions and access MATLAB workspace variables by using the `ml` namespace operator or the `ml` function. For more information, see “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20.

In charts that use MATLAB as the action language, you can call MATLAB functions supported for code generation directly. To call extrinsic functions that are not supported for code generation, you must use the `coder.extrinsic` function. When you declare a function with `coder.extrinsic(function_name)`, Stateflow creates a call to the function during simulation. In a Stateflow chart, you only declare `coder.extrinsic` once. You cannot declare reserved keywords with `coder.extrinsic`. For more information, see “Guidelines for Naming Stateflow Objects” on page 2-5.

For charts that include atomic subcharts, you must declare functions that are not supported for code generation with `coder.extrinsic` separately within the atomic subchart.

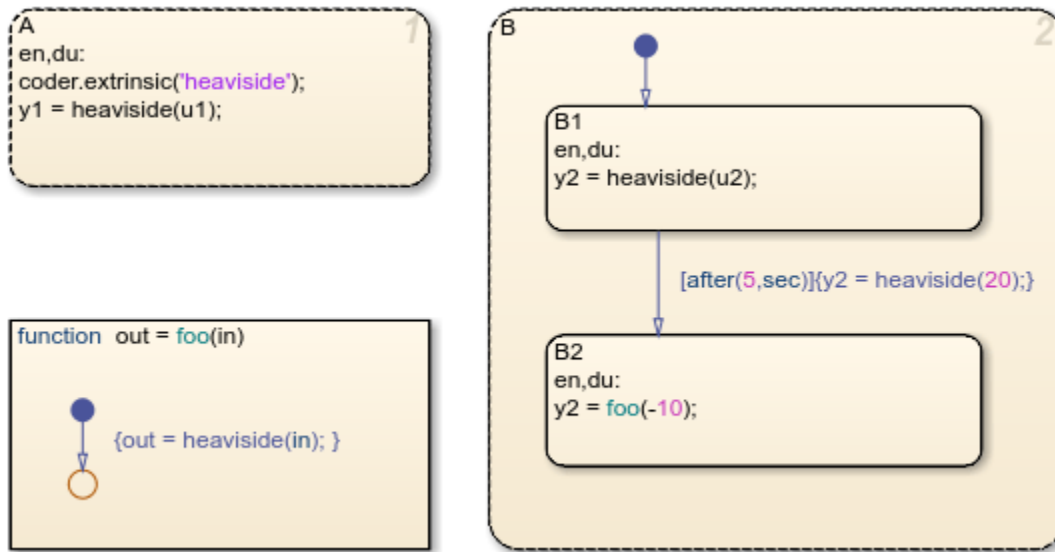
### Use the `coder.extrinsic` Function

To enable calls to the extrinsic function `heaviside` (Symbolic Math Toolbox), this model uses `coder.extrinsic`.



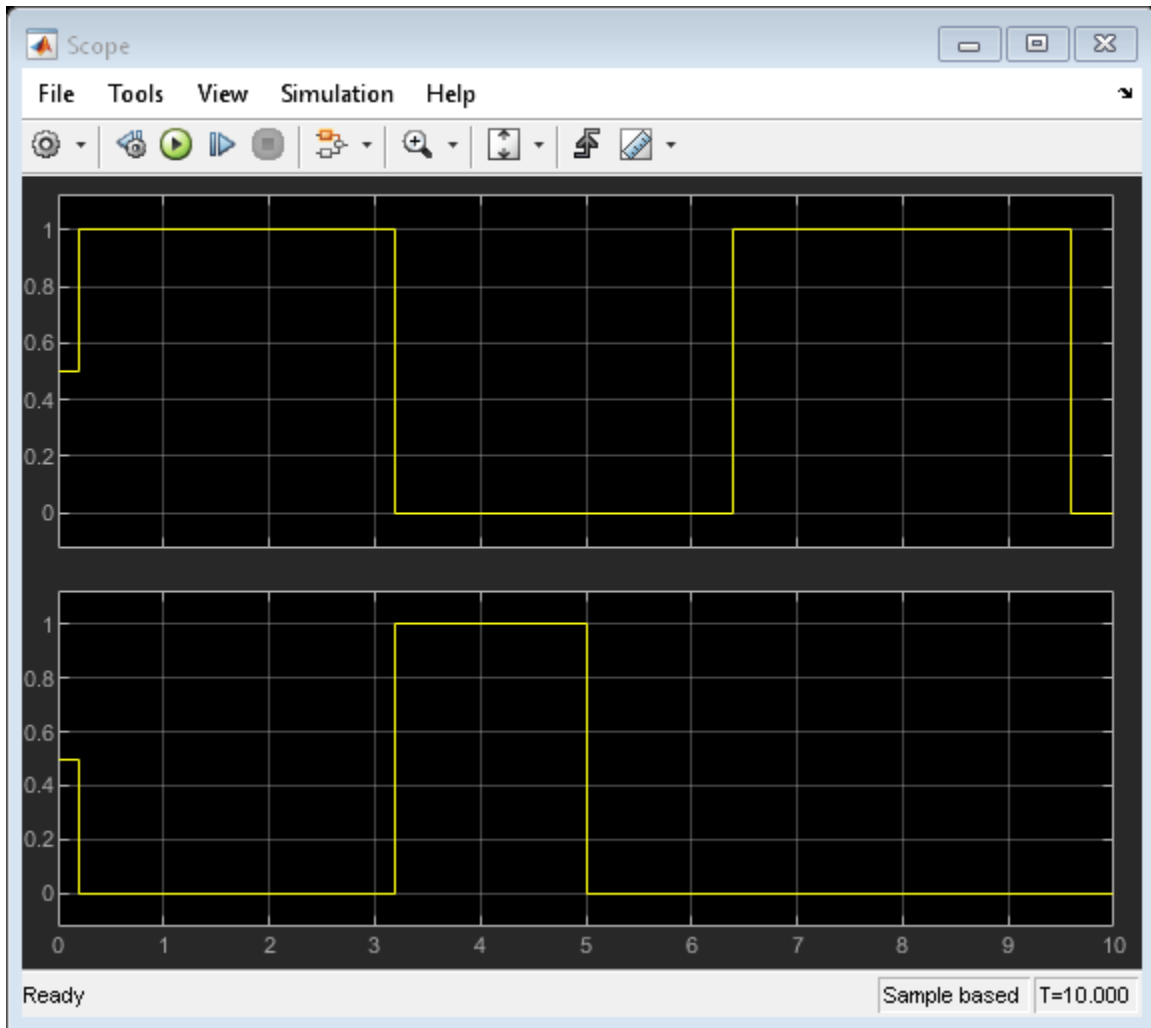
The chart contains two parallel states, A and B, and one graphical function block, `foo`. State A declares the function `heaviside`, which is not supported for code generation, by using `coder.extrinsic`. State B and the graphical function block also use `heaviside` without `coder.extrinsic`.

The input for state A is `u1`, a sine wave, and the input for state B is `u2`, a cosine wave. The graphical function out outputs the value of the `heaviside` function for the input `in`.



You only need to declare `heaviside` once in your chart using `coder.extrinsic`. After this you can use the `heaviside` function anywhere within your chart without `coder.extrinsic`. When generating code the functions that you declare using `coder.extrinsic` will have a call to the extrinsic function, and that function will not appear in the generated code.

To visualize the result of this chart, open the scope.



## See Also

`coder.extrinsic` | `heaviside`

## More About

- "Access MATLAB Functions and Workspace Data in C Charts" on page 16-20
- "Generate Code for Global Data" (MATLAB Coder)
- "Functions and Objects Supported for C/C++ Code Generation" (Simulink)



# Code Generation

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- “Generate C or C++ Code from Stateflow Blocks” on page 32-2
- “Select Array Layout for Matrices in Generated Code” on page 32-5
- “Code Generation Using Variant Transitions” on page 32-8
- “Variant Lamp Design” on page 32-13
- “Generate Code from Atomic Subcharts” on page 32-14
- “Using Absolute Time Temporal Logic in Stateflow Charts” on page 32-16

## Generate C or C++ Code from Stateflow Blocks

To generate C or C++ code from Simulink models that include a Stateflow chart, you must use Simulink Coder. In addition to Simulink Coder, you may use Embedded Coder to further enhance the generated code. Embedded Coder enhancements make your code more readable, more compact, and faster to execute.

When you generate code for a target, the Stateflow parser evaluates the graphical and nongraphical objects and data in each Stateflow machine against the supported chart notation and the action language syntax. For more information, see “Detect Common Modeling Errors During Chart Simulation” on page 33-33.

### Generate Code by Using Simulink Coder

Simulink Coder allows you to generate C and C++ code from models that contain Stateflow charts. You can then use the generated code for real-time and non-real-time applications, including:

- Simulation acceleration
- Rapid prototyping
- Hardware-in-the-loop (HIL) testing

Using Simulink Coder also allows you access to Classic Accelerator and Rapid Accelerator modes. Accelerator modes work by generating target code, which is then used for execution. For more information about these modes, see “How Acceleration Modes Work” (Simulink).

HIL testing allows you to test your controller design and determine if your physical system (plant) model is valid. For more information about HIL testing, see “Basics of Hardware-In-The-Loop simulation” (Simscape).

To get started setting up a model for code generation with Simulink Coder, see “Configure Model and Generate Code” (Simulink Coder).

### Generate Code by Using Embedded Coder

With the addition of Embedded Coder you can generate C or C++ code that is more compact, easier to read, and faster to run. Embedded Coder additionally extends the abilities of Simulink Coder by allowing you control over generated functions, files, and data. Further, Embedded Coder enables easy integration for legacy code, data types, and calibration parameters. Embedded Coder supports software standards for:

- AUTOSAR
- MISRA C
- ASAP2

Embedded Coder also provides support packages with advanced optimizations and device drivers for specific hardware.

To get started setting up a model for code generation with Embedded Coder, see “Generate Code by Using the Quick Start Tool” (Embedded Coder).

## Design Tips for Optimizing Generated Code for Stateflow Objects

### Do Not Access Machine-Parented Data

This restriction prevents long parameter lists from appearing in the code generated for a graphical function. You can access local data that resides in the same chart as the graphical function. For more information, see “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18.

Additionally, Embedded Coder does not support the use of code replacement libraries for machine-parented data. For more information, see “Code You Can Replace From Simulink Models” (Embedded Coder).

### Be Explicit About the Inline Option of a Graphical Function

When you use a graphical function in a Stateflow chart, select **Inline** or **Function** for the property **Function Inline Option**. Otherwise, the code generated for a graphical function may not appear as you want. For more information, see “Specify Properties of Graphical Functions” on page 8-20.

### Avoid Using Multiple Edge-Triggered Events in Stateflow Charts

If you use more than one trigger, you generate multiple code statements to handle rising or falling edge detections. If multiple triggers are required, use function-call events instead. For more information, see “Activate a Stateflow Chart by Sending Input Events” on page 14-7.

### Combine Input Signals of a Chart Into a Single Bus Object

When you use a bus object, you reduce the number of parameters in the parameter list of a generated function. This guideline also applies to output signals of a chart. For more information, see “Define Stateflow Structures” on page 29-2.

### Use Discrete Sample Times

The code generated for discrete charts that are not inside a triggered or enabled subsystem uses integer counters to track time instead of Simulink provided time. The generated code uses less memory, and enables code for use in Software-in-the-Loop (SIL) and Processor-in-the-Loop (PIL) simulation modes.

## Generate Code for Rapid Prototyping and Production Deployment

This table directs you to information about code generation based on your goals.

Goal	Simulink Coder Documentation	Embedded Coder Documentation
Generate C/C++ source code	“Source Code Generation in Simulink Coder” (Simulink Coder)	“Code Generation Basics” (Embedded Coder)
Generate C/C++ source code and build executable	“Program Building, Interaction, and Debugging in Simulink Coder” (Simulink Coder)	
Integrate external code	“External Code Integration” (Simulink Coder)	“Code Integration” (Embedded Coder)

Goal	Simulink Coder Documentation	Embedded Coder Documentation
Include external code only for library charts in a portable, self-contained library for use in multiple models	"Integrate External Code for Library Charts" (Simulink Coder)	"Integrate External Code for Library Charts" (Embedded Coder)
Optimize generated code	"Reduce Memory Usage for Boolean and State Configuration Variables" (Simulink Coder)	"Reduce Memory Usage for Boolean and State Configuration Variables" (Embedded Coder)

## Traceability of Stateflow Objects in Generated Code

Traceability comments provide a way to:

- Verify generated code. You can identify which Stateflow object corresponds to a line of code and track code from different objects that you have or have not reviewed.
- Include comments in code generated for large-scale models. You can identify objects in generated code and avoid manually entering comments or descriptions.

To enable traceability comments, you must have Embedded Coder or HDL Coder software. For C/C++ code generation, comments appear in the generated code for embedded real-time (ert) based targets only. For more information, see "Trace Stateflow Elements in Generated Code" (Embedded Coder) and "Navigate Between Simulink Model and HDL Code by Using Traceability" (HDL Coder).

## See Also

### More About

- "Generate Code from Atomic Subcharts" on page 32-14
- "Select Array Layout for Matrices in Generated Code" on page 32-5

## Select Array Layout for Matrices in Generated Code

When generating code from a Stateflow chart that uses C as the action language, you can specify the array layout for matrices. For example, consider this matrix:

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$$

By default, the code generator uses column-major layout to flatten the matrix as a one-dimensional array. The array is stored in memory with this arrangement:

```
{1, 4, 2, 5, 3, 6}
```

If you select row-major layout, the code generator flattens the matrix and stores it in memory with this arrangement:

```
{1, 2, 3, 4, 5, 6}
```

If you have Embedded Coder, you can preserve the multidimensionality of Stateflow local data, prevent its flattening, and implement the matrix as a two-dimensional array with this arrangement:

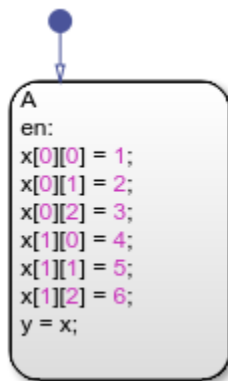
```
{{1, 2, 3}, {4, 5, 6}}
```

Row-major and multidimensional array layout can ease the integration with external code. For more information, see “Code Generation of Matrices and Arrays” (Simulink Coder) and “Dimension Preservation of Multidimensional Arrays” (Embedded Coder).

### Column-Major Array Layout

By default, the **Array Layout** configuration parameter for a Simulink® model is **Column-Major**. When you press **Ctrl-B**, the code generator flattens all matrix data into one-dimensional arrays, arranging their contents in a column-major layout.

For example, this Stateflow chart contains local data  $x$  of size [2 3]. The state actions index the elements in  $x$  by row and column number.



If you generate code, the file `sf_matrix_layout.c` implements the local data  $x$  in column-major layout with these lines of code:

```

...
sf_matrix_layout_DW.x[0] = 1.0;
sf_matrix_layout_DW.x[2] = 2.0;
sf_matrix_layout_DW.x[4] = 3.0;
sf_matrix_layout_DW.x[1] = 4.0;
sf_matrix_layout_DW.x[3] = 5.0;
sf_matrix_layout_DW.x[5] = 6.0;
...

```

The generated code refers to the elements of `x` by using only one index.

## Row-Major Array Layout

Row-major layout can improve the performance of certain algorithms. For example, see “Interpolation Algorithm for Row-Major Array Layout” (Embedded Coder).

To generate code that uses row-major array layout:

- 1 Open the Model Configuration Parameters dialog box.
- 2 In the **Code Generation > Interface** pane, set the **Array Layout** parameter to Row-Major.
- 3 Press **Ctrl+B**.

When you select row-major layout for the previous example, the file `sf_matrix_layout.c` implements the local data `x` with these lines of code:

```

...
sf_matrix_layout_DW.x[0] = 1.0;
sf_matrix_layout_DW.x[1] = 2.0;
sf_matrix_layout_DW.x[2] = 3.0;
sf_matrix_layout_DW.x[3] = 4.0;
sf_matrix_layout_DW.x[4] = 5.0;
sf_matrix_layout_DW.x[5] = 6.0;
...

```

The generated code refers to the elements of `x` by using only one index.

In charts that use C as the action language, you can include data and message inputs for multidimensional custom code functions with row-major as the array layout. To implement row-major as the default array layout for inputs in functions, open the Configuration Parameters dialog box. In the **Simulation Target** pane, click **Import custom code** and set **Default function array layout** to Row-major.

In charts that use C as the action language, you can use multidimensional custom code variables. To implement row-major as the default array layout for functions, open the Configuration Parameters dialog box. In the **Simulation Target** pane, click **Import custom code**. In the **Code Generation > Interface** pane, under the **Data exchange interface** section, ensure that **Array layout** is set to Row-major.

You can also specify individual functions for row-major array layout. In the **Simulation Target** pane, click **Specify by function**. From this window, you can add or remove functions and specify their individual array layout.

---

**Note** If you enable row-major array layout in a chart that uses custom C code, all global variables and arguments of functions defined in the custom code must be scalars, vectors, or structures of scalars and vectors. Specify the size of an  $n$ -element vector as  $n$ , and not as  $[n\ 1]$  or  $[1\ n]$ .

---

When you enable row-major array layout in charts that use change detection operators, code generation produces an error. Before generating code in charts that use change detection operators, enable column-major array layout. See Change Detection Operators on page 16-64.

## Multidimensional Array Layout

If you have Embedded Coder, you can generate code that preserves the multidimensionality of Stateflow data without flattening the data as one-dimensional arrays.

For the previous example, the file `sf_matrix_layout.c` implements the local data `x` with these lines of code:

```
...
sf_matrix_layout_DW.x[0][0] = 1.0;
sf_matrix_layout_DW.x[0][1] = 2.0;
sf_matrix_layout_DW.x[0][2] = 3.0;
sf_matrix_layout_DW.x[1][0] = 4.0;
sf_matrix_layout_DW.x[1][1] = 5.0;
sf_matrix_layout_DW.x[1][2] = 6.0;
...
```

The generated code refers to the elements of `x` by using two indices.

Multidimensional array layout is available for:

- Constant and local data in Stateflow charts.
- Charts that contain messages.
- Parameters and root-level inport and output data in Simulink models.

Multidimensional layout is not available for bus signals containing multidimensional array data. Multidimensional layout is not supported in:

- Reusable charts or charts in reusable parent subsystems.

For more information, see “Preserve Dimensions of Multidimensional Arrays in Generated Code” (Embedded Coder).

## See Also

### More About

- “Generate C or C++ Code from Stateflow Blocks” on page 32-2
- “Code Generation of Matrices and Arrays” (Simulink Coder)
- “Interpolation Algorithm for Row-Major Array Layout” (Embedded Coder)
- “Dimension Preservation of Multidimensional Arrays” (Embedded Coder)

## Code Generation Using Variant Transitions

With variant transitions, you can create Stateflow charts in Simulink models that generate code that can be used in a variety of different software situations. Variant transitions allow you to model a full subset of variations within one Stateflow chart so that you can choose which variation you want when you generate code or when you compile the generated code.

Variant transitions are guarded by Simulink parameters or MATLAB variables in a condition and connect states within your chart that are variations from the core chart configuration. Variant transition conditions are evaluated during code compile or code generation instead of at runtime. In addition to this, the generated code only contains the data members needed to execute the currently selected software configuration.

Chart variations are supported only in code generation. Stateflow charts that you develop with variant transitions simulate according to which portion of your chart is active.

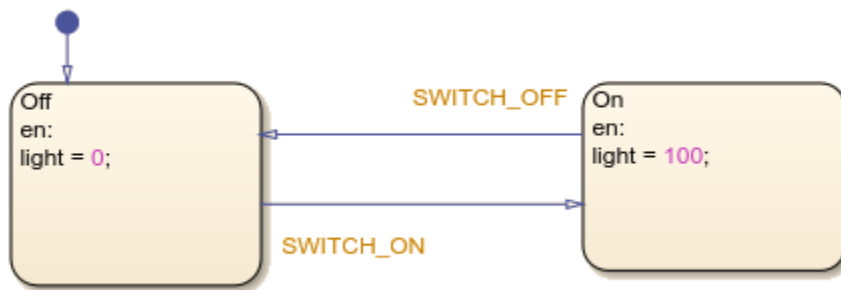
Variant transitions can not be used in conjunction with actions on default transition paths of a state or a chart.

### Create a Variant Configuration

Variant transitions connect variant configurations to your core Stateflow chart. Variant configurations are only active when the variant transition condition is true.

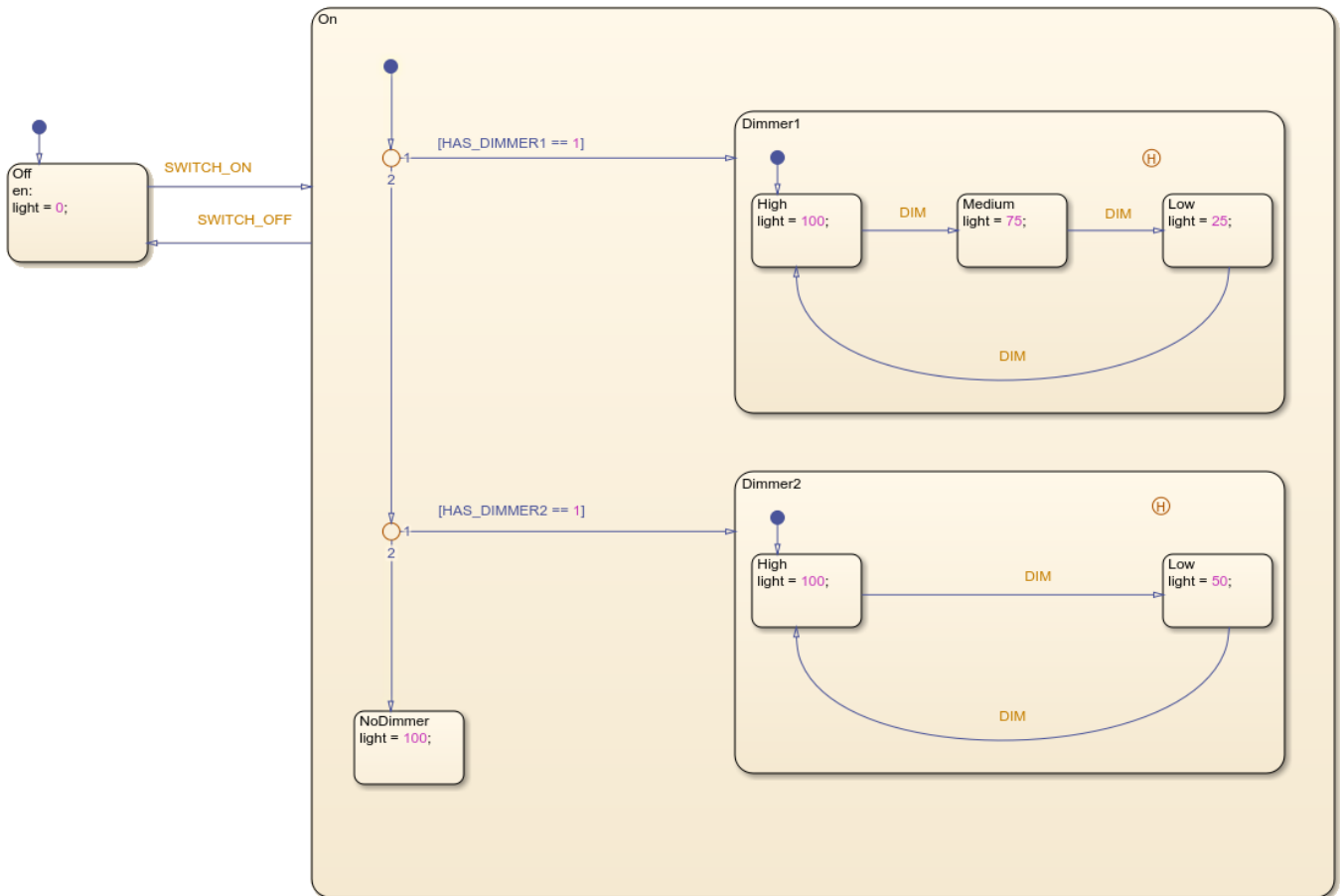
In this example, you will add variant configurations to a basic control system that turns a lamp on and off. The variant configurations allow the lamp to dim in multiple ways. Once you add in the variant configurations to your Stateflow chart, you can choose to generate code for any configuration.

Initially, your Stateflow chart includes two states, `Off` and `On`. The light turns on when the event, `SWITCH_ON`, is sent to the chart. The light turns off when the event, `SWITCH_OFF`, is sent to the chart.

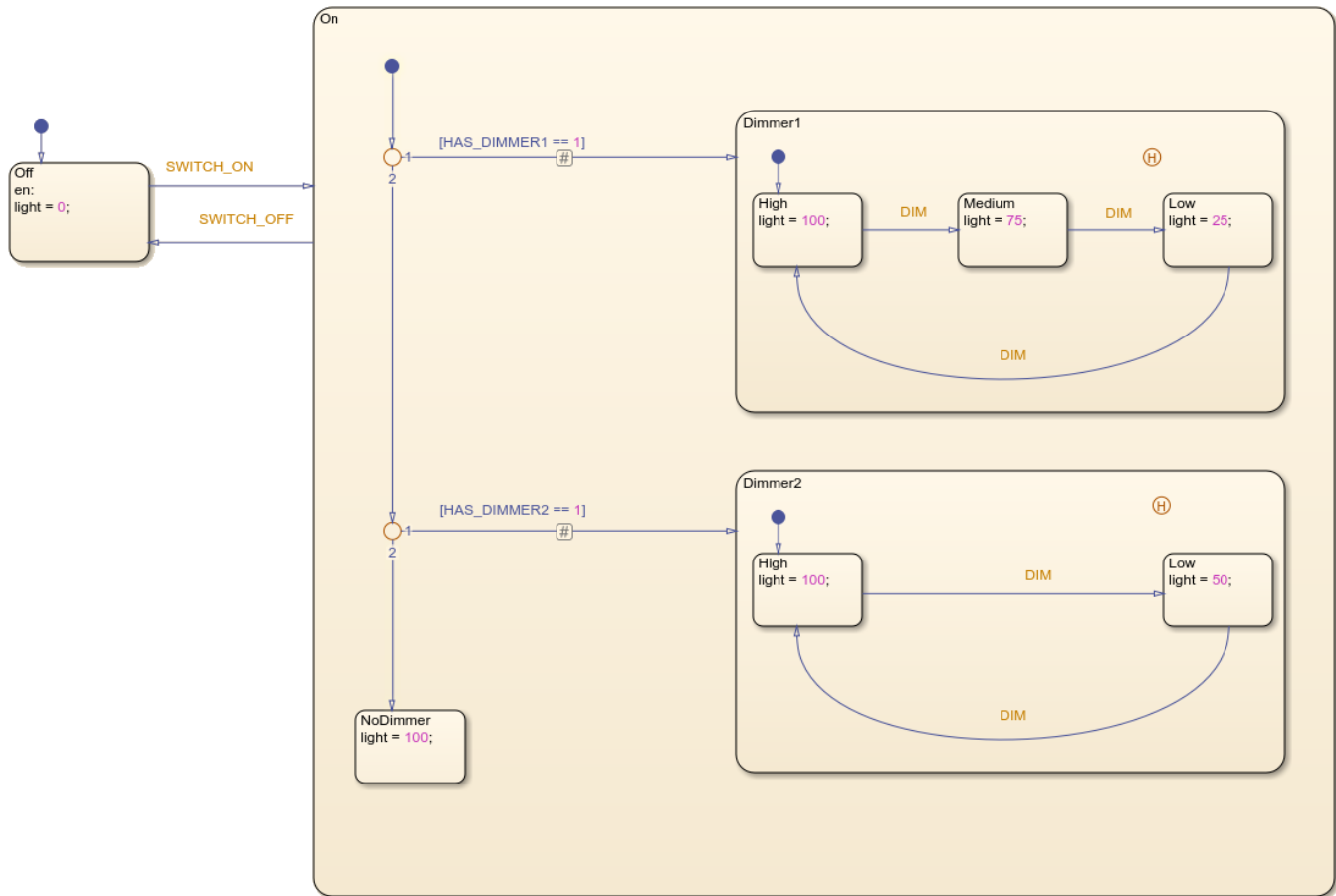


Some of the lamps have the ability to be dimmed. Within that subset, there are lamps that can be set high or low and lamps that can only be set to high, medium, or low. To add these capabilities to the Stateflow chart, you add in three variations: `Dimmer1`, `Dimmer2`, and `NoDimmer`. `Dimmer1` has three substates, `High`, `Medium`, and `Low`. `Dimmer2` has two substates, `High` and `Low`.





Entry to the variant configurations are guarded by a transition condition that uses a Simulink parameter or MATLAB variable that is defined in the base workspace. To change the transition to a variant transition, click the transition. In the **Transition** tab, select **Variant Transition**. The transition appears on the chart with a # symbol, which indicates that the transition is a variant transition.



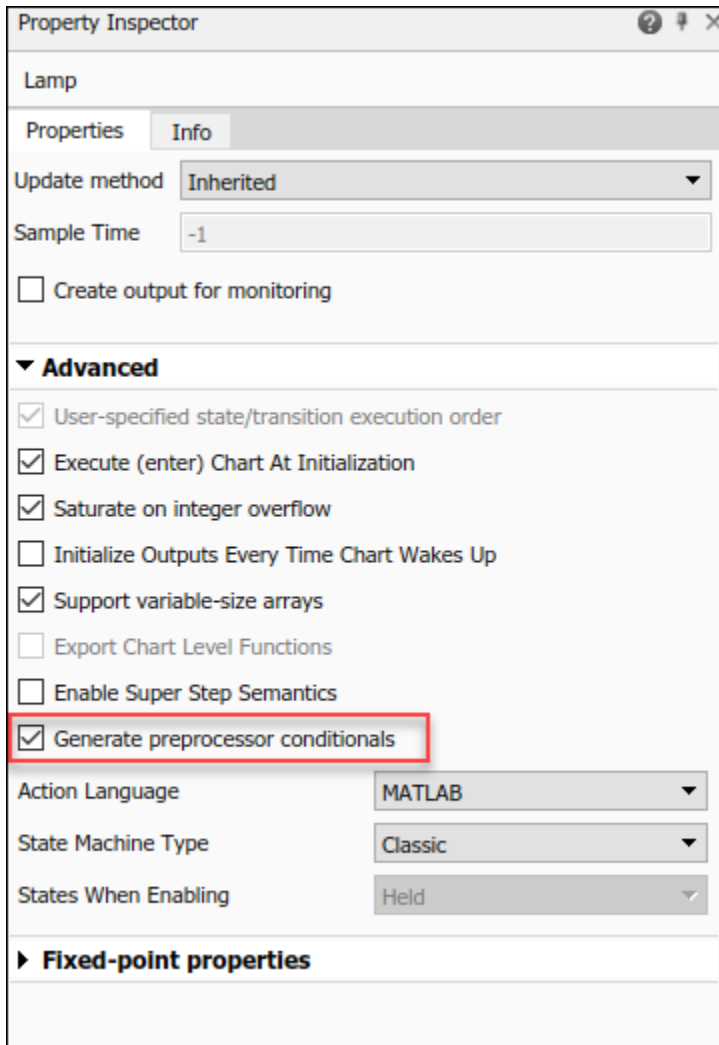
In this example, the variant configurations are guarded by a condition with a Simulink parameter. In this case, `HAS_DIMMER1` is a parameter object. In order for the variant configuration to be active, the condition `[HAS_DIMMER1 == 1]` must be true. For more information about Simulink parameters, see “Set Block Parameter Values” (Simulink).

During simulation, your Stateflow chart executes only the active portion of your Stateflow chart. The inactive portion appears grayed out on the Stateflow canvas. To change which portion of the chart is currently active, update the guarding parameter in the base workspace.

## Generate Code for Variant Configurations

You must have Simulink Coder or Embedded Coder to generate code from your Stateflow chart. By default, the generated code only contains the active variant state machine.

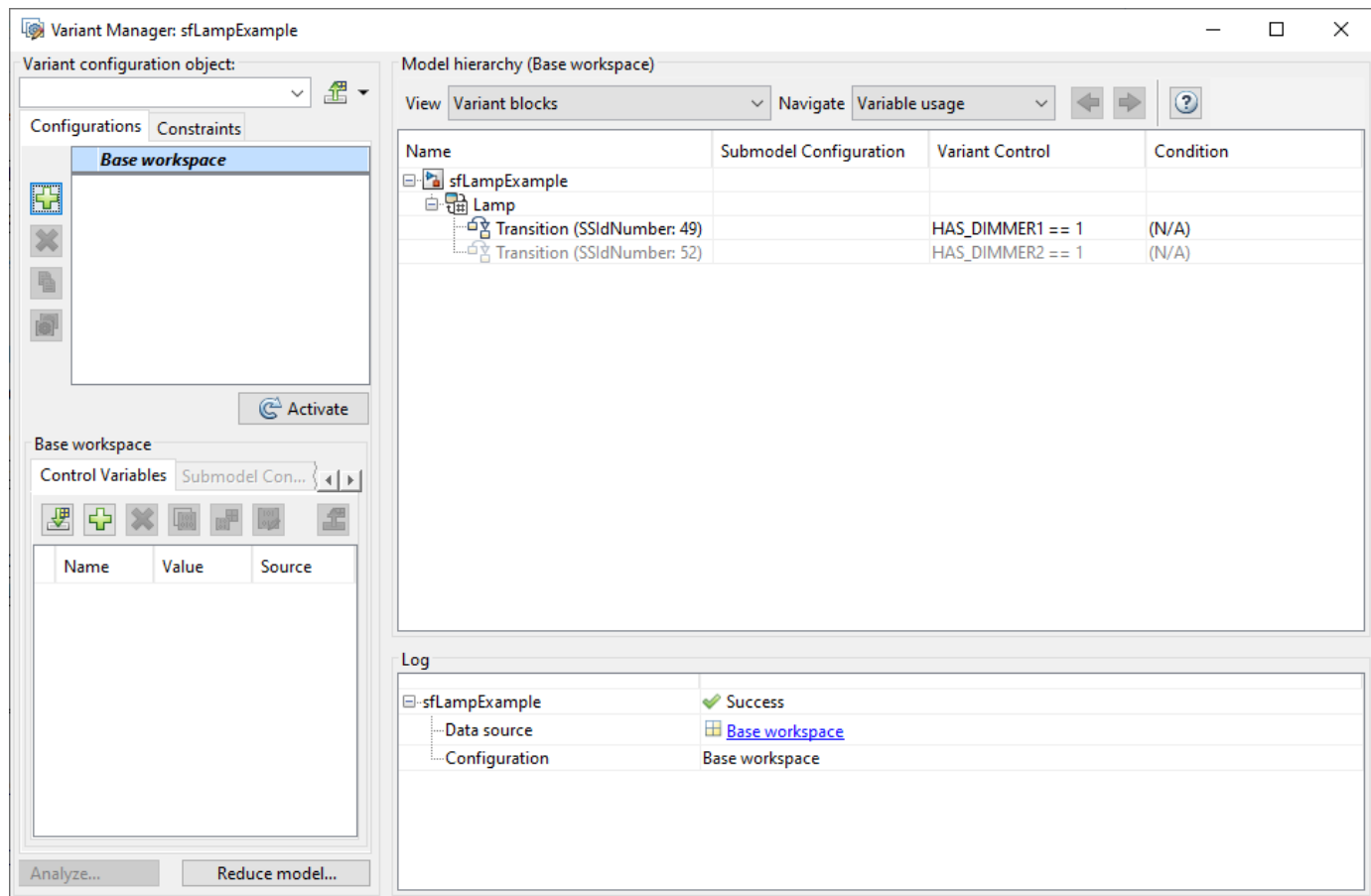
If you are using Embedded Coder, you can choose to include a preprocessor conditional statement in your generated code. In the Stateflow editor, on the **Modeling** tab, under **Design Data**, select **Property Inspector**. Under **Advanced**, select **Generate preprocessor conditionals**.



For more information about generating code, see “Generate Code Using Simulink® Coder™” (Simulink Coder) and “Generate Code Using Embedded Coder®” (Embedded Coder).

## Using the Variant Manager

The Variant Manager is a central tool that allows you to manage variant configurations in your system model. In the Stateflow editor, on the **Modeling** tab, under **Design Data**, select **Variant Manager**.



For more information about the Variant Manager, see “Variant Manager Overview” (Simulink).

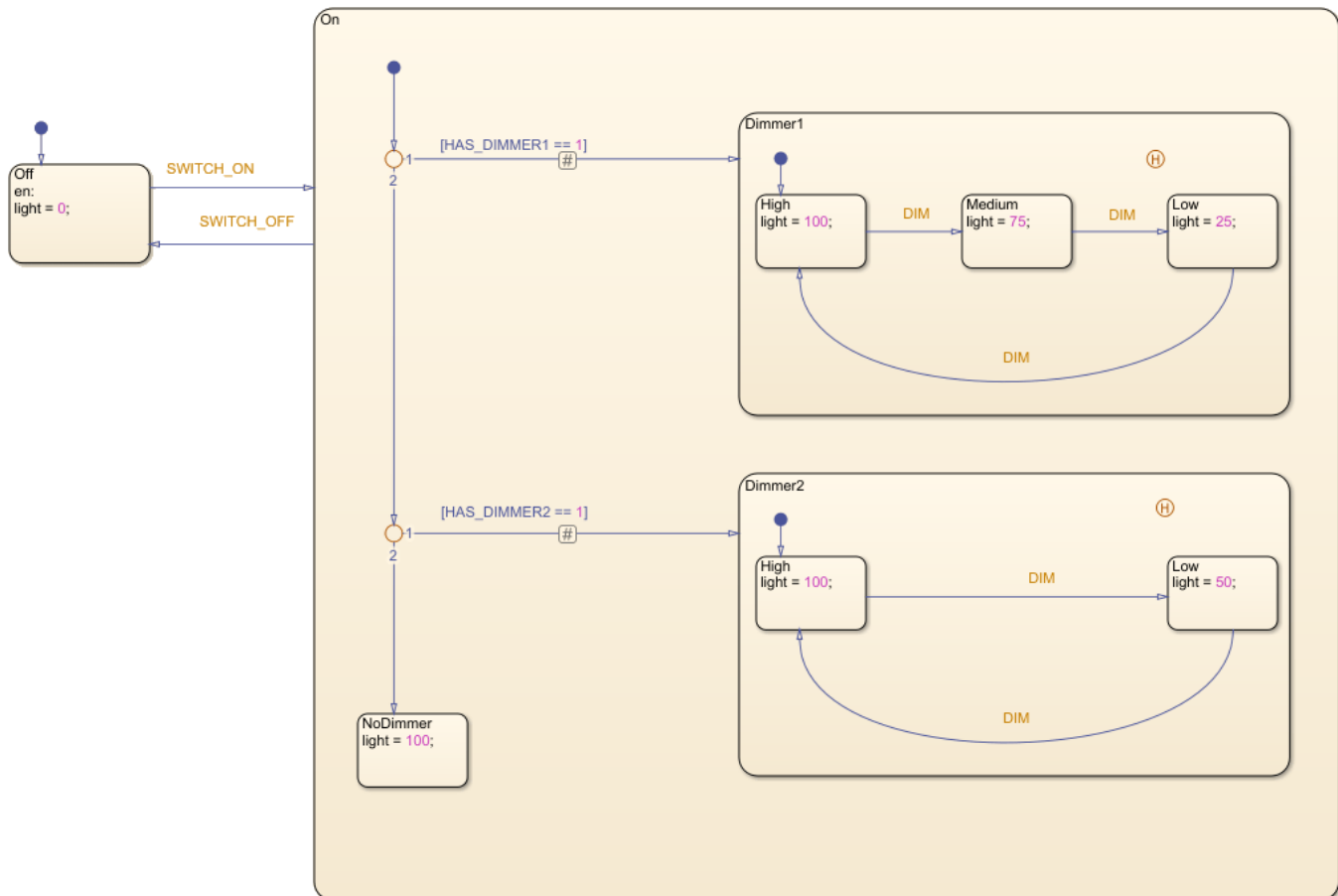
## See Also

### More About

- “Variant Lamp Design” on page 32-13
- “Generate C or C++ Code from Stateflow Blocks” on page 32-2
- “Choose Storage Class for Controlling Data Representation in Generated Code” (Simulink Coder)

## Variant Lamp Design

This example shows how to design a system that uses variant transitions to generate code that can be used in a variety of different software situations.



Some of the lamps have the ability to be dimmed. Within that subset, there are lamps that can be set high or low and lamps that can only be set to high, medium, or low.

Entry to the variant configurations are guarded by a transition condition that uses a Simulink parameter or MATLAB variable that is defined in the base workspace.

In this example, the variant configurations are guarded by a condition with a Simulink parameter. In this case, `HAS_DIMMER1` and `HAS_DIMMER2` are parameter objects.

When you generate code from the Simulink model, your code includes only the active variant state machine. If you are using Embedded Coder, you have the option to include a preprocessor conditional statement in the generated code.

For more information, see “Code Generation Using Variant Transitions” on page 32-8.

## Generate Code from Atomic Subcharts

To unit test a Stateflow chart in a Simulink model, first break the chart into smaller, independent components by using atomic subcharts. When you generate code for your chart, a separate file stores the code for the atomic subchart. Generating reusable code from atomic subcharts is useful for testing individual parts of your Stateflow chart. For more information, see “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2.

### Generate Reusable Code for Unlinked Atomic Subcharts

To specify code generation parameters for an unlinked atomic subchart:

- 1 In your chart, right-click the atomic subchart and select **Properties**.
- 2 In the dialog box, specify these parameters:
  - a Set **Code generation function packaging** to `Reusable function`.
  - b Set **Code generation file name options** to `User specified`.
  - c For **Code generation file name**, enter the name of the file with no extension.
- 3 Open the Configuration Parameters dialog box by pressing **Ctrl+E**.
- 4 In the **Code Generation** tab, set the **System target file** parameter to `ert.tlc`.
- 5 (OPTIONAL) Customize the generated function names for atomic subcharts. In the Configuration Parameters dialog box, in the **Code Generation > Identifiers** tab, set the **Subsystem methods** parameter. Specify the format of the function names by using a combination of these tokens:
  - `$R` — root model name
  - `$F` — type of interface function for the atomic subchart
  - `$N` — block name
  - `$H` — subsystem index
  - `$M` — name-mangling text

For more information, see “Generate Separate Code for an Atomic Subchart” on page 19-35.

### Generate Reusable Code for Linked Atomic Subcharts

To specify code generation parameters for linked atomic subcharts from the same library:

- 1 Open the library model that contains your atomic subchart.
- 2 Unlock the library.
- 3 Right-click the library chart and select **Block Parameters**.
- 4 In the dialog box, specify these parameters:
  - a On the **Main** tab, select **Treat as atomic unit**.
  - b On the **Code Generation** tab, set **Function packaging** to `Reusable function`.
  - c Set **File name options** to `User specified`.
  - d For **File name**, enter the name of the file with no extension.
- 5 In the **Code Generation** tab, set the **System target file** parameter to `ert.tlc`.

- 6** (OPTIONAL) Customize the generated function names for atomic subcharts. In the Configuration Parameters dialog box, in the **Code Generation > Identifiers** tab, set the **Subsystem methods** parameter. Specify the format of the function names by using a combination of these tokens:
- \$R — root model name
  - \$F — type of interface function for the atomic subchart
  - \$N — block name
  - \$H — subsystem index
  - \$M — name-mangling text

When you generate code for your model, a separate file stores the code for linked atomic subcharts from the same library.

## See Also

### More About

- “Create Reusable Subcomponents by Using Atomic Subcharts” on page 19-2
- “Generate C or C++ Code from Stateflow Blocks” on page 32-2
- “Generate Separate Code for an Atomic Subchart” on page 19-35

## Using Absolute Time Temporal Logic in Stateflow Charts

When you use absolute time temporal logic in your Stateflow Chart blocks in your model for HDL code generation, use these settings.

For the sample rate of the chart:

- If you use seconds (sec), then the sample time must be an integer 65535 or lower, or a decimal between 65.535 and 0.001 with no more than three decimal places.
- If you use milliseconds (msec), the sample time must be a decimal between 65.535 and 0.001 with no more than three decimal places, or a decimal between 0.065535 and 0.000001 with no more than six decimal places.
- If you use microseconds (usec), the sample time must be a decimal between 0.065535 and 0.000001 with no more than six decimal places, or a decimal between 0.000065535 and 0.000000001 with no more than nine decimal places.
- If the sample time is an integer below  $2^{16}$ , then use 'sec'.
- If  $1000 * \text{sample time}$  is an integer below  $2^{16}$ , then use 'sec' or 'msec'.
- If  $1000000 * \text{sample time}$  is an integer below  $2^{16}$ , then use 'msec' or 'usec'.
- If  $1000000000 * \text{sample time}$  is an integer below  $2^{16}$ , then use 'usec'.



# Debug and Test Stateflow Charts

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- “Debugging Stateflow Charts” on page 33-2
- “Set Breakpoints to Debug Charts” on page 33-3
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Control Chart Execution After a Breakpoint” on page 33-16
- “Debug Run-Time Errors in a Chart” on page 33-20
- “Animate Stateflow Charts” on page 33-23
- “Detect Modeling Errors During Edit Time” on page 33-24
- “Detect Common Modeling Errors During Chart Simulation” on page 33-33
- “Avoid Unwanted Recursion in a Chart” on page 33-37
- “Monitor Test Points in Stateflow Charts” on page 33-39
- “Log Simulation Output for States and Data” on page 33-43
- “Log Data in Library Charts” on page 33-50
- “Commenting Stateflow Objects in a Chart” on page 33-54

## Debugging Stateflow Charts

For Stateflow charts in Simulink models, you can perform most debugging tasks directly from the Stateflow Editor:

- Set breakpoints to stop execution in specific objects, such as charts, states, transitions, graphical functions, truth table functions, local events, and input events.
- Enable, disable, and set conditions on breakpoints in the Breakpoints and Watch window.
- Add data that you want to monitor during simulation in the Breakpoints and Watch window.
- After execution stops at a breakpoint, change data values and step through the simulation.

In addition, during simulation, you can display and change the values of Stateflow data in the MATLAB Command Window.

For information on debugging Stateflow chart objects that you execute in MATLAB, see “Debug a Standalone Stateflow Chart” on page 35-13.

### See Also

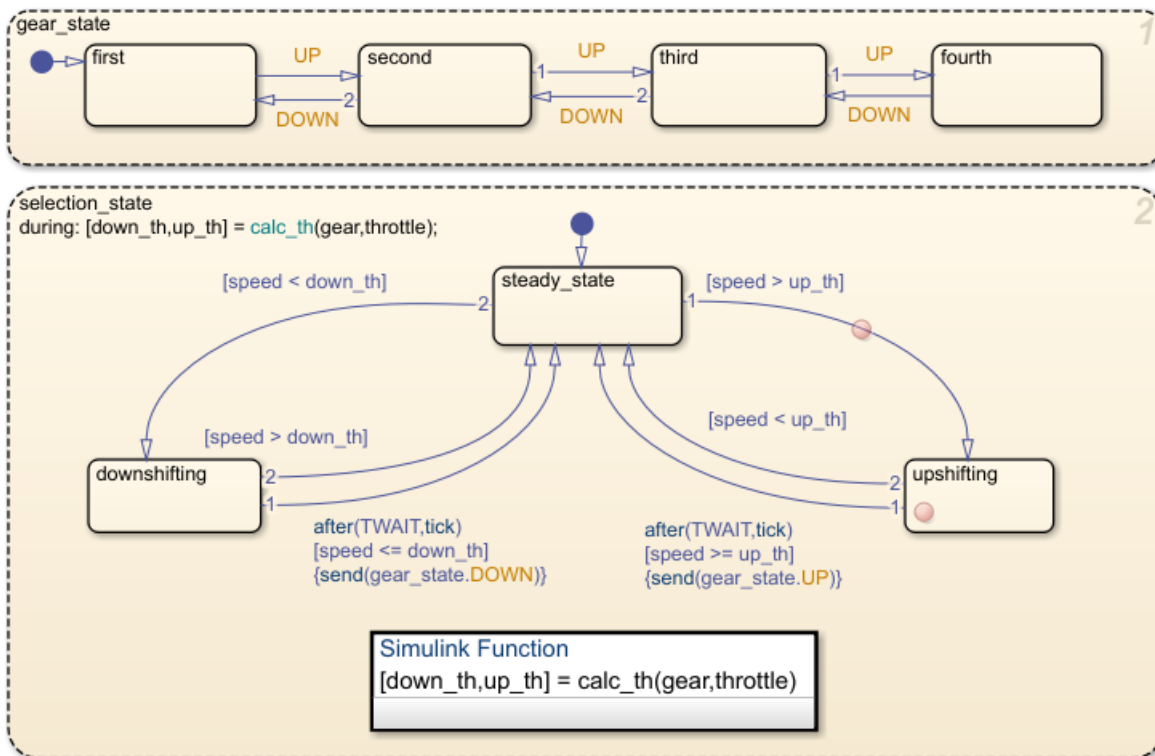
#### More About

- “Set Breakpoints to Debug Charts” on page 33-3
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Control Chart Execution After a Breakpoint” on page 33-16
- “Debug Run-Time Errors in a Chart” on page 33-20

## Set Breakpoints to Debug Charts

You enable debugging for a Stateflow chart when you set a breakpoint. A breakpoint is a point on a Stateflow chart that pauses the simulation so you can examine the status of the chart. While simulation is paused, you can view Stateflow data, interact with the MATLAB workspace, and step through the simulation. For more information, see “Debugging Stateflow Charts” on page 33-2.

Breakpoints appear as circular red badges. For example, this chart contains breakpoints on the `upshifting` state and the transition from `steady_state` to `upshifting`.



### Set a Breakpoint for a Stateflow Object

You can set breakpoints on charts, states, transitions, graphical or truth table functions, and events.

#### Breakpoints on Charts

To set a breakpoint on a chart, right-click inside the chart and select **Set Breakpoint on Chart Entry**. This type of breakpoint pauses the simulation before entering the chart.

To remove the breakpoint, right-click inside the chart and clear the **Set Breakpoint on Chart Entry** option.

#### Breakpoints on States and Transitions

You can set different types of breakpoints on states and transitions.

Object	Breakpoint Type
State	On State Entry — Pause the simulation before performing the state entry actions.
	During State — Pause the simulation before performing the state during actions.
	On State Exit — Pause the simulation after performing the state exit actions.
Transition	When Transition is Tested — Pause the simulation before testing that the transition is a valid path. If no condition exists on the transition, this breakpoint type is not available.
	When Transition is Valid — Pause the simulation after the transition is valid, but before taking the transition.

To set a breakpoint on a state or transition, right-click the state or transition and select **Set Breakpoint**. For states, the default breakpoints are **On State Entry** and **During State**. For transitions, the default breakpoint is **When Transition is Valid**. To change the type of breakpoint, click the breakpoint badge and select a different configuration of breakpoints. For more information, see “Change Breakpoint Types” on page 33-5.

To remove the breakpoint, right-click the state or transition and select **Clear Breakpoint**.

### Breakpoints on Stateflow Functions

To set a breakpoint on a graphical or truth table function, right-click the function and select **Set Breakpoint During Function Call**. This type of breakpoint pauses the simulation before calling the function.

To remove the breakpoint, right-click the function and clear the **Set Breakpoint During Function Call** option.

### Breakpoints on Events

You can select two types of breakpoints on events:

- **Start of Broadcast** — Pause the simulation before broadcasting the event.
- **End of Broadcast** — Pause the simulation after a Stateflow object reads the event.

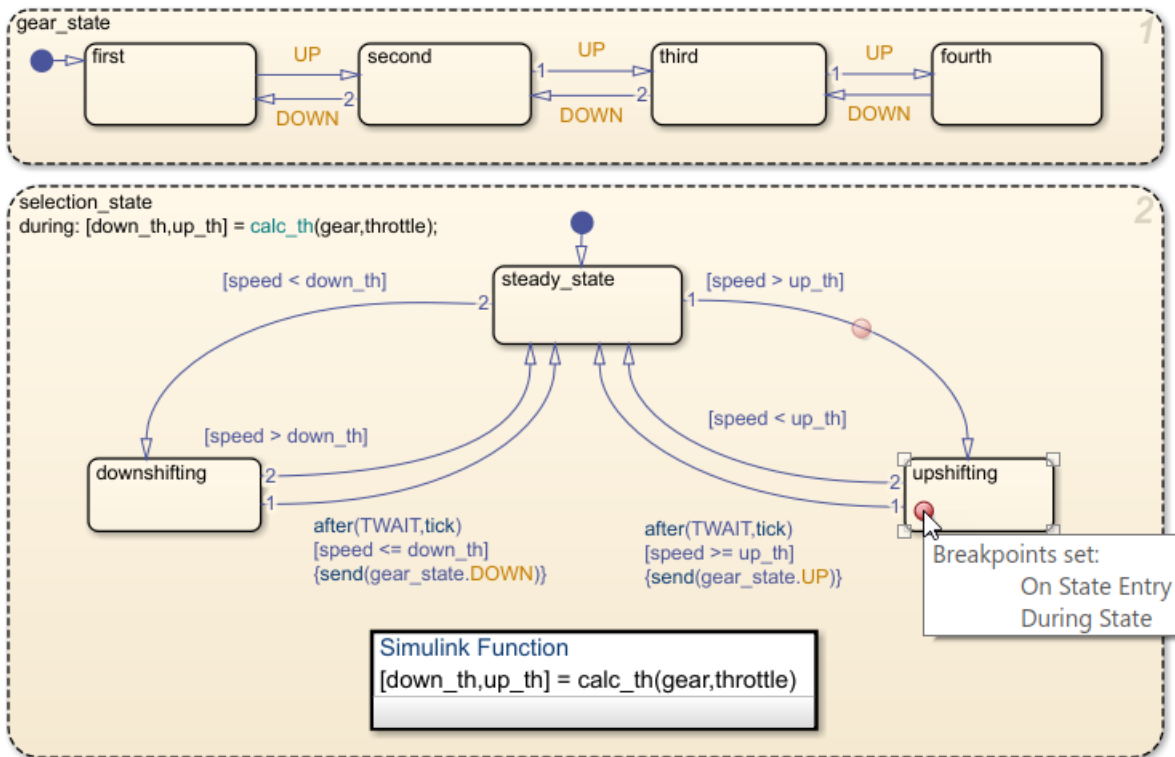
Available breakpoints depend on the scope of the event.

Scope of Event	Start of Broadcast	End of Broadcast
Local	Available	Available
Input	Available	Not available
Output	Not available	Not available

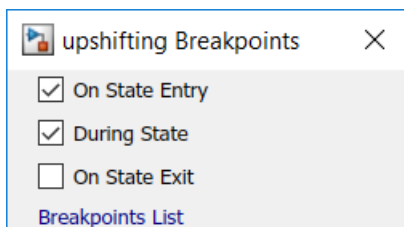
To set or clear breakpoints on an event, use the Property Inspector or the Model Explorer to modify the **Debugger Breakpoints** properties. For more information, see “Debugger Breakpoints” on page 14-6.

## Change Breakpoint Types

A breakpoint badge can represent more than one type of breakpoint. To see a tooltip that lists the breakpoint types that are set on a Stateflow object, point to its badge. In this example, the badge on the state upshifting represents two breakpoint types: On State Entry and During State.



To change the type of breakpoint on an object, click the breakpoint badge. In the Breakpoints dialog box, you can select a different configuration of breakpoints, depending on the object type.



Clearing all of the check boxes in the Breakpoints dialog box removes the breakpoint.

## Add Breakpoint Conditions

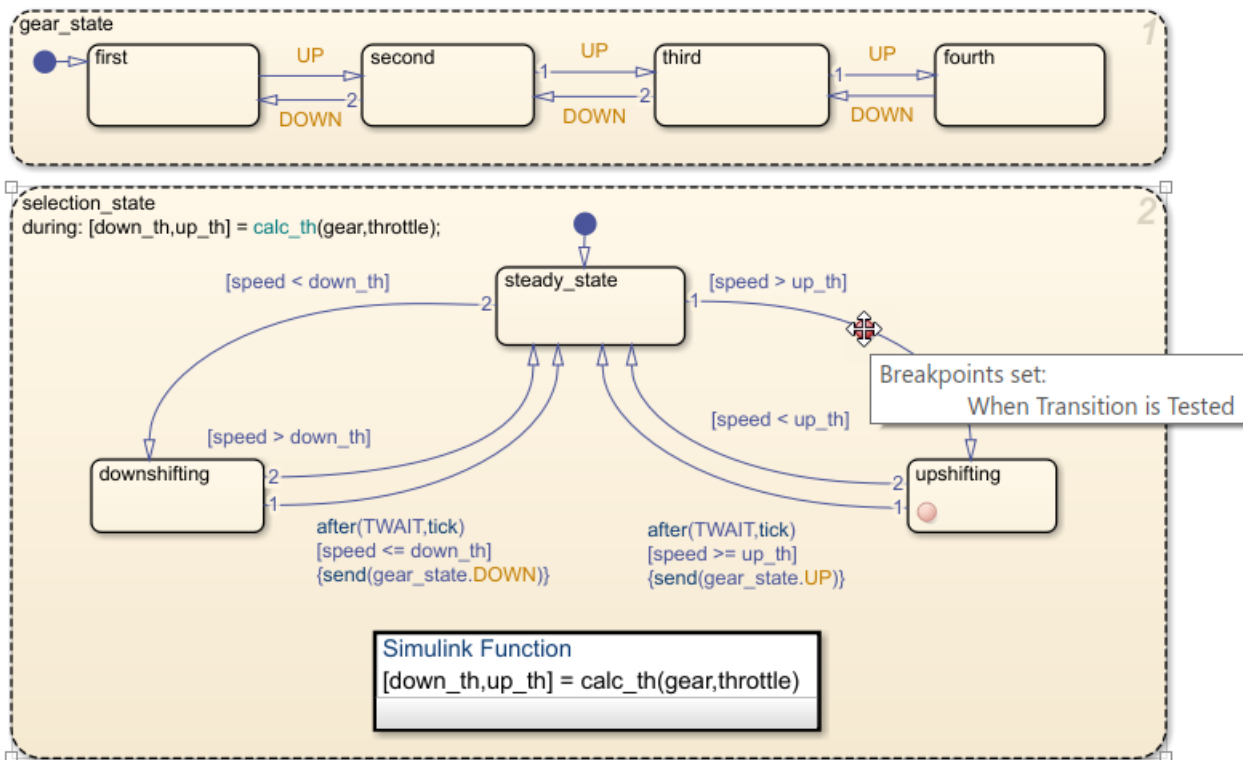
To limit the number of times that the simulation stops at a breakpoint, add a condition to the breakpoint. By default, a Stateflow chart pauses whenever it reaches a breakpoint. When you add a condition to a breakpoint, the chart pauses at the breakpoint only when the condition is true.

To add a condition to a breakpoint:

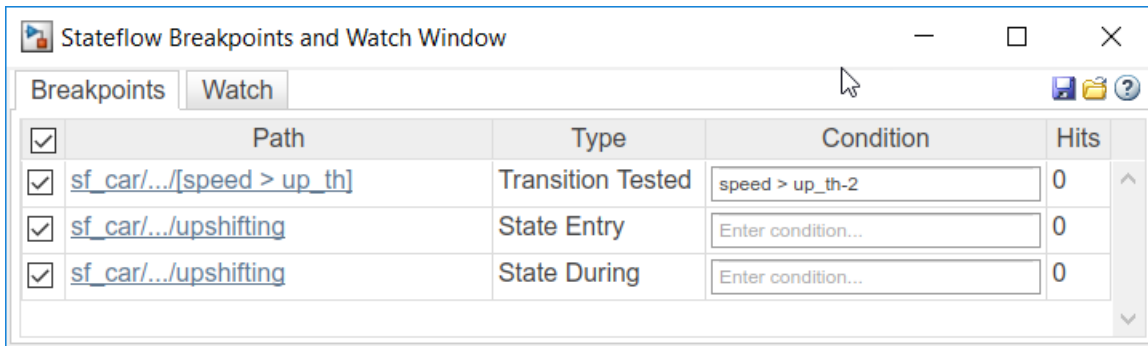
- 1 On the **Debug** tab, click **Breakpoints List** to open the Stateflow Breakpoints and Watch window. Alternatively, you can open the Breakpoints and Watch window by clicking the **Breakpoints List** link in the Breakpoints dialog box.
- 2 Select the **Breakpoints** tab. The **Breakpoints** tab lists all of the breakpoints in the chart. For more information, see “Manage Breakpoints Through the Breakpoints and Watch Window” on page 33-7.
- 3 Under the **Condition** column, enter a condition for the breakpoint. You can use any valid MATLAB expression that combines numerical values and Stateflow data objects that are in scope at the breakpoint.

**Note** You cannot use message data in a breakpoint condition expression.

For example, this chart has a breakpoint on the transition from `steady_state` to `upshifting`. This breakpoint stops the simulation every time that the transition is tested, even if the value of `speed` is far below `up_th`.



To inspect the chart before the transition is taken, you want the breakpoint to pause the simulation only when the value of `speed` is approaching the value of `up_th`. When you set the condition `speed > up_th - 2` on the breakpoint, the simulation pauses only when the value of `speed` is within 2 of the value of `up_th`.



When the simulation pauses, you can inspect the values of the variables `speed` and `up_th` and step through the simulation. For more information, see “Inspect and Modify Data and Messages While Debugging” on page 33-9 and “Control Chart Execution After a Breakpoint” on page 33-16.

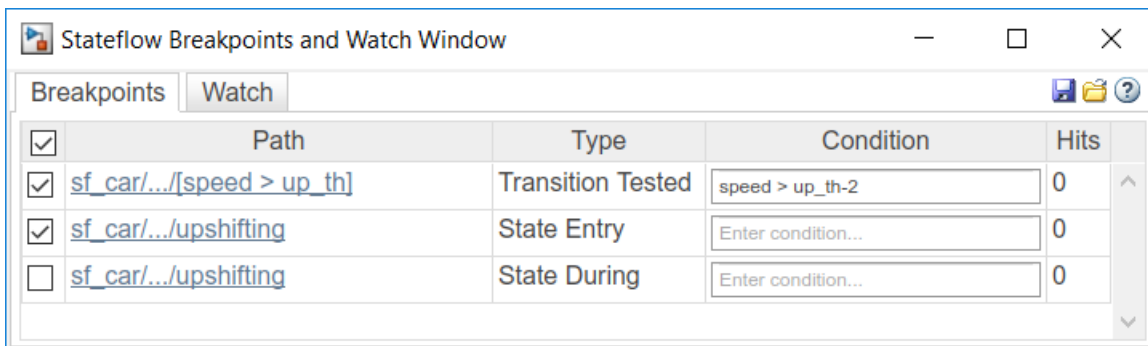
## Manage Breakpoints Through the Breakpoints and Watch Window

You can manage all of the breakpoints in the chart in the Stateflow Breakpoints and Watch window. To open the Breakpoints and Watch window, on the **Debug** tab, click **Breakpoints List**. Alternatively, open the Breakpoints dialog box and click the **Breakpoints List** link.

- To see a list of all of the breakpoints and their associated conditions, select the **Breakpoints** tab.
- To inspect data and message values, select the **Watch** tab. For more information, see “View Data in the Breakpoints and Watch Window” on page 33-11.

### Disable and Reenable Breakpoints

To disable a breakpoint without deleting its associated condition, clear the check box next to the breakpoint name. For example, in this chart, the breakpoint on the During State breakpoint for the `upshifting` state is disabled.

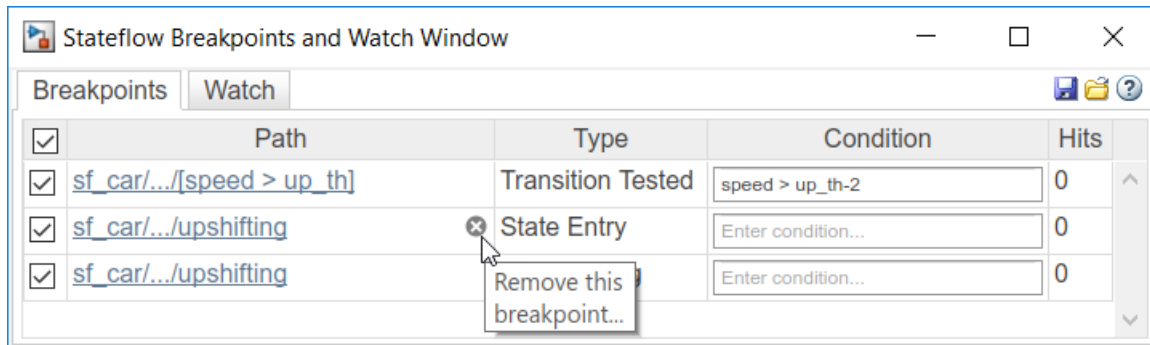


If you disable all the breakpoints for a graphical object, its breakpoint badge changes color from red to gray. If there is at least one breakpoint enabled for an object, the breakpoint badge remains red.

To reenableView a breakpoint, select the box next to the breakpoint name. To disable or reenableView all breakpoints, clear or select the check box at the top of the window.

## Remove Breakpoints

To remove a breakpoint from the chart, point to the name of the breakpoint and click the **Remove this breakpoint** icon that appears to the right of the name. When you remove a breakpoint, you also delete its associated condition.



## View Breakpoint Hits

The **Hits** column displays the number of times that the simulation has paused on each breakpoint. When you change the condition for a breakpoint, the chart resets the number of hits.

## Save and Restore Breakpoints

Breakpoints persist during a MATLAB session. When you close a model, its breakpoints remain in the Breakpoints and Watch window. If you reopen a model during the same MATLAB session, all of the breakpoints and their associated conditions are restored.

You can save the breakpoint and watch data lists and reload them in a later MATLAB session. To save a snapshot of the breakpoint and watch data lists, at the top of the Breakpoints and Watch Window, click the **Save current breakpoints and watches** icon. To restore a snapshot, click the **Load breakpoints and watches** icon.

## See Also

### More About

- “Debugging Stateflow Charts” on page 33-2
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Control Chart Execution After a Breakpoint” on page 33-16
- “Debug Run-Time Errors in a Chart” on page 33-20



## Inspect and Modify Data and Messages While Debugging

While your Stateflow chart is in debugging mode, you can examine the status of the chart by inspecting the values of data, messages, and temporal logic expressions. You can also test the design of the chart by modifying data values and sending local and output messages. This table summarizes the interfaces that you can use to perform these debugging tasks. For more information, see “Debugging Stateflow Charts” on page 33-2.

Debugging Task	Stateflow Editor	Symbols Pane	Breakpoints and Watch Window	MATLAB Command Window
Inspect values of data and messages	Yes on page 33-9	Yes on page 33-10	Yes on page 33-11	Yes on page 33-12
Inspect temporal logic expressions	Yes on page 33-9	No	No	No
Modify values of data and messages	No	Yes on page 33-10	No	Yes on page 33-13
Send messages	No	No	No	Yes on page 33-14

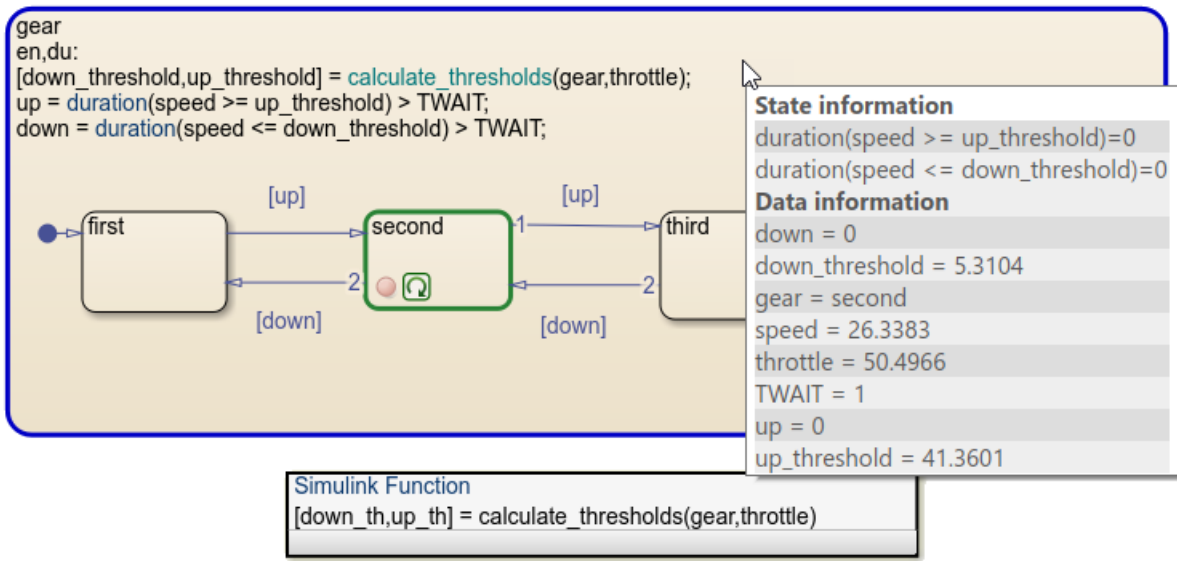
### View Data in the Stateflow Editor

While the simulation is paused at a breakpoint, you can examine data values by pointing to a state, transition, or function in the chart. A tooltip displays the value of the data and the messages that the selected object uses.

Object Type	Tooltip Information
States and transitions	Values of data, messages, and temporal logic expressions that the object uses
Graphical, truth table, and MATLAB functions	Values of local data, messages, inputs, and outputs in the scope of the function

For example, the breakpoint in this chart pauses the simulation when the second state evaluates its during actions. Pointing to the superstate gear displays a tooltip that shows the values of:

- Temporal logic expressions `duration(speed >= up_threshold)` and `duration(speed <= down_threshold)`.
- Data, including `speed`, `up_threshold`, and `up`.



**Note** If you select the chart properties **Export chart level functions** and **Treat exported functions as globally visible**, the tooltip does not display temporal logic data.

### View and Modify Data in the Symbols Pane

While a chart is in debugging mode, the Symbols pane displays the value of each data and message object in the chart. For example, when this chart pauses at the breakpoint, you can see the values of all chart data listed in the **Value** column. The highlighted values changed during the last time step.

TYPE	NAME	VALUE	PORT
	calculate_thresholds		
	TWAIT	1	
	throttle	50.4966	1
	gear	second	1
	down	0	
	up	0	
	down_threshold	5.3104	
	up_threshold	41.3601	
	speed	26.3383	2

During: State second      80%      T=7.080      7%      ode5

In the Symbols pane, you can change the value of:

- Data store memory, local, and output data.

- Local and output messages.

Click the **Value** field for a data or message object to enter a new value.

You cannot change the values of constants, parameters, or input data and messages during simulation.

For more information, see “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2.

## View Data in the Breakpoints and Watch Window

In the Stateflow Breakpoints and Watch window, you can view current data and message values while the simulation is paused at a breakpoint. To open the Breakpoints and Watch window, on the **Debug** tab, click **Breakpoints List**. Alternatively, open the Breakpoints dialog box and click the **Breakpoints List** link.

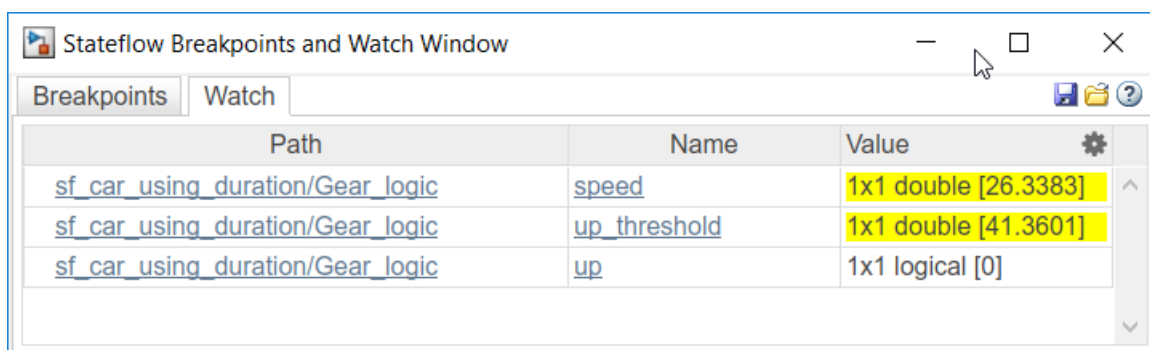
- To see a list of all of the breakpoints and their associated conditions, select the **Breakpoints** tab. For more information, see “Manage Breakpoints Through the Breakpoints and Watch Window” on page 33-7.
- To inspect data and message values, select the **Watch** tab.

### Track Data in the Watch List

You can use the Breakpoints and Watch window to:

- Add data and message objects to a watch list.
- Track the values that changed since the last time step.
- Expand a message to view the message queue and message data values.


For example, you can add `speed`, `up_threshold`, and `up` to the watch list and track their values as you step through the simulation. The highlighting indicates that the values of `speed` and `up_threshold` changed during the last time step.

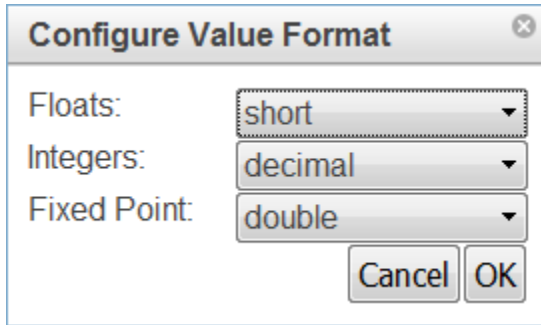


To add a data or message object to the watch list, open the Property Inspector or the Model Explorer. Select the data or message object you want to watch and click the **Add to Watch Window** link.

Alternatively, in the Stateflow Editor, right-click a state or transition that uses the data or message. Select **Add to Watch Window** and choose the variable name from the drop-down list.

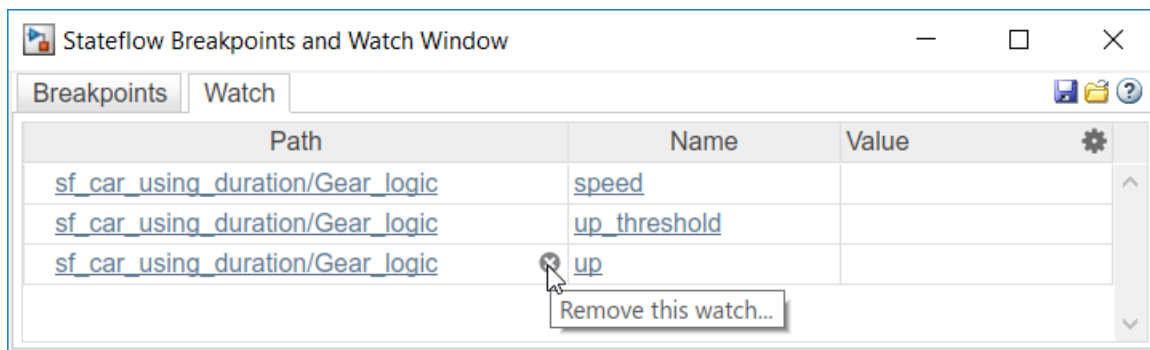
### Format Watch Display

To change the format used to display watch data, select the gear icon  at the top of the window. Use the drop-down lists to choose a MATLAB format for each data type.



### Remove Data from the Watch List

To remove a data or message object from the watch list, point to the path for the watch data and click the **Remove this watch** icon that appears to the left of the variable name.



### Save and Restore Watch Data

Watch data persists during a MATLAB session. When you close a model, its watch data list remains in the Breakpoints and Watch Window. If you reopen a model during the same MATLAB session, the watch data list for that model is restored.

You can save the breakpoint and watch data lists and reload them in a later MATLAB session. To save a snapshot of the breakpoint and watch data lists, at the top of the Breakpoints and Watch Window, click the **Save current breakpoints and watches** icon. To restore a snapshot, click the **Load breakpoints and watches** icon.

### View and Modify Data in the MATLAB Command Window

While the simulation is paused at a breakpoint, the MATLAB command prompt changes to `debug>>`. At this prompt, you can inspect and change the values of Stateflow data, send local and output messages, and interact with the MATLAB workspace.

For example, suppose that the previous chart has reached a breakpoint. To view the data that is visible at the current scope, use the `whos` command.

whos

Name	Size	Bytes	Class	Attributes
TWAIT	1x1	1	uint8	
down	1x1	1	logical	
down_th	1x1	8	double	
down_threshold	1x1	8	double	
gear	1x1	4	gearType	
speed	1x1	8	double	
throttle	1x1	8	double	
up	1x1	1	logical	
up_th	1x1	8	double	
up_threshold	1x1	8	double	

To inspect the values of `speed` and `up_threshold`, enter:

```
speed
```

```
speed =
```

```
    26.3383
```

```
up_threshold
```

```
up_threshold =
```

```
    41.3601
```

### Modify Data by Using the Debugging Prompt

At the debugging prompt, you can change the value of data store memory, local, and output data. For example, in the previous chart, you can change the value of `up_threshold`, `up`, and `gear`:

```
up_threshold = 25;
```

```
up = true;
```

```
gear = gearType.third;
```

Follow these rules when modifying data at the debugging prompt.

- To modify vectors and matrices, use MATLAB syntax for indexing, regardless of the action language property of your chart. See “Indexing Notation” on page 21-4.

For example, to change the element in the diagonal of a 2-by-2 matrix `u`, enter:

```
u(1,1) = 6.022e23;
u(2,2) = 6.626e-34
```

- You can change the dimensions of variable-size data as long as the new size is within the dimension bounds specified for the data. For example, suppose that `v` is a variable-size array with a maximum size of [16 16]. To change the value of `v` to a 5-by-7 array of ones, enter:

```
v = ones(5,7);
```

- To modify enumerated data, explicitly specify the enumerated type by using prefixed identifiers. See “Notation for Enumerated Values” on page 23-3.

For example, suppose that `w` has an enumerated data type `Colors`. To change the value of `w` to the enumerated value `Red`, enter:

```
w = Colors.Red
```

- To modify numerical data, cast to an explicit data type by using a MATLAB type conversion function. Explicit casting is not required for data of a type `double`. See “Type Cast Operations” on page 16-8.

For example, suppose that `x` has type `single`, `y` has type `int32`, and `z` has type `fixdt(1,16,12)`. To change the value of these data objects, enter:

```
x = single(98.6);
y = int32(100);
z = fi(0.5413,1,16,12);
```

- You cannot change the values of constants, parameters, or input data at the debugging prompt.

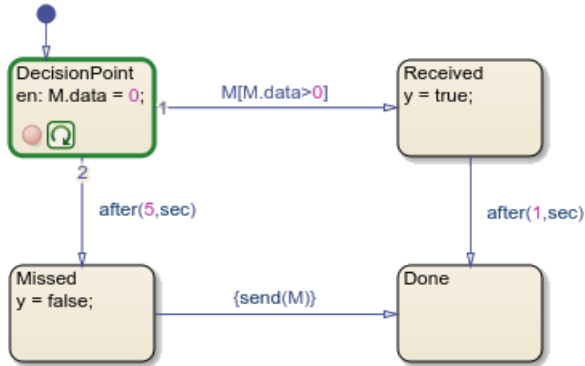
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**Note** To modify data of type `int64` or `uint64`, use the function `fi` to cast the new value to a fixed-point type.

---

### Send Messages by Using the Debugging Prompt

At the debugging prompt, you can send local and output messages. For example, in this chart, the local message `M` determines which state becomes active after the state `DecisionPoint`. If the chart receives the message `M` with a positive value, the state `Received` becomes active and the chart outputs a value of `true`. Otherwise, the state `Missed` becomes active and the chart outputs a value of `false`.



The initial value of the message is zero. To change the value of the data field to a positive number and send the message to its local queue, enter:

```
M = 5;
send(M);
```

When you advance to the next step of the simulation, the message triggers the transition to the state `Received`. For more information, see “Control Chart Execution After a Breakpoint” on page 33-16.

Follow these rules when sending messages from the debugging prompt:

- To read or write to the message data field of a valid message, use the name of the message object. Do not use dot notation syntax.
- You can send a message from the debugging prompt only when the chart explicitly sends the message by calling the `send` operator.

- You cannot send input messages from the debugging prompt.

For more information, see “Control Message Activity in Stateflow Charts” on page 15-9.

### Access the MATLAB Workspace While Debugging

You can enter other MATLAB commands at the debugging prompt, but the results are executed in the Stateflow workspace. For example, you can save all of the chart variables in a MAT-file by using the `save` function:

```
save(chartVars)
```

To enter a command in the MATLAB base workspace, use the `evalin` command with the first argument `'base'`. For example, to list the variables in the MATLAB workspace, use the command:

```
evalin('base','whos')
```

### See Also

`evalin` | `save` | `send` | `whos`

### More About

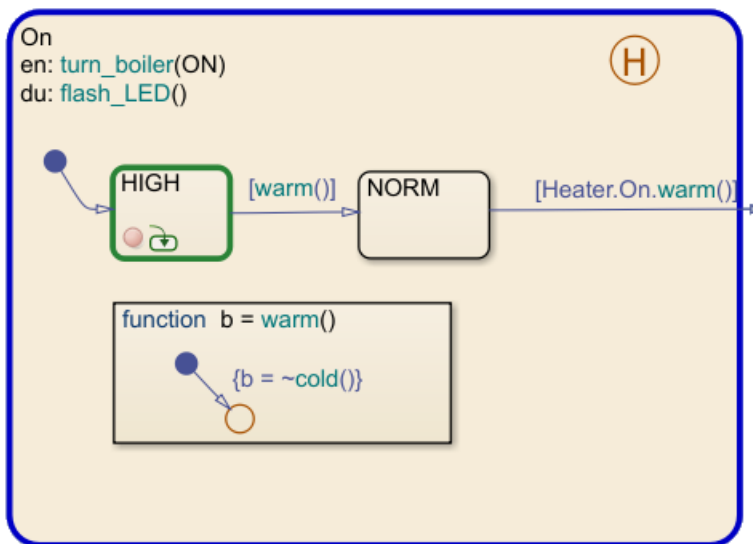
- “Debugging Stateflow Charts” on page 33-2
- “Set Breakpoints to Debug Charts” on page 33-3
- “Control Chart Execution After a Breakpoint” on page 33-16
- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2

## Control Chart Execution After a Breakpoint

When the simulation of a Stateflow chart pauses at a breakpoint, the chart enters debugging mode. You can examine the state of the chart and step through the simulation. For more information, see “Debugging Stateflow Charts” on page 33-2.

### Examine the State of the Chart

When a Stateflow chart enters debugging mode, the editor highlights the active elements in blue and the currently executing object in green. For example, this chart is paused at an entry breakpoint in the HIGH state. The active state (On) is highlighted in blue and the currently executing substate (HIGH) is highlighted in green.



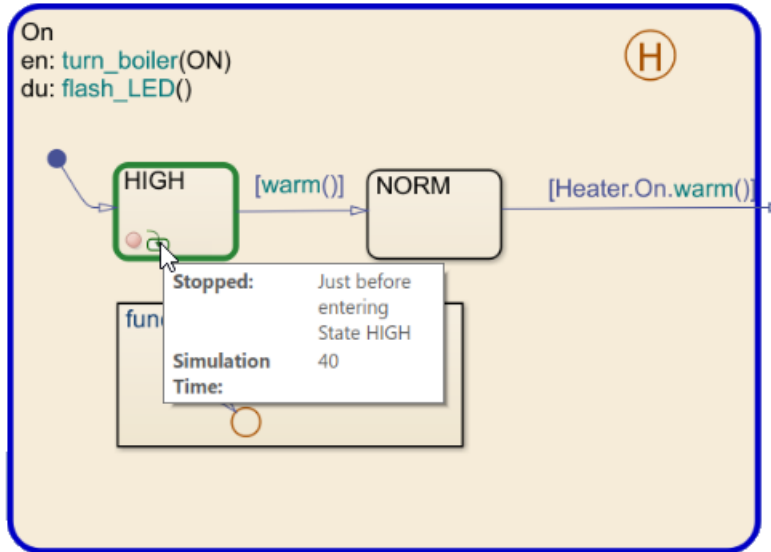
An execution status badge appears in the graphical object where the simulation is paused.

Badge	Description
	Simulation is paused before entering a chart or in a state entry action.
	Simulation is paused in a state during action, graphical function, or truth table function.
	Simulation is paused in a state exit action.
	Simulation is paused before testing a transition.
	Simulation is paused before taking a valid transition.

To see the execution status, point to the badge. A tooltip indicates:

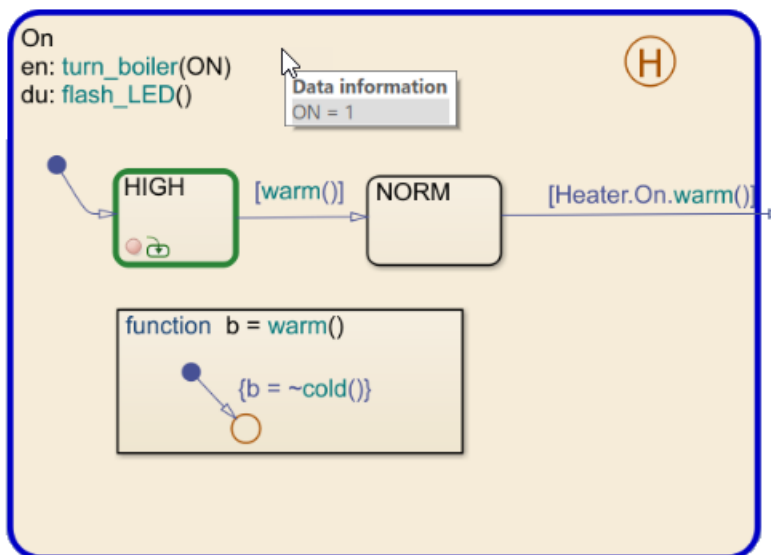
- Where the simulation is paused
- The simulation time
- The current event (if the simulation is paused during a local or input event)





To view the values of chart, point to a chart object. A tooltip displays:

- The values of the data and messages that the selected object uses
- Temporal information (if the object contains a temporal logic operator)



For more information, see “Inspect and Modify Data and Messages While Debugging” on page 33-9.


## Step Through the Simulation

When the chart is paused at a breakpoint, you can continue the simulation by using:

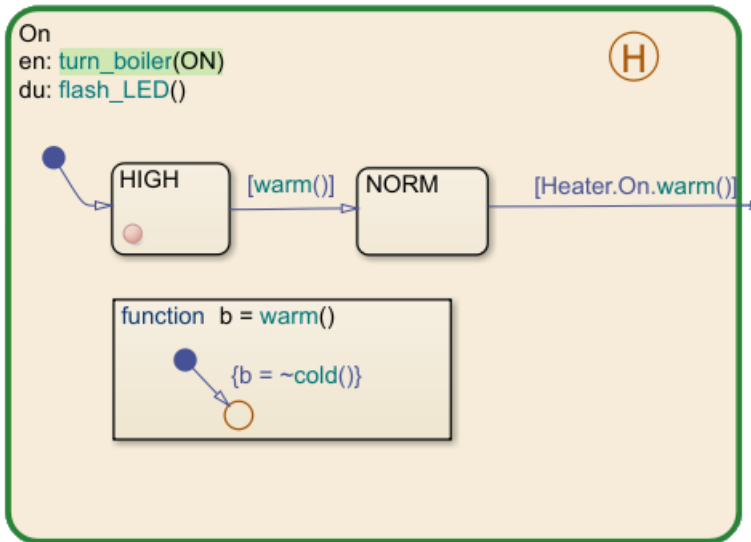
- Buttons in the **Debug** tab
- The MATLAB Command Window

- Keyboard shortcuts

Action	Debug Tab Button	MATLAB Command	Keyboard Shortcut	Description
<b>Continue</b>		dbcont	<b>Ctrl+T</b>	Continue simulation to the next breakpoint.
<b>Step Forward</b>				Exit debug mode and pause simulation before next time step.
<b>Step Over</b>		dbstep	<b>F10</b>	Advance to the next step in the chart execution. At the chart level, possible steps include: <ul style="list-style-type: none"> <li>• Enter the chart</li> <li>• Test a transition</li> <li>• Execute a transition action</li> <li>• Activate a state</li> <li>• Execute a state action</li> </ul> For more information, see “Execution of a Stateflow Chart” on page 3-23.
<b>Step In</b>		dbstep in	<b>F11</b>	From a state or transition action that calls a function, advance to the first executable statement in the function.  From a statement in a function containing another function call, advance to the first executable statement in the second function.  Otherwise, advance to the next step in the chart execution. (See <b>Step Over</b> .)
<b>Step Out</b>		dbstep out	<b>Shift+F11</b>	From a function call, return to the statement calling the function.  Otherwise, continue simulation to the next breakpoint. (See <b>Continue</b> .)
<b>Run to Cursor</b>				In state or transition actions containing more than one statement, execute a group of statements together.

Action	Debug Tab Button	MATLAB Command	Keyboard Shortcut	Description
Stop		dbquit	Ctrl+Shift+T	Exit debug mode and stop simulation.

In state or transition actions that contain more than one statement, you can step through the individual statements one at a time by selecting **Step Over**. The Stateflow Editor highlights each statement before executing it.



To execute a group of statements together, click the last statement in the group and select **Run to Cursor**.

## See Also

### More About

- “Debugging Stateflow Charts” on page 33-2
- “Set Breakpoints to Debug Charts” on page 33-3
- “Inspect and Modify Data and Messages While Debugging” on page 33-9
- “Debug Run-Time Errors in a Chart” on page 33-20

## Debug Run-Time Errors in a Chart

### In this section...

“Create the Model and the Stateflow Chart” on page 33-20

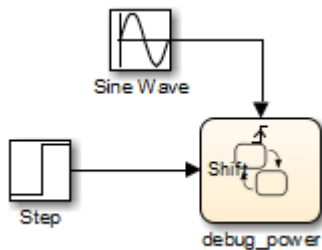
“Debug the Stateflow Chart” on page 33-21

“Correct the Run-Time Error” on page 33-21

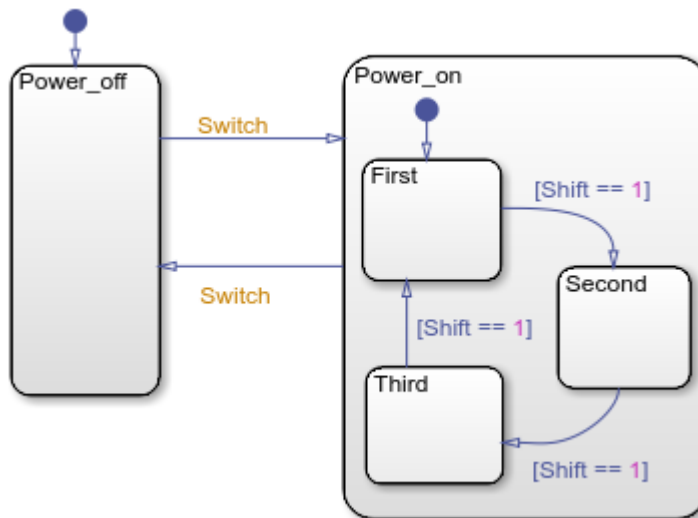
### Create the Model and the Stateflow Chart

In this topic, you create a Simulink model with a Stateflow chart to debug. Follow these steps:

- 1 Create the following Simulink model:



- 2 Add the following states and transitions to your chart:



- 3 In your chart, add an event **Switch** with a scope of **Input from Simulink** and a **Rising** edge trigger.
- 4 Add a data **Shift** with a scope of **Input from Simulink**.

The chart has two states at the highest level in the hierarchy, **Power\_off** and **Power\_on**. By default, **Power\_off** is active. The event **Switch** toggles the system between the **Power\_off** and **Power\_on** states. **Power\_on** has three substates: **First**, **Second**, and **Third**. By default, when **Power\_on** becomes active, **First** also becomes active. When **Shift** equals 1, the system transitions from

First to Second, Second to Third, Third to First, for each occurrence of the event `Switch`, and then the pattern repeats.

In the model, there is an event input and a data input. A Sine Wave block generates a repeating input event that corresponds with the Stateflow event `Switch`. The Step block generates a repeating pattern of 1 and 0 that corresponds with the Stateflow data object `Shift`. Ideally, the `Switch` event occurs at a frequency that allows at least one cycle through `First`, `Second`, and `Third`.

## Debug the Stateflow Chart

To debug the chart in “Create the Model and the Stateflow Chart” on page 33-20, follow these steps:

- 1 Right-click in the chart, and select **Set Breakpoint on Chart Entry**.
- 2 Start the simulation.

Because you specified a breakpoint on chart entry, execution stops at that point.

- 3 Click the Step In button, .

The Step In button executes the next step and stops.

- 4 Continue clicking the Step In button and watching the animating chart.

After each step, watch the chart animation to see the sequence of execution.

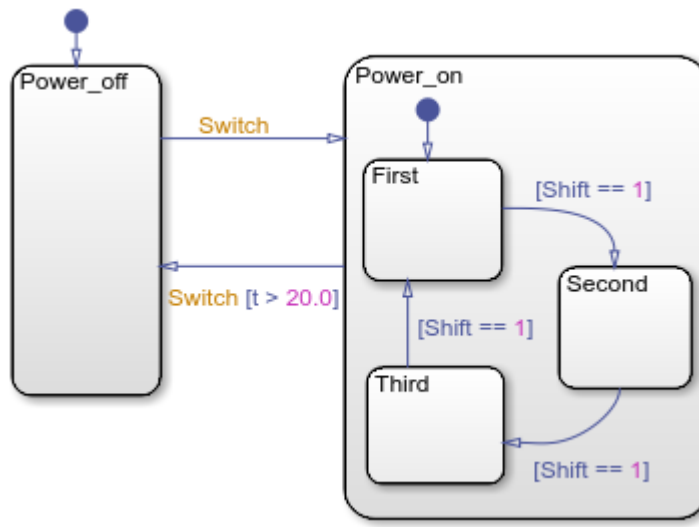
Single-stepping shows that the chart does not exhibit the desired behavior. The transitions from `First` to `Second` to `Third` inside the state `Power_on` are not occurring because the transition from `Power_on` to `Power_off` takes priority. The output display of code coverage also confirms this observation.

## Correct the Run-Time Error

In “Debug the Stateflow Chart” on page 33-21, you step through a simulation of a chart and find an error: the event `Switch` drives the simulation but the simulation time passes too quickly for the input data object `Shift` to have an effect.

Correct this error as follows:

- 1 Stop the simulation so that you can edit the chart.
- 2 Add the condition `[ t > 20.0 ]` to the transition from `Power_on` to `Power_off`.



Now the transition from **Power\_on** to **Power\_off** does not occur until simulation time is greater than 20.0.

- 3 Begin simulation again.
- 4 Click the Step In button repeatedly to observe the new behavior.

# Animate Stateflow Charts

## Set Animation Speeds


During simulation, animation provides visual verification that your chart behaves as you expect. Animation highlights active objects in a chart as execution progresses. For charts in a Simulink model, you can control the speed of chart animation during simulation, or turn off animation. In the Stateflow Editor, in the **Debug** tab, under **Animation Speed**:

- Lightning Fast
- Fast
- Medium
- Slow
- None


**Lightning Fast** animation provides the fastest simulation speed by buffering the highlights. During **Lightning Fast** animation, the more recently highlighted objects are in a bolder, lighter blue. These highlights fade away as simulation time progresses.

The default animation speed, **Fast**, shows the active highlights at each time step. To add a delay with each time step, set the animation speed to **Medium** or **Slow**.

## Maintain Highlighting

To maintain highlighting of active states in the chart after simulation ends, in the **Debug** tab, select **Maintain highlighting of active states after simulation ends** .

## Disable Animation

Animation is enabled by default in Stateflow charts. To turn off animation for a chart, in the **Debug** tab, select **Remove animation highlighting** .

## Animate Charts as Generated Code Executes on a Target System

If you have Simulink Coder, you can use external mode to establish communication between a Simulink model and generated code downloaded to and executing on a target system. Stateflow software can use the external mode communication channel to animate chart states. Also, you can designate chart data of local scope to be test points and view the test point data in floating scopes and signal viewers.

For more information, see:

- “External Mode Simulation by Using XCP Communication” (Simulink Coder)
- “External Mode Simulation with TCP/IP or Serial Communication” (Simulink Coder)

## Detect Modeling Errors During Edit Time

When edit-time checking is enabled, the Stateflow Editor detects potential errors and warnings as you work on your chart. By fixing these issues early in the design process, you can avoid compile-time or run-time warnings and errors.

The Stateflow editor highlights objects that violate the edit-time checks in red (for errors) or orange (for warnings). When you point to an object that is highlighted and click the error or warning badge, a tooltip displays details and possible fixes.

### Manage Edit-Time Checks

By default, edit-time checking and syntax error highlighting are enabled. To disable the edit-time checks, in the **Debug** tab, clear the **Diagnostics > Edit-Time Errors & Warnings** check box.

This table lists edit-time checks that have an associated diagnostic configuration parameter on the **Diagnostics > Stateflow** pane of the Configuration Parameters dialog box.

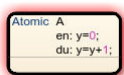
Edit-Time Check Issue	Diagnostic Configuration Parameter
"Dangling Transition" on page 33-26	"Unreachable execution path" (Simulink)
"Default Transition Path Does Not Terminate in a State" on page 33-27	"No unconditional default transitions" (Simulink)
"Transition Action Precedes a Condition Action Along This Path" on page 33-27	"Transition action specified before condition action" (Simulink)
"Transition Loops Outside Natural Parent" on page 33-29	"Transition outside natural parent" (Simulink)
"Transition Shadowing" on page 33-29	"Unreachable execution path" (Simulink)
"Unconditional Path Out of State with During Actions or Child States" on page 33-29	"Transition outside natural parent" (Simulink)
"Unexpected Backtracking" on page 33-31	"Unexpected backtracking" (Simulink)
"Unreachable Junction" on page 33-31	"Unreachable execution path" (Simulink)

You can control the level of diagnostic action for these edit-time checks by setting the value of their configuration parameter to **error**, **warning**, or **none**. When you change the setting for a configuration parameter, the diagnostic level for the corresponding edit-time checks also changes. For example, if you set the **Unreachable execution path** configuration parameter to **none**, then the Stateflow Editor does not highlight dangling transitions, transition shadowing, or unreachable states.

### Edit-Time Checks on States and Subcharts

#### Atomic Subchart Contains State Actions

- **Issue:** State actions are not supported on atomic subcharts.
- **Diagnostic level:** Error.
- **Solution:** Delete the state actions or move them to a substate of the atomic subchart.





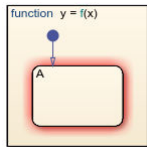
### Default Transition Is Missing

- **Issue:** In a chart or state with exclusive (OR) decomposition and at least two substates or junctions, a default transition is required to indicate where the execution begins.
- **Diagnostic level:** Error.
- **Solution:** Specify an initial state by adding a default transition. For more information, see “Default Transitions” on page 2-33.



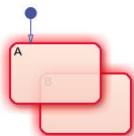
### Graphical Function Contains a State

- **Issue:** Because graphical functions execute completely in a single time step, they must not contain any states.
- **Diagnostic level:** Error.
- **Solution:** Replace the states with junctions. For more information, see “Reuse Logic Patterns by Defining Graphical Functions” on page 8-18.



### Invalid Intersection

- **Issue:** States and junctions must not overlap in the Stateflow Editor.
- **Diagnostic level:** Error.
- **Solution:** Avoid intersections by separating the states and junctions.



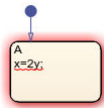
### Monitoring Leaf or Child State Activity of Parallel States

- **Issue:** Charts and states with parallel (AND) decomposition do not support monitoring of leaf or child state activity because parallel substates are active simultaneously.
- **Diagnostic level:** Warning.
- **Solution:** Open the Property Inspector or the Model Explorer. Clear the **Create output for monitoring** check box or select **Self** activity from the drop-down list. For more information, see “Monitor State Activity Through Active State Data” on page 13-2.



### State Contains a Syntax Error

- **Issue:** A state action does not follow the Stateflow syntax rules. The Stateflow Editor underlines syntax errors with a red, wavy line. See also [Transition Contains a Syntax Error](#) on page 33-27.
- **Diagnostic level:** Error.
- **Solution:** Correct the syntax error in the state action. For more information, see “State Labels” on page 2-10.




---

**Note** In the parent chart, subcharts with syntax errors are highlighted in red and an error badge indicates the syntax issue. In the subchart editor, the syntax error is underlined in red, but there is no badge to indicate the issue.

---

### Unreachable State

- **Issue:** A state is unreachable when no valid execution path leads to it.
- **Diagnostic level:** Depends on the configuration parameter “Unreachable execution path” (Simulink).
- **Solution:** Connect the unreachable state with a transition from a reachable state or junction.



## Edit-Time Checks on Transitions

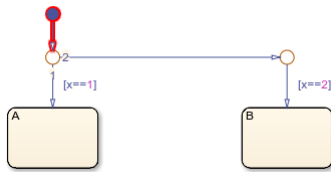
### Dangling Transition

- **Issue:** Every transition must have a valid destination state or junction.
- **Diagnostic level:** Depends on the configuration parameter “Unreachable execution path” (Simulink).
- **Solution:** Connect the transition to a state or junction. For more information, see “Transitions” on page 2-21.



### Default Transition Path Does Not Terminate in a State

- **Issue:** In charts or states with exclusive (OR) decomposition and at least one substate:
  - Every path along the default transition must lead to a substate.
  - There must be one default transition path that is not guarded by a condition or triggered by an event.
- **Diagnostic level:** Depends on the configuration parameter “No unconditional default transitions” (Simulink).
- **Solution:** Terminate every path along the default transition in a substate. Ensure that one default transition path is not guarded by a condition or triggered by an event.



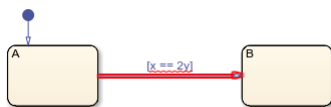
### Invalid Default Transition Path

- **Issue:** A default transition path must not exit the parent state.
- **Diagnostic level:** Error.
- **Solution:** Modify the default transition path so it stays within the parent state.



### Transition Contains a Syntax Error

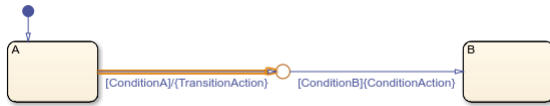
- **Issue:** In a transition, a condition or action does not follow the Stateflow syntax rules. The Stateflow Editor underlines syntax errors with a red, wavy line. See also [State Contains a Syntax Error](#), on page 33-26.
- **Diagnostic level:** Error.
- **Solution:** Correct the syntax error in the transition condition or action. For more information, see “Transition Labels” on page 2-22.



### Transition Action Precedes a Condition Action Along This Path

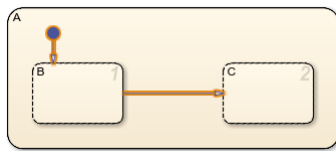
- **Issue:** When a transition with a transition action is followed by a transition with a condition action, the actions are not executed in the order of the transitions. Stateflow charts execute condition actions when the associated condition is evaluated as true. In contrast, charts execute transition actions only when the transition path is fully executed. As a consequence, a chart takes a transition path, the condition actions occur before the transition actions.

- **Diagnostic level:** Depends on the configuration parameter “Transition action specified before condition action” (Simulink).
- **Solution:** Place the transition action after the last condition action on the path.



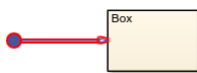
### Transition Begins or Ends in a Parallel State

- **Issue:** In charts and states with parallel (AND) decomposition, all sibling substates are active or inactive at the same time.
- **Diagnostic level:** Warning.
- **Solution:** Remove the transitions or change the decomposition of the parent state to exclusive (OR).



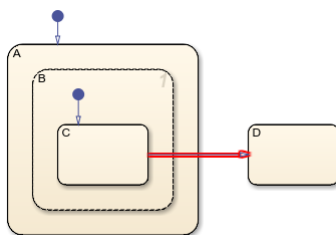
### Transition Connects to a Box

- **Issue:** Transitions can only connect to states and junctions.
- **Diagnostic level:** Error.
- **Solution:** Move or delete the transitions attached to the box.



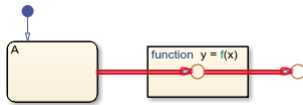
### Transition Crosses Parallel States

- **Issue:** Standalone Stateflow charts do not support transitions that cross the boundary of a parallel state.
- **Diagnostic level:** Error.
- **Solution:** Delete the transition crossing into or out of the parallel states.



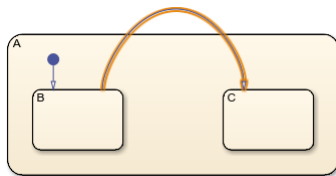
### Transition Enters or Exits Graphical Function

- **Issue:** Transitions must not enter or exit a graphical function. Flow charts in graphical functions must be completely contained inside the function.
- **Diagnostic level:** Error.
- **Solution:** Delete the transition entering or exiting the graphical function.



### Transition Loops Outside Natural Parent

- **Issue:** If a transition goes outside the parent state between the source and destination, the chart executes the exit and entry actions of the parent state before the destination state becomes active.
- **Diagnostic level:** Depends on the configuration parameter “Transition outside natural parent” (Simulink).
- **Solution:** Move the transition so that it is contained within the parent state.



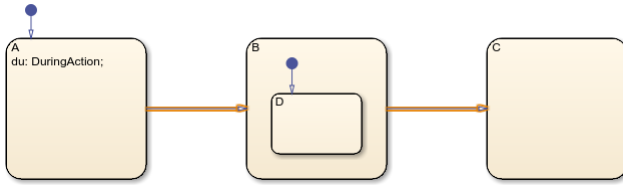
### Transition Shadowing

- **Issue:** When an unconditional transition executes before other outgoing transitions from the same source, it prevents the other transitions from executing.
- **Diagnostic level:** Depends on the configuration parameter “Unreachable execution path” (Simulink).
- **Solution:** Create no more than one unconditional transition from each state or junction. Explicitly specify that the unconditional transition executes after any transitions with conditions. For more information, see “Transition Evaluation Order” on page 3-38.



### Unconditional Path Out of State with During Actions or Child States

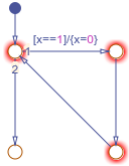
- **Issue:** Unconditional transitions leading out of a state inhibit the execution of the during actions in the state and the default transitions to child states.
- **Diagnostic level:** Depends on the configuration parameter “Transition outside natural parent” (Simulink).
- **Solution:** Add a condition to the transition or remove during actions and child states from the state.



## Edit-Time Checks on Junctions

### Cycle Contains Transitions with Transition Actions

- **Issue:** Cycles should not contain transitions with transition actions.
- **Diagnostic level:** Error.
- **Solution:** Remove the transition action or remove the cycle by deleting a transition.



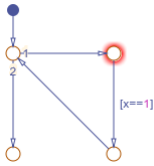
### Invalid History Junction

- **Issue:** A history junction is invalid when:
  - The history junction is contained in the chart level of the hierarchy.
  - The history junction is contained in a state with parallel (AND) decomposition.
  - The history junction is contained inside a graphical function.
  - There are multiple history junctions contained in the same state.
  - The history junction is the source of a transition.
- **Diagnostic level:** Error.
- **Solution:** Remove the history junction from the chart level of the hierarchy, a state with parallel (AND) decomposition, or a graphical function. Remove all but one history junction from the state. Move the transition source to a connective junction or a state. For more information, see “Record State Activity by Using History Junctions” on page 8-2.



### Junction Has No Unconditional Escape from Cycle

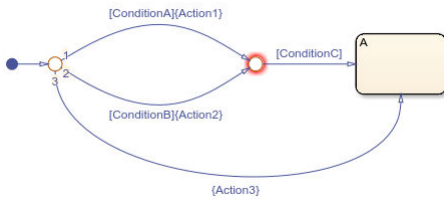
- **Issue:** A junction must have an unconditional escape path from a cycle to a state or terminating junction.
- **Diagnostic level:** Error.
- **Solution:** Create an unconditional path from the junction to a state or terminating junction.



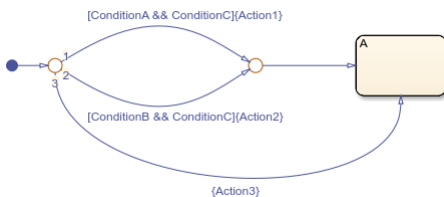
### Unexpected Backtracking

- **Issue:** Unexpected backtracking of control flow can occur when multiple transition paths from the same source lead to a junction and the junction does not have an unconditional path to a state or terminating junction.
- **Diagnostic level:** Depends on the configuration parameter “Unexpected backtracking” (Simulink).
- **Solution:** Create an unconditional path from the junction to a state or terminating junction. For more information, see “Backtrack in Flow Charts” on page B-30.

For example, the highlighted junction in this chart does not have an unconditional transition path to state A. If `ConditionA` and `ConditionB` are true and `ConditionC` is false, the chart backtracks to the first junction in the path multiple times. As a result, the chart executes the three condition actions.

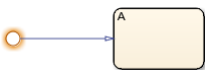


To avoid backtracking, combine the conditions and create an unconditional path from the second junction to the destination state. After the change, the chart executes only one condition action.



### Unreachable Junction

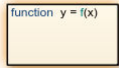
- **Issue:** A junction is unreachable when no valid execution path leads to it.
- **Diagnostic level:** Depends on the configuration parameter “Unreachable execution path” (Simulink).
- **Solution:** Connect the unreachable junction with a transition from a reachable state or junction.



## Edit-Time Checks on Functions

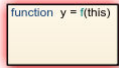
### Function is Unused

- **Issue:** A function is unused when a chart when there are no statements that call the function.
- **Diagnostic level:** Warning.
- **Solution:** Call the function from a state or transition action or from another function.



### Invalid Use of Keywords as Function Arguments

- **Issue:** A function definition uses a reserved keyword as an argument.
- **Diagnostic level:** Error.
- **Solution:** Rename the argument to the function. For a list of reserved keywords, see “Guidelines for Naming Stateflow Objects” on page 2-5.



## See Also

### More About

- “Detect Common Modeling Errors During Chart Simulation” on page 33-33
- “Modeling Guidelines for Stateflow Charts” on page 3-19
- “Stateflow Semantics” on page 3-2
- “Model Configuration Parameters: Stateflow Diagnostics” (Simulink)



## Detect Common Modeling Errors During Chart Simulation

To avoid common design errors, you can run diagnostic checks that test the completeness of your Stateflow chart during compilation and simulation. Stateflow diagnostics detect state inconsistencies, violations in data ranges, and cyclic behavior in Stateflow charts in Simulink models.

When you simulate a model, the Stateflow parser evaluates the graphical and nongraphical objects and data in each Stateflow machine against the supported chart notation and the action language syntax. You can also check the syntax of your chart by selecting **Update Chart** in the **Modeling** tab of the Stateflow Toolstrip.

If syntax errors exist in your chart, the chart automatically appears with the highlighted object that causes the first error. You can select the error in the diagnostic window to bring its source chart to the front with the source object highlighted. Any unresolved data or events in the chart are flagged in the Symbol Wizard.

### State Inconsistencies

In a Stateflow chart, states are inconsistent if they violate one of these rules:

- An active state with exclusive (OR) decomposition and at least one substate has exactly one active substate.
- All substates of an active state with parallel (AND) decomposition are active.
- All substates of an inactive state are inactive regardless of the state decomposition.

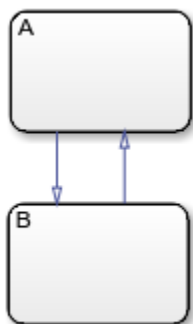
While you edit your chart, the Stateflow Editor displays potential causes for state inconsistencies by highlighting objects in red or orange. For more information, see “Detect Modeling Errors During Edit Time” on page 33-24.

### Causes of State Inconsistency

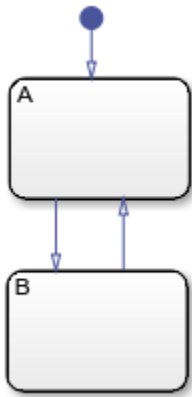
One type of state inconsistency occurs when all of these conditions are true:

- A state with multiple substates has exclusive (OR) decomposition.
- The state does not contain a history junction.
- Every default path that leads to a substate is guarded by a condition or triggered by an event.
- Not all transitions into the state are supertransitions leading directly to a substate.

For example, this chart has a state inconsistency because there is no default transition to indicate which substate becomes active first.



Adding an unconditional default transition to one of the states resolves the state inconsistency.



### Detect State Inconsistencies

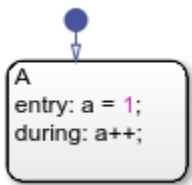
At compile time, Stateflow charts detect state inconsistencies caused by the omission of an unconditional default transition. To control the level of diagnostic action, open the Model Configuration Parameters dialog box. In the **Diagnostics > Stateflow** pane, for the diagnostic **No unconditional default transitions**, you can select error, warning, or none. The default setting is error. For more information, see “No unconditional default transitions” (Simulink).

### Data Range Violations

During simulation, a data range violation occurs when:

- An integer or fixed-point operation overflows the numeric capacity of its result type. See “Handle Integer Overflow for Chart Data” on page 12-36 and “Fixed-Point Operations in Stateflow Charts” on page 26-19.
- The value of a data object is outside the range of the values specified by the **Initial value**, **Minimum**, and **Maximum** properties. See “Initial Value” on page 12-8 and “Limit Range” on page 12-10.

For example, this chart contains local data **a** that has a **Minimum** value of 0 and a **Maximum** value of 2. The entry action in state A initializes **a** to 1. The during action increments the value of **a** by 1. After two time steps, the value of **a** exceeds its specified range, resulting in a data range violation.



### Detect Data Range Violations

At run time, Stateflow charts detect data range violations. To control the level of diagnostic action, open the Model Configuration Parameters dialog box. In the **Diagnostics > Data Validity** pane, you can select error, warning, or none for these diagnostics:

- **Simulation range checking** detects violations based on minimum-and-maximum range checks. The default setting is none.
- **Wrap on overflow** and **Saturate on overflow** detect violations that occur when integer or fixed-point operations exceed the numeric capacity of their result type. The default setting is warning.

For more information, see “Simulation range checking” (Simulink), “Wrap on overflow” (Simulink), and “Saturate on overflow” (Simulink).

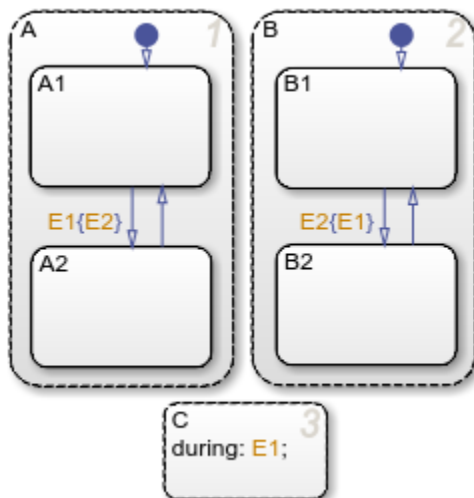
## Cyclic Behavior

Cyclic behavior occurs when a step or sequence of steps is repeated indefinitely during chart simulation.

For example, the actions in this chart produce an infinite cycle of recursive event broadcasts.

- The during action in state C broadcasts the event E1.
- The event E1 triggers the transition from state A.A1 to state A.A2. The condition action for this transition broadcasts the event E2.
- The event E2 triggers the transition from state B.B1 to state B.B2. The condition action for this transition broadcasts the event E1.

The event broadcasts in states A and B occur in condition actions, so the transitions do not take place until the chart processes the resulting events. The substates A.A1 and B.B1 remain active, so new event broadcasts continue to trigger the transitions and the process repeats indefinitely.



Because undirected local event broadcasts can cause unwanted recursive behavior, use of the **send** operator to broadcast directed local events is recommended. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

### Detect Cyclic Behavior During Simulation

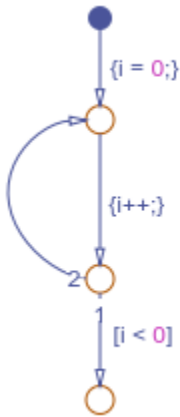
During chart simulation, Stateflow charts use cycle detection algorithms to detect a class of infinite recursions caused by event broadcasts. To enable cycle detection, open your Stateflow chart. In the **Debug** tab, select **Diagnostics > Detect Cyclical Behavior**. Cyclic behavior checking is selected by default.

Stateflow charts also detect undirected local event broadcasts. To control the level of diagnostic action, open the Model Configuration Parameters dialog box. In the **Diagnostics > Stateflow** pane, for the **Undirected event broadcasts** diagnostic, you can select **error**, **warning**, or **none**. The default setting is **warning**. For more information, see “Undirected event broadcasts” (Simulink).

### Limitations of Cyclic Behavior Detection

Stateflow cycle detection is limited to cases of recursion due to event broadcasts and does not extend to other types of cyclic behavior.

For instance, Stateflow cannot detect the infinite cycle in this flow chart. In this example, the default transition initializes the local data `i` to 0. The next transition segment increments `i`. The transition to the terminating junction is valid only when the condition `[ i < 0 ]` is true. Because this condition is never true, an infinite cycle results.



The model `sf_cycle_error_fix` provides suggestions for fixing cyclic behavior in flow charts. At the MATLAB command prompt, enter:

```
sfhelp('cycle_error');
```

### See Also

#### More About

- “Detect Modeling Errors During Edit Time” on page 33-24
- “Model Configuration Parameters: Stateflow Diagnostics” (Simulink)

## Avoid Unwanted Recursion in a Chart

Recursion can be useful for controlling substate transitions among parallel states at the same level of the chart hierarchy. For example, you can send a directed event broadcast from one parallel state to a sibling parallel state to specify a substate transition. This type of recursive behavior is desirable and efficient. For details, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

However, unwanted recursion can also occur during chart execution. To avoid unwanted recursion, do not use recursive function calls or undirected local event broadcasts.

### Recursive Function Calls

Suppose that you have functions named *f*, *g*, and *h* in a chart. These functions can be any combination of graphical functions, truth table functions, MATLAB functions, or Simulink functions.

To avoid recursive behavior, do not:

- Have *f* calling *g* calling *h* calling *f*.
- Have *f*, *g*, or *h* calling itself.

### Undirected Local Event Broadcasts

An undirected event broadcast sends a local event to all states in which it is visible. The format of an undirected event broadcast is

```
send(event_name)
```

where *event\_name* is a local event.

To avoid recursive behavior, replace undirected event broadcasts with directed event broadcasts by using the syntax

```
send(event_name, state_name)
```

where *event\_name* is a local event in the chart and *state\_name* is a destination state.

- If the local event broadcast occurs in a state action, ensure that the destination state is not an ancestor of the source state in the chart hierarchy.
- If the local event broadcast occurs in a transition, ensure that:
  - The destination state is not an ancestor of the transition in the chart hierarchy.
  - The transition does not connect to the destination state.

For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

During simulation, Stateflow charts can detect undirected local event broadcasts. To control the level of diagnostic action, open the Model Configuration Parameters dialog box. In the **Diagnostics > Stateflow** pane, for the **Undirected event broadcasts** diagnostic, you can select none, warning, or error. The default setting is warning. For more information, see “Undirected event broadcasts” (Simulink).

### See Also

send

### **More About**

- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Detect Common Modeling Errors During Chart Simulation” on page 33-33
- “Model Configuration Parameters: Stateflow Diagnostics” (Simulink)

## Monitor Test Points in Stateflow Charts

This example shows you how to specify data or states as test points that you can plot with a floating scope or log to the MATLAB® base workspace during simulation.

### About Test Points in Stateflow Charts

A Stateflow® test point is a signal that you can observe during simulation, for example, by using a Floating Scope block. You can designate states or local data with these properties as test points:

- **Size** - scalar, one-dimensional, or two-dimensional
- **Type** - any data type except `m1`
- **Location** - descendant of a Stateflow chart

You can specify individual data or states as test points by setting their **TestPoint** property via the Stateflow API, in the Property Inspector, or in the Model Explorer.

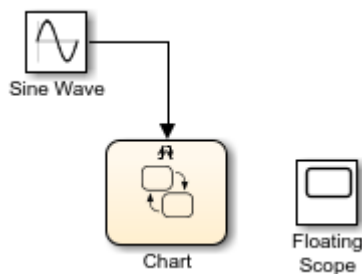
You can monitor individual Stateflow test points with a floating scope during model simulation. You can also log test point values into MATLAB workspace objects.

You can also use active state output to view or log state activity data in Simulink®. For more information, see “Monitor State Activity Through Active State Data” on page 13-2.

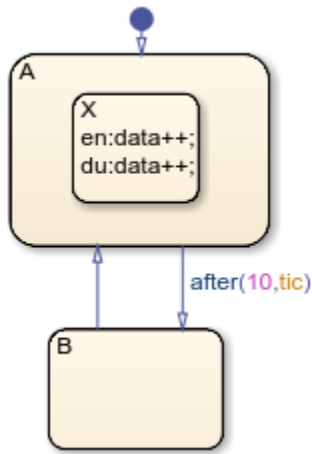
### Set Test Points for Stateflow States and Data with the Property Inspector

You can explicitly set individual states, local data, and output data as test points in the Model Explorer. The following procedure shows how to set individual test points for Stateflow states and data.

1. Open the model.



In the Stateflow chart, state A and its substate X are entered on the first `tic` event. State A and substate X stay active until 10 `tic` events have occurred, and then state B is entered. On the next event, state A and substate X are entered and the cycle continues. The data `data` belongs to substate X. The entry and during actions for substate X increment `data` while X is active for 10 `tic` events. When state B is entered, `data` reinitializes to zero, and then the cycle repeats.

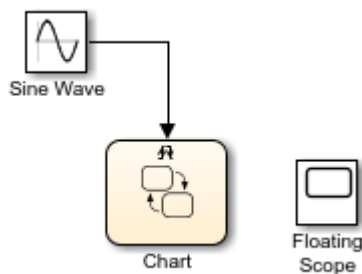


2. Open the Property Inspector. In the **Modeling** tab, click **Property Inspector**.
  3. Select state A. Then, in the **Logging** section of the Property Inspector, select **Test Point**.
  4. Repeat this for state X and B.
  5. Open the Symbol viewer. In the **Modeling** tab, click **Symbols Pane**.
  6. Select the data data. Then, in the **Logging** section of the Property Inspector, select **Test Point**.
- You can also log these test points. For instructions, see “Log Multiple Signals” on page 33-44.

### Monitor Data Values and State Self Activity Using a Floating Scope

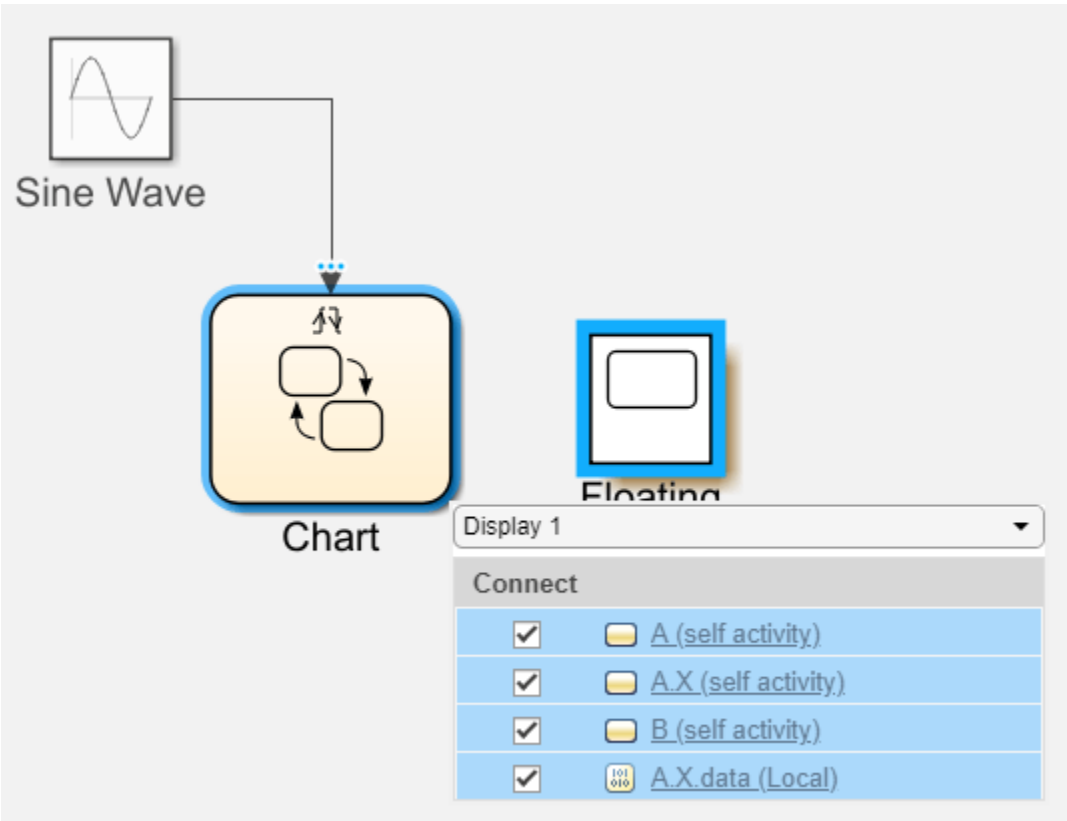
In this section, you configure a Floating Scope block to monitor a data value and the self activity of a state.

1. Open the model.

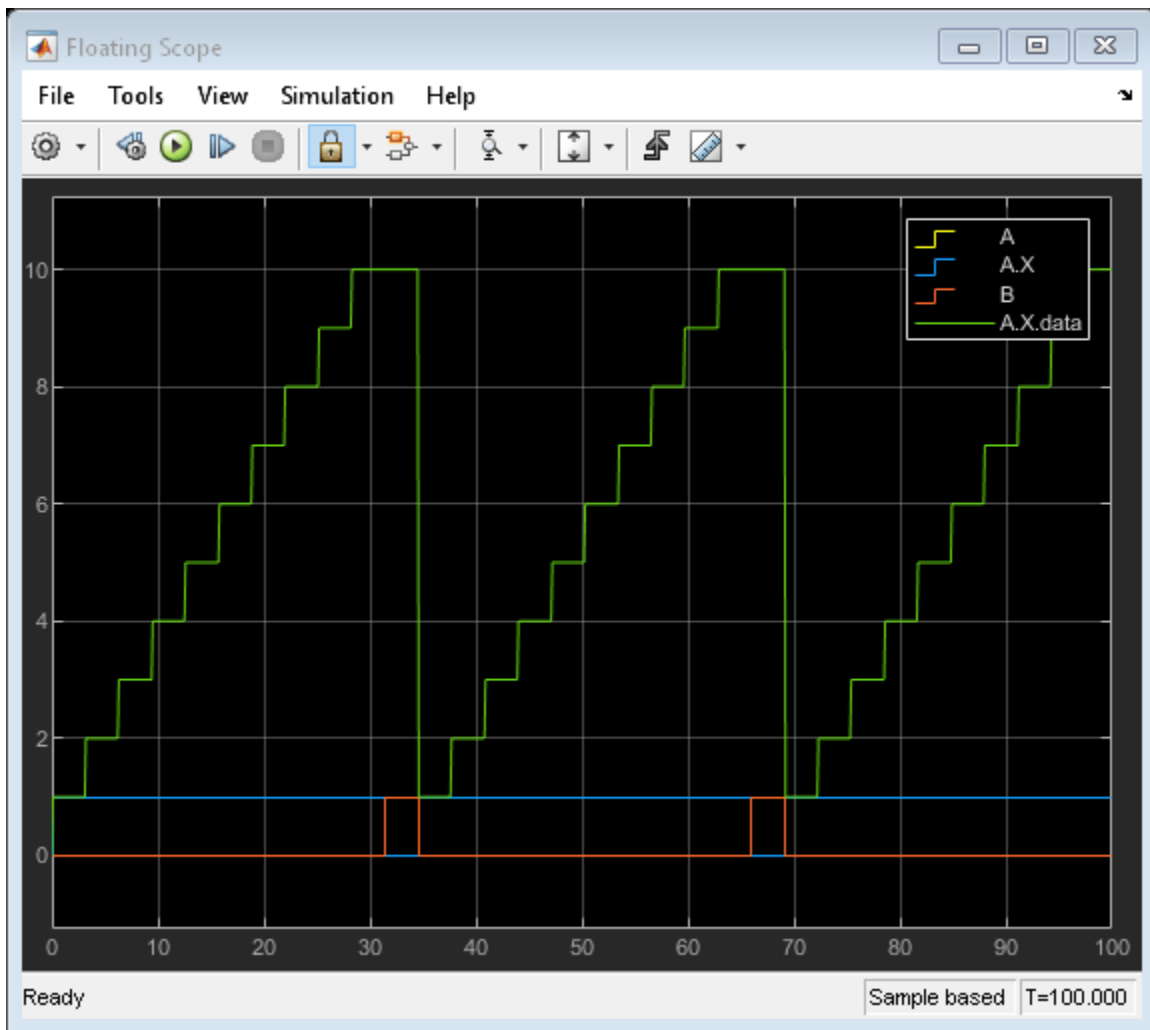


2. Double-click the Floating Scope block.
3. In the Floating Scope window, select **Simulation > Signal Selector**. The Simulink canvas changes to selection mode.
4. From the canvas, select the chart. In the Connect pop-up window, select the signals.
5. To exit selection mode, click the **X** in the upper-right corner of the canvas.





5. Simulate the model.



When state A.X is active, the signal value is 1. When that state is inactive, the signal value is 0. Because this value can be very low or high compared to other data, you might want to add a second Floating Scope block to compare the activity signal with other data.

## See Also

## More About

- “Configure Signals as Test Points” (Simulink)

## Log Simulation Output for States and Data

When you simulate a Stateflow chart in a Simulink model, you can log values for local, output, and active state data into a `Simulink.SimulationData.Dataset` object. After simulation, you can access this object through the Simulation Data Inspector, the Logic Analyzer, or in the MATLAB workspace. The workflow for logging data is:

- 1 Enable signal logging for the chart and choose a logging format. See “Enable Signal Logging” on page 33-43.
- 2 Configure states and data for signal logging. See “Configure States and Data for Logging” on page 33-43.
- 3 Simulate the chart.
- 4 Access the logged data. See “Access Signal Logging Data” on page 33-46.

### Enable Signal Logging

Signal logging is enabled by default for models and charts. To disable or reenable signal logging:

- 1 Open the Model Configuration Parameters dialog box.
- 2 Select **Data Import/Export**.
- 3 In the **Signals** pane, select the **Signal logging** check box to enable logging for the chart. To disable logging, clear the check box.
- 4 (Optional) Specify a custom name for the signal logging object. The default name is `logout`. Using this object, you can access the logging data in a MATLAB workspace variable. For more information, see “Export Signal Data Using Signal Logging” (Simulink).
- 5 (Optional) In the **Format** field, select a signal logging format. Options include:
  - Array
  - Structure
  - Structure with time
  - Dataset

The default setting is `Dataset`. For more information, see “Time, State, and Output Data Format” (Simulink).

- 6 Click **OK**.

### Configure States and Data for Logging

You can set logging properties for states, local data, and output data from inside the chart, through the Stateflow Signal Logging dialog box, or programmatically from the command line.

#### Log Individual States and Data

Configure logging properties for one state or data object at a time through the Property Inspector, the Model Explorer, or the properties dialog box for the state or data object. Select the **Logging** tab and modify properties as needed. For more information, see “Logging Properties” on page 12-16.


For example, in the `sf_semantics_hotel_checkin` model:

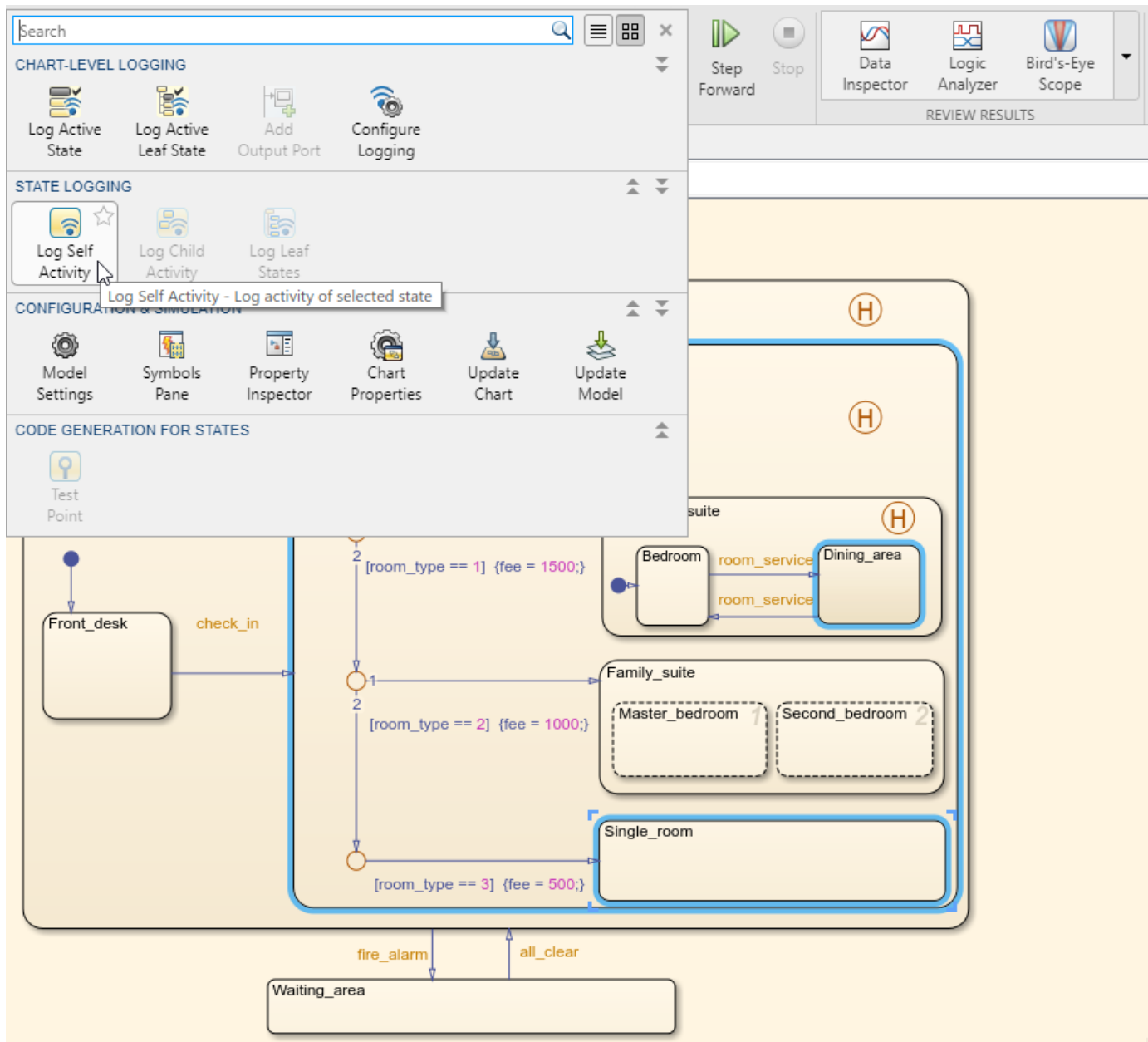
- 1 Open the Hotel chart.
- 2 Open the Symbols pane. In the **Simulation** tab, in **Prepare**, click **Symbols Pane**.
- 3 Open the Property Inspector. In the **Simulation** tab, in **Prepare**, click **Property Inspector**.
- 4 Configure the service local data for logging.
  - a In the Symbols pane, select service.
  - b In the Property Inspector, under **Logging**, select the **Log signal data** check box.
- 5 Configure the Dining\_area state for logging.
  - a On the Stateflow Editor, select the Dining\_area state.
  - b In the **Simulation** tab, in **Prepare**, select **Log Self Activity**. Alternatively, in the Property Inspector, under **Logging**, select the **Log self activity** check box.
  - c By default, the logging name for this state is the hierarchical signal name Check\_in.Checked\_in.Executive\_suite.Dining\_area. To assign a shorter name to the state, set **Logging Name** to Custom and enter Dining Room.

### Log Multiple Signals

Configure logging properties for multiple states and data objects through the Stateflow Signal Logging dialog box. Select which chart objects to log from a list of all states, local, and output data. For more information, see “Logging Properties” on page 12-16.

For example, in the sf\_semantics\_hotel\_checkin model:

- 1 Open the Hotel chart.
- 2 To log multiple signals, press and hold shift to select the states for logging. In the **Simulation** tab, under **Prepare**, select **Log Self Activity**.
- 3 The logging badge  marks logged signals in the model.



### Add an Output Port

You can add an output port to monitor chart activity. From the Stateflow Editor, in the **Simulation** tab, click **Add Output Port**. A new port appears on your Stateflow chart. Connect this port to a viewer to monitor the chart child activity.

### Log Chart Signals by Using the Command-Line API

Configure logging properties for states and data objects programmatically from the command line. To enable logging for a states or data object, get a handle for the object and set its `LoggingInfo.DataLogging` property to 1. For more information on the Stateflow Programmatic Interface, see “Overview of the Stateflow API”.

For example, in the `sf_semantics_hotel_checkin` model:

- 1 Open the Hotel chart.
- 2 Get a handle for the Dining\_area state:
 

```
rt = sfroot;
diningState = rt.find('-isa','Stateflow.State','Name','Dining_area');
```
- 3 Get a handle for the local data service:
 

```
serviceData = rt.find('-isa','Stateflow.Data','Name','service');
```
- 4 Enable logging for the Dining\_area state and the service data:
 

```
diningState.LoggingInfo.DataLogging = 1;
serviceData.LoggingInfo.DataLogging = 1;
```
- 5 Change the logging name of the Dining\_area state to the custom name Dining Room:
 

```
% Enable custom naming
diningState.LoggingInfo.NameMode = 'Custom';

% Enter the custom name
diningState.LoggingInfo.LoggingName = 'Dining Room';
```


## Access Signal Logging Data

During simulation, Stateflow saves logged data in a `Simulink.SimulationData.Dataset` signal logging object.

For example, suppose that you configure the `sf_semantics_hotel_checkin` model to log the service local data and the activity of the Dining\_area state. After starting the simulation, you check into the hotel by toggling the first switch and order room service multiple times by toggling the second switch. After stopping the simulation, you can view the logged data through the Simulation Data Inspector, Logic Analyzer, or in the MATLAB workspace.


### View Logged Data Through the Simulation Data Inspector

When you simulate the model, the **Simulation Data Inspector** icon is highlighted to indicate that it has new simulation data.

- 1 To open the Simulation Data Inspector, in the **Simulation** tab, click the icon .
- 2 Inspect and compare the signals logged during simulation. See Simulation Data Inspector (Simulink).

### View Logged Data Through the Logic Analyzer

When you simulate the model, the **Logic Analyzer** icon is highlighted to indicate that it has new simulation data. To use the Logic Analyzer, you must have DSP System Toolbox or SoC Blockset.

- 1 To open the Logic Analyzer, in the **Simulation** tab, click the icon .
- 2 View, measure and compare the states logged during simulation. See Logic Analyzer (DSP System Toolbox).

### View Logged Data in the MATLAB Workspace

- 1 To access the signal logging object, at the MATLAB command prompt, enter:
 

```
logcout = out.logcout
```

```
logout =
```

```
Simulink.SimulationData.Dataset 'logout' with 2 elements
```

		Name	BlockPath
1	[1x1 State]	Dining Room	sf_semantics_hotel_checkin/Hotel
2	[1x1 Data ]	service	sf_semantics_hotel_checkin/Hotel

- 2** To access logged elements, use the `get` method. You can access logged elements by name, index, or block path.

```
diningLog = logout.get('Dining Room')
```

```
diningLog =
```

```
Stateflow.SimulationData.State  
Package: Stateflow.SimulationData
```

```
Properties:
```

```
  Name: 'Dining Room'  
  BlockPath: [1x1 Simulink.SimulationData.BlockPath]  
  Values: [1x1 timeseries]
```

```
serviceLog = logout.get('service')
```

```
serviceLog =
```

```
Stateflow.SimulationData.Data  
Package: Stateflow.SimulationData
```

```
Properties:
```

```
  Name: 'service'  
  BlockPath: [1x1 Simulink.SimulationData.BlockPath]  
  Values: [1x1 timeseries]
```

- 3** To access the logged data and time of each logged element, use the `Values.Data` and `Values.Time` properties. For example:

- Arrange logged data in tabular form by using the `table` function.

```
T1 = table(diningLog.Values.Time,diningLog.Values.Data);  
T1.Properties.VariableNames = {'Time','Data'}
```

```
T1 =
```

```
6x2 table
```

Time	Data
0	0
1.8607e+06	1
1.9653e+06	0
1.9653e+06	1
1.9653e+06	0
2.2912e+06	1

```
T2 = table(serviceLog.Values.Time,serviceLog.Values.Data);  
T2.Properties.VariableNames = {'Time','Data'}
```

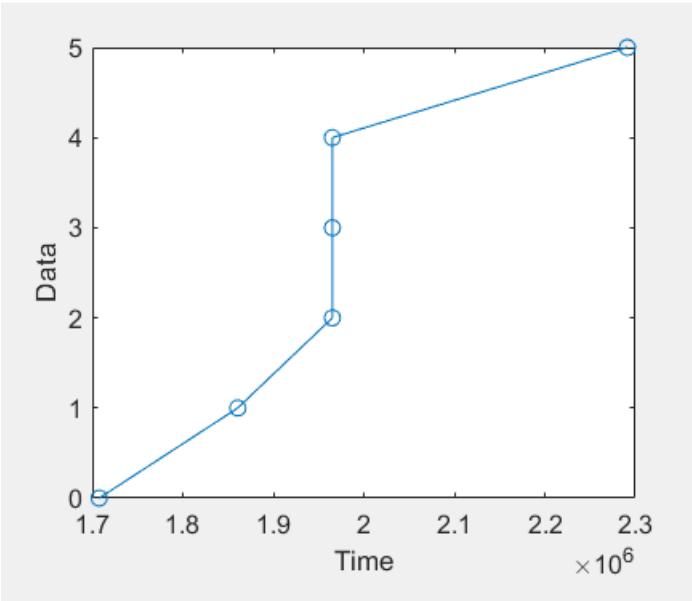
T2 =

6×2 table

Time	Data
1.7076e+06	0
1.8607e+06	1
1.9653e+06	2
1.9653e+06	3
1.9653e+06	4
2.2912e+06	5

- View logged data in a figure window by using the `plot` function.

```
X = serviceLog.Values.Time;
Y = serviceLog.Values.Data;
plot(X,Y,'-o')
xlabel('Time')
ylabel('Data')
```



- Export logged data to an Excel® spreadsheet by passing an array of logged values to the `xlswrite` function:

```
A = [double(diningLog.Values.Time) double(diningLog.Values.Data)];
xlswrite('dining_log.xls',A);
```

## Log Multidimensional Data

Stateflow logs each update to a multidimensional signal as a single change. For example, updating two elements of a matrix `A` separately

```
A[1][1] = 1;
A[1][2] = 1;
```

produces two different changes in the logged data. In contrast, updating a matrix `A` in a single command



A = 1;

produces a single change in the logged data, even though the command implies  $A[i][j] = 1$  for all values of  $i$  and  $j$ .

## Limitations on Logging Data

When simulating models in external mode, logging of Stateflow data is not supported.

If you log state activity or data from a chart with **Fast Restart** enabled, any run after the first run duplicates the first logged data points. When you run algorithms that process these data points, you must account for this duplication.

## See Also

[Simulink.SimulationData.Dataset](#) | [Stateflow.SimulationData.Data](#) | [Stateflow.SimulationData.State](#) | [get](#) | [plot](#) | [table](#) | [xlswrite](#)

## More About

- “Configure a Signal for Logging” (Simulink)
- “Logging and Accessibility Options” (Simulink)
- “Export Signal Data Using Signal Logging” (Simulink)

## Log Data in Library Charts

In Simulink, you can create your own block libraries as a way to reuse the functionality of blocks or subsystems in one or more models. Similarly, you can reuse a set of Stateflow algorithms by encapsulating the functionality in a library chart.

As with other Simulink block libraries, you can specialize each instance of chart library blocks in your model to use different data types, sample times, and other properties. Library instances that inherit the same properties can reuse generated code.

For more information about Simulink block libraries, see “Custom Libraries” (Simulink).

### How Library Log Settings Influence Linked Instances

Chart instances inherit logging properties from the library chart to which they are linked. You can override logging properties in the instance, but only for signals you select in the library. You cannot select additional signals to log from the instance.

### Override Logging Properties in Chart Instances

To override properties of logged signals in chart instances, use one of the following approaches.

Approach	How To Use
Simulink Signal Logging Selector dialog box	See “Override Logging Properties with the Logging Selector” on page 33-50
Command-line interface	See “Override Logging Properties with the Command-Line API” on page 33-51

### Override Logging Properties in Atomic Subcharts

The model `sf_atomic_sensor_pair` simulates a redundant sensor pair as atomic subcharts `Sensor1` and `Sensor2` in the chart `RedundantSensors`. Each atomic subchart contains instances of the states `Fail`, `FailOnce`, and `OK` from the library chart `sf_atomic_sensor_lib`.

#### Override Logging Properties with the Logging Selector

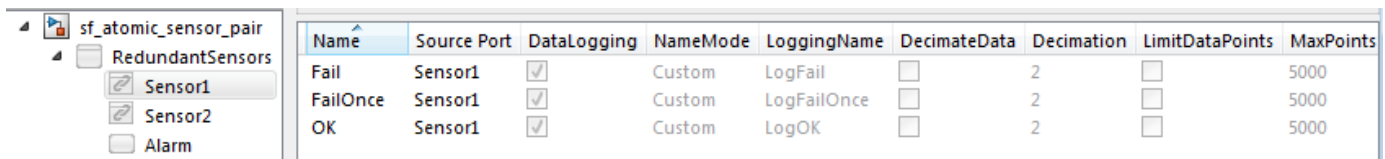
- 1 Open the example library `sf_atomic_sensor_lib`.
- 2 Unlock the library. In the **Simulation** tab, click **Locked Library**.
- 3 In the Simulink Editor, select the Stateflow `SingleSensor` chart. In the **Simulation** tab, click **Log States from List**.
- 4 In Stateflow Signal Logging dialog box, set the following logging properties, then click **OK**.

For Signal:	What to Specify:
Fail	<ul style="list-style-type: none"> <li>• Select the <b>Log signal data</b> check box.</li> <li>• Change <b>Logging name</b> to the custom name <code>LogFail</code>.</li> <li>• Click <b>Apply</b>.</li> </ul>

For Signal:	What to Specify:
FailOnce	<ul style="list-style-type: none"> <li>Select the <b>Log signal data</b> check box.</li> <li>Change <b>Logging name</b> to the custom name LogFailOnce.</li> <li>Click <b>Apply</b>.</li> </ul>
OK	<ul style="list-style-type: none"> <li>Select the <b>Log signal data</b> check box.</li> <li>Change <b>Logging name</b> to the custom name LogOK.</li> <li>Click <b>Apply</b>.</li> </ul>

- Open the model `sf_atomic_sensor_pair`. This model contains two instances of the library chart.
- Open the Model Configuration Parameters dialog box.
- In the **Data Import/Export** pane, click **Configure Signals to Log** to open the Simulink Signal Logging Selector.
- In the **Model Hierarchy** pane, expand `RedundantSensors`, and click `Sensor1` and `Sensor2`.

Each instance inherits logging properties from the library chart. For example:



Name	Source Port	DataLogging	NameMode	LoggingName	DecimateData	Decimation	LimitDataPoints	MaxPoints
Fail	Sensor1	<input checked="" type="checkbox"/>	Custom	LogFail	<input type="checkbox"/>	2	<input type="checkbox"/>	5000
FailOnce	Sensor1	<input checked="" type="checkbox"/>	Custom	LogFailOnce	<input type="checkbox"/>	2	<input type="checkbox"/>	5000
OK	Sensor1	<input checked="" type="checkbox"/>	Custom	LogOK	<input type="checkbox"/>	2	<input type="checkbox"/>	5000

- Now, override some logging properties for `Sensor1`:
  - In the **Model Hierarchy** pane, select `Sensor1`.
  - Change **Logging Mode** to `Override signals`.

The selector clears all **DataLogging** check boxes for the model.

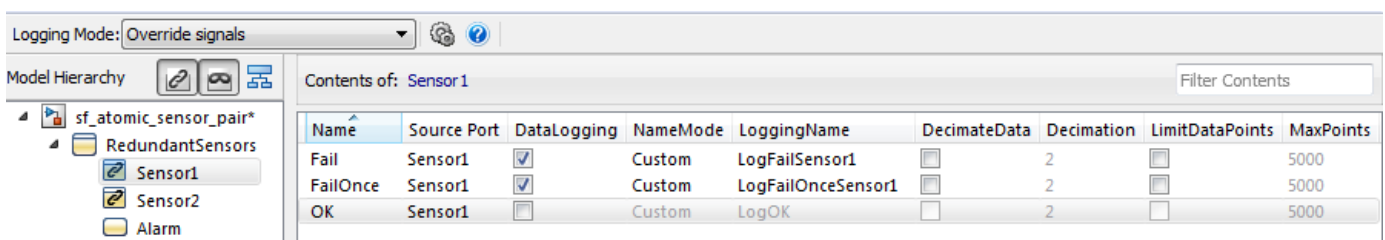
- Enable logging only for the `Fail` and `FailOnce` states in `Sensor1`:

Select **DataLogging** for these two signals. Leave **DataLogging** cleared for the `OK` signal.

- Append the text `Sensor1` to the logging names for `Fail` and `FailOnce`:

Double-click the logging names for signals `Fail` and `FailOnce`, and rename them `LogFailSensor1` and `LogFailOnceSensor1`, respectively.

The settings should look like this:



Name	Source Port	DataLogging	NameMode	LoggingName	DecimateData	Decimation	LimitDataPoints	MaxPoints
Fail	Sensor1	<input checked="" type="checkbox"/>	Custom	LogFailSensor1	<input type="checkbox"/>	2	<input type="checkbox"/>	5000
FailOnce	Sensor1	<input checked="" type="checkbox"/>	Custom	LogFailOnceSensor1	<input type="checkbox"/>	2	<input type="checkbox"/>	5000
OK	Sensor1	<input type="checkbox"/>	Custom	LogOK	<input type="checkbox"/>	2	<input type="checkbox"/>	5000

## Override Logging Properties with the Command-Line API

- Open the example library `sf_atomic_sensor_lib`.

- 2 Log the signals Fail, FailOnce, and OK in the SingleSensor chart using these commands:

```
% Get states in the SingleSensor chart
rt=sfroot;
states = rt.find('-isa', 'Stateflow.State');

% Enable logging for each state
for i = 1: length(states)
    states(i).LoggingInfo.DataLogging = 1;
end
```

- 3 Open the model sf\_atomic\_sensor\_pair. This model contains two instances of the library chart.
- 4 Create a ModelLoggingInfo object for the model.

This object contains a vector Signals that stores all logged signals.

```
mi = Simulink.SimulationData.ModelLoggingInfo. ...
    createFromModel('sf_atomic_sensor_pair')
```

The result is:

```
mi =
Simulink.SimulationData.ModelLoggingInfo
Package: Simulink.SimulationData

Properties:
    Model: 'sf_atomic_sensor_pair'
    LoggingMode: 'OverrideSignals'
    LogAsSpecifiedByModels: {}
    Signals: [1x6 Simulink.SimulationData.SignalLoggingInfo]
```

The Signals vector contains the signals marked for logging in the library chart:

- Library instances of Fail, FailOnce, and OK states in atomic subchart Sensor1
  - Library instances of Fail, FailOnce, and OK states in atomic subchart Sensor2
- 5 Make sure that LoggingMode equals 'OverrideSignals'.
  - 6 Create a block path to each logged signal whose properties you want to override.

To access signals inside Stateflow charts, use `Simulink.SimulationData.BlockPath(paths, subpath)`, where subpath represents a signal inside the chart.

To create block paths for the signals Fail, FailOnce, and OK in the atomic subchart Sensor1 in the RedundantSensors chart:

```
failPath = Simulink.SimulationData. ...
BlockPath('sf_atomic_sensor_pair/RedundantSensors/Sensor1','Fail')

failOncePath = Simulink.SimulationData. ...
BlockPath('sf_atomic_sensor_pair/RedundantSensors/Sensor1','FailOnce')

OKPath = Simulink.SimulationData. ...
BlockPath('sf_atomic_sensor_pair/RedundantSensors/Sensor1','OK')
```

- 7 Get the index of each logged signal in the `Simulink.SimulationData.BlockPath` object.

To get the index for the signals Fail, FailOnce, and OK:

```
failIdx = mi.findSignal(failPath);
failOnceIdx = mi.findSignal(failOncePath);
OKIdx = mi.findSignal(OKPath);
```

**8** Override some logging properties for the signals in Sensor1:**a** Disable logging for signal OK:

```
mi.Signals(OKidx).LoggingInfo.DataLogging = 0;
```

**b** Append the text Sensor1 to the logging names for Fail and FailOnce:

```
% Enable custom naming
mi.Signals(failidx).LoggingInfo.NameMode = 1;
mi.Signals(failOnceidx).LoggingInfo.NameMode = 1;

% Enter the custom name
mi.Signals(failidx).LoggingInfo.LoggingName = 'LogFailSensor1';
mi.Signals(failOnceidx).LoggingInfo.LoggingName = 'LogFailOnceSensor1';
```

**9** Apply the changes:

```
set_param(bdroot, 'DataLoggingOverride', mi);
```

**See Also**

[Simulink.SimulationData.BlockPath](#) | [Simulink.SimulationData.ModelLoggingInfo](#)

## Commenting Stateflow Objects in a Chart

### In this section...

“Comment Out a Stateflow Object” on page 33-54

“How Commenting Affects the Chart and Model” on page 33-54

“Add Text to a Commented Object” on page 33-56

“Limitations on Commenting Objects” on page 33-56

### Comment Out a Stateflow Object

Commenting out a Stateflow object excludes it from simulation. To comment out a Stateflow object, right-click the object and select **Comment Out**. Use commenting to:


- Debug a chart by making minor changes between simulation runs.
- Test and verify the effects of objects on simulation results.
- Create incremental changes for rapid, iterative design.

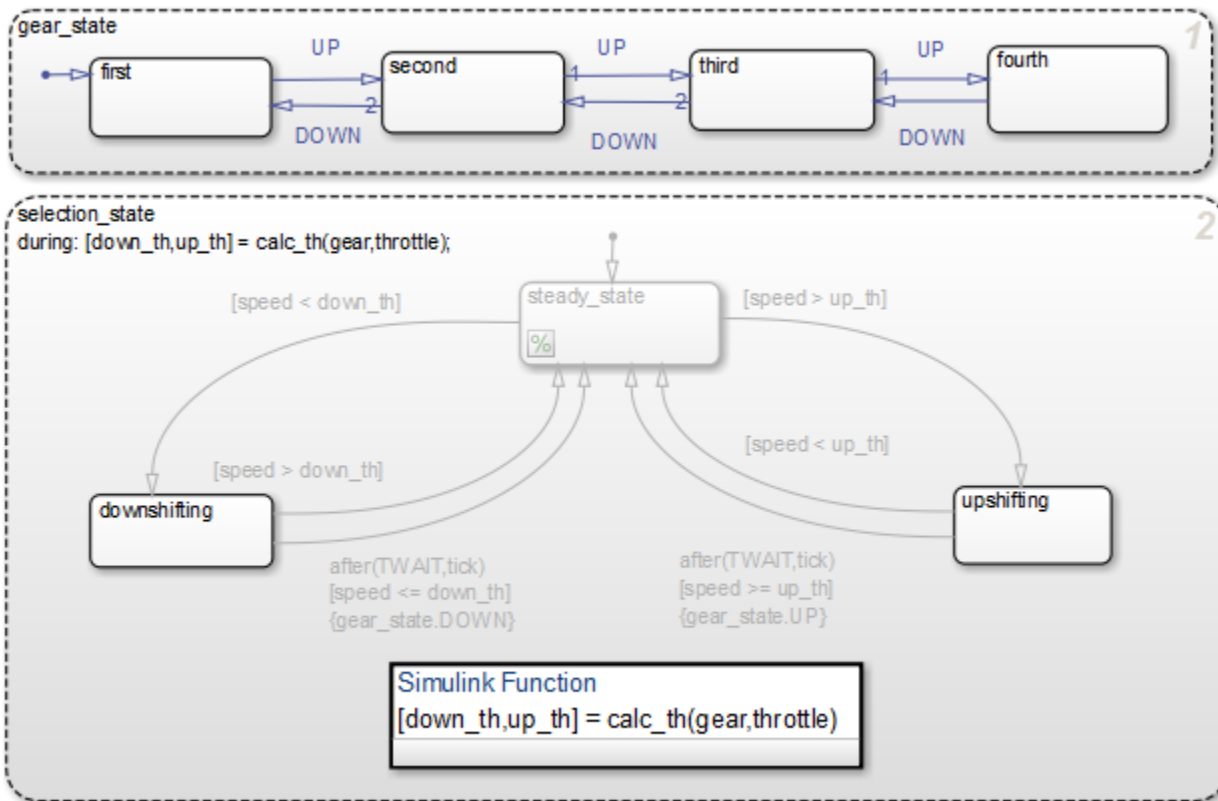
### How Commenting Affects the Chart and Model

A commented object is not visible to the rest of the chart and the model. Commented objects in a chart are excluded from:

- Simulation
- Logging
- Code generation
- Animation
- Debugging
- Active state output

References to commented functions or states result in compile-time errors.


When you explicitly comment out a Stateflow object with **Comment Out**, the object appears gray with a badge . The software implicitly comments out some associated objects. Implicitly commented objects also appear gray, but do not have a badge. For example, if you explicitly comment out a state or junction, all incoming and outgoing transitions are implicitly commented out. In this image of `sf_car`, the state `steady_state` is explicitly commented. The transitions in and out of `steady_state` are implicitly commented.



Explicitly Commented Stateflow Object	Implicit Results
States	All incoming and outgoing transitions, and child objects are implicitly commented out.
Transitions	None
Junctions	All connected transitions are implicitly commented out.
Functions	The software cannot invoke a commented function from any chart or model.
Data	You cannot explicitly comment out data. If you comment out the parent object, then the software cannot reference the data.
Events	You cannot explicitly comment out events. If you comment out the parent object, then the software cannot reference the event.

To uncomment an object, right-click the commented object and select **Uncomment**. All implicitly commented objects are restored as well. Implicitly commented objects cannot be uncommented directly.

## Add Text to a Commented Object

Add a note to the commented object by clicking the badge . Point to a badge to see the associated comments. You cannot add notes to implicitly commented objects.

## Limitations on Commenting Objects

When you comment out an atomic subchart, the objects inside the chart do not appear implicitly commented. However, a commenting badge is displayed in the lower-left corner of the chart.



# Explore and Modify Charts

---

- “Manage Data, Events, and Messages in the Symbols Pane” on page 34-2
- “Use the Model Explorer with Stateflow Objects” on page 34-10
- “Use the Search and Replace Tool” on page 34-14
- “Visualize Chart Execution with the Activity Profiler” on page 34-23
- “Connect Dashboard Blocks to Stateflow” on page 34-28

## Manage Data, Events, and Messages in the Symbols Pane

In the Symbols pane, you can view and manage data, events, and messages while working in the Stateflow Editor. In the **Modeling** tab, select **Symbols Pane**.

From the Symbols pane you can:

- Add and delete data, events, and messages.
- Set the object type and scope.
- Change the port number.
- Edit the name of an object and update all instances of the object name in the chart.
- Undo and redo changes in type, name, and port number.
- Detect unused objects.
- Detect and fix unresolved objects.
- Trace between objects in the window and where the objects are used in the chart.
- View and edit object properties in the Property Inspector.

TYPE	NAME	PORT
▶	MainArea	
▶	WaitingArea	
▶	rotateAC	
▶	rotateC	
▶	randInput	1
▶	left	2
▶	right	3
▶	drop	4
▶	rotc	5
▶	rotac	6
▶	down	7
▶	ARENA_HEIGHT	
▶	ARENA_WIDTH	
▶	GAME_OVER	1




The rows in the Symbols pane display object hierarchy. Expand an object in the window to see data, events, and messages parented by that object. By default, all the nongraphical objects in a chart are listed in the window. To view only the objects that are used at the current level of hierarchy and

below, select the  icon. To search for specific symbols, type in the Filter search box .

## Add and Modify Data, Events, and Messages

To add a nongraphical object to a Stateflow block, in the Symbols pane:

- 1 Select one of these icons.

Object	Icon
Data	
Event	
Message	

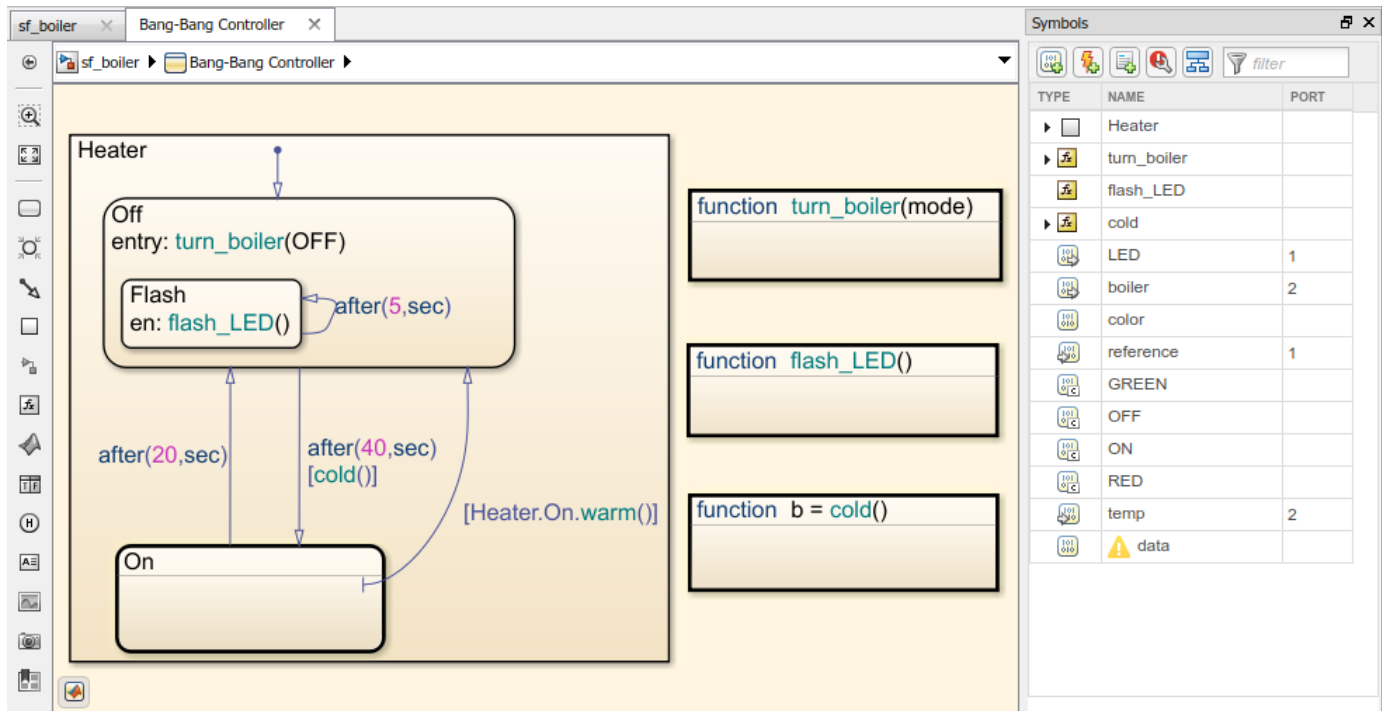
- 2 In the row for the new object, under **TYPE**, choose the object type.
- 3 Edit the name of the object.
- 4 For input and output objects, under **PORT**, choose a port number.
- 5 To view the object in the Property Inspector, right-click the object and select **Inspect**.
- 6 In the Property Inspector, modify the object properties.

After you add objects through the Symbols pane, the objects appear as unused until you reference them in your Stateflow design.

In the Symbols pane, you can modify the name, type, and port number of Stateflow objects. Edit the name of objects in the **NAME** field. When you rename an object, select **Shift+Enter** to rename all instances of the object throughout the state machine. To change the type or port number of an object, click the corresponding field and select from the available options. To delete an object from the state machine, right-click the object and select **Delete**.

## Detect Unused Data in the Symbols Pane

The Symbols pane indicates unused data, messages, functions, and events with a yellow warning icon. To delete unused objects, right-click the object in the Symbols pane and select **Delete**. By removing objects that have no effect on simulation, you can reduce the size of your model. In this chart, after you add `data`, it first appears as unused. After you reference `data` in the chart, the warning sign disappears.




The following types of unused data are not detected:

- Machine-parented data
- Inputs and outputs of MATLAB functions
- Data of parameter scope in a chart that contains atomic subcharts

## Trace Data, Events, and Messages

Stateflow provides traceability between the state machine and nongraphical symbols. When you select a symbol in the Symbols pane, Stateflow highlights sections of the chart that access that symbol. When you select an object in your chart, Stateflow highlights the symbols that the object uses.

To control when the objects and symbols are highlighted, select the preference button . A drop-down menu appears.

**SYMBOL SELECTION ACTION**

Highlight uses on diagram

Highlight all uses

Highlight reads

Highlight writes

**EDITOR SELECTION ACTION**

Highlight used symbols

**VALUE DISPLAY FORMAT**

Floats:


Integers:

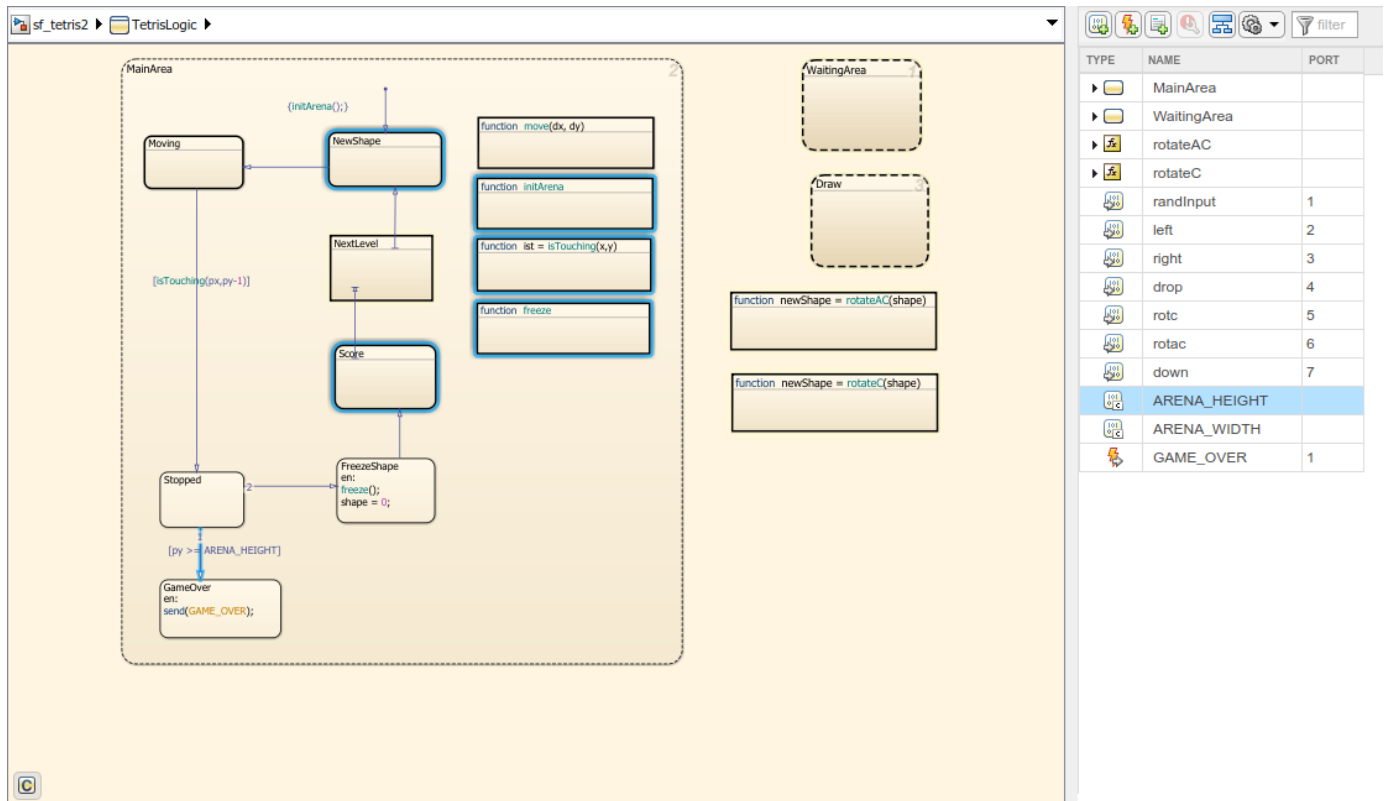
Fixed Point:

For Stateflow to highlight symbols in the Symbols pane that an object uses, select **Highlight used symbols**. For Stateflow to highlight objects in the chart that use an symbol, select **Highlight uses on diagram**. With **Highlight uses on diagram** you can choose to highlight:

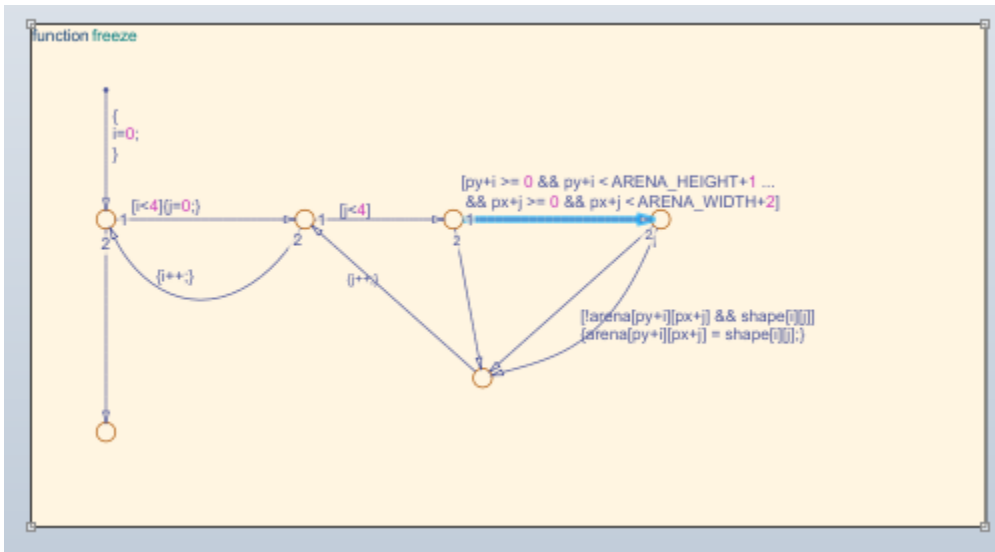
- All uses of the symbol in your chart.
- Objects from where the symbol is read.
- Objects to where the symbol is written.

For example, open the model `sf_tetris2` and double-click the chart `TetrisLogic`. In the Symbols pane, when you select constant `ARENA_HEIGHT`, the states and functions that use `ARENA_HEIGHT` are highlighted. If the chart does not use an object, the symbol appears in the window with a yellow

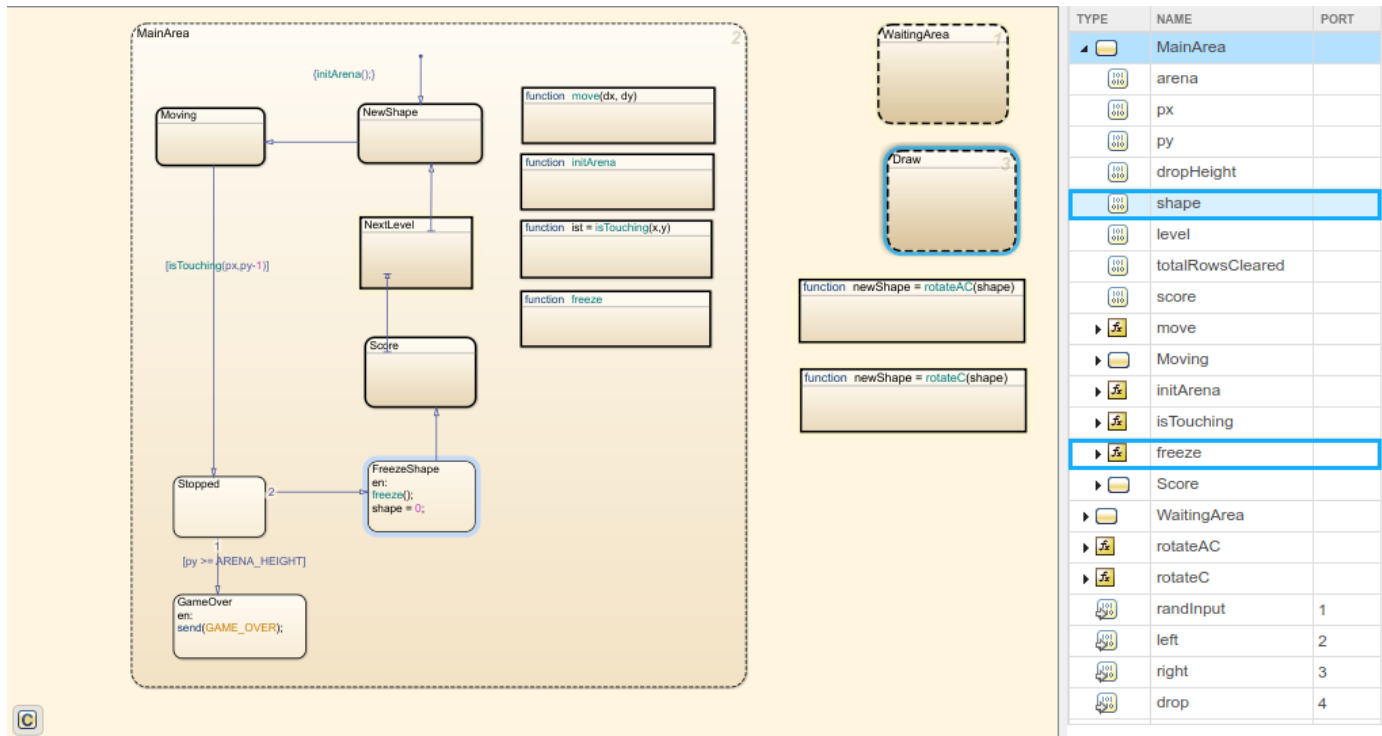
warning icon .



To see the uses of the constant `ARENA_HEIGHT`, open the function `freeze`.



You can also select a graphical object such as a state, transition, or function in the chart and view the symbols that the object uses. For example, in the chart `TetrLogic`, expand the symbol `MainArea` in the Symbols pane. If you select the state `FreezeShape` in the chart, then the local data `shape` and the function `freeze()` are highlighted in the Symbols pane. This highlighting indicates that those objects are used inside the state `FreezeShape`.



When in debugging mode, the values of each data are displayed in the **VALUE** column of the Symbols pane. Stateflow updates the values periodically when the simulation is running. The value column highlights changes to data values as the changes occur. When the debugger is stopped at a breakpoint, you can update the initial value or change the value of a symbols in either the command prompt or the Symbols pane.

Data or Message	Update Initial Value	Update During Debugging
Input	No	No
Output	Yes	Yes
Parameter	No	No
Constant	Yes	No
Data Store Memory	No	Yes
Local	Yes	Yes

For bus elements, you can change the value of a symbols in either the command prompt or the Symbols pane.

Bus Element	Update Initial Value	Update During Debugging
Input	No	No
Output	No	Yes
Parameter	No	No
Constant	No	No
Data Store Memory	No	Yes

Bus Element	Update Initial Value	Update During Debugging
Local	No	Yes

In the Symbols pane multidimensional arrays appear as the data type and size of the array. If the array does not exceed more than 100 elements, hover over the symbol to view the elements. For arrays that contain more than 100 elements, view the elements by using the command prompt.

When simulation is paused, hover over messages in the canvas to view payloads in the queue. This is similar to the hover functionality on the canvas. For other non-scalar objects, the size and data type appear. To see these values, use the Watch window. See “Inspect and Modify Data and Messages While Debugging” on page 33-9 and “Track Data in the Watch List” on page 33-11.

The screenshot displays a simulation environment for a Tetris game. On the left, a state machine diagram for 'MainArea' is shown, including states like 'Moving', 'NewShape', 'NextLevel', 'Score', 'Stopped', 'FreezeShape', and 'GameOver'. On the right, a Symbols pane table lists various variables and their values.

TYPE	NAME	VALUE	PORT
	randInput	6.9825	1
	left	0	2
	right	0	3
	drop	0	4
	rotc	0	5
	rotac	0	6
	down	0	7
	ARENA_HEIGHT	20	
	ARENA_WIDTH	10	
	GAME_OVER		1
	MainArea		
	arena	21x12 uint8	
	px	6	
	py	0	
	dropHeight	0	
	shape	4x4 uint8	
	level	1	
	totalRowsCleare	0	
	score	0	
	move		
	Moving		
	initArena		

### Symbols Pane Limitations

You cannot add the types of objects listed in the table via the Symbols pane. To add these types of objects, use the Model Explorer. As a best practice, avoid using machine-parented data.

Object	Via Symbols Pane	Visible in Symbols Pane
Data, events, and messages parented by a state	No	Yes
Data, events, and messages inside a function	No	Yes
Data and events parented by the state machine	No	No

Additional limitations:



- When you modify the code in a MATLAB function, the changes are not updated in the Symbols pane until after you save the MATLAB function.
- You cannot undo or redo changes to input and output for MATLAB functions.
- You cannot recover deleted data, events, or messages from a state transition table.
- You cannot undo scope changes to data parented by graphical functions, MATLAB functions, and truth tables.
- You cannot undo renaming an object for truth tables.
- When you delete data for objects contained in a Simulink based state, the object remains in your Simulink based state and the data symbol is shown as undefined in the Symbols pane.

## **See Also**

### **More About**

- “Resolve Undefined Symbols in Your Chart” on page 31-37
- “Add Stateflow Data” on page 12-2
- “Set Data Properties” on page 12-5

## Use the Model Explorer with Stateflow Objects

### In this section...

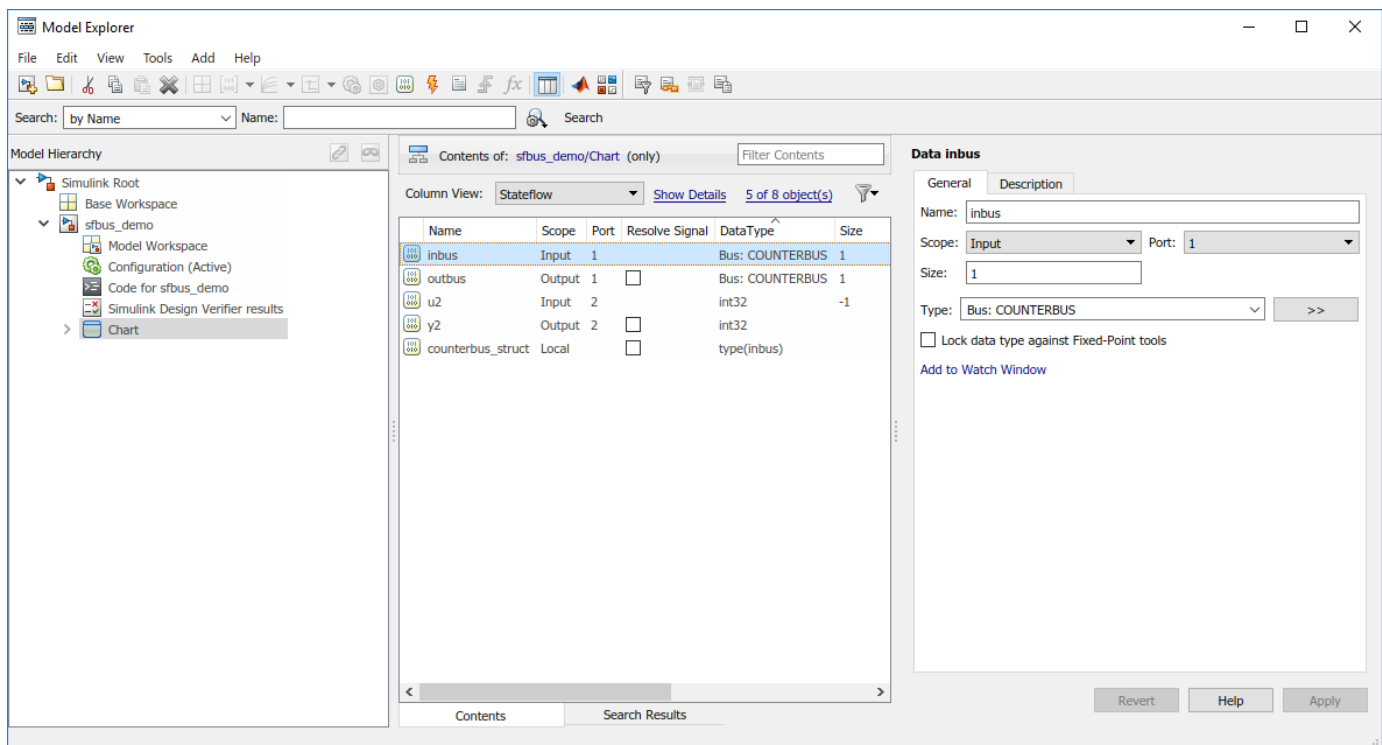
- “View Stateflow Objects in the Model Explorer” on page 34-10
- “Edit Chart Objects in the Model Explorer” on page 34-11
- “Add Data and Events in the Model Explorer” on page 34-11
- “Rename Objects in the Model Explorer” on page 34-11
- “Set Properties for Chart Objects in the Model Explorer” on page 34-11
- “Move and Copy Data and Events in the Model Explorer” on page 34-12
- “Change the Port Order of Input and Output Data and Events” on page 34-13
- “Delete Data and Events in the Model Explorer” on page 34-13

### View Stateflow Objects in the Model Explorer

You can use one of these methods for opening the Model Explorer:

- In the **Modeling** tab, select **Model Explorer**.
- Right-click an empty area in the chart and select **Explore**.

The Model Explorer appears something like this:



The main window has two panes: a **Model Hierarchy** pane on the left and a **Contents** pane on the right. When you open the Model Explorer, the Stateflow object you are editing appears highlighted in the **Model Hierarchy** pane and its objects appear in the **Contents** pane. This example shows how the Model Explorer appears when opened from the chart.

The **Model Hierarchy** pane displays the elements of all loaded Simulink models, which includes Stateflow charts. A preceding plus (+) character for an object indicates that you can expand the display of its child objects by double-clicking the entry or by clicking the plus (+). A preceding minus (-) character for an object indicates that it has no child objects.

Clicking an entry in the **Model Hierarchy** pane selects that entry and displays its child objects in the **Contents** pane. A hypertext link to the currently selected object in the **Model Hierarchy** pane appears after the **Contents of:** label at the top of the **Contents** pane. Click this link to display that object in its native editor. In the preceding example, clicking the link `sfbus_demo/Chart` displays the contents of the chart in its editor.

Each type of object, whether in the **Model Hierarchy** or **Contents** pane, appears with an adjacent icon. Subcharted objects (states, boxes, or graphical functions) appear altered with shading.

The display of child objects in the **Contents** pane includes properties for each object, most of which are directly editable. You can also access the properties dialog box for an object from the Model Explorer. See “Set Properties for Chart Objects in the Model Explorer” on page 34-11 for more details.

## Edit Chart Objects in the Model Explorer

To edit a chart object that appears in the **Model Hierarchy** pane of the Model Explorer:

- 1 Right-click the object.
- 2 Select **Open** from the context menu.

The selected object appears highlighted in the chart.

## Add Data and Events in the Model Explorer

To add data or events using the Model Explorer, see the following links:

- “Add Data Through the Model Explorer” on page 12-3
- “Add Events Through the Model Explorer” on page 14-3

## Rename Objects in the Model Explorer

To rename a chart object in the Model Explorer:

- 1 Right-click the object row in the **Contents** pane of the Model Explorer and select **Rename**.

The name of the selected object appears in a text edit box.

- 2 Change the name of the object and click outside the edit box.

## Set Properties for Chart Objects in the Model Explorer

To change the property of an object in the **Contents** pane of the Model Explorer:

- 1 In the **Contents** pane, click in the row of the displayed object.
- 2 Click an individual entry for a property column in the highlighted row.

- For text properties, such as the Name property, a text editing field with the current text value overlays the displayed value. Edit the field and press the **Enter** key or click anywhere outside the edit field to apply the changes.
- For properties with enumerated entries, such as the Scope, Trigger, or Type properties, select from a drop-down combo box that overlays the displayed value.
- For Boolean properties (properties that are set on or off), select or clear the box that appears in place of the displayed value.

To set all the properties for an object displayed in the **Model Hierarchy** or **Contents** pane of the Model Explorer:

- 1 Right-click the object and select **Properties**.

The properties dialog box for the object appears.

- 2 Edit the appropriate properties and click **Apply** or **OK**.

To display the properties dialog box dynamically for the selected object in the **Model Hierarchy** or **Contents** pane of the Model Explorer:

- 1 Select **View > Show Dialog Pane**.

The properties dialog box for the selected object appears in the far right pane of the Model Explorer.

## Move and Copy Data and Events in the Model Explorer

---

**Note** If you move an object to a level in the hierarchy that does not support the **Scope** property for that object, the **Scope** automatically changes to **Local**.

---

To move data and event objects to another parent:

- 1 Select the data or event to move in the **Contents** pane of the Model Explorer.

You can select a contiguous block of items by highlighting the first (or last) item in the block and then using **Shift** + click for highlighting the last (or first) item.

- 2 Click and drag the highlighted objects from the **Contents** pane to a new location in the **Model Hierarchy** pane to change its parent.

A shadow copy of the selected objects accompanies the mouse cursor during dragging. If no parent is chosen or the parent chosen is the current parent, the mouse cursor changes to an X enclosed in a circle, indicating an invalid choice.

To cut or copy the selected data or event:

- 1 Select the event or data to cut or copy in the **Contents** pane of the Model Explorer.
- 2 In the Model Explorer, select **Edit > Cut** or **Edit > Copy**.

If you select **Cut**, the selected items are deleted and then copied to the clipboard for copying elsewhere. If you select **Copy**, the selected items are left unchanged.

You can also right-click a single selection and select **Cut** or **Copy** from the context menu. The Model Explorer also uses the keyboard equivalents of **Ctrl+X** (Cut) and **Ctrl+C** (Copy) on a computer running the UNIX or Windows operating system.

- 3 Select a new parent object in the **Model Hierarchy** pane of the Model Explorer.
- 4 Select **Edit > Paste**. The cut items appear in the **Contents** pane of the Model Explorer.

You can also paste the cut items by right-clicking an empty part of the **Contents** pane and selecting **Paste** from the context menu. The Model Explorer also uses the keyboard equivalent of **Ctrl+V** (Paste) on a computer running the UNIX or Windows operating system.

## Change the Port Order of Input and Output Data and Events

Input data, output data, input events, and output events each have numerical sequences of port index numbers. You can change the order of indexing for event or data objects with a scope of **Input** or **Output** in the **Contents** pane of the Model Explorer as follows:

- 1 Select one of the input or output data or event objects.
- 2 Click the **Port** property for the object.
- 3 Enter a new value for the Port property for the object.

The remaining objects in the affected sequence are automatically assigned a new value for their **Port** property.

## Delete Data and Events in the Model Explorer

Delete data and event objects in the **Contents** pane of the Model Explorer as follows:

- 1 Select the object.
- 2 Press the **Delete** key.

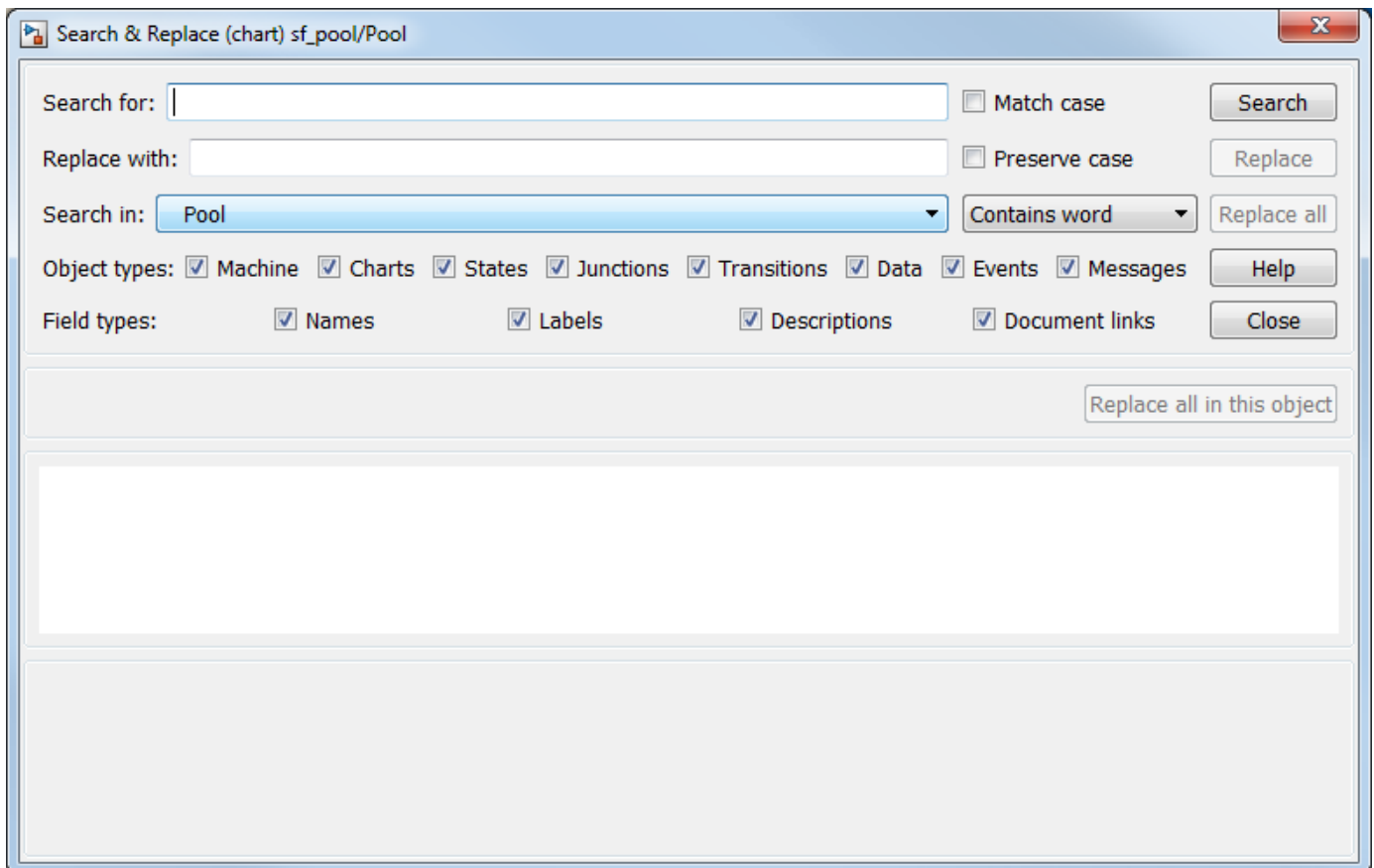
You can also select **Edit > Cut** or **Ctrl+X** from the keyboard to delete an object.

## Use the Search and Replace Tool

### Open the Search & Replace Tool

To open the Search & Replace dialog box:

- 1 Open a chart.
- 2 In the **Modeling** tab, select **Find > Find & Replace in Chart**.



The Search & Replace dialog box contains the following fields:

- **Search for**

Enter search pattern text in the **Search for** text box. You can select the interpretation of the search pattern with the **Match case** check box and the **Match options** field (unlabeled and just to the right of the **Search in** field).

- **Match case**

If you select this check box, the search is case sensitive and the Search & Replace tool finds only text matching the search pattern exactly.

- **Replace with**

Specify the text to replace the text found when you select any of the **Replace** buttons (**Replace**, **Replace all**, **Replace all in this object**). See “Use Replace Buttons” on page 34-20.

- **Preserve case**

This option modifies replacement text. For an understanding of this option, see “Replacing with Case Preservation” on page 34-20.

- **Search in**

By default, the Search & Replace tool searches for and replaces text only within the current Stateflow chart that you are editing in the Stateflow Editor. You can select to search the machine owning the current Stateflow chart or any other loaded machine or chart by accessing this selection box.

- **Match options**

This field is unlabeled and just to the right of the **Search in** field. You can modify the meaning of your search text by entering one of the selectable search options. See “Refine Searches” on page 34-15.

- **Object types** and **Field types**

Under the **Search in** field are the selection boxes for **Object types** and **Field types**. These selections further refine your search and are described below.

- **Search** and **Replace** buttons

These are described in “Use the Search Button and View Area” on page 34-17 and “Use Replace Buttons” on page 34-20.

- **View Area**

The bottom half of the Search & Replace dialog box displays the result of a search. This area is described in “A Breakdown of the View Area” on page 34-19.

## Refine Searches

Enter search pattern text in the **Search for** text box. You can use one of the following settings to further refine the meaning of the text entered.

### Match case

By selecting the **Match case** option, you enable case-sensitive searching. In this case, the Search & Replace tool finds only text matching the search pattern exactly.

By clearing the **Match case** option, you enable case-insensitive searching. In this case, search pattern characters entered in lower- or uppercase find matching text with the same sequence of base characters in lower- or uppercase. For example, the search entry "AnDrEw" finds the matching text "andrew" or "Andrew" or "ANDREW".

### Preserve case

This option modifies replacement text and not search text. For details, see “Replacing with Case Preservation” on page 34-20.

### Contains word

Select this option to specify that the search pattern text is a whole word expression used in a Stateflow chart with no specific beginning and end delimiters. In other words, find the specified text in any setting.

Suppose that you have a state with this label and entry action:

```
throt_fail
entry: fail_state[THROT] = 1;
```

Searching for the text `fail` with the **Contains word** option finds two occurrences of `fail`.

### Match whole word

Select this option to specify that the search pattern in the **Search for** field is a whole word expression used in a Stateflow chart with beginning and end delimiters consisting of a blank space or a character that is not alphanumeric and not an underscore character (`_`).

In the previous example of a state named `throt_fail`, if **Match whole word** is selected, searching for `fail` finds no text within that state. However, searching for `"fail_state"` does find the text `"fail_state"` as part of the second line since it is delimited by a space at the beginning and a left square bracket (`[`) at the end.

### Regular expression

Set the **Match options** field to **Regular expression** to search for text that varies from character to character within defined limits.

A regular expression is text composed of letters, numbers, and special symbols that defines one or more candidates. Some characters have special meaning when used in a regular expression, while other characters are interpreted as themselves. Any other character appearing in a regular expression is ordinary, unless a back slash (`\`) character precedes it.

If the **Match options** field is set to **Regular expression** in the previous example of a state named `throt_fail`, searching for `"fail_"` matches the `"fail_"` text that is part of the second line, character for character. Searching with the regular expression `"\w*_"` also finds the text `"fail_"`. This search uses the regular expression shorthand `"\w"` that represents any part-of-word character, an asterisk (`*`) that represents any number of any characters, and an underscore (`_`) that represents itself.

For a list of regular expression meta characters, see “Regular Expressions”.

## Specify the Search Scope

You specify the scope of your search by selecting from the field regions discussed in the topics that follow.

### Search in

You can select a whole machine or individual chart for searching in the **Search in** field. By default, the current chart in which you opened the Search & Replace tool is selected.

To select a machine, follow these steps:



- 1 Select the down arrow of the **Search in** field.

A list of the currently loaded machines appears with the current machine expanded to reveal its Stateflow charts.

- 2 Select a machine.

To select a Stateflow chart for searching, follow these steps:

- 1 Select the down arrow of the **Search in** field again.

This list contains the previously selected machine expanded to reveal its Stateflow charts.

- 2 Select a chart from the expanded machine.

### Object Types

Limit your search by deselecting one or more object types.

---

**Note** You cannot search in state transition tables with this tool.

---

### Field Types

Limit your search by deselecting one or more field types.

Available field types are as follows.

#### Names

Machines, charts, data, and events have valid **Name** fields. States have a **Name** defined as the top line of their labels. You can search and replace text belonging to the **Name** field of a state in this sense. However, if the Search & Replace tool finds matching text in a state's **Name** field, the rest of the label is subject to later searches for the specified text whether or not the label is chosen as a search target.

---

**Note** The **Name** field of machines and charts is an invalid target for the Search & Replace tool. Use the Simulink model window to change the names of machines and charts.

---

#### Labels

Only states and transitions have labels.

#### Descriptions

All objects have searchable **Description** fields.

#### Document links

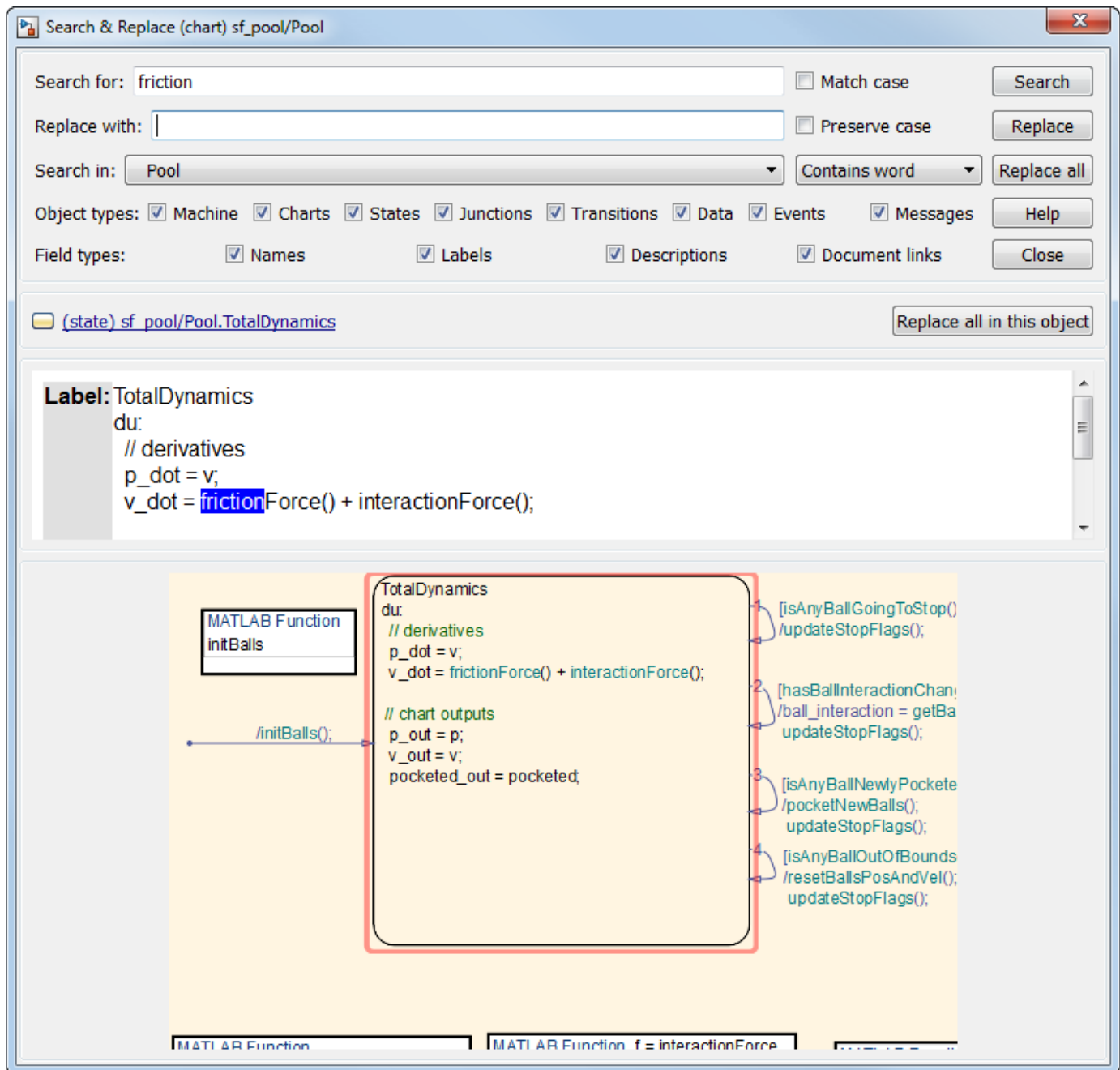
All objects have searchable **Link** fields.

## Use the Search Button and View Area

This topic contains the following subtopics:

- “A Breakdown of the View Area” on page 34-19
- “The Search Order” on page 34-19

Click **Search** to initiate a single-search operation. If an object match is made, its text fields appear in the **Viewer** pane in the middle of the Search & Replace dialog box. If the object is graphical (state, transition, junction, chart), the matching object appears highlighted in a **Portal** pane below the **Viewer** pane.



## A Breakdown of the View Area

The view area of the Search & Replace dialog box displays matching text and its containing object, if viewable. In the previous example, taken from the `sf_pool` model, a search for the word "friction" finds the **Description** field for the state `TotalDynamics`. The resulting view area consists of these parts:

### Icon

Displays an icon appropriate to the object containing the matching text. These icons are identical to the icons in the Model Explorer that represent Stateflow objects displayed in "View Stateflow Objects in the Model Explorer" on page 34-10.

### Full Path Name of Containing Object

This area displays the full path name for the object that contains the matching text:

```
(<type>) <machine name>/<subsystem>/<chart
name>.[p1]. . . [pn].<object name> (<id>)
```

where  $p_1$  through  $p_n$  denote the object's parent states.

### Viewer

This area displays the matching text as a highlighted part of all search-qualified text fields for the owner object. If other occurrences exist in these fields, they too are highlighted, but in lighter shades.

To invoke the properties dialog box for the owner object, double-click anywhere in the Viewer pane.

### Portal

This area contains a graphic display of the object that contains the matching text. That object appears highlighted.

To display the highlighted object in the Stateflow Editor, double-click anywhere in the Portal pane.

## The Search Order

If you specify an entire machine as your search scope in the **Search in** field, the Search & Replace tool starts searching at the beginning of the first chart of the model, regardless of the Stateflow chart that appears in the Stateflow Editor when you begin your search. After searching the first chart, the Search & Replace tool continues searching each chart in model order until all charts for the model have been searched.

If you specify a Stateflow chart as your search scope, the Search & Replace tool begins searching at the beginning of the chart. The Search & Replace tool continues searching the chart until all the chart objects have been searched.

The search order when searching an individual chart for matching text is equivalent to a depth-first search of the Model Explorer. Starting at the highest level of the chart, the Model Explorer hierarchy is traversed downward from parent to child until an object with no child is encountered. At this point, the hierarchy is traversed upward through objects already searched until an unsearched sibling is found and the process repeats.

## Specify the Replacement Text

The Search & Replace tool replaces matching text with the exact (case-sensitive) text you entered in the **Replace With** field unless you selected the **Preserve case** option.

### Replacing with Case Preservation

If you choose the **Preserve case** option, matching text is replaced based on one of these conditions:

- Whisper

Matching text has only lowercase characters. Matching text is replaced entirely with the lowercase equivalent of all replacement characters. For example, if the replacement text is "ANDREW", the matching text "bill" is replaced by "andrew".

- Shout

Matching text has only uppercase characters. Matching text is replaced entirely with the uppercase equivalent of all replacement characters. For example, if the replacement text is "Andrew", the matching text "BILL" is replaced by "ANDREW".

- Proper

Matching text has uppercase characters in the first character position of each word. Matching text is replaced entirely with the case equivalent of all replacement characters. For example, if the replacement text is "andrew johnson", the matching text "Bill Monroe" is replaced by "Andrew Johnson".

- Sentence

Matching text has an uppercase character in the first character position of a sentence with all other sentence characters in lowercase. Matching text is replaced in like manner, with the first character of the sentence given an uppercase equivalent and all other sentence characters set to lowercase. For example, if the replacement text is "andrew is tall.", the matching text "Bill is tall." is replaced by "Andrew is tall."

If the matching text does not follow any of these patterns, then the text and case replacement match the user input.

## Use Replace Buttons

You can activate the replace buttons (**Replace**, **Replace all**, **Replace all in this object**) only after a search that finds text.

### Replace

When you select the **Replace** button, the current instance of text matching the text in the **Search for** field is replaced by the text you entered in the **Replace with** field. The Search & Replace tool then searches for the next occurrence of the **Search for** text.

### Replace all

When you select the **Replace all** button, all instances of text matching the **Search for** field are replaced by the text entered in the **Replace with** field. Replacement starts at the point of invocation to the end of the current Stateflow chart. If you initially skip through some search matches with the **Search** button, these matches are also skipped when you select the **Replace all** button.

## Replace all in this object

When you select the **Replace all in this object** button, all instances of text matching the **Search for** field are replaced by text you entered in the **Replace with** field everywhere in the current Stateflow object regardless of previous searches.

## Search and Replace Messages

Informational and warning messages appear in the **Full Path Name Containing Object** field along with a defining icon.



- Informational Messages



- Warnings

The following messages are informational:

### Please specify a search string

A search was attempted without search text specified.

### No Matches Found

No matches exist in the selected search scope.

### Search Completed

No more matches exist in the selected search scope.

The following warnings refer to invalid conditions for searching or replacing:

### Invalid option set

The object types and field types that you selected are incompatible.

### Match object not currently editable

The matching object is not editable by replacement due to one of these problems.

Problem	Solution
A simulation is running.	Stop the simulation.
You are editing a locked library block.	Unlock the library.
The current object or its parent has been manually locked.	Unlock the object or its parent.

The following warnings appear if the Search & Replace tool must find the object again and its matching text field. If the original matching object is deleted or changed before an ensuing search or replacement, the Search & Replace tool cannot continue.

**Search object not found**

If you search for text, find it, and then delete the containing object, this warning appears if you continue to search.

**Match object not found**

If you search for text, find it, and then delete the containing object, this warning appears if you perform a replacement.

**Match not found**

If you search for text, find it, and then change the object containing the text, this warning appears if you perform a replacement.

**Search string changed**

If you search for text, find it, and then change the **Search for** field, this warning appears if you perform a replacement.

## Visualize Chart Execution with the Activity Profiler

The Activity Profiler allows you to examine the behavior of your Stateflow chart. When you enable the Activity Profiler, after simulation, your Stateflow chart is highlighted to show which states were entered, transitions were taken, or functions were executed during the time that the simulation is running, also known as the simulation time. Additionally, you can see the duration of time that was spent in each state. To adjust the simulation time, in the Simulation tab, change the Stop time number.

With the Activity Profiler, you can quickly

- 1 Assess the behavior of your chart.
- 2 View states and transitions of your chart that are never entered or taken.

The Activity Profiler is not supported in referenced models or with fast restart mode.

### Debug with the Activity Profiler

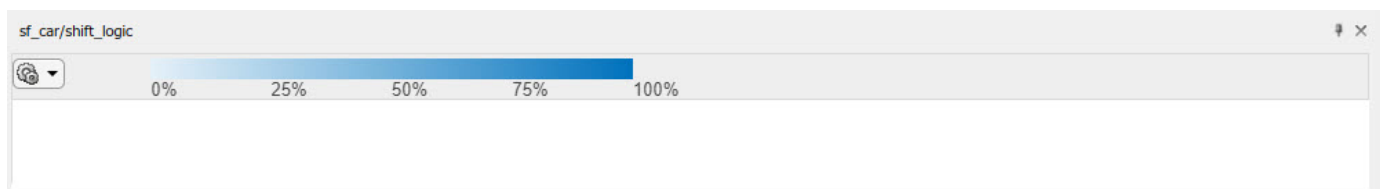
You can use the Activity Profiler as a complement to the Stateflow debugger. With the Activity Profiler, you can immediately see areas in your chart that were never reached or were constantly active, which can result in a faster debugging process. Additionally, you can view atomic states to see how often they are entered and how often their corresponding transitions are taken. With this information, it is easier to identify transition logic issues and solve problem areas in your chart such as:

- Transitions that are taken too often and serve no purpose
- Charts that are activated too often and slow down performance, such as an unexpected loop
- A bottleneck, such as a controller state that has multiple incoming transitions

After finding the specific problem areas, you can then set breakpoints to debug your chart. Without the Activity Profiler, you would have to set many breakpoints within your chart to pinpoint the problem area.

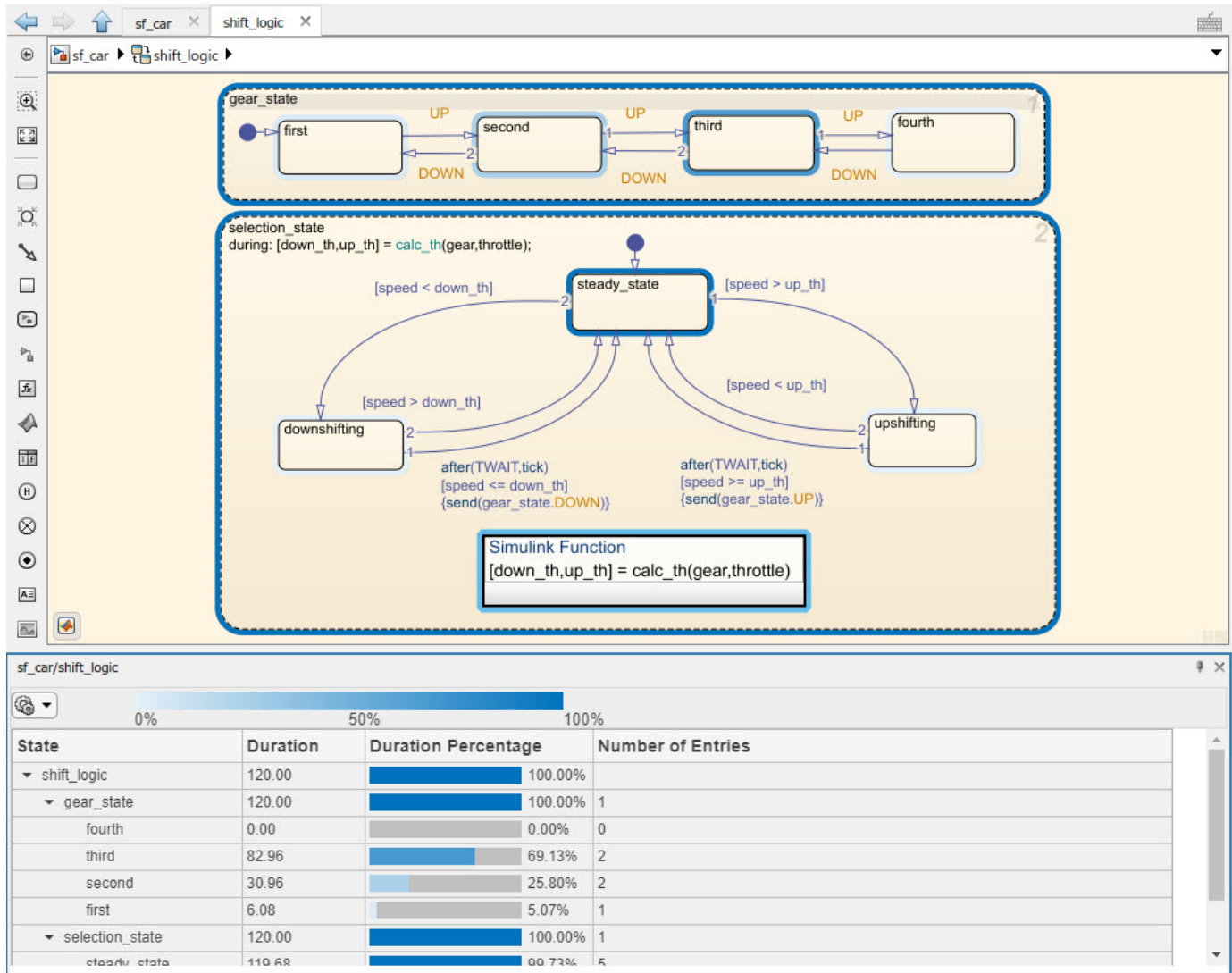
### Enable the Activity Profiler

To enable the Activity Profiler, in the Stateflow editor, in the **Debug** tab, click **Activity Profiler**. On the bottom of the Stateflow Editor, the Activity Profiler pane appears below your chart.



To show how each state, transition, and function is executed, click **Run**. In the Stateflow editor, your chart is highlighted to show how many times a state is entered, a transition is taken, or a function is executed. The Activity Profiler pane shows four columns: State, Duration, Duration Percentage, and Number of Entries.

The Activity Profiler pane remains empty any time that the simulation is running, or paused for debugging. Once the simulation is complete the Activity Profiler pane populates and the canvas highlighting appears.

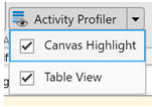


The **State** column lists the states in your Stateflow chart, along with their child states. The **Duration** column displays the duration of time (in seconds) spent in each state during the simulation. The **Duration Percentage** column shows a bar that represents what percentage of the runtime was spent in each state in relation to the parent chart. The **Number of Entries** column is the number of times each state was entered during simulation time.

You can also hover over a state or transition to see this data.

After running the simulation, you can toggle the highlighting and the Activity Profiler table off and on. In the Debug tab, open the Activity Profiler drop-down.






To turn off the canvas highlighting, clear **Canvas Highlight**. To turn off the Activity Profiler table, clear **Table View**.

## Activity Profiler Preferences

The Activity Profiler is customizable. You have the option to highlight specific group of objects in the chart or change the color scheme. Specifying the highlighting allows you to focus on only one area. Changing the color scheme can help you visualize the data in different ways.


### Highlighting Options

To change the highlighting options, in the Activity Profiler table, select the Activity Profiler preferences drop-down menu . Under **Canvas Highlight Options**, you can choose to enable highlighting for:

- States
- Transitions
- Functions

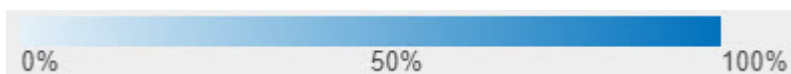
This is a global setting. If you change this setting in one model, all other models will only appear this way.

### Color Scheme Options

The Stateflow Activity Profiler allows you to configure how to view the Activity Profiler through different color schemes. To change the color scheme, select the Activity Profiler preferences drop-down menu . Under **Color Scheme**, select a color. You can choose from the following color schemes:

- Blue
- Red
- Green
- HotCold
- Autumn
- Cool
- Jet
- Parula

The table at the top of the Activity Profiler table shows how the colors appear on the map.

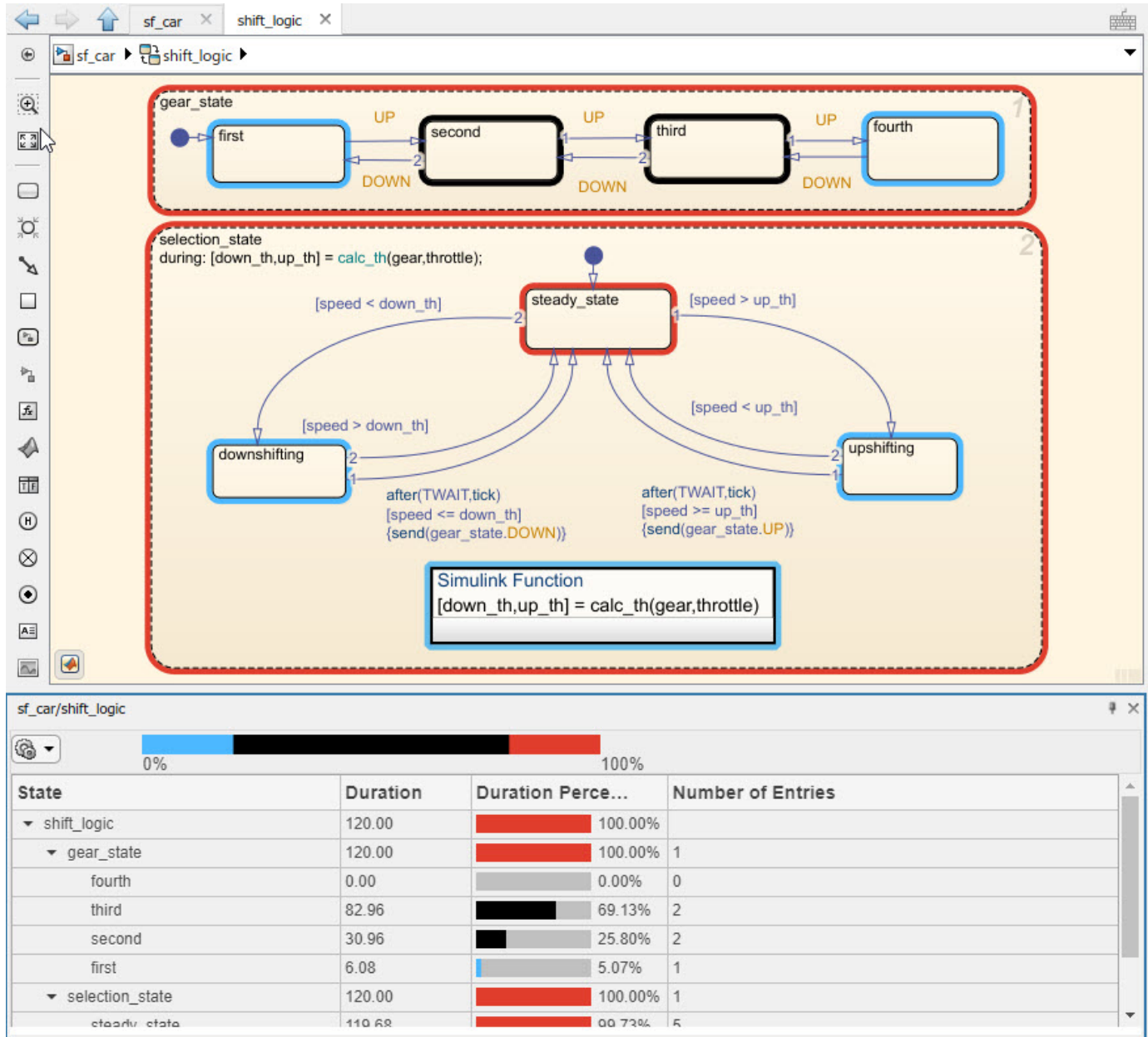


This legend for the **Blue** scheme shows how the color becomes gradually darker as the state is entered more often.

HotCoId is a highlighting scheme that is used to visualize the top 80% and low 20% of objects in a Stateflow chart.



The legend for HotCoId shows how states or transitions that are entered: 0% to 20% relative to the parent chart are highlighted blue. States that are entered 80% to 100% are highlighted in red.



In this chart, you can see that the states **upshifting**, **downshifting**, and **first** were active for 20% or less of the total runtime. The states **gear\_state**, **selection\_state**, and **steady\_state** were all active

for 80% or more of the runtime. The states **second** and **third** were active between 20 and 80% of the runtime. The state **fourth** was not entered at all and remains not highlighted.

## Explore

To view only subcharts and their child states, in the Activity Profiler table, right-click on the subchart name and select **Explore**. The Activity Profiler table adjusts to only include data about that subchart and its child states. Once you select the subchart as the current scope for the Activity Profiler pane, the duration percentage is in relation to the selected subchart.

## See Also

### More About

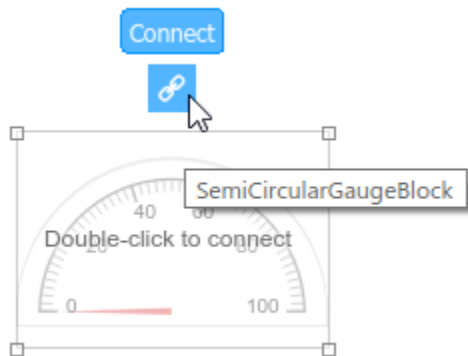
- “Resolve Undefined Symbols in Your Chart” on page 31-37
- “Detect Common Modeling Errors During Chart Simulation” on page 33-33
- “Set Data Properties” on page 12-5

## Connect Dashboard Blocks to Stateflow

Dashboard blocks help you to control and visualize your Stateflow chart during simulation and while your simulation is paused. Dashboard blocks can be used to bind to Stateflow in order to:

- Monitor self, child, and leaf activity of a state.
- Monitor local and output data within states, transitions, or graphical functions.

To connect a Dashboard block to data or to a Stateflow state, point to the Dashboard block. Above the block, a connect button appears.



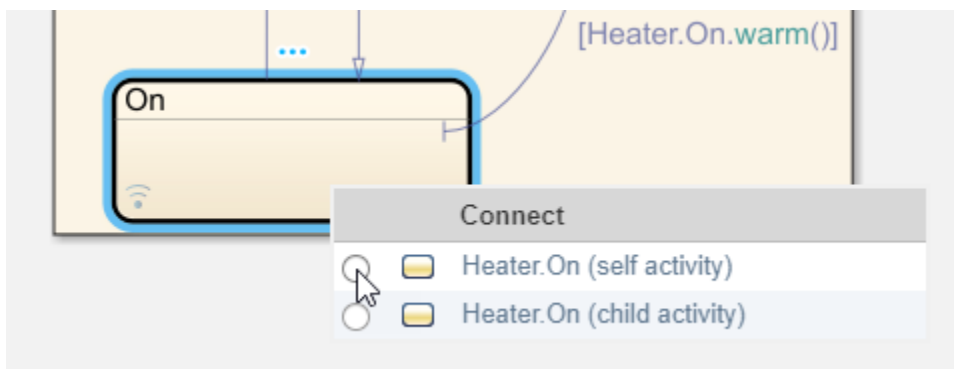
Click the Connect button, and navigate to the Stateflow object you want to connect to.

---

**Note** The **Double-click to connect** feature is not supported in Stateflow.

---

Click a state or transition, and choose which activity or data you want to connect.



Dashboard block connection is not supported for MATLAB Functions, Simulink Functions, or truth tables. For more information on Dashboard blocks, see “Control Simulations with Interactive Displays” (Simulink).

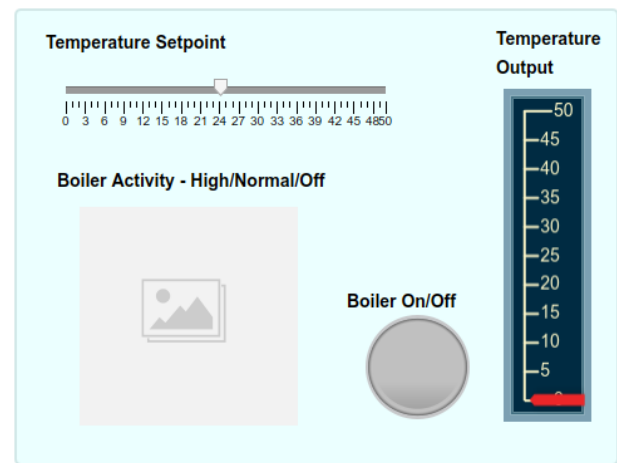
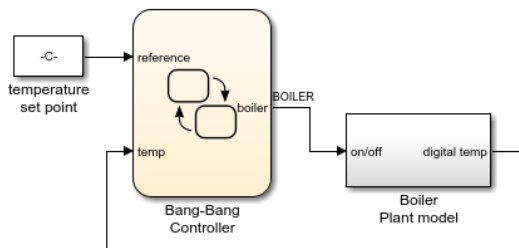
## Monitor a Boiler with Dashboard Blocks

In this Stateflow chart, Dashboard blocks are used to control the temperature setpoint for a boiler, visualize when the boiler is on or off and what mode it is operating in.

To open the model, in the command prompt type:

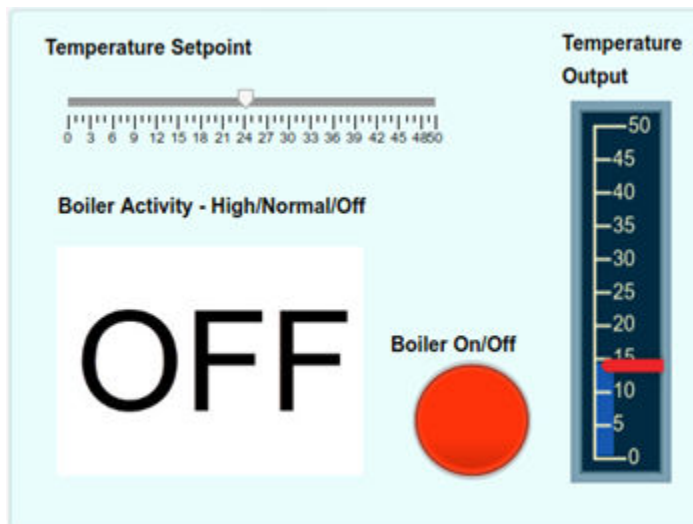
```
openExample('stateflow/DashboardBoilerExample')
sfDashboardBoiler
```

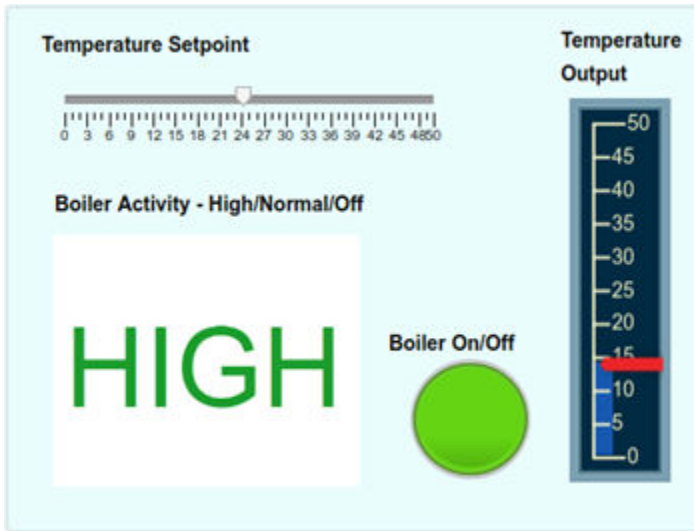
**A bang-bang temperature control system for a boiler**



Dashboard blocks are also used to visualize the temperature output by the boiler, which should match the temperature setpoint.

When you simulate the model, the LED light flashes to show if the boiler is off or on. A red light indicates that the boiler is off, while a green light indicates that the boiler is on. The **Boiler Activity - High/Normal/Off** block shows you if the boiler is operating in high or normal mode. When the boiler is not active, this block displays **OFF**.





## See Also

### More About

- "Tune and Visualize Your Model with Dashboard Blocks" (Simulink)
- "Decide How to Visualize Simulation Data" (Simulink)
- "Model Battery Management with Custom Code" on page 31-28

# Standalone Stateflow Charts for Execution in MATLAB

---

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Execute and Unit Test Stateflow Chart Objects” on page 35-8
- “Debug a Standalone Stateflow Chart” on page 35-13
- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24
- “Model a Communications Protocol by Using Chart Objects” on page 35-28
- “Implement a Financial Strategy by Using Stateflow” on page 35-32
- “Model a Fitness App by Using Standalone Charts” on page 35-35
- “Automate Control of Intelligent Vehicles by Using Stateflow Charts” on page 35-40
- “Model Bluetooth Low Energy Link Layer Using Stateflow” on page 35-44
- “Create an App for Analog Triggered Data Acquisition by Using Stateflow Charts” on page 35-47

## Create Stateflow Charts for Execution as MATLAB Objects

To combine the advantages of state machine programming with the full functionality of MATLAB, create a standalone Stateflow chart outside of a Simulink model. Save the standalone chart with the extension `.sfx` and execute it as a MATLAB object. Refine your design by using chart animation and graphical debugging tools.

With standalone charts, you can create MATLAB applications such as:

- MATLAB App Designer user interfaces that use mode logic to manage the behavior of widgets. See “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24.
- Communication protocols and data stream processing applications that use sequential logic. See “Model a Communications Protocol by Using Chart Objects” on page 35-28.
- Data Acquisition Toolbox™ or Instrument Control Toolbox™ applications that use timer-based logic to monitor and control external tasks. See “Implement a Financial Strategy by Using Stateflow” on page 35-32.

These applications can be shared and executed without requiring a Stateflow license. For more information, see “Share Standalone Charts” on page 35-4.

### Construct a Standalone Chart

To construct a standalone Stateflow chart, open the Stateflow Editor by using the `edit` function. For example, at the MATLAB Command Window, enter:

```
edit chart.sfx
```

If the file `chart.sfx` does not exist, the Stateflow Editor opens an empty chart with the name `chart`. Otherwise, the editor opens the chart defined by the `sfx` file.

After you save a standalone chart, the `help` function displays information about executing it in MATLAB:

```
help chart.sfx
```

To close a standalone chart from the MATLAB Command Window, use the `sfclose` function:

```
sfclose chart
```

### Create a Stateflow Chart Object

To execute a standalone chart in MATLAB, first create a Stateflow chart object. Use the name of the `sfx` file for the standalone chart as a function. Specify the initial values of data as name-value pairs. For example, this command creates the chart object `chartObject`, initializes `data1` and `data2`, and executes its default transition:

```
chartObject = chart('data1',value1,'data2',value2)
```

To display chart information, such as the syntax for execution, the values of the chart data, and the list of active states, use the `disp` function:

```
disp(chartObject)
```



## Execute a Standalone Chart

After you define a Stateflow chart object, you can execute the standalone chart by calling the `step` function (with data values, if necessary):

```
step(chartObject, 'data1', value1, 'data2', value2)
```

Alternatively, you can call one of the input event functions:

```
event_name(chartObject, 'data1', value1, 'data2', value2)
```

In either case, the values are assigned to local data before the chart executes.

If your chart has graphical or MATLAB functions, you can call them directly in the MATLAB Command Window. Calling a chart function does not execute the standalone chart.

```
function_name(chartObject, u1, u2)
```

---

**Note** If you use `nargin` in a graphical or MATLAB function in your chart, `nargin` counts the chart object as one of the input arguments. The value of `nargin` is the same whether you call the function from the chart or from the MATLAB Command Window.

---

You can execute a standalone chart without opening the Stateflow Editor. If the chart is open, then the Stateflow Editor highlights active states and transitions through chart animation.

For the purposes of debugging and unit testing, you can execute a standalone chart directly from the Stateflow Editor. During execution, you enter data values and broadcast events from the user interface. For more information, see “Execute and Unit Test Stateflow Chart Objects” on page 35-8.

You can execute a standalone chart from a MATLAB script, a Simulink model, or an App Designer user interface. For more information, see:

- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24

## Stop Chart Execution

To stop executing a chart, destroy the chart object by calling the `delete` function:

```
delete(chartObject)
```

After the chart object is deleted, any handles to the chart object remain in the workspace, but become invalid. To remove the invalid handle from the workspace, use the command `clear`:

```
clear chartObject
```

If you clear a valid chart object handle and there are other handles to the same chart object, the chart object is not destroyed. For example, when you are executing a chart, the Stateflow Editor contains internal handles to the chart object. Clearing the chart object handle from the workspace does not destroy the chart object or remove the chart animation highlighting in the editor. To reset the animation highlighting, right-click the chart canvas and select **Remove Highlighting**.

## Share Standalone Charts

You can share standalone charts with collaborators who do not have a Stateflow license.

If your collaborators have the same or a later version of MATLAB than you have, they can execute your standalone charts as MATLAB objects without opening the Stateflow Editor. Chart animation and debugging are not supported. Run-time error messages do not link to the state or transition in the chart where the error occurs.

---

**Note** To run standalone charts that you saved in R2019a or R2019b, your collaborators must have the same version of MATLAB.

---

If your collaborators have an earlier version of MATLAB, export a standalone chart to a format that they can use. You can only export to R2019a and later releases. To complete the export process, you need access to the versions of Stateflow from which and to which you are exporting.

- 1 Using the later version of Stateflow, open the standalone chart.
- 2 On the **State Chart** tab, select **Save > Previous Version**.
- 3 In the Export to Previous Version dialog box, specify a file name for the exported chart.
- 4 From the **Save as type** list, select the earlier version to which to export the chart.
- 5 Click **Save**.
- 6 Using the earlier version of Stateflow, open and resave the exported chart.

To export a chart from the MATLAB Command Window, call the Stateflow function `exportToVersion`. For more information, see “Export Chart to an Earlier Version of MATLAB”.

---

**Note** Attempting to execute an exported chart before resaving it will result in an error.

---

## Properties and Functions of Stateflow Chart Objects

A Stateflow chart object encapsulates data and operations in a single structure by providing:

- Private properties that contain the internal state variables for the standalone chart.
- A `step` function that calls the various operations implementing the chart semantics.

A chart object can have other properties and functions that correspond to the various elements present in the chart.

Standalone Chart Elements	Chart Object Elements
Local and constant data	Public properties
Input events	Functions that execute the chart
Graphical and MATLAB functions	Functions that you can call from the MATLAB Command Window

### Chart Object Configuration Options

When you create a chart object, you can specify chart behavior by including these configuration options as name-value pairs.

Configuration Option	Description	Example
-animationDelay	Specify the delay that the chart animation uses to highlight each transition segment. The default value is 0.01 seconds. To produce a chart with no animation delays, set to zero.	Create a chart object that has slow animation by specifying one-second delays.  <code>chartObject = chart('-animationDelay',1)</code>
-enableAnimation	Enable chart animation and debugging instrumentation. The default value is true.	Create a chart object that has animation and debugging instrumentation disabled.  <code>chartObject = chart('-enableAnimation',false)</code>
-eventQueueSize	Specify the size of the queue used for events and temporal logic operations. The default value is 20. To disable the queuing of events, set to zero. For more information, see “Events in Standalone Charts” on page 3-55.	Create a chart object that ignores all events without warning if they occur when the chart is processing another operation.  <code>chartObject = chart('-eventQueueSize',0)</code>
-executeInitStep	Enable the initial execution of default transitions. The default value is true.	Create a chart object but do not execute the default transition.  <code>chartObject = chart('-executeInitStep',false)</code>
-warningOnUninitializedData	Enable the warning about empty chart data after initializing the chart object. The default value is true.	Eliminate the warning when creating a chart object.  <code>chartObject = chart('-warningOnUninitializedData',false)</code>

### Initialization of Chart Data

In the Stateflow Editor, you can use the Symbols pane to specify initial values for chart data. When you create a chart object, chart data is initialized in alphabetical order according to its scope. Constant data is initialized first. Local data is initialized last.

If you use an expression to specify an initial value, then the chart attempts to resolve the expression by:

- Using the values of other data in the chart.
- Calling functions on the search path.

For example, suppose that you specify an initial value for the local data *x* by using the expression *y*. Then:

- If the chart has a constant called *y*, *y* is initialized before *x*. The local data *x* is assigned the same initial value as *y*.
- If the chart has a local data called *y*, *x* is initialized before *y*. The local data *x* is assigned to an empty array. If the configuration option `-warningOnUninitializedData` is set to `true`, a warning occurs.
- If the chart has no data named *y*, *x* is initialized by calling the function *y*. If the file *y.m* is not on the search path, this error occurs:

```
Undefined function or variable 'y'.
```

Stateflow does not search the MATLAB workspace to resolve initial values, so this error occurs even if there is a variable called `y` in the MATLAB workspace.

## Capabilities and Limitations

### Supported Features

- Classic chart semantics with MATLAB as the action language. You can use the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink. See “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18.

---

**Note** In standalone Stateflow charts, the operating system command symbol `!` is not supported. To execute operating system commands, use the function `system`.

---

- Exclusive (OR) and Parallel (AND) state decomposition with hierarchy. See “State Decomposition” on page 2-19 and “State Hierarchy” on page 2-17.
- Flow charts, graphical functions, and MATLAB functions. See “Reusable Components in Charts”.
- Conversion of MATLAB code to graphical functions by using the Pattern Wizard. See “Convert MATLAB Code into Stateflow Flow Charts” on page 5-18.
- Chart local and constant data without restriction to type. See “Execute and Unit Test Stateflow Chart Objects” on page 35-8.
- Input events. See “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24.
- Operators `hasChanged`, `hasChangedFrom`, and `hasChangedTo` that detect changes in the values of local data.

---

**Note** Standalone Stateflow charts do not support change detection on an element of a matrix or a field in a structure.

---

- Temporal logic operators:
  - `after`, `at`, and `every` operate on the number of input events, chart invocations (`tick`), and absolute time (`sec`). Use these operators in state on actions and as transition triggers.
  - `count` operates on the number of chart invocations (`tick`).
  - `temporalCount` operates on absolute time (`sec`, `msec`, and `usec`).
  - `elapsed` operates on absolute time (`sec`).

Standalone charts define absolute-time temporal logic in terms of wall-clock time, which is limited to 1 millisecond precision.

- Function `getActiveStates` to access the states that are active during execution of the chart. To store the active states as a cell array, enter:

```
states = getActiveStates(chartObject)
```

- Stateflow function `exportAsClass` that exports the standalone chart as the equivalent MATLAB class. Use this function to debug run-time errors that are otherwise difficult to diagnose. For example, suppose that you encounter an error while executing a Stateflow chart that controls a MATLAB application. If you export the chart as a MATLAB class file, you can replace the chart with the class in your application and diagnose the error by using the MATLAB debugger. To export the chart `chart.sfx` as a class file `chart.m`, enter:

```
Stateflow.exportAsClass('chart.sfx')
```

When you execute the MATLAB class, the Stateflow Editor does not animate the original chart.

### Limitations

Content specific to Simulink:

- Sample time and continuous-time semantics.
- C action language.
- Simulink functions and Simulink subsystems as states.
- Input, output, and parameter data.
- Data store memory data.
- Output and local events.
- Input, output, and local messages.

Other limitations:

- No Mealy or Moore semantics.
- No State Transition Tables.
- No Truth Table functions.
- No state-parented local data or functions.
- No transition actions (actions that execute after the source state for the transition is exited but before the destination state is entered).

### See Also

`disp` | `edit` | `exportAsClass` | `exportToVersion` | `help` | `sfclose`

### More About

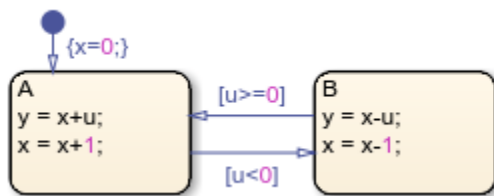
- “Execute and Unit Test Stateflow Chart Objects” on page 35-8
- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24
- “Implement a Financial Strategy by Using Stateflow” on page 35-32
- “Model a Communications Protocol by Using Chart Objects” on page 35-28

## Execute and Unit Test Stateflow Chart Objects

A standalone Stateflow chart is a MATLAB class that defines the behavior of a finite state machine. Standalone charts implement classic chart semantics with MATLAB as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

### Example of a Standalone Stateflow Chart

The file `sf_chart.sfx` contains the standalone Stateflow chart `sf_chart`. The chart has local data `u`, `x`, and `y`.



This example shows how to execute this chart from the Stateflow Editor and in the MATLAB Command Window.


### Execute a Standalone Chart from the Stateflow Editor

To unit test and debug a standalone chart, you can execute the chart directly from the Stateflow Editor. During execution, you enter data values and broadcast events from the user interface.

- 1 Open the chart in the Stateflow Editor:

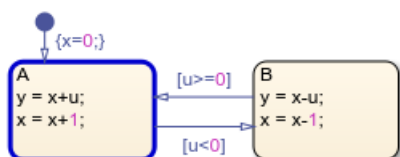
```
edit sf_chart.sfx
```

- 2


In the Symbols pane, enter a value of `u = 1` and click **Run** . The chart executes its default transition and:

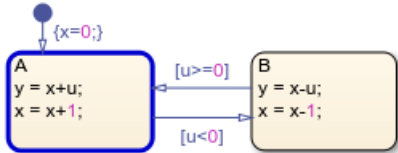
- Initializes `x` to the value of 0.
- Makes state A the active state.
- Assigns `y` to the value of 1.
- Increases the value of `x` to 1.

The chart animation highlights the active state A. The Symbols pane displays the values `u = 1`, `x = 1`, and `y = 1`. The chart maintains its current state and local data until the next execution command.




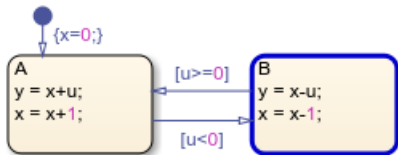
3

Click **Step** . Because the value of  $u$  does not satisfy the condition  $[u < 0]$  to transition out of state A, this state remains active and the values of  $x$  and  $y$  increase to 2. The Symbols pane now displays the values  $u = 1$ ,  $x = 2$ , and  $y = 2$ .




4

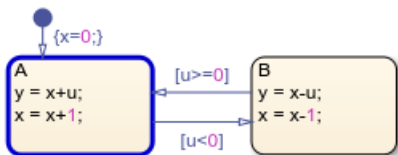
In the Symbols pane, enter a value of  $u = -1$  and click **Step** . The negative data value triggers the transition to state B. The Symbols pane displays the values  $u = -1$ ,  $x = 1$ , and  $y = 3$ .




5 You can modify the value of any chart data in the Symbols pane. For example, enter a value of  $x = 3$ . The chart will use this data value in the next time execution step.

6

Enter a value of  $u = 2$  and click **Step** . The chart transitions back to state A. The Symbols pane displays the values  $u = 2$ ,  $x = 4$ , and  $y = 5$ .



7

To stop the chart animation, click **Stop** .

To interrupt the execution and step through each action in the chart, add breakpoints before you execute the chart. For more information, see “Debug a Standalone Stateflow Chart” on page 35-13.

## Execute a Standalone Chart in MATLAB

You can execute a standalone chart in MATLAB without opening the Stateflow Editor. If the chart is open, then the editor highlights active states and transitions through chart animation.

1 Open the chart in the Stateflow Editor. In the MATLAB Command Window, enter:

```
edit sf_chart.sfx
```

2 Create the Stateflow chart object by using the name of the sfx file for the standalone chart as a function. Specify the initial value for the data  $u$  as a name-value pair.

```
s = sf_chart('u', 1)
```

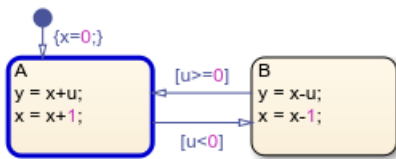
Stateflow Chart

```
Execution Function
y = step(s)
```

## Local Data

```
u      : 1
x      : 1
y      : 1
Active States: {'A'}
```

This command creates the chart object `s`, executes the default transition, and initializes the values of `x` and `y`. The Stateflow Editor animates the chart and highlights the active state `A`.



- 3 To execute the chart, call the `step` function. For example, suppose that you call the `step` function with a value of `u = 1`:

```
step(s, 'u', 1)
```

```
disp(s)
```

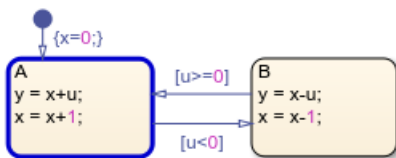
Stateflow Chart

```
Execution Function
y = step(s)
```

## Local Data

```
u      : 1
x      : 2
y      : 2
Active States: {'A'}
```

Because the value of `u` does not satisfy the condition `[u<0]` to transition out of state `A`, this state remains active and the values of `x` and `y` increase to 2.



- 4 Execute the chart again, this time with a value of `u = -1`:

```
step(s, 'u', -1)
```

```
disp(s)
```

Stateflow Chart

```
Execution Function
y = step(s)
```

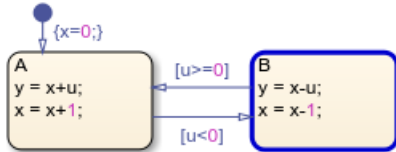


```

Local Data
  u      : -1
  x      : 1
  y      : 3
Active States: {'B'}

```

The negative data value triggers the transition to state B. The value of x decreases to 1 and the value of y increases to 3.



- 5 To access the value of any chart data, use dot notation. For example, you can assign a value of 3 to the local data x by entering:

```
s.x = 3
```

Stateflow Chart

```

Execution Function
y = step(s)

```

```

Local Data
  u      : -1
  x      : 3
  y      : 3
Active States: {'B'}

```

The standalone chart will use this data value in the next time execution step.

- 6 Execute the chart with a value of u = 2:

```
step(s, 'u', 2)
```

```
disp(s)
```

Stateflow Chart

```

Execution Function
y = step(s)

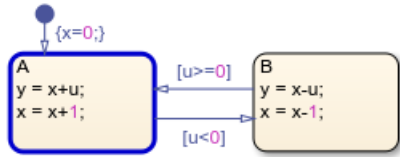
```

```

Local Data
  u      : 2
  x      : 4
  y      : 5
Active States: {'A'}

```

The chart transitions back to state A and modifies the values of x and y.



- 7 To stop the chart animation, delete the Stateflow chart object `s`:  
`delete(s)`

## Execute Multiple Chart Objects

You can execute multiple chart objects defined by the same standalone chart. Concurrent chart objects maintain their internal state independently, but remain associated to the same chart in the editor. The chart animation reflects the state of the chart object most recently executed. Executing multiple chart objects while the Stateflow Editor is open can produce confusing results and is not recommended.

## See Also

`delete` | `disp` | `edit`

## More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Debug a Standalone Stateflow Chart” on page 35-13
- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24

## Debug a Standalone Stateflow Chart

A standalone Stateflow chart is a MATLAB class that defines the behavior of a finite state machine. Standalone charts implement classic chart semantics with MATLAB as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

To enable debugging, set a breakpoint in the standalone chart or in a MATLAB script that executes the chart. Breakpoints pause the execution of a chart. While the execution is paused, you can step through each action in the chart, view data values, and interact with the MATLAB workspace to examine the state of the chart.

---

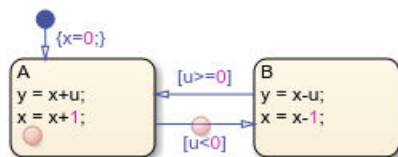
**Note** When debugging a standalone chart that you execute from a MATLAB script, first open the Stateflow Editor. Attempting to debug a standalone chart before opening the editor at least once can produce unexpected results.

---

For information on debugging Stateflow charts in Simulink models, see “Debugging Stateflow Charts” on page 33-2.

### Set and Clear Breakpoints

Breakpoints appear as circular red badges. For example, this chart contains breakpoints on the state A and on the transition from A to B.



You can set breakpoints on charts, states, and transitions.

#### Breakpoints on Charts

To set a breakpoint on a chart, right-click inside the chart and select **Set Breakpoint on Chart Entry**. This type of breakpoint pauses the execution before entering the chart.

To remove the breakpoint, right-click inside the chart and clear the **Set Breakpoint on Chart Entry** option.

#### Breakpoints on States and Transitions

You can set different types of breakpoints on states and transitions.

Object	Breakpoint Type
State	On State Entry — Pause the execution before performing the state entry actions.

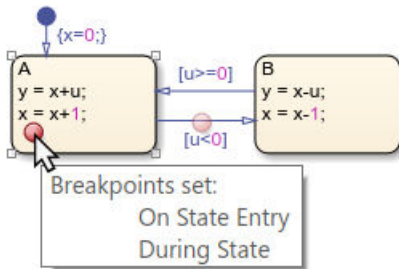
Object	Breakpoint Type
	During State — Pause the execution before performing the state during actions.
	On State Exit — Pause the execution after performing the state exit actions.
Transition	When Transition is Tested — Pause the execution before testing that the transition is a valid path. If no condition exists on the transition, this breakpoint type is not available.
	When Transition is Valid — Pause the execution after the transition is valid, but before taking the transition.

To set a breakpoint on a state or transition, right-click the state or transition and select **Set Breakpoint**. For states, the default breakpoints are **On State Entry** and **During State**. For transitions, the default breakpoint is **When Transition is Valid**. To change the type of breakpoint, click the breakpoint badge and select a different configuration of breakpoints. For more information, see “Manage Breakpoint Types and Conditions” on page 35-14.

To remove the breakpoint, right-click the state or transition and select **Clear Breakpoint**. To remove all of the breakpoints in a chart, right-click inside the chart and select **Clear All Breakpoints In Chart**.

### Manage Breakpoint Types and Conditions

A breakpoint badge can represent more than one type of breakpoint. To see a tooltip that lists the breakpoint types that are set on a state or transition, point to its badge. In this example, the badge on the state A represents two breakpoint types: **On State Entry** and **During State**.



To change the type of breakpoint on an object, click the breakpoint badge. In the Breakpoints dialog box, you can select a different configuration of breakpoints, depending on the object type. Clearing all of the check boxes in the Breakpoints dialog box removes the breakpoint.

<input checked="" type="checkbox"/> On State Entry	<input type="text"/>
<input checked="" type="checkbox"/> During State	<input type="text"/>
<input type="checkbox"/> On State Exit	<input type="text"/>

To limit the number of times that the execution stops at a breakpoint, add a condition to the breakpoint. By default, a Stateflow chart pauses whenever it reaches a breakpoint. When you add a condition to a breakpoint, the chart pauses at the breakpoint only when the condition is true. For

example, with these conditions, the breakpoints on state A pause the execution of the chart only when the value of x is negative.

<input checked="" type="checkbox"/> On State Entry	<input type="text" value="x&lt;0"/>
<input checked="" type="checkbox"/> During State	<input type="text" value="x&lt;0"/>
<input type="checkbox"/> On State Exit	<input type="text"/>

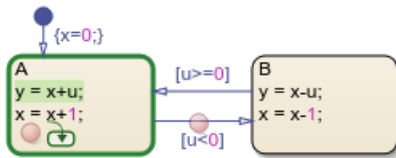
To specify a condition for the breakpoint, you can use any valid MATLAB expression that combines numerical values and Stateflow data objects that are in scope at the breakpoint.

### Control Chart Execution After a Breakpoint

When execution stops at a breakpoint, Stateflow enters debugging mode.

- The MATLAB command prompt changes to K>>.
- The Symbols pane displays the value of each data object in the chart.
- The chart highlights active elements in blue and the currently executing object in green.

For example, when the execution stops at the breakpoint in state A, the border of the state and the first statement in the state entry action appear highlighted in green.





An execution status badge appears in the graphical object where execution pauses.

Badge	Description
	Execution is paused before entering a chart or in a state entry action.
	Execution is paused in a state during action.
	Execution is paused in a state exit action.
	Execution is paused before testing a transition.
	Execution is paused before taking a valid transition.

When the chart is paused at a breakpoint, you can continue the execution by using:

- Buttons in the **Debug** tab
- The MATLAB Command Window
- Keyboard shortcuts

Action	Debug Tab Button	MATLAB Command	Keyboard Shortcut	Description
Continue		dbcont	<b>Ctrl+T</b>	Continue execution to the next breakpoint.
Step Over		dbstep	<b>F10</b>	Advance to the next step in the chart execution. At the chart level, possible steps include: <ul style="list-style-type: none"> <li>• Enter the chart</li> <li>• Execute a transition action</li> <li>• Activate a state</li> <li>• Execute a state action</li> </ul> For more information, see “Execution of a Stateflow Chart” on page 3-23.
Step In		dbstep in	<b>F11</b>	From a state or transition action that calls a function, advance to the first executable statement in the function.  From a statement in a function containing another function call, advance to the first executable statement in the second function.  Otherwise, advance to the next step in the chart execution. (See the Step Over option.)
Step Out		dbstep out	<b>Shift+F11</b>	From a function call, return to the statement calling the function.  Otherwise, continue execution to the next breakpoint. (See the Continue option.)
Stop		dbquit	<b>Ctrl+Shift+T</b>	Exit debug mode and interrupt the execution.  When you execute the standalone chart from the Stateflow Editor, this action removes the chart object from the MATLAB workspace.

In state or transition actions containing more than one statement, you can step through the individual statements one at a time by selecting **Step Over**. The Stateflow Editor highlights each statement before executing it.

**Note** Because standalone charts define temporal logic in terms of wall-clock time, a temporal logic operator can become valid while a chart is paused at a breakpoint. In this case, the chart exits debugging mode and the execution continues to the next breakpoint.

---

## Examine and Change Values of Chart Data

When Stateflow is in debug mode, the Symbols pane displays the value of each data object in the chart. You can also examine data values by pointing to a state or a transition in the chart. A tooltip displays the value of each data object used in the selected state or transition.

To test the behavior of your chart, in the Symbols pane, you can change the value of a data object during execution. Alternatively, at the debugging prompt, enter the new value by using the keyword `this` in place of the chart object name. For instance, to change the value of the local data `x`, enter:

```
this.x = 7
```

The new value appears in the Symbols pane.

**Note** When debugging a chart in a Simulink model, do not use the keyword `this`. Instead, you can access all Stateflow data directly at the debugging prompt. For more information, see “View and Modify Data in the MATLAB Command Window” on page 33-12.

---

## See Also

### More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Execute and Unit Test Stateflow Chart Objects” on page 35-8
- “Debugging Stateflow Charts” on page 33-2

## Execute Stateflow Chart Objects Through Scripts and Models

A standalone Stateflow chart is a MATLAB class that defines the behavior of a finite state machine. Standalone charts implement classic chart semantics with MATLAB as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

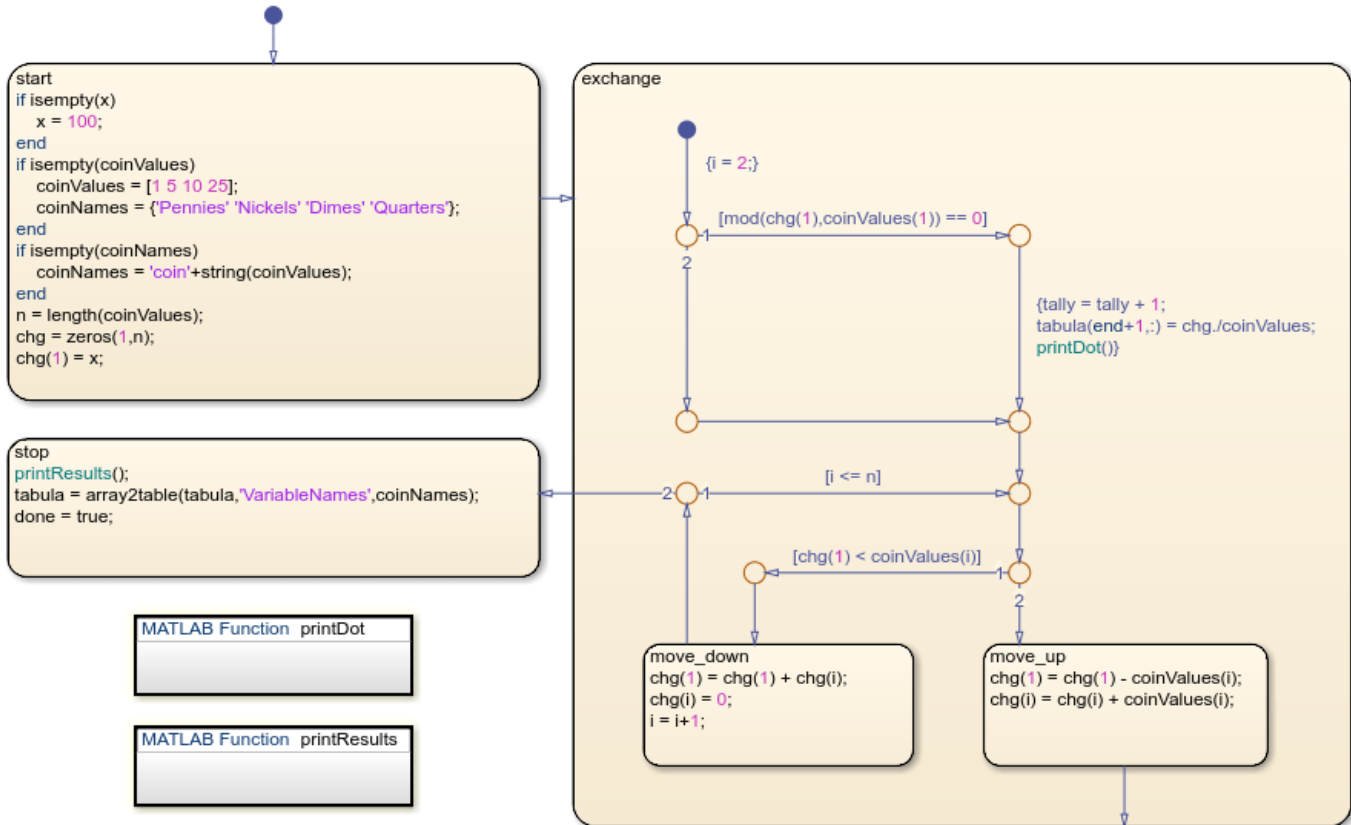
This example shows how to execute a standalone Stateflow chart by using a MATLAB script or a Simulink model.

### Count Ways to Make Change for Currency

The file `sf_change.sfx` defines a standalone Stateflow chart that counts the number of ways to make change for a given amount of money. The chart contains these data objects:

- `x` is the amount of money to change. The default value is 100.
- `coinValues` is a vector of coin denominations arranged in increasing order. `coinNames` is an array of corresponding coin names. The default values represent standard American coins (pennies, nickels, dimes, and quarters).
- `tally` is the number of valid change configurations.
- `tabula` is an array containing the different valid change configurations.
- `chg`, `done`, `i`, and `n` are local data used by the change-counting algorithm.
- `textWidth` and `quietMode` are local data that control how the chart displays its results.





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The chart begins with a potential change configuration consisting entirely of the lowest-value coins, specified by an index of 1. At each execution step, the state exchange modifies this configuration in one of two ways:

- The substate `move_up` exchanges some lowest-value coins for a coin with a higher value, specified by the index `i`.
- The substate `move_down` exchanges all of the coins with the value specified by the index `i` for lowest-value coins. Then `move_up` exchanges some lowest-value coins for a coin with a value specified by the index `i+1` or higher.

A potential change configuration is valid when the number of cents represented by the lowest-value coins is divisible by the value of that type of coin. When the chart encounters a new valid configuration, it increments `tally` and appends the new configuration to `tabula`.

When no more coin exchanges are possible, the state `stop` becomes active. This state prints the results of the computation, transforms the contents of `tabula` to a table, and sets the value of `done` to `true`.

## Execute Standalone Chart in a MATLAB Script

To run the change-counting algorithm to completion, you must execute the standalone chart multiple times. For example, the MATLAB script `sf_change_script.m` creates a chart object `chartObj` and initializes the value of the local data `x` to 27. The configuration option `'` -

`warningOnUninitializedData`, which the script sets to `false`, eliminates the warning that `tabula` is an empty array in the new chart object. The `while` loop executes the chart until the local data `done` becomes `true`. Finally, the script displays the value of `tabula`.

```
chartObj = sf_change('x',27,'-warningOnUninitializedData',false);

while ~chartObj.done
    step(chartObj);
end

disp(chartObj.tabula)
```

When you run this script, the standalone chart calculates the number of ways to make change for 27 cents by using standard American coins:

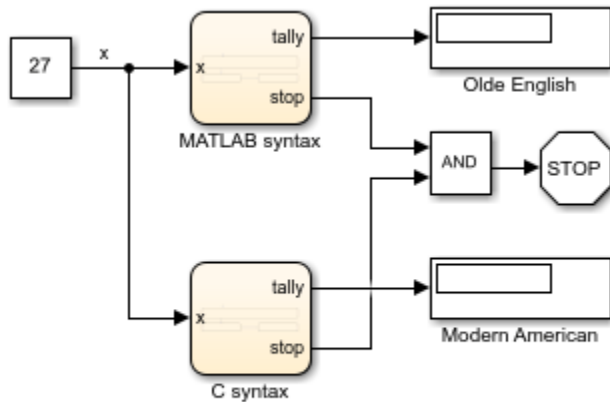
```
sf_change_script
```

```
.....
There are 13 ways to make change for 27 cents.
  Pennies   Nickels   Dimes   Quarters
  _____
    27         0         0         0
    22         1         0         0
    17         2         0         0
    12         3         0         0
     7         4         0         0
     2         5         0         0
    17         0         1         0
    12         1         1         0
     7         2         1         0
     2         3         1         0
     7         0         2         0
     2         1         2         0
     2         0         0         1
```

To determine the number of ways to make change for a different amount, or to use a different system of currency, change the values of `x` and `coinValues`. For example, to use British currency, initialize `coinValues` to `[1 2 5 10 20 25 50]`.

## Execute Standalone Chart in a Simulink Model

You can execute a standalone Stateflow chart from within a Simulink model. For example, the model `sf_change_model` contains two Stateflow charts that use the standalone chart `sf_change` to count the number of ways to make change for 27 cents in two different currency systems. You can simulate the model, but the functions that execute the standalone chart do not support code generation.



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Each chart contains these states:

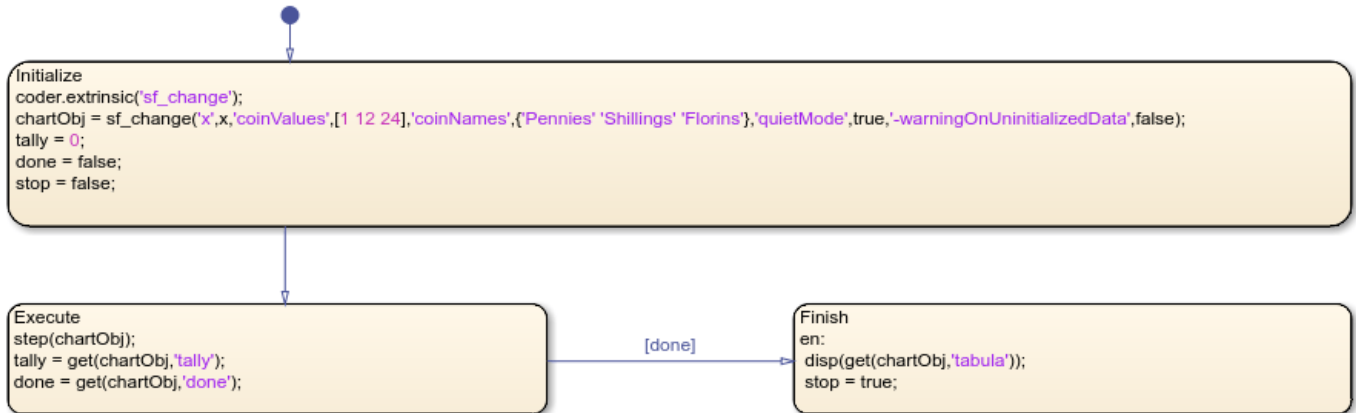
- **Initialize** creates a local chart object `chartObj` that implements the change-counting algorithm for the input value `x`.
- **Execute** calls the `step` function to execute the standalone chart and stores the result as the output data `tally`.
- **Finish** displays the results of the algorithm in the Diagnostic Viewer window and sets the value of the output data `done` to `true`.

When both charts reach their respective **Finish** state, the simulation of the model stops and the **Display** blocks show the final values of the two tallies.

### Execution Using MATLAB as the Action Language

The chart `MATLAB syntax` uses MATLAB as the action language. To execute the standalone Stateflow chart, this chart must follow these guidelines:

- The local variable `chartObj` that contains the handle to the chart object has type `Inherit`:  
From definition in `chart`.
- Before creating the chart object, the **Initialize** state calls the `coder.extrinsic` function to declare `sf_change` as an extrinsic function that is restricted for code generation in Simulink. See “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40.
- The **Execute** and **Finish** states access the local data for the standalone chart by calling the `get` function.



When you simulate this chart with an input of  $x = 27$ , the Display block *Old English* shows a tally of 4. The Diagnostic Viewer window shows these results:

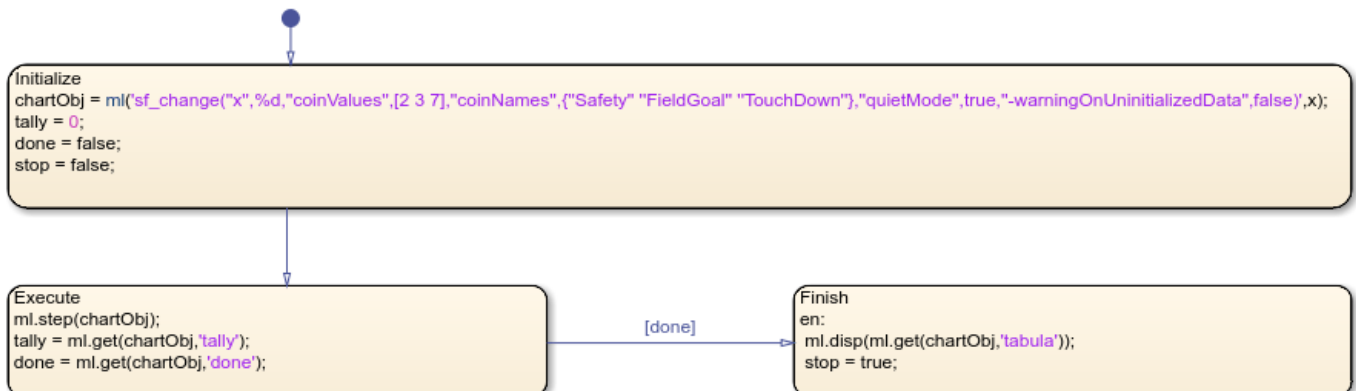
Pennies	Shillings	Florins
27	0	0
15	1	0
3	2	0
3	0	1

### Execution Using C as the Action Language

The chart C syntax uses C as the action language. To execute the standalone Stateflow chart, this chart must follow these guidelines:

- The local variable `chartObj` that contains the handle to the chart object has type `ml`.
- The `Initialize` state calls the `ml` function to create the chart object.
- The `Execute` and `Finish` states use the `ml` namespace operator to access the `step`, `get`, and `disp` functions to execute the standalone chart, access its local data, and display the results of the algorithm.

For more information, see “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20.



When you simulate this chart with an input of  $x = 27$ , the Display block Modern American shows a tally of 13. The Diagnostic Viewer window shows these results:

Safety	FieldGoal	TouchDown
12	1	0
9	3	0
6	5	0
3	7	0
0	9	0
10	0	1
7	2	1
4	4	1
1	6	1
5	1	2
2	3	2
3	0	3
0	2	3

## See Also

### More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Execute and Unit Test Stateflow Chart Objects” on page 35-8
- “Call Extrinsic MATLAB Functions in Stateflow Charts” on page 31-40
- “Access MATLAB Functions and Workspace Data in C Charts” on page 16-20

## Design Human-Machine Interface Logic by Using Stateflow Charts

This example shows how to model the logic of a graphical user interface in a standalone Stateflow® chart. Standalone charts implement classic chart semantics with MATLAB® as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink®. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

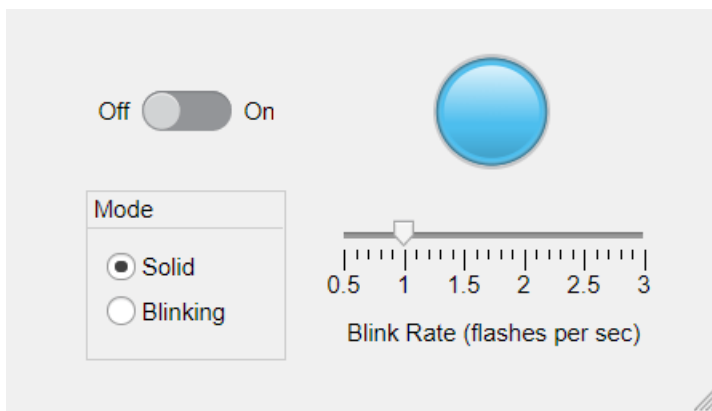
You can execute a standalone Stateflow chart by invoking its input events and using temporal operators. The event- and timer-driven execution workflow is suitable for designing the logic underlying human-machine interfaces (HMIs) and graphical user interfaces (UIs).

- When you use the MATLAB App Designer, callback functions from the interface widgets invoke events in the chart.
- In the Stateflow chart, temporal operators and local data control the properties of the user interface.

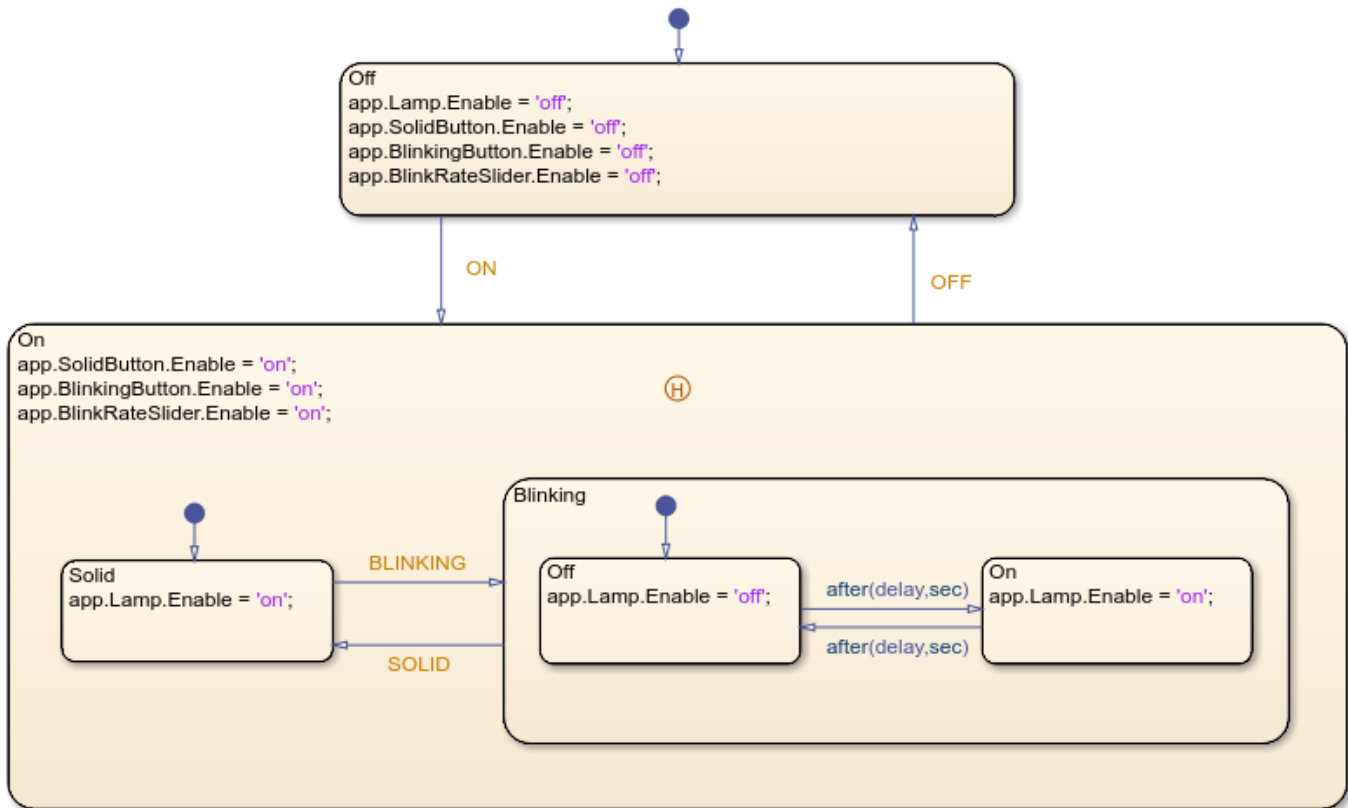
For more information on how to use MATLAB to create graphical user interfaces, see “Develop Apps Using App Designer”.

### Control an App Designer User Interface

This user interface contains an On-Off switch that controls a lamp. When the switch is in the On position, the lamp lights up in one of two modes, solid or blinking, depending on the position of the Mode option button. You control the rate of blinking by moving the Blink Rate slider.



The file `sf_lamp_logic.sfx` defines a standalone Stateflow chart that implements the logic for the user interface. The chart has input events (`ON`, `OFF`, `BLINKING`, and `SOLID`) and local data (`delay` and `app`). The actions in the chart control which widgets are accessible from each state. For instance, the actions in the `Off` state cause the Lamp widget, the Mode option buttons, and the Blink Rate slider in the user interface to appear dimmed.



In the **On** state, the substates **Solid** and **Blinking** denote the two modes of operation. To implement a blinking lamp, the chart relies on the temporal logic operator `after`. When the chart enters the state **Blinking.Off**, the expression `after(delay,sec)` on the outgoing transition creates a MATLAB timer object that executes the chart after a number of seconds. The chart then transitions to the state **Blinking.On** and creates another timer object to trigger the transition back to **Blinking.Off**. While the chart continually transitions between the two states, you can adjust the rate of blinking by changing the value of the local data `delay` or transition out of blinking mode by invoking the input events **SOLID** or **OFF**.

The history junction in the **On** state preserves information on the most recently active substate so that the user interface returns to the previous mode of operation when you turn on the lamp.

### Execute Standalone Chart by Using Events

You can execute the standalone chart by calling its input event functions in the MATLAB Command Window. The Stateflow Editor shows the effects of each of these commands by highlighting active states and transitions through chart animation.

1. Open the standalone chart in the Stateflow Editor.

```
edit sf_lamp_logic.sfx
```

2. Create the chart object `L` and initialize the value of `delay` to 0.5. This value corresponds to a blinking rate of one flash per second.

```
L = sf_lamp_logic('delay',0.5);
```

3. Turn on the lamp.

```
ON(L)
```

4. Switch to blinking mode.

```
BLINKING(L)
```

5. Set the value of `delay` to 0.25. This value corresponds to a blinking rate of two flashes per second.

```
L.delay = 0.25;
```

6. Switch to solid mode.

```
SOLID(L)
```

7. Turn off the lamp.

```
OFF(L)
```

8. Delete the chart object `L` from the MATLAB workspace.

```
delete(L)
```

### Connect Standalone Chart to User Interface

To establish a bidirectional connection between the user interface and the standalone Stateflow chart, open the App Designer window and select **Code View**.

1. In the App Designer window, create a private property `lampLogic` to store the handle to the Stateflow chart object.

```
properties (Access = private)
    lampLogic
end
```

2. Create a `StartupFcn` callback function that creates the chart object and sets its local data `app` to the user interface handle. Assign the chart object handle to the `lampLogic` private property.

```
% Code that executes after component creation
function StartupFcn(app)
    app.lampLogic = sf_lamp_logic('delay',0.5,'app',app);
end
```

3. Create a `CloseRequestFcn` callback function that deletes the chart object when you close the user interface.

```
% Close request function: UIFigure
function UIFigureCloseRequest(app, event)
    delete(app.lampLogic);
    delete(app);
end
```

4. For each one of the user interface widgets, add a callback function that invokes the appropriate event on the standalone chart.

- `ValueChangedFcn` callback function for Switch widget:

```
function SwitchValueChanged(app,event)
    value = app.Switch.Value;
```



```

switch lower(value)
    case 'off'
        OFF(app.lampLogic);
    case 'on'
        ON(app.lampLogic);
end
end
end

```

- SelectionChangedFcn callback function for Mode Button widget:

```

function ModeButtonGroupSelectionChanged(app,event)
    selectedButton = app.ModeButtonGroup.SelectedObject;
    if app.SolidButton == selectedButton
        SOLID(app.lampLogic);
    else
        BLINKING(app.lampLogic);
    end
end
end

```

- ValueChangedFcn callback function for Blink Rate Slider widget:

```

function BlinkRateSliderValueChanged(app,event)
    app.lampLogic.delay = round(0.5/app.BlinkRateSlider.Value,2);
end

```

When you run the user interface, you can observe the effects of adjusting the control widgets on the chart canvas and on the lamp widget.

## See Also

after

## More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Activate a Stateflow Chart by Sending Input Events” on page 14-7
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “Record State Activity by Using History Junctions” on page 8-2
- “Develop Apps Using App Designer”

## Model a Communications Protocol by Using Chart Objects

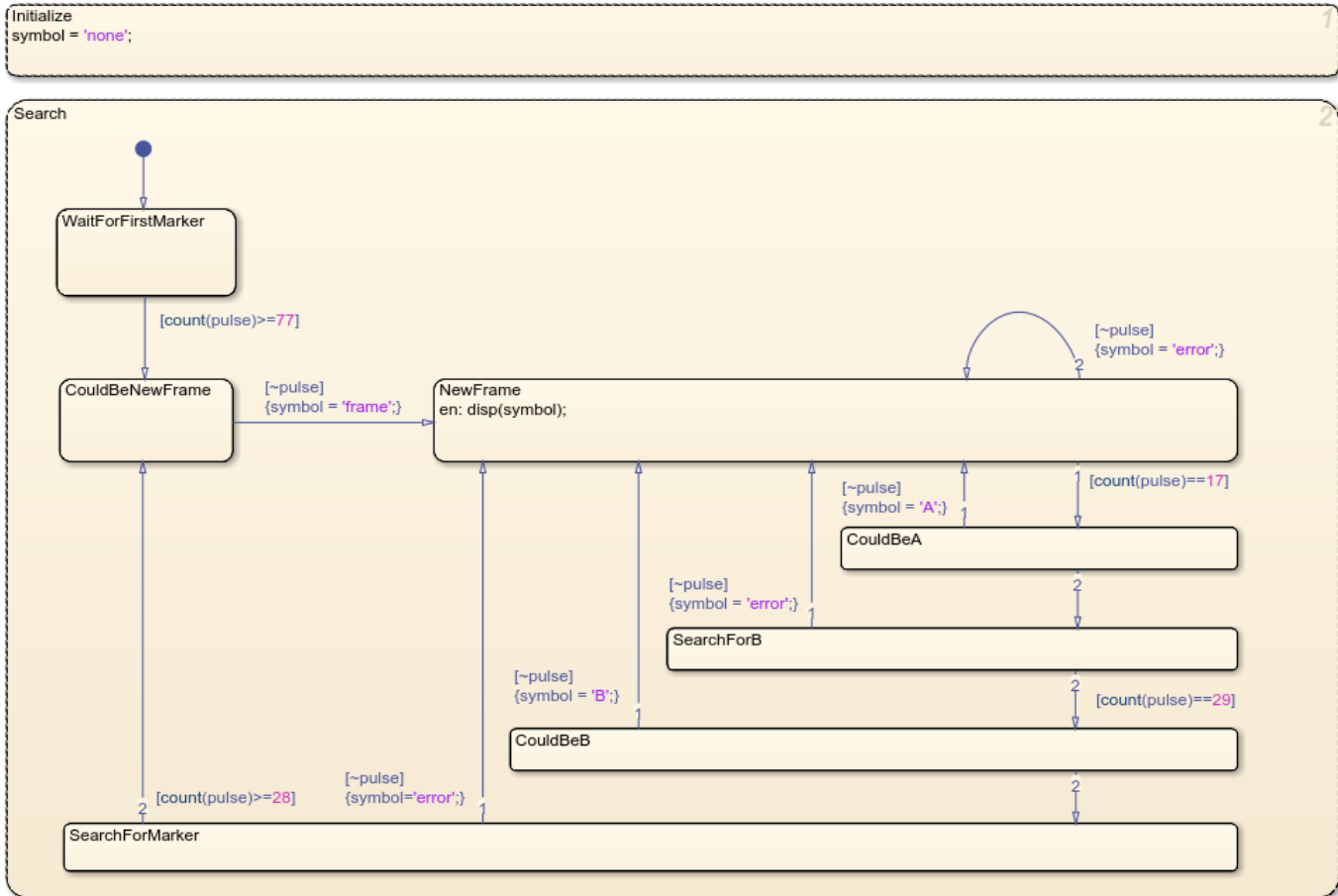
This example shows how to use a standalone Stateflow® chart to model a frame-synchronization and symbol-detection component in a communications system. Standalone charts implement classic chart semantics with MATLAB® as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink®. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

### Implement a Symbol-Detection Algorithm

In this example, the input to the communications system consists of a binary signal of zeros and ones received every 10 milliseconds. The input signal can contain any combination of:

- A 770-ms pulse (77 consecutive ones) to mark the beginning and end of a frame of data and to ensure system synchronization.
- A 170-ms pulse (17 consecutive ones) to indicate symbol A.
- A 470-ms pulse (47 consecutive ones) to indicate symbol B.

The file `sf_frame_search.sfx` defines a standalone Stateflow chart that implements this communication protocol. The chart consists of two outer states in parallel decomposition. The `Initialize` state resets the value of the local data `symbol` at the start of each execution step. The `Search` state contains the logic that defines the symbol-detection algorithm. When this state detects one of the pulses allowed by the communication protocol, the name of the corresponding symbol is stored as `symbol` and displayed in the MATLAB Command Window. Parallel decomposition enables the chart to preprocess the input data. For more information, see “State Decomposition” on page 2-19.



To track the length of a pulse through several execution steps, the chart uses the `count` operator. This operator simplifies the design of the chart by eliminating the need for a manual counter. For example, the condition `[count(pulse)==17]` guards the outgoing transition from the substate `NewFrame`. This condition becomes true when the data `pulse` is one for 17 consecutive execution steps. In this case, the chart transitions to the `CouldBeA` substate. If this transition is followed by an input of zero, then the chart registers the reception of symbol A and transitions back to the `NewFrame` substate. Otherwise, the chart transitions to the `SearchForB` state from which the condition `[count(pulse)==29]` searches for an additional 29 ones to mark symbol B.

### Execute Standalone Chart

In the MATLAB script `sf_frame_tester.m`, the sample code generates a short signal consisting of several valid pulses and one transmission error. The error consists of a 470-ms pulse that is too long to represent symbol A and too short to represent symbol B.

```
%% Test Symbol Detection Algorithm
% Generate a short signal consisting of several valid pulses and one
% transmission error.

f = sf_frame_search('pulse','0'); % create chart object
sendPulse(f,77);                 % frame marker
sendPulse(f,17);                 % A
```

```

sendPulse(f,47);           % B
sendPulse(f,37);         % transmission error
sendPulse(f,47);         % B
sendPulse(f,17);         % A
sendPulse(f,77);         % frame marker
delete(f);               % delete chart object

function sendPulse(f,n)
% Send a pulse of n ones and one zero to chart object f.

for i = 1:n
    step(f,'pulse',1);
    printDot(1)
end

printDot(0)
step(f,'pulse',0);

function printDot(x)
    persistent k
    if isempty(k)
        k = 1;
    end

    if x == 0
        fprintf('\n');
        k = 1;
    elseif k == 50
        fprintf('\n');
        k = 1;
    else
        fprintf('.');
        k = k+1;
    end
end
end
end

```

Running the script produces these results in the MATLAB Command Window:

```

.....
.....
frame
.....
A
.....
B
.....
error
.....
B
.....
A
.....
.....
frame

```

During the simulation, the chart animation provides a visual indication of the runtime behavior of the algorithm.

## **See Also**

count

## **More About**

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “State Decomposition” on page 2-19

## Implement a Financial Strategy by Using Stateflow

This example shows how to use a standalone Stateflow® chart to model a financial trading strategy known as *Bollinger Bands*. Standalone charts implement classic chart semantics with MATLAB® as the action language. You can program the chart by using the full functionality of MATLAB, including those functions that are restricted for code generation in Simulink®. For more information, see “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2.

### Compute Bollinger Bands

The Bollinger Bands trading strategy is to maintain a moving average of  $N$  stock prices for some commodity and issuing trading instructions depending on the value of the stock:

- "Buy" when the value of the stock drops  $K$  standard deviations below the moving average.
- "Sell" when the value of the stock rises  $K$  standard deviations above the moving average.
- "Hold" when the value of the stock is within  $K$  standard deviations of the moving average.

Typical implementations for this strategy use values of  $N = 20$  and  $K = 2$ .

The file `sf_stock_watch.sfx` defines a standalone Stateflow chart that implements this financial strategy. The chart consists of two outer states in parallel decomposition.

- The `StockTicker` subchart records the current price of a stock. The subchart hides the details for calculating stock prices. To access real-time market data from financial data providers, one possible implementation involves the use of the Datafeed Toolbox™. For details, see “Datafeed Toolbox”.
- The `FinancialAdvisor` state uses the last  $N$  stock prices to compute high and low bands. Depending on the current price relative to these bands, the state generates "buy," "sell," or "hold" instructions. The action on `every(1, sec)` creates a MATLAB® timer to execute the chart every second. See “Control Chart Execution by Using Temporal Logic” on page 16-36.

Parallel decomposition is a common design pattern that enables your algorithm to preprocess input data. For more information, see “State Decomposition” on page 2-19.

StockTicker

1

FinancialAdvisor

2

```

entry:
buffer = [price];
on every(1,sec):
if length(buffer) == N
    buffer(1) = [];
end
buffer(end+1) = price;

```

```

BurnIn
en:
fprintf('Loading data... Ready in 5 ');
du:
fprintf('%d ', 5 - length(buffer));
ex:
fprintf('0: \n');

```

[length(buffer)&gt;=5]

Trade

```

en,du:
sigma = std(buffer);
mid = mean(buffer);
low = mid-K*sigma;
high = mid+K*sigma;

```

```

flat
fprintf('HOLD at %g\n',price);

```

[price&gt;=0.5\*(mid+low)]

2 [price&lt;low]

[price&gt;high]

[price&lt;=0.5\*(mid+high)]

```

long
fprintf('BUY at %g\n',price);

```

```

short
fprintf('SELL at %g\n',price);

```

### Execute Standalone Chart

To execute the standalone chart, create a Stateflow chart object w:

```
w = sf_stock_watch();
```

The chart generates a stream of stock prices and issues "buy," "sell," or "hold" instructions.

Note: Chart execution continues until you delete the chart object.

```

Loading data... Ready in 5 4 3 2 1 0:
HOLD at 14.1942
SELL at 14.2802
SELL at 14.2471

```

HOLD at 14.2025  
BUY at 14.1444

To stop the chart execution, delete the chart object w:

```
delete(w);
```

## **See Also**

### **More About**

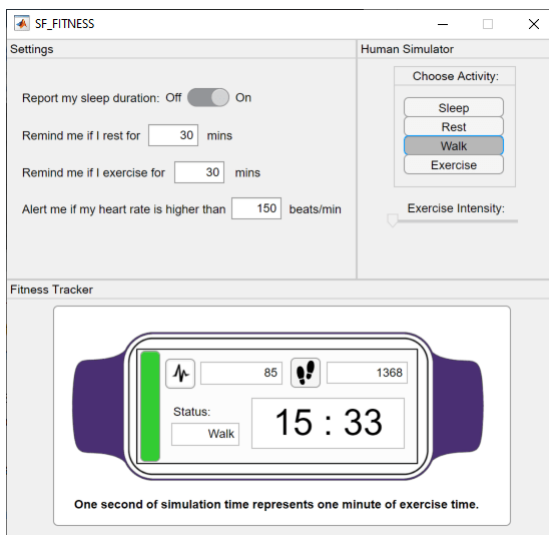
- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Control Chart Execution by Using Temporal Logic” on page 16-36
- “State Decomposition” on page 2-19
- “Datafeed Toolbox”



## Model a Fitness App by Using Standalone Charts

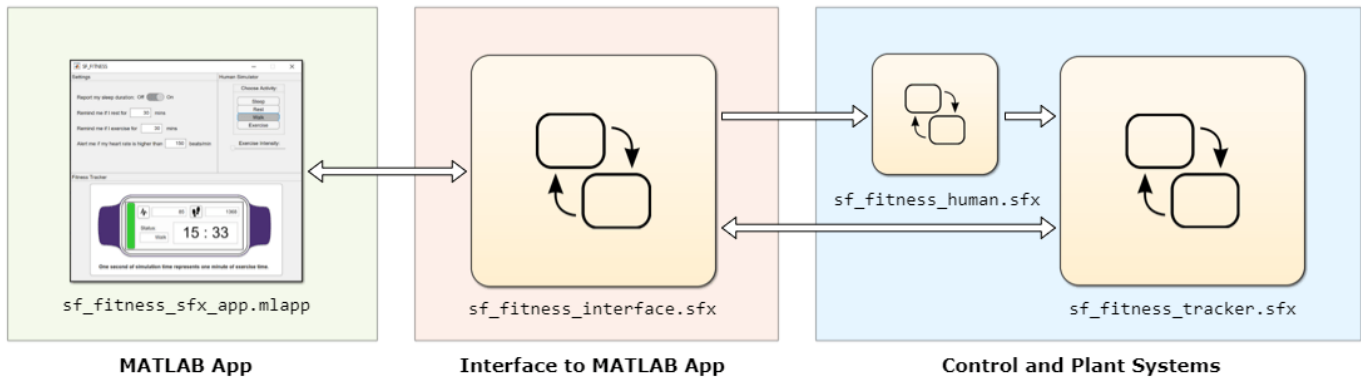
This example shows how to create an application composed of multiple standalone Stateflow® charts and a MATLAB® app. The standalone charts model the control and plant systems for the application and interface with the MATLAB app. For more information on connecting a standalone chart to a MATLAB app, see “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24. For a version of this example that uses Stateflow charts in a Simulink® model, see “Model a Fitness Tracker” on page 30-57.

In this example, a MATLAB app models a fitness tracker. When you run the app, you can adjust the settings for the tracker and select an activity (**Sleep**, **Rest**, **Walk**, or **Exercise**). When you choose **Exercise**, you can also set the intensity of your workout.



The standalone chart `sf_fitness_interface` provides a bidirectional connection between the MATLAB app and the other standalone charts in the example, `sf_fitness_human` and `sf_fitness_tracker`. These charts model a human simulator and provide the core logic for the fitness tracker, respectively. When you interact with the widgets in the app, the `sf_fitness_interface` chart communicates your selections to the other charts in the example. Conversely, the chart uses the output of the fitness tracker to update the numeric and text fields in the app.

This schematic diagram illustrates the transfer of information between the app and the charts in the example.



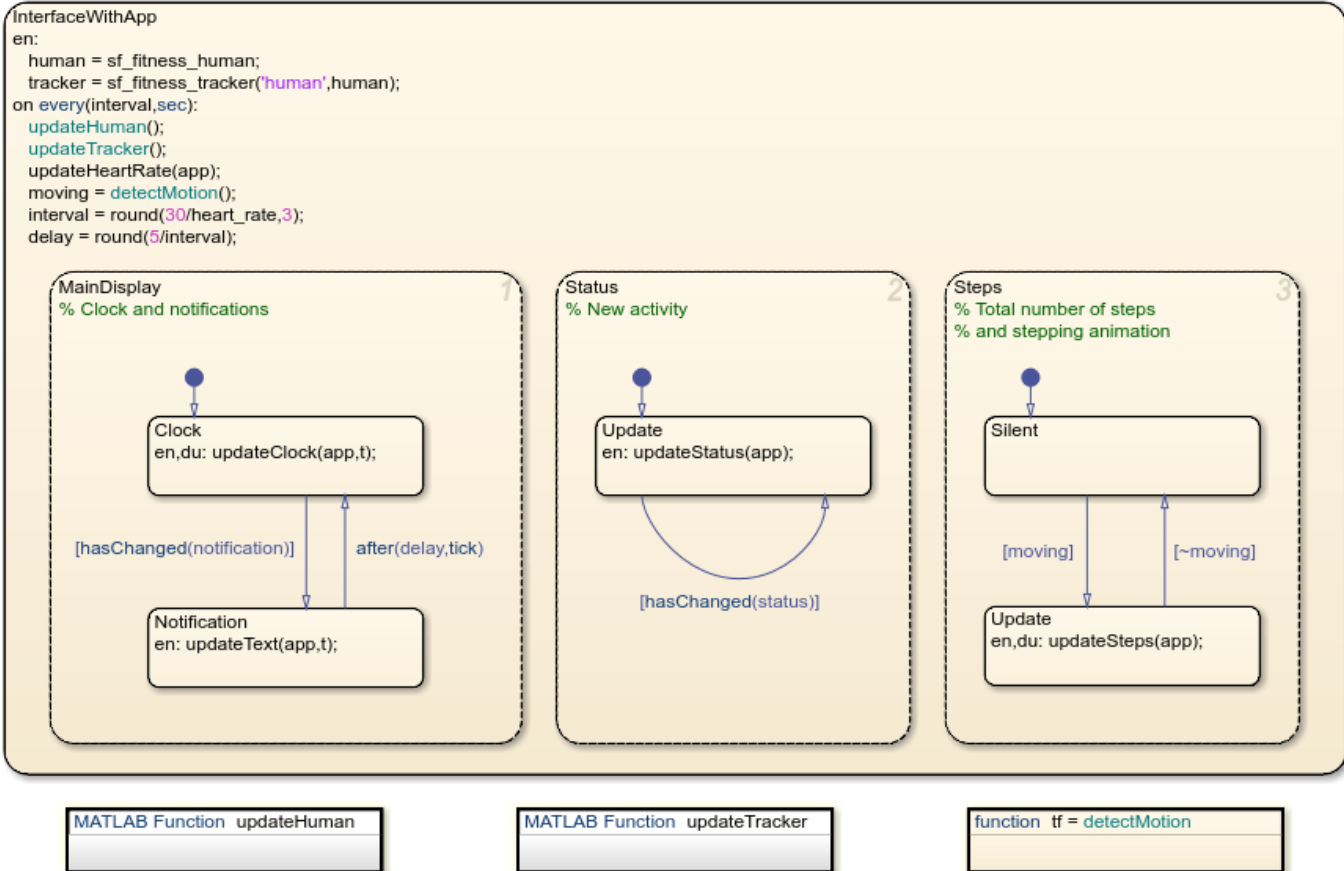
To start the example, run the `sf_fitness_sfx_app` app. The app creates a chart object for `sf_fitness_interface`. This chart, in turn, creates chart objects for the other two charts in the example. The chart also creates a MATLAB timer object that executes all three charts at a frequency proportional to the heart rate in the human simulator chart. While the example is running, one second of simulation represents one minute of exercise time. To stop the example, close the app.

### Connect Chart to MATLAB App

The chart `sf_fitness_interface` is configured to communicate with the MATLAB app `sf_fitness_sfx_app`.

- The chart uses the local data object `app` to interface with the MATLAB app. The chart uses this local data object when it calls the helper functions `updateStatus`, `updateClock`, `updateText`, `updateSteps`, and `updateHeartRate`. In the app, these helper functions change the contents of the activity status, clock, and step counter fields, and create the animation effects in the heartbeat and footstep displays. For example, when there is a new notification from the fitness tracker, the substate `MainDisplay` calls the helper function `updateText`. This function replaces the contents of the clock display with a customized notification. After a short delay, the substate calls the helper function `updateClock` to restore the clock display.
- The app uses a property called `chart` to interface with the chart. The app uses this property to read the chart local data. For example, the helper functions `updateHeartRate` and `updateSteps` read the chart local data `heart_rate` and `total_steps`, respectively. Additionally, when you close the app, the `UIFigureCloseRequest` callback uses the `chart` property to stop the execution of the charts in the example by deleting their chart objects.

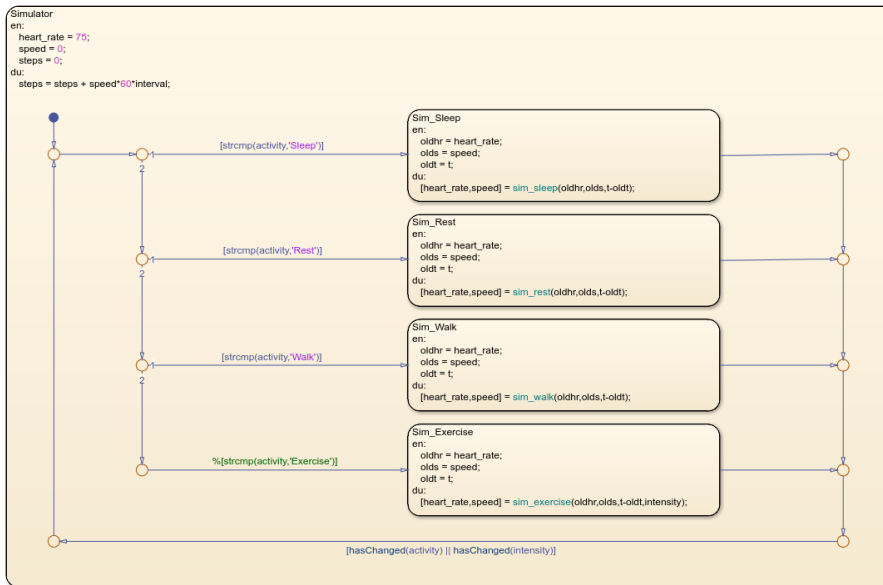
For more information on how to create a bidirectional connection between your MATLAB app and a standalone Stateflow chart, see “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24.



To establish communications with the human simulator and fitness tracker charts, the `sf_fitness_interface` chart saves their chart objects as the local data `human` and `tracker`. The chart-level MATLAB functions `updateHuman` and `updateTracker` use these objects to write to and read from the local data in the charts. For example, when you select a new activity or change the intensity of your workout in the **Human Simulator** pane of the app, `updateHuman` sets the value of the local data `activity` and `intensity` in the human simulator chart. Similarly, when you change the value of one of the fields in the **Settings** pane of the app, `updateTracker` updates the value of the corresponding local data in the fitness tracker chart.

### Simulate Vital Signs Based on Activity

The human simulator chart `sf_fitness_human` models the vital signs of a human engaged in the activity you select in the app. The chart stores these vital signs (representing your heart rate, speed, and the number of steps that you have taken) as local variables that the fitness tracker can access. When you select a new activity or adjust the intensity of your workout, the chart calls the function `transition` to ensure that these vital signs change gradually over time. To detect changes in activity or exercise intensity, the chart calls the `hasChanged` operator. For more information, see “Detect Changes in Data Values” on page 16-64.

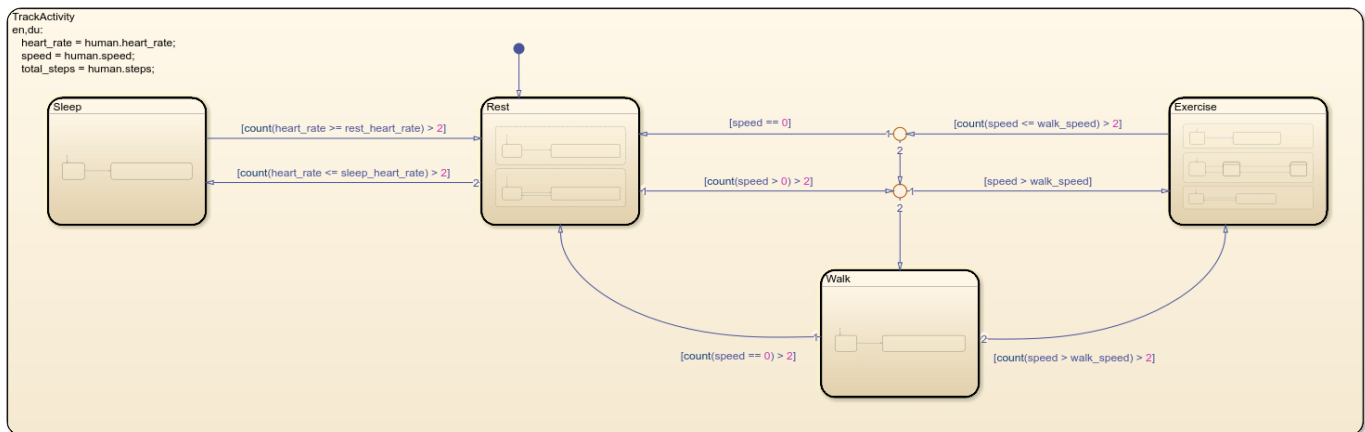


Units for variables:  
 speed: number of steps per second  
 heart\_rate: beats per minute



### Determine Fitness Tracker Output

The chart `sf_fitness_tracker` models the core logic of the fitness tracker. The chart consists of four subcharts that correspond to the possible activities. The chart registers your activity status based on the heart rate and speed produced by the human simulator chart and transitions between these subcharts. To filter out signal noise, the chart uses the `count` operator to implement simple debouncing logic. For instance, when you are at rest, you can make some quick and sudden movements that do not correspond to exercise. The chart determines that you are walking or exercising only if your motion lasts longer than two evaluations of the chart object.



The chart uses other temporal logic operators to track the amount of time you spend in each activity and determine when to send notifications to the app:

- The exit actions in each subchart call the `elapsed` operator to determine how long the subchart was active.
- The chart uses the `after` operator to determine when you sleep or walk for longer than five minutes, rest or exercise for longer than the threshold you specify in the app, or exercise at a high intensity (taking more than 4 steps a second) for longer than 15 minutes. In each of these cases,

the chart updates the value of the local data notification. The `sf_fitness_interface` chart reads this value and causes a notification to appear in the main display of the app. Depending on the type of notification, the notification button changes color.

## See Also

`count` | `elapsed` | `hasChanged`

## More About

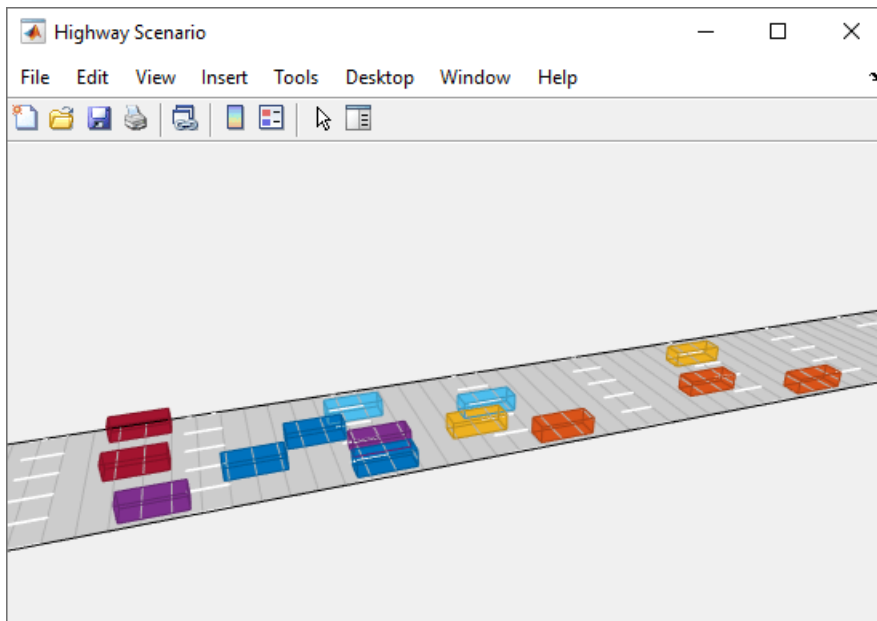
- “Model a Fitness Tracker” on page 30-57
- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24
- “Detect Changes in Data Values” on page 16-64

## Automate Control of Intelligent Vehicles by Using Stateflow Charts

This example shows how to model a highway scenario with intelligent vehicles that are controlled by the same decision logic. Each vehicle determines when to speed up, slow down, or change lanes based on the logic defined by a standalone Stateflow® chart. Because the driving conditions (including the relative position and speed of nearby vehicles) differ from vehicle to vehicle, separate chart objects in MATLAB® control the individual vehicles on the highway.

### Open Driving Scenario

To start the example, run the script `sf_driver_demo.m`. The script displays a 3-D animation of a long highway and several vehicles. The view focuses on a single vehicle and its surroundings. As this vehicle moves along the highway, the standalone Stateflow chart `sf_driver` shows the decision logic that determines its actions.



Starting from a random position, each vehicle attempts to travel at a target speed. Because the target speeds are chosen at random, the vehicles can obstruct one another. In this situation, a vehicle will try to change lanes and resume its target speed.

The class file `HighwayScenario` defines a `drivingScenario` (Automated Driving Toolbox) object that represents the 3-D environment that contains the highway and the vehicles on it. To control the motion of the vehicles, the `drivingScenario` object creates an array of Stateflow chart objects. Each chart object controls a different vehicle in the simulation.

### Execute Decision Logic for Vehicles

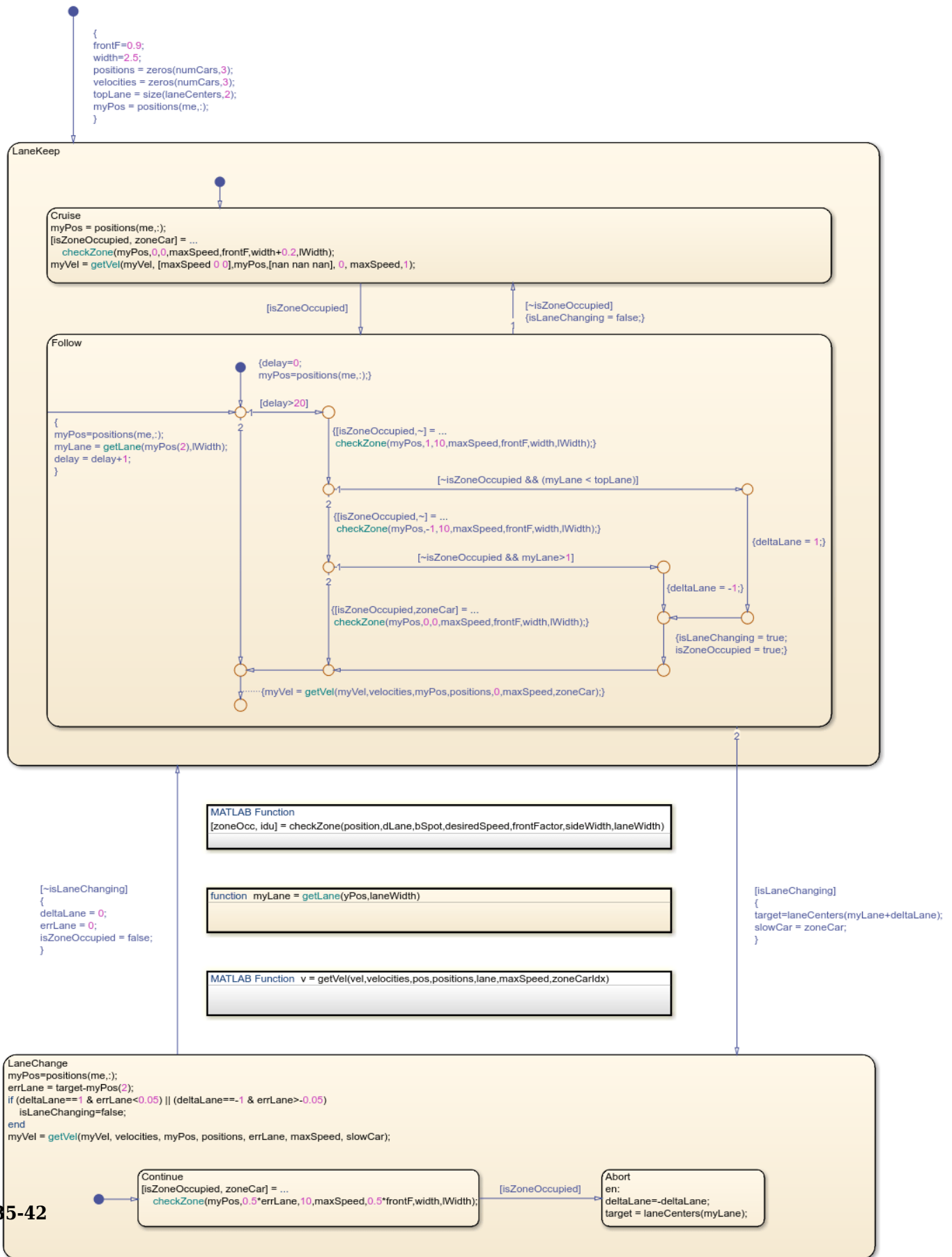
The Stateflow chart `sf_driver` consists of two top-level states, `LaneKeep` and `LaneChange`.

When the `LaneKeep` state is active, the corresponding vehicle stays in its lane of traffic. In this state, there are two possible substates:

- **Cruise** is active when the zone directly in front of the vehicle is empty and the vehicle can travel at its target speed.
- **Follow** becomes active when the zone directly in front of the vehicle is occupied and its target speed is faster than the speed of the vehicle in front. In this case, the vehicle is forced to slow down and attempt to change lanes.

When the LaneChange state is active, the corresponding vehicle attempts to change lanes. In this state, there are two possible substates:

- **Continue** is active when the zone next to the vehicle is empty and the vehicle can change lanes safely.
- **Abort** becomes active when the zone next to the vehicle is occupied. In this case, the vehicle is forced to remain in its lane.





The transitions between the states `LaneKeep` and `LaneChange` are guarded by the value of `isLaneChanging`. In the `LaneKeep` state, the chart sets this local data to `true` when the substate `Follow` is active and there is enough room beside the vehicle to change lanes. In the `LaneChange` state, the chart sets this local data to `false` when the vehicle finishes changing lanes.

## See Also

`drivingScenario`

## More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Create Driving Scenario Programmatically” (Automated Driving Toolbox)
- “Create Actor and Vehicle Trajectories Programmatically” (Automated Driving Toolbox)
- “Define Road Layouts Programmatically” (Automated Driving Toolbox)

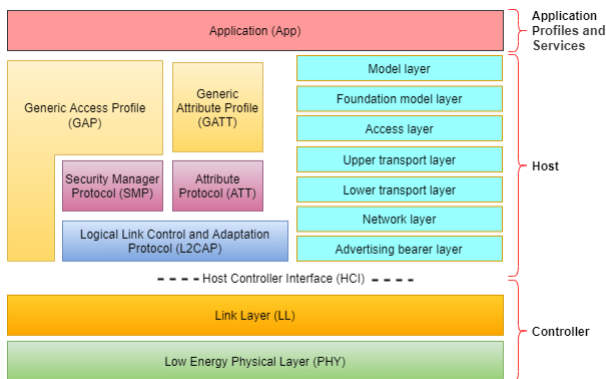
## Model Bluetooth Low Energy Link Layer Using Stateflow

This example shows how to use a standalone Stateflow® chart to model the state machine in a Bluetooth® low energy (BLE) link layer.

Bluetooth technology is a wireless interface intended to replace the cables connecting portable and fixed electronic equipment. The Bluetooth Special Interest Group industry consortium defines two groups of standards for this technology: Bluetooth low energy (BLE) and Bluetooth basic rate/enhanced data rate (BR/EDR). BLE devices are characterized by low power consumption and low cost. These devices have an operating radio frequency in the range 2.4000 GHz to 2.4835 GHz. The operating band is divided into 40 channels, each with a bandwidth of 2 MHz. User data packets are transmitted using channels in the range from 0 to 36. Advertising data packets are transmitted in channels 37, 38, and 39.

The functionality of the BLE protocol stack is divided between three main layers:

- The controller layer includes the low energy physical layer (PHY), the link layer (LL), and the controller-side host controller interface (HCI). The state machine modeled by this example is part of the link layer in this portion of the BLE protocol stack.
- The host layer includes the host-side HCI, logical link control and adaptation protocol (L2CAP), attribute protocol (ATT), generic attribute profile (GATT), security manager protocol (SMP), and generic access profile (GAP). This layer also contains the BLE mesh stack, which consists of the advertising bearer, network, lower transport, upper transport, access, foundation model, and model layers.
- The application profiles and services layer (APP) is the user interface that defines usage profiles and enables interoperability between Bluetooth applications.



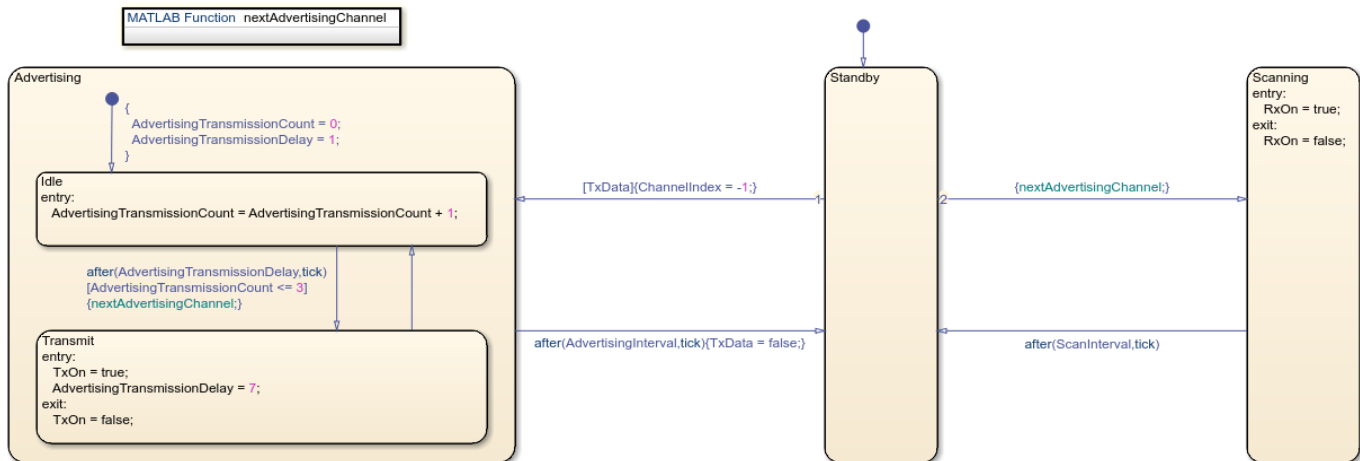
For more information, see “What Is Bluetooth?” (Communications Toolbox), “Bluetooth Protocol Stack” (Communications Toolbox), and “Bluetooth Mesh Networking” (Communications Toolbox).

### Determine the Operating Mode of the BLE Device

In the BLE protocol stack, the link layer manages the state of the radio to define the role of a device as advertiser or scanner. This layer interfaces directly with the PHY layer, which uses the three advertising channels (37, 38, and 39) to transmit and receive data packets.

In this example, the standalone Stateflow chart `sf_bluetooth.sfx` defines the operating modes of the link layer. The chart has three states: **Standby**, **Advertising**, and **Scanning**. Initially, the **Standby** state is active, indicating that the device is idle. In the next time step, the chart transitions

to the Advertising or Scanning state, depending on the value of the local data TxData. This value indicates whether there is data from the advertising bearer in the host layer available for transmission.



If there is data available, the chart transitions to the Advertising state. When this state is active, the device cycles through the three advertising channels and transmits the same data packet in each channel. The chart remains in the Advertising state for an advertising interval before it returns to the Standby state. The advertising interval is divided into three checkpoint timestamps that correspond to the three advertising channels. In this example, the advertising interval consists of a minimum of 20 milliseconds, with checkpoint timestamps at 1 millisecond (for channel 37), 9 milliseconds (for channel 38), and 17 milliseconds (for channel 39).

If there is no data available, the chart transitions to the Scanning state. When this state is active, the PHY layer passively scans one of the advertising channels for new data. If the PHY layer receives a data packet, the link layer passes it to the advertising bearer layer. The chart remains in the Scanning state for a scanning interval before it returns to the Standby state. At that point, if there is still no data available, the chart selects a new advertising channel and starts another scanning interval. In this example, the scanning interval consists of 50 milliseconds.

### Simulate the BLE Link Layer

The script `sf_bluetooth_demo.m` creates a BLE link layer object `bleLinkLayer` and simulates 10 seconds of mesh communications over an advertising bearer. The link layer object relies on the standalone chart `sf_bluetooth.sfx` for control logic and on the link layer queue object `bleQueue` for storing data from the advertising bearer.

The simulation consists of 10,000 time steps. Each time step represents an execution of the link layer object (which corresponds to 1 millisecond of simulation time) and typically consists of these steps:

- 1 If the link layer queue is not empty, read a data packet. The data in the queue represents the advertising data packets that the link layer obtains from the advertising bearer layer.
- 2 Set the value of the chart data `TxData` and execute the standalone chart. In this step, the chart determines whether the device acts as an advertiser or scanner.
- 3 If the chart is in the Advertising.Transmit state, generate a BLE link layer advertising channel protocol data unit (PDU) using the data read from the link layer queue. The PDU represents a transmission by the PHY layer. For more information on generating and configuring

the advertising channel PDU, see `bleLLAdvertisingChannelPDU` (Communications Toolbox) and `bleLLAdvertisingChannelPDUConfig` (Communications Toolbox).

There are two exceptional cases:

- Every 1000 time steps, the script pushes data into the link layer queue before executing the link layer object. This data represents the advertising data packets that the link layer obtains from the advertising bearer layer.
- Every 2500 time steps, the script generates a BLE link layer advertising channel PDU that represents an advertising data packet received by the PHY layer. Then the script executes the link layer object. If the chart is in the `Scanning` state, the link layer object attempts to decode the PDU and, if the decoding is successful, passes the PDU to the advertising bearer layer. For more information on PDU decoding, see `bleLLAdvertisingChannelPDUDecode` (Communications Toolbox).

When the simulation is complete, the script prints a summary that lists the number of data packets and bytes transmitted and received by the link layer.

```
Number of PDUs transmitted from link layer: 27
Number of bytes transmitted from link layer: 702
Number of PDUs received at link layer: 4
Number of bytes received at link layer: 112
```

During the simulation, the chart animation provides a visual indication of the runtime behavior of the algorithm. Note that chart animation slows down performance. To reduce the running time of the example, close the chart before running the script.

## See Also

`bleLLAdvertisingChannelPDU` | `bleLLAdvertisingChannelPDUConfig` | `bleLLAdvertisingChannelPDUDecode`

## More About

- “Create Stateflow Charts for Execution as MATLAB Objects” on page 35-2
- “Execute Stateflow Chart Objects Through Scripts and Models” on page 35-18
- “What Is Bluetooth?” (Communications Toolbox)
- “Bluetooth Protocol Stack” (Communications Toolbox)
- “Bluetooth Mesh Networking” (Communications Toolbox)
- “Bluetooth Packet Structure” (Communications Toolbox)
- “Link Layer State Machine for BLE Devices using Stateflow” (Communications Toolbox)

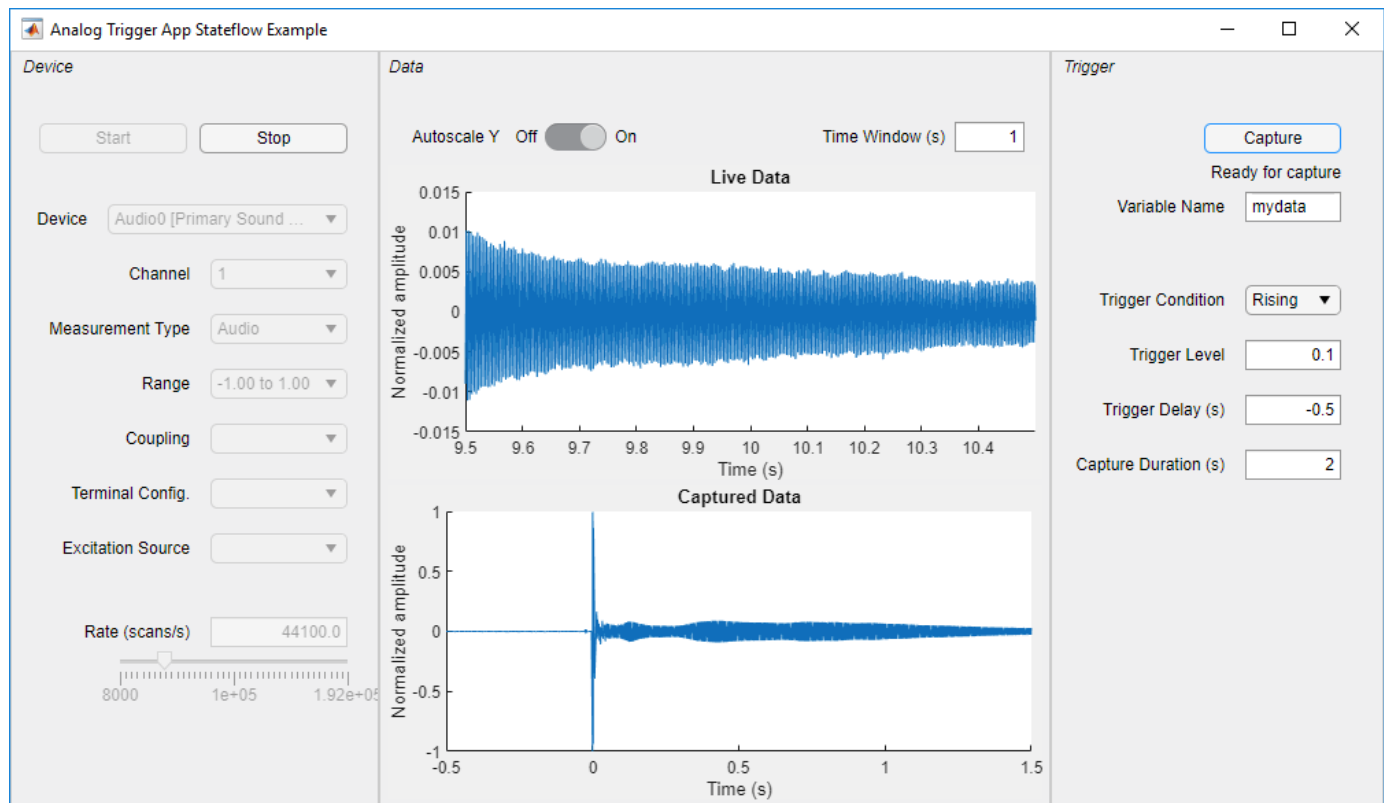
## Create an App for Analog Triggered Data Acquisition by Using Stateflow Charts

This example shows how to create an analog-triggered data acquisition app by using Stateflow®, Data Acquisition Toolbox™, and App Designer.

Data Acquisition Toolbox provides functionality for acquiring measurement data from a DAQ device or audio soundcard. For certain applications, an analog-triggered acquisition that starts capturing or logging data based on a condition in the analog signal being measured is recommended. Software-analog triggered acquisition enables you to capture only a segment of interest out of a continuous stream of measurement data. For example, you can capture an audio recording when the signal level passes a certain threshold.

This example app, created by using App Designer and Stateflow, shows how to implement these operations:

- Control the app state logic by using a Stateflow chart.
- Discover available DAQ devices and select which device to use.
- Configure device acquisition parameters.
- Display a live plot in the app UI during acquisition.
- Perform a triggered data capture based on a programmable trigger condition.
- Save captured data to a MATLAB® base workspace variable.



By default, the app opens in design mode in App Designer. To run the app click the **Run** button or execute the app from the command line:

```
AnalogTriggerAppStateflow
```

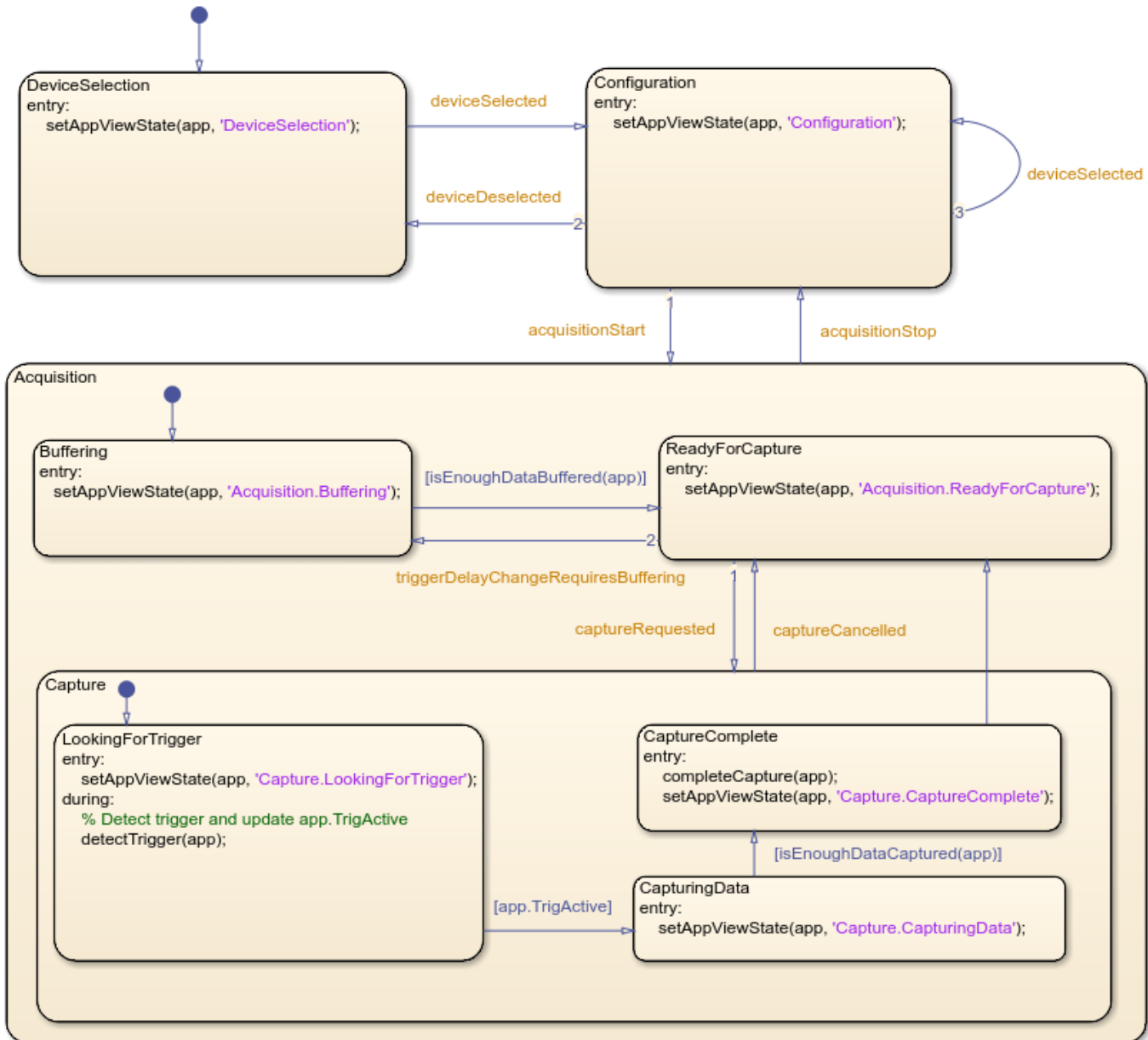
### **Requirements**

This example app requires:

- MATLAB R2020a or later.
- Data Acquisition Toolbox (supported on Windows® only).
- Stateflow (for creating and editing charts only).
- A supported DAQ device or sound card. For example, any National Instruments or Measurement Computing device that supports analog input **Voltage** or **IEPE** measurements and background acquisition.
- Corresponding hardware support package and device drivers.

### **App States and the Stateflow Chart**

When creating an app that has complex logic, consider the various states that correspond to the operating modes of the app. You can use a Stateflow chart to visualize and organize these app states. Use transitions between states to implement the control logic of your app. For example, the file `AnalogTriggerAppLogic.sfx` defines the Stateflow chart that controls the logic for this app. The chart can transition between states based on an action in the app UI or on a data-driven condition. For example, if you click the **Start** button, the chart transitions from the **Configuration** state to the **Acquisition** state. If the value of the signal crosses the specified trigger level, the chart transitions from the **LookingForTrigger** state to the **CapturingData** state.



### Integrating the App with the Stateflow Chart

To establish a bidirectional connection between the MATLAB app and the Stateflow chart, in the `startupFcn` function of your app, create a chart object and store its handle in an app property.

```
app.Chart = AnalogTriggerAppLogic('app',app);
```

The app uses this handle to trigger state transitions in the chart. For example, when you click **Start**, the `StartButtonPushed` app callback function calls the `acquisitionStart` input event for the chart. This event triggers the transition from the `Configuration` state to the `Acquisition` state.

To evaluate transition conditions that are not events in the chart, the app calls the `step` function for the chart object. For example, while acquiring data from the device, the `dataAvailable_Callback`

app function periodically calls the `step` function. When the trigger condition is detected, the chart transitions from the `LookingForTrigger` State to the `CapturingData` state.

In the Stateflow chart, store the app object handle as chart local data. To share public properties and call public functions of the app, the Stateflow chart can use this handle in state actions, transition conditions, or transition actions.

## **See Also**

Chart

## **More About**

- “Design Human-Machine Interface Logic by Using Stateflow Charts” on page 35-24



# Semantic Rules Summary

## Summary of Chart Semantic Rules

In this section...
"Enter a Chart" on page A-2
"Execute an Active Chart" on page A-2
"Enter a State" on page A-2
"Execute an Active State" on page A-3
"Exit an Active State" on page A-3
"Execute a Set of Flow Charts" on page A-3
"Execute an Event Broadcast" on page A-4

### Enter a Chart

The set of default flow paths execute (see "Execute a Set of Flow Charts" on page A-3). If this action does not cause a state entry and the chart has parallel decomposition, then each parallel state becomes active (see "Enter a State" on page A-2).

If executing the default flow paths does not cause state entry, a state inconsistency error occurs.

### Execute an Active Chart

If the chart has no states, each execution is equivalent to initializing a chart. Otherwise, the active children execute. Parallel states execute in the same order that they become active.

### Enter a State

- 1 If the parent of the state is not active, perform steps 1 through 4 for the parent.
- 2 If this state is a parallel state, check that all siblings with a higher (that is, earlier) entry order are active. If not, perform steps 1 through 5 for these states first.

Parallel (AND) states are ordered for entry based on whether you use explicit ordering (default) or implicit ordering. For details, see "Explicit Ordering of Parallel States" on page 3-60 and "Implicit Ordering of Parallel States" on page 3-61.

- 3 Mark the state active.
- 4 Perform any entry actions.
- 5 Enter children, if needed:
  - a If the state contains a history junction and there was an active child of this state at some point after the most recent chart initialization, perform the entry actions for that child. Otherwise, execute the default flow paths for the state.
  - b If this state has children that are parallel states (parallel decomposition), perform entry steps 1 through 5 for each state according to its entry order.
  - c If this state has only one child substate, the substate becomes active when the parent becomes active, regardless of whether a default transition is present. Entering the parent state automatically makes the substate active. The presence of any inner transition has no effect on determining the active substate.

- 6 If this state is a parallel state, perform all entry steps for the sibling state next in entry order if one exists.
- 7 If the transition path parent is not the same as the parent of the current state, perform entry steps 6 and 7 for the immediate parent of this state.

### **Execute an Active State**

- 1 The set of outer flow charts execute (see “Execute a Set of Flow Charts” on page A-3). If this action causes a state transition, execution stops. (Note that this step never occurs for parallel states.)
- 2 During actions and valid on-event actions are performed.
- 3 The set of inner flow charts execute. If this action does not cause a state transition, the active children execute, starting at step 1. Parallel states execute in the same order that they become active.

### **Exit an Active State**

- 1 If this is a parallel state, make sure that all sibling states that became active after this state have already become inactive. Otherwise, perform all exiting steps on those sibling states.
- 2 If there are any active children, perform the exit steps on these states in the reverse order that they became active.
- 3 Perform any exit actions.
- 4 Mark the state as inactive.

### **Execute a Set of Flow Charts**

Flow charts execute by starting at step 1 below with a set of starting transitions. The starting transitions for inner flow charts are all transition segments that originate on the respective state and reside entirely within that state. The starting transitions for outer flow charts are all transition segments that originate on the respective state but reside at least partially outside that state. The starting transitions for default flow charts are all default transition segments that have starting points with the same parent:

- 1 Ordering of a set of transition segments occurs.
- 2 While there are remaining segments to test, testing a segment for validity occurs. If the segment is invalid, testing of the next segment occurs. If the segment is valid, execution depends on the destination:

#### **States**

- a Testing of transition segments stops and a transition path forms by backing up and including the transition segment from each preceding junction until the respective starting transition.
- b The states that are the immediate children of the parent of the transition path exit (see “Exit an Active State” on page A-3).
- c The transition action from the final transition path executes.
- d The destination state becomes active (see “Enter a State” on page A-2).

#### **Junctions with no outgoing transition segments**

Testing stops without any state exits or entries.

**Junctions with outgoing transition segments**

Step 1 is repeated with the set of outgoing segments from the junction.

- 3 After testing all outgoing transition segments at a junction, backtrack the incoming transition segment that brought you to the junction and continue at step 2, starting with the next transition segment after the backtrack segment. The set of flow charts finishes execution when testing of all starting transitions is complete.

**Execute an Event Broadcast**

Output edge-trigger event execution is equivalent to changing the value of an output data value. All other events have the following execution:

- 1 If the *receiver* of the event is active, then it executes (see “Execute an Active Chart” on page A-2 and “Execute an Active State” on page A-3). (The event *receiver* is the parent of the event unless a direct event broadcast occurs using the `send()` function.)

If the receiver of the event is not active, nothing happens.

- 2 After broadcasting the event, the broadcaster performs early return logic based on the type of action statement that caused the event.

Action Type	Early Return Logic
State Entry	If the state is no longer active at the end of the event broadcast, any remaining steps in entering a state do not occur.
State Exit	If the state is no longer active at the end of the event broadcast, any remaining exit actions and steps in state transitioning do not occur.
State During	If the state is no longer active at the end of the event broadcast, any remaining steps in executing an active state do not occur.
Condition	If the origin state of the inner or outer flow chart or parent state of the default flow chart is no longer active at the end of the event broadcast, the remaining steps in the execution of the set of flow charts do not occur.
Transition	If the parent of the transition path is not active or if that parent has an active child, the remaining transition actions and state entry do not occur.

# Semantic Examples

## Categories of Semantic Examples

The following examples show the detailed semantics (behavior) of Stateflow charts.

“Transition Between Exclusive States” on page B-4

- “Transition from State to State with Events” on page B-4
- “Transition from a Substate to a Substate with Events” on page B-7

“Control Chart Execution by Using Condition Actions” on page B-9

- “Condition Action Behavior” on page B-9
- “Condition and Transition Action Behavior” on page B-9
- “Create Condition Actions Using a For-Loop” on page B-10
- “Broadcast Events to Parallel (AND) States Using Condition Actions” on page B-11
- “Avoid Cyclic Behavior” on page B-12

“Control Chart Execution by Using Default Transitions” on page B-14

- “Default Transition in Exclusive (OR) Decomposition” on page B-14
- “Default Transition to a Junction” on page B-14
- “Default Transition and a History Junction” on page B-15
- “Labeled Default Transitions” on page B-16

“Process Events in States Containing Inner Transitions” on page B-18

- “Process One Event in an Exclusive (OR) State” on page B-18
- “Process a Second Event in an Exclusive (OR) State” on page B-18
- “Process a Third Event in an Exclusive (OR) State” on page B-19
- “Process the First Event with an Inner Transition to a Connective Junction” on page B-20
- “Process a Second Event with an Inner Transition to a Connective Junction” on page B-21
- “Inner Transition to a History Junction” on page B-21

“Represent Multiple Paths by Using Connective Junctions” on page B-23

- “If-Then-Else Decision Construct” on page B-23
- “Self-Loop Transition” on page B-24
- “For-Loop Construct” on page B-25
- “Flow Chart Notation” on page B-26
- “Transition from a Common Source to Multiple Destinations” on page B-28
- “Transition from Multiple Sources to a Common Destination” on page B-29
- “Transition from a Source to a Destination Based on a Common Event” on page B-30

“Control Chart Execution by Using Event Actions in a Superstate” on page B-32

“Undirected Broadcast Events in Parallel States” on page B-33

- “Broadcast Events in State Actions” on page B-33

- “Broadcast Events in Transition Actions” on page B-34
- “Broadcast Events in Condition Actions” on page B-36

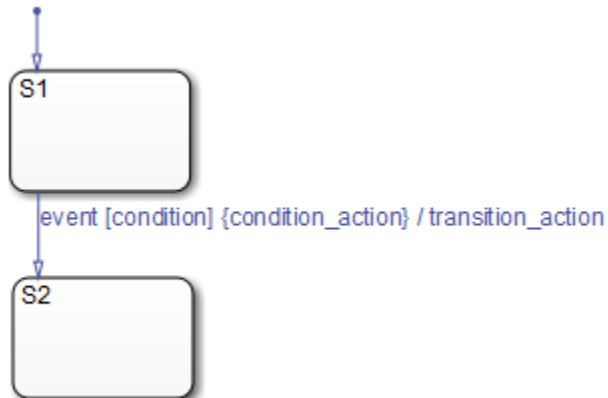
“Broadcast Local Events in Parallel States” on page B-39

- “Directed Event Broadcast Using Send” on page B-39
- “Directed Event Broadcast Using Qualified Event Name” on page B-40

## Transition Between Exclusive States

### Label Format for a State-to-State Transition

The following example shows the general label format for a transition entering a state.



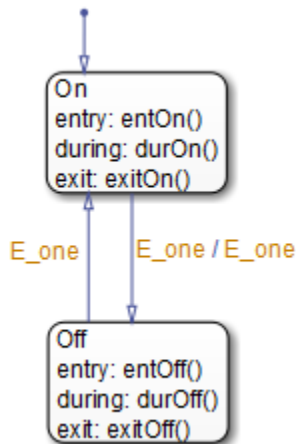
A chart executes this transition as follows:

- 1 When an event occurs, state S1 checks for an outgoing transition with a matching event specified.
- 2 If a transition with a matching event is found, the condition for that transition ([condition]) is evaluated.
- 3 If the condition is true, condition\_action is executed.
- 4 If there is a valid transition to the destination state, the transition is taken.
- 5 State S1 is exited.
- 6 The transition\_action is executed when the transition is taken.
- 7 State S2 is entered.

### Transition from State to State with Events

The following example shows the behavior of a simple transition focusing on the implications of whether states are active or inactive.





### Process a First Event

Initially, the chart is asleep. State `On` and state `Off` are OR states. State `On` is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. A valid transition from state `On` to state `Off` is detected.
- 2 State `On` exit actions (`exitOn()`) execute and complete.
- 3 State `On` is marked inactive.
- 4 The event `E_one` is broadcast as the transition action.

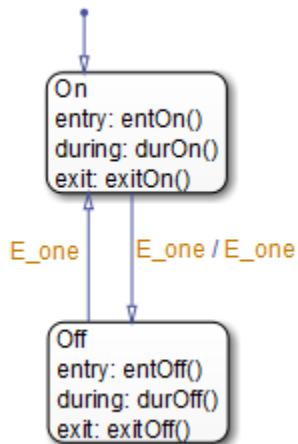
This second event `E_one` is processed, but because neither state is active, it has no effect. If the second broadcast of `E_one` resulted in a valid transition, it would preempt the processing of the first broadcast of `E_one`. See “Early Return Logic” on page 3-54.

- 5 State `Off` is marked active.
- 6 State `Off` entry actions (`entOff()`) execute and complete.
- 7 The chart goes back to sleep.

This sequence completes the execution of the Stateflow chart associated with event `E_one` when state `On` is initially active.

### Process a Second Event

Using the same example, what happens when the next event, `E_one`, occurs while state `Off` is active?



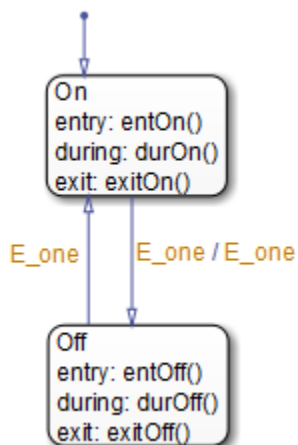
Initially, the chart is asleep. State **Off** is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`.  
A valid transition from state **Off** to state **On** is detected.
- 2 State **Off** exit actions (`exitOff()`) execute and complete.
- 3 State **Off** is marked inactive.
- 4 State **On** is marked active.
- 5 State **On** entry actions (`entOn()`) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of the Stateflow chart associated with the second event `E_one` when state **Off** is initially active.

### Process a Third Event

Using the same example, what happens when a third event, `E_two`, occurs?



Notice that the event `E_two` is not used explicitly in this example. However, its occurrence (or the occurrence of any event) does result in behavior. Initially, the chart is asleep and state **On** is active.

- 1 Event `E_two` occurs and awakens the chart.

Event `E_two` is processed from the root of the chart down through the hierarchy of the chart.

- 2 The chart root checks to see if there is a valid transition as a result of `E_two`. There is none.
- 3 State `On` during actions (`durOn()`) execute and complete.
- 4 The chart goes back to sleep.

This sequence completes the execution of the Stateflow chart associated with event `E_two` when state `On` is initially active.

---

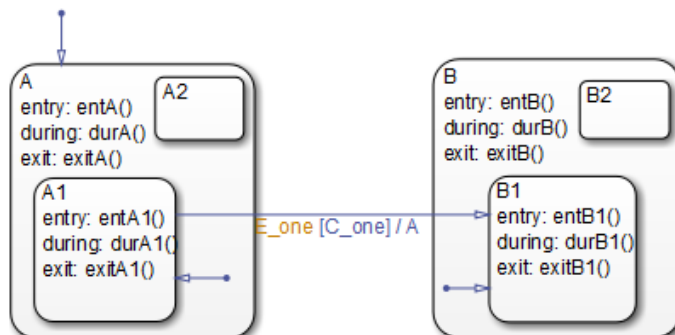
**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

---

## Transition from a Substate to a Substate with Events

This example shows the behavior of a transition from an OR substate to an OR substate.



Initially, the chart is asleep. State `A.A1` is active. Condition `C_one` is true. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. There is a valid transition from state `A.A1` to state `B.B1`. (Condition `C_one` is true.)
- 2 State `A` during actions (`durA()`) execute and complete.
- 3 State `A.A1` exit actions (`exitA1()`) execute and complete.
- 4 State `A.A1` is marked inactive.
- 5 State `A` exit actions (`exitA()`) execute and complete.
- 6 State `A` is marked inactive.
- 7 The transition action, `A`, is executed and completed.
- 8 State `B` is marked active.
- 9 State `B` entry actions (`entB()`) execute and complete.

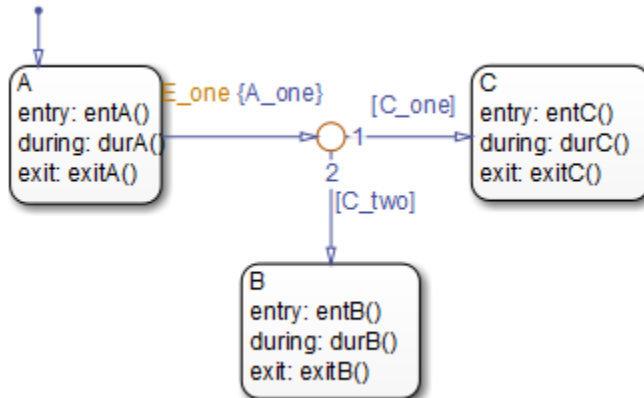
- 10** State B.B1 is marked active.
- 11** State B.B1 entry actions (`entB1()`) execute and complete.
- 12** The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

## Control Chart Execution by Using Condition Actions

### Condition Action Behavior

This example shows the behavior of a simple condition action in a transition path with multiple segments. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A is active. Conditions C\_one and C\_two are false. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. A valid transition segment from state A to a connective junction is detected. The condition action A\_one is detected on the valid transition segment and is immediately executed and completed. State A is still active.
- 2 Because the conditions on the transition segments to possible destinations are false, none of the complete transitions is valid.
- 3 State A during actions (durA()) execute and complete.

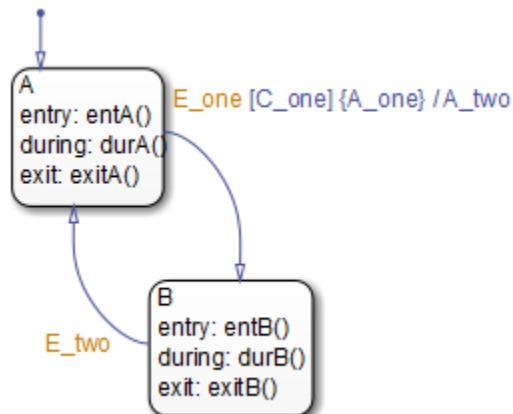
State A remains active.

- 4 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one when state A is initially active.

### Condition and Transition Action Behavior

This example shows the behavior of a simple condition and transition action specified on a transition from one exclusive (OR) state to another.



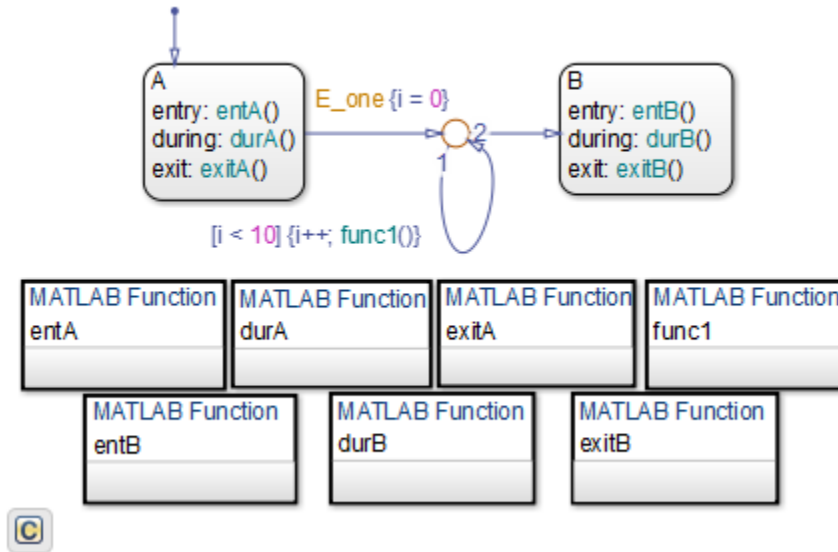
Initially, the chart is asleep. State A is active. Condition C\_one is true. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. A valid transition from state A to state B is detected. The condition C\_one is true. The condition action A\_one is detected on the valid transition and is immediately executed and completed. State A is still active.
- 2 State A exit actions (ExitA()) execute and complete.
- 3 State A is marked inactive.
- 4 The transition action A\_two is executed and completed.
- 5 State B is marked active.
- 6 State B entry actions (entB()) execute and complete.
- 7 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one when state A is initially active.

## Create Condition Actions Using a For-Loop

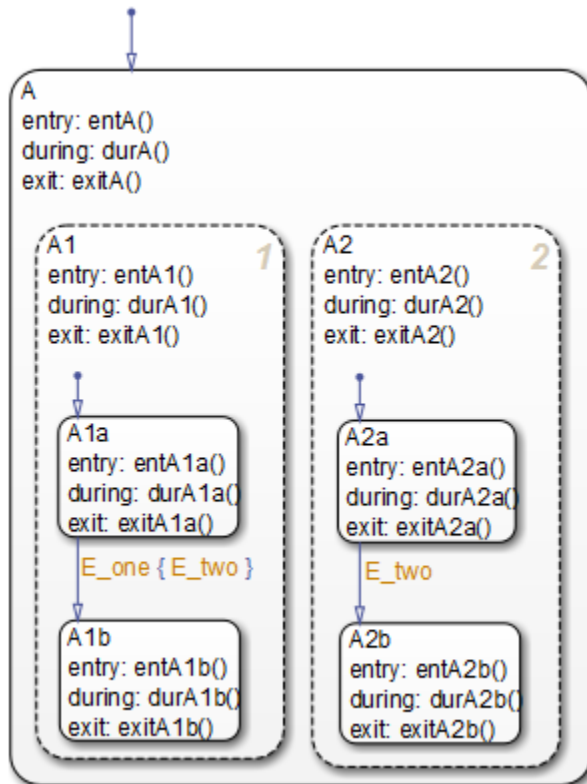
Condition actions and connective junctions are used to design a for loop construct. This example shows the use of a condition action and connective junction to create a for loop construct. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



See “For-Loop Construct” on page B-25 to see the behavior of this example.

## Broadcast Events to Parallel (AND) States Using Condition Actions

This example shows how to use condition actions to broadcast events immediately to parallel (AND) states. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).



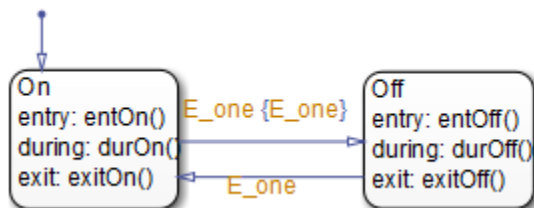
See “Broadcast Events in Condition Actions” on page B-36 to see the behavior of this example.

**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

## Avoid Cyclic Behavior

This example shows a notation to avoid when using event broadcasts as condition actions because the semantics results in cyclic behavior.



Initially, the chart is asleep. State On is active. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:



- 1 The chart root checks to see if there is a valid transition as a result of E\_one.  
A valid transition from state On to state Off is detected.
- 2 The condition action on the transition broadcasts event E\_one.
- 3 Event E\_one is detected on the valid transition, which is immediately executed. State On is still active.
- 4 The broadcast of event E\_one awakens the chart a second time.
- 5 Go to step 1.

Steps 1 through 5 continue to execute in a cyclical manner. The transition label indicating a trigger on the same event as the condition action broadcast event results in unrecoverable cyclic behavior. This sequence never completes when event E\_one is broadcast and state On is active.

---

**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

---

## See Also

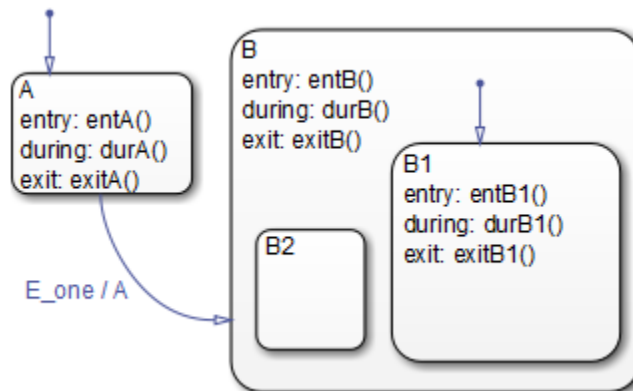
### More About

- “Transitions” on page 2-21
- “Broadcast Local Events to Synchronize Parallel States” on page 14-23
- “Supported Operations for Chart Data” on page 16-5

## Control Chart Execution by Using Default Transitions

### Default Transition in Exclusive (OR) Decomposition

This example shows a transition from an OR state to a superstate with exclusive (OR) decomposition, where a default transition to a substate is defined.



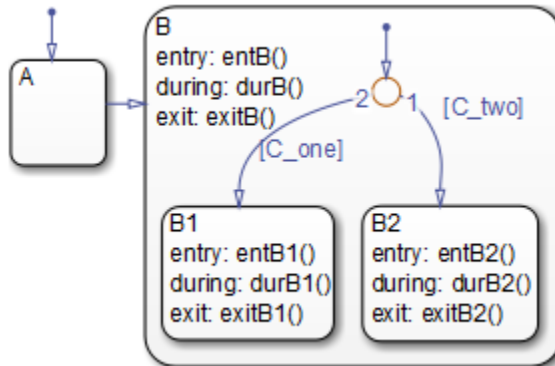
Initially, the chart is asleep. State A is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. There is a valid transition from state A to superstate B.
- 2 State A exit actions (`exitA()`) execute and complete.
- 3 State A is marked inactive.
- 4 The transition action, A, is executed and completed.
- 5 State B is marked active.
- 6 State B entry actions (`entB()`) execute and complete.
- 7 State B detects a valid default transition to state B.B1.
- 8 State B.B1 is marked active.
- 9 State B.B1 entry actions (`entB1()`) execute and complete.
- 10 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one` when state A is initially active.

### Default Transition to a Junction

The following example shows the behavior of a default transition to a connective junction. The default transition to the junction is valid only when state B is first entered, not every time the chart wakes up.



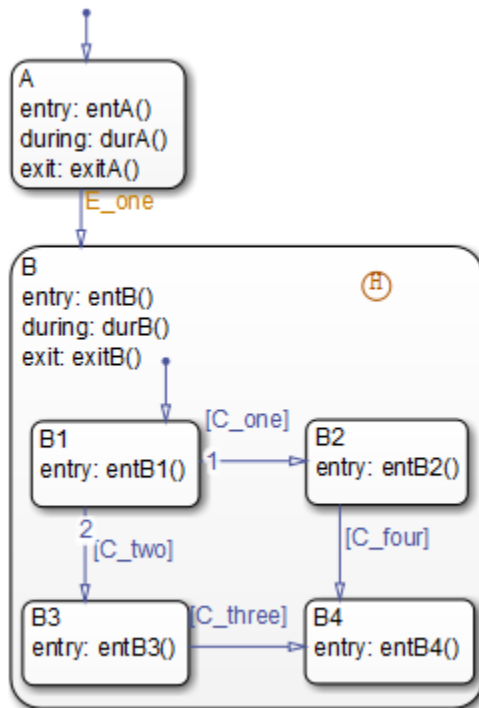
For this example, initially, the chart is asleep. State B.B1 is active. Condition [C\_two] is true. An event occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 State B checks to see if there is a valid transition as a result of any event. There is none.
- 2 State B during actions (durB()) execute and complete.
- 3 State B1 checks to see if there is a valid transition as a result of any event. There is none.
- 4 State B1 during actions (durB1()) execute and complete.

This sequence completes the execution of this Stateflow chart associated with the occurrence of any event.

## Default Transition and a History Junction

This example shows the behavior of a superstate with a default transition and a history junction. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



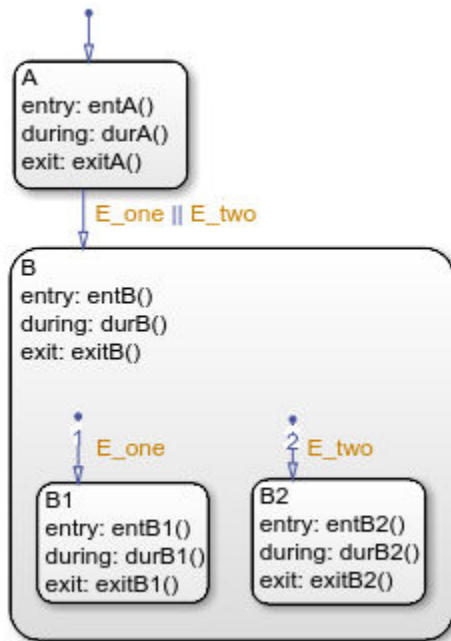
Initially, the chart is asleep. State A is active. A history junction records the fact that state B4 is the previously active substate of superstate B. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one.  
There is a valid transition from state A to superstate B.
- 2 State A exit actions (exitA()) execute and complete.
- 3 State A is marked inactive.
- 4 State B is marked active.
- 5 State B entry actions (entB()) execute and complete.
- 6 State B uses the history junction to determine the substate destination of the transition into the superstate.  
The history junction indicates that substate B.B4 was the last active substate, which becomes the destination of the transition.
- 7 State B.B4 is marked active.
- 8 State B.B4 entry actions (entB4()) execute and complete.
- 9 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one.

### Labeled Default Transitions

This example shows the use of a default transition with a label. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`.  
There is a valid transition from state A to superstate B. The transition is valid if event `E_one` or `E_two` occurs.
- 2 State A exit actions execute and complete (`exitA()`).
- 3 State A is marked inactive.
- 4 State B is marked active.
- 5 State B entry actions execute and complete (`entB()`).
- 6 State B detects a valid default transition to state B.B1. The default transition is valid as a result of `E_one`.
- 7 State B.B1 is marked active.
- 8 State B.B1 entry actions execute and complete (`entB1()`).
- 9 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one` when state A is initially active.

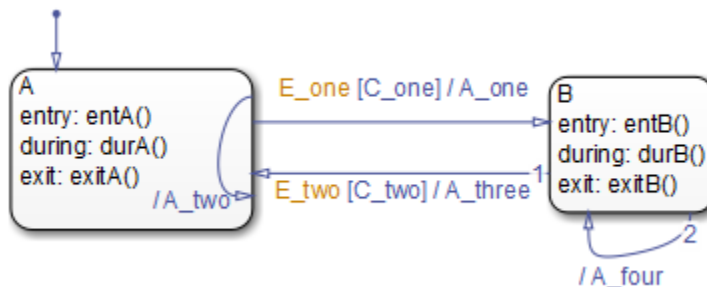
## Process Events in States Containing Inner Transitions

### Process Events with an Inner Transition in an Exclusive (OR) State

This example shows what happens when processing three events using an inner transition in an exclusive (OR) state.

#### Process One Event in an Exclusive (OR) State

This example shows the behavior of an inner transition. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



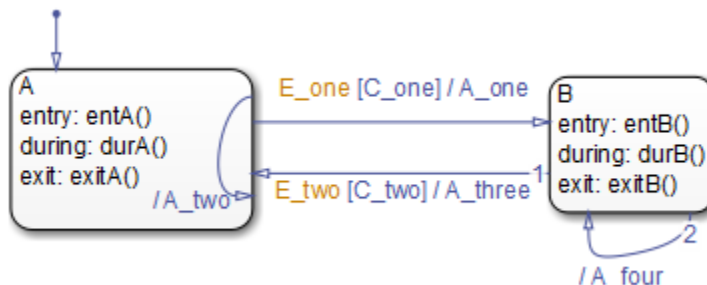
Initially, the chart is asleep. State A is active. Condition [C\_one] is false. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. A potentially valid transition from state A to state B is detected. However, the transition is not valid, because [C\_one] is false.
- 2 State A during actions (durA()) execute and complete.
- 3 State A checks its children for a valid transition and detects a valid inner transition.
- 4 State A remains active. The inner transition action A\_two is executed and completed. Because it is an inner transition, state A's exit and entry actions are not executed.
- 5 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one.

#### Process a Second Event in an Exclusive (OR) State

Using the previous example, this example shows what happens when a second event E\_one occurs. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A is still active. Condition `[C_one]` is true. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`.

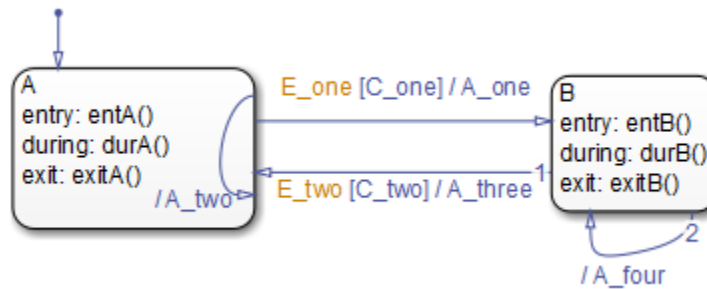
The transition from state A to state B is now valid because `[C_one]` is true.

- 2 State A exit actions (`exitA()`) execute and complete.
- 3 State A is marked inactive.
- 4 The transition action `A_one` is executed and completed.
- 5 State B is marked active.
- 6 State B entry actions (`entB()`) execute and complete.
- 7 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

### Process a Third Event in an Exclusive (OR) State

Using the previous example, this example shows what happens when a third event, `E_two`, occurs. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State B is now active. Condition `[C_two]` is false. Event `E_two` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_two`.

A potentially valid transition from state B to state A is detected. The transition is not valid because `[C_two]` is false. However, active state B has a valid self-loop transition.

- 2 State B exit actions (`exitB()`) execute and complete.
- 3 State B is marked inactive.
- 4 The self-loop transition action, `A_four`, executes and completes.
- 5 State B is marked active.
- 6 State B entry actions (`entB()`) execute and complete.
- 7 The chart goes back to sleep.

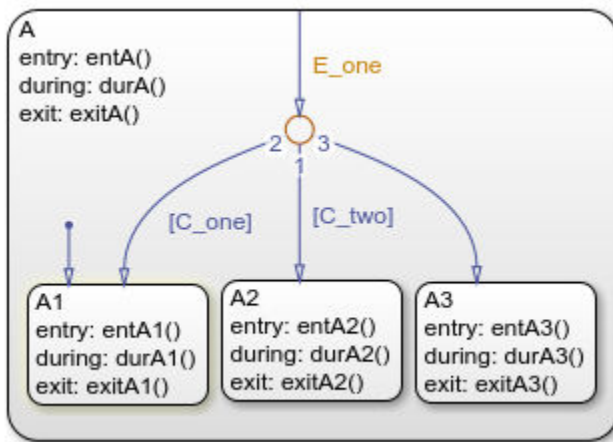
This sequence completes the execution of this Stateflow chart associated with event `E_two`. This example shows the difference in behavior between inner and self-loop transitions.

## Process Events with an Inner Transition to a Connective Junction

This example shows the behavior of handling repeated events using an inner transition to a connective junction.

### Process the First Event with an Inner Transition to a Connective Junction

This example shows the behavior of an inner transition to a connective junction for the first event. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A1 is active. Condition [C\_two] is true. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition at the root level as a result of E\_one. There is no valid transition.
- 2 State A during actions (durA()) execute and complete.
- 3 State A checks itself for valid transitions and detects that there is a valid inner transition to a connective junction.

The conditions are evaluated to determine whether one of the transitions is valid. Because implicit ordering applies, the segments labeled with a condition are evaluated before the unlabeled segment. The evaluation starts from a 12 o'clock position on the junction and progresses in a clockwise manner. Because [C\_two] is true, the inner transition to the junction and then to state A.A2 is valid.

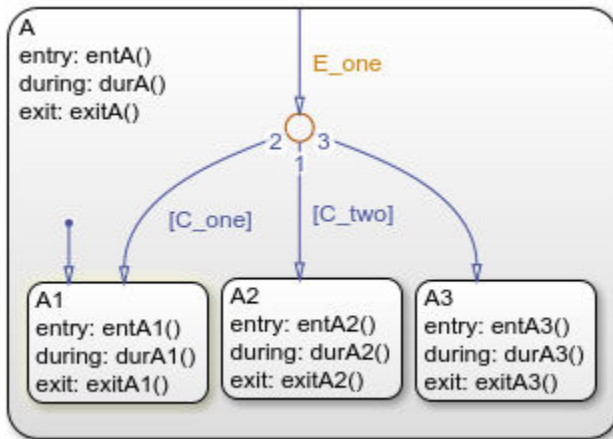
- 4 State A.A1 exit actions (exitA1()) execute and complete.
- 5 State A.A1 is marked inactive.
- 6 State A.A2 is marked active.
- 7 State A.A2 entry actions (entA2()) execute and complete.
- 8 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one when state A1 is active and condition [C\_two] is true.



## Process a Second Event with an Inner Transition to a Connective Junction

Continuing the previous example, this example shows the behavior of an inner transition to a junction when a second event `E_one` occurs. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A2 is active. Condition `[C_two]` is true. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition at the root level as a result of `E_one`. There is no valid transition.
- 2 State A during actions (`durA()`) execute and complete.
- 3 State A checks itself for valid transitions and detects a valid inner transition to a connective junction.

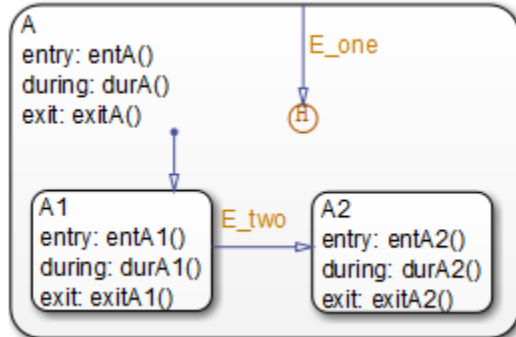
The conditions are evaluated to determine whether one of the transitions is valid. Because implicit ordering applies, the segments labeled with a condition are evaluated before the unlabeled segment. The evaluation starts from a 12 o'clock position on the junction and progresses in a clockwise manner. Because `[C_two]` is true, the inner transition to the junction and then to state A.A2 is valid.

- 4 State A.A2 exit actions (`exitA2()`) execute and complete.
- 5 State A.A2 is marked inactive.
- 6 State A.A2 is marked active.
- 7 State A.A2 entry actions (`entA2()`) execute and complete.
- 8 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one` when state A2 is active and condition `[C_two]` is true. For a state with a valid inner transition, an active substate can be exited and reentered immediately.

## Inner Transition to a History Junction

This example shows the behavior of an inner transition to a history junction.



Initially, the chart is asleep. State A.A1 is active. History information exists because superstate A is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

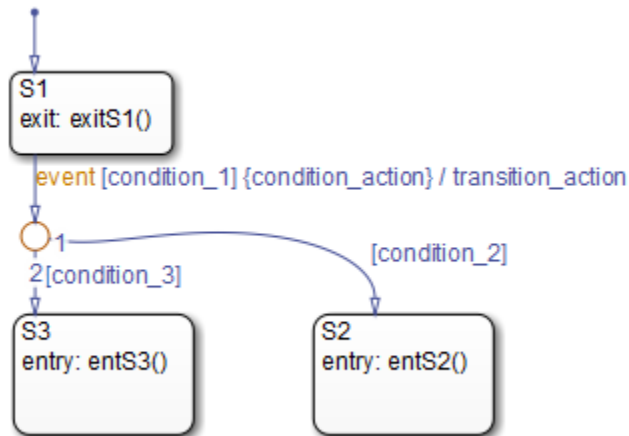
- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. There is no valid transition.
- 2 State A during actions execute and complete.
- 3 State A checks itself for valid transitions and detects that there is a valid inner transition to a history junction. Based on the history information, the last active state, A.A1, is the destination state.
- 4 State A.A1 exit actions execute and complete.
- 5 State A.A1 is marked inactive.
- 6 State A.A1 is marked active.
- 7 State A.A1 entry actions execute and complete.
- 8 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one` when there is an inner transition to a history junction and state A.A1 is active. For a state with a valid inner transition, an active substate can be exited and reentered immediately.

## Represent Multiple Paths by Using Connective Junctions

### Label Format for Transition Segments

The label format for a transition segment entering a junction is the same as for transitions entering states, as shown in the following example. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).

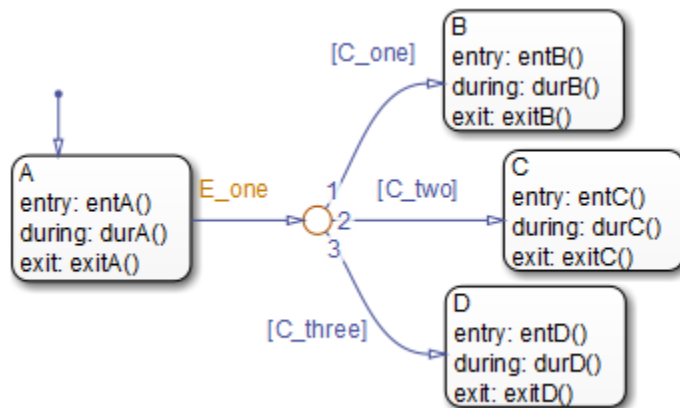


Execution of a transition in this example occurs as follows:

- 1 When an event occurs, state S1 is checked for an outgoing transition with a matching event specified.
- 2 If a transition with a matching event is found, the transition condition for that transition (in brackets) is evaluated.
- 3 If `condition_1` evaluates to true, the condition action `condition_action` (in braces) is executed.
- 4 The outgoing transitions from the junction are checked for a valid transition. Since `condition_2` is true, a valid state-to-state transition from S1 to S2 exists.
- 5 State S1 exit actions execute and complete.
- 6 State S1 is marked inactive.
- 7 The transition action `transition_action` executes and completes.
- 8 The completed state-to-state transition from S1 to S2 occurs.
- 9 State S2 is marked active.
- 10 State S2 entry actions execute and complete.

### If-Then-Else Decision Construct

This example shows the behavior of an if-then-else decision construct. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A is active. Condition `[C_two]` is true. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`.

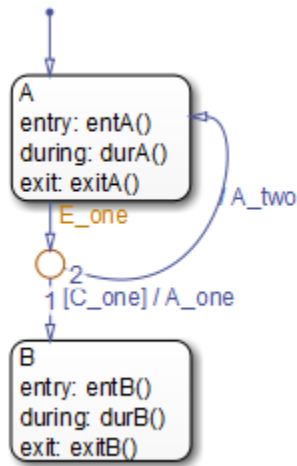
A valid transition segment from state A to the connective junction exists. Because implicit ordering applies, the transition segments beginning from a 12 o'clock position on the connective junction are evaluated for validity. The first transition segment, labeled with condition `[C_one]`, is not valid. The next transition segment, labeled with the condition `[C_two]`, is valid. The complete transition from state A to state C is valid.

- 2 State A exit actions (`exitA()`) execute and complete.
- 3 State A is marked inactive.
- 4 State C is marked active.
- 5 State C entry actions (`entC()`) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

## Self-Loop Transition

This example shows the behavior of a self-loop transition using a connective junction. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



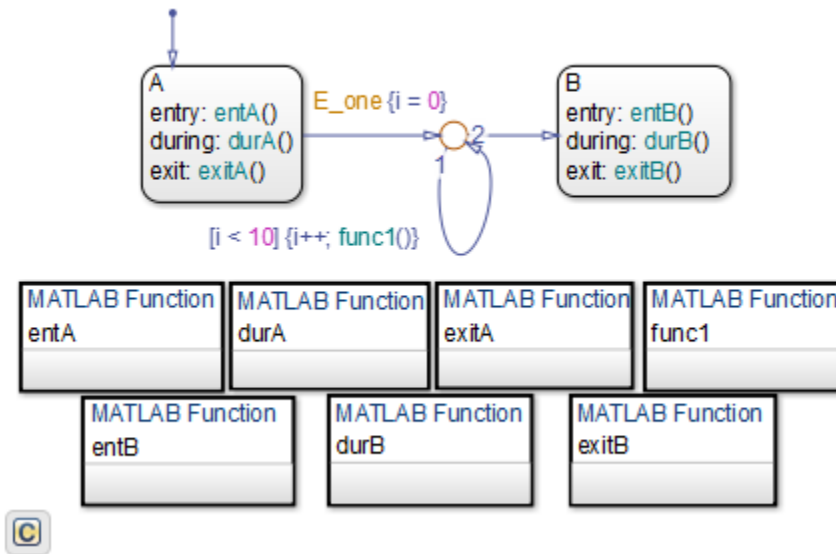
Initially, the chart is asleep. State A is active. Condition [C\_one] is false. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. A valid transition segment from state A to the connective junction exists. Because implicit ordering applies, the transition segment labeled with a condition is evaluated for validity. Because the condition [C\_one] is not valid, the complete transition from state A to state B is not valid. The transition segment from the connective junction back to state A is valid.
- 2 State A exit actions (exitA()) execute and complete.
- 3 State A is marked inactive.
- 4 The transition action A\_two is executed and completed.
- 5 State A is marked active.
- 6 State A entry actions (entA()) execute and complete.
- 7 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one.

## For-Loop Construct

This example shows the behavior of a for loop using a connective junction. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



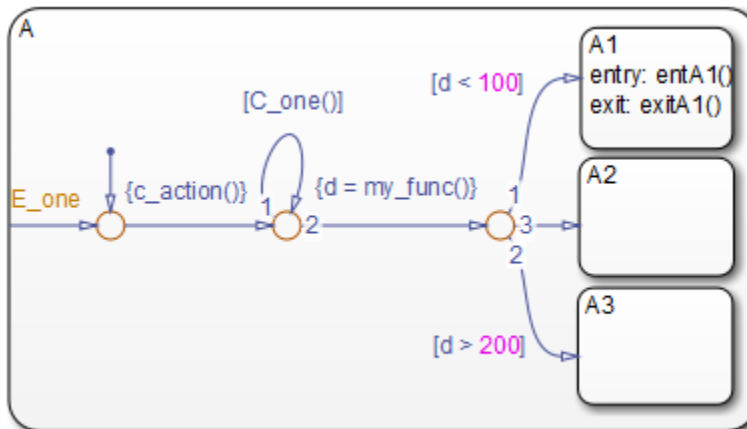
Initially, the chart is asleep. State A is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. There is a valid transition segment from state A to the connective junction. The transition segment condition action, `i = 0`, executes and completes. Of the two transition segments leaving the connective junction, the transition segment that is a self-loop back to the connective junction evaluates next for validity. That segment takes priority in evaluation because it has a condition, whereas the other segment is unlabeled. This evaluation behavior reflects implicit ordering of outgoing transitions in the chart.
- 2 The condition `[i < 10]` evaluates as true. The condition actions `i++` and a call to `func1` execute and complete until the condition becomes false. Because a connective junction is not a final destination, the transition destination is still unknown.
- 3 The unconditional segment to state B is now valid. The complete transition from state A to state B is valid.
- 4 State A exit actions (`exitA()`) execute and complete.
- 5 State A is marked inactive.
- 6 State B is marked active.
- 7 State B entry actions (`entB()`) execute and complete.
- 8 The chart goes back to sleep.

This sequence completes the execution of this chart associated with event `E_one`.

## Flow Chart Notation

This example shows the behavior of a Stateflow chart that uses flow chart notation. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A.A1 is active. The condition `[C_one()]` is initially true. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. There is no valid transition.
- 2 State A checks itself for valid transitions and detects a valid inner transition to a connective junction.
- 3 The next possible segments of the transition are evaluated. Only one outgoing transition exists, and it has a condition action defined. The condition action executes and completes.
- 4 The next possible segments are evaluated. Two outgoing transitions exist: a conditional self-loop transition and an unconditional transition segment. Because implicit ordering applies, the conditional transition segment takes precedence. Since the condition `[C_one()]` is true, the self-loop transition is taken. Since a final transition destination has not been reached, this self-loop continues until `[C_one()]` is false.

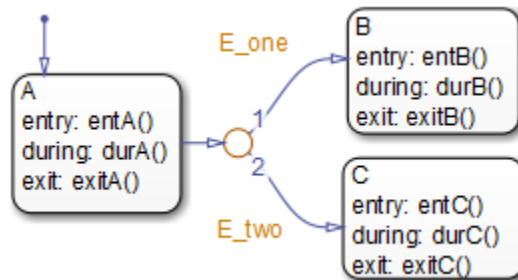
Assume that after five iterations, `[C_one()]` is false.

- 5 The next possible transition segment (to the next connective junction) is evaluated. It is an unconditional transition segment with a condition action. The transition segment is taken and the condition action, `{d=my_func()}`, executes and completes. The returned value of `d` is 84.
- 6 The next possible transition segment is evaluated. Three outgoing transition segments exist: two conditional and one unconditional. Because implicit ordering applies, the segment labeled with the condition `[d < 100]` evaluates first based on the geometry of the two outgoing conditional transition segments. Because the returned value of `d` is 84, the condition `[d < 100]` is true and this transition to the destination state A.A1 is valid.
- 7 State A.A1 exit actions (`exitA1()`) execute and complete.
- 8 State A.A1 is marked inactive.
- 9 State A.A1 is marked active.
- 10 State A.A1 entry actions (`entA1()`) execute and complete.
- 11 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

## Transition from a Common Source to Multiple Destinations

This example shows the behavior of transitions from a common source to multiple conditional destinations using a connective junction. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, the chart is asleep. State A is active. Event E\_two occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_two. A valid transition segment exists from state A to the connective junction. Because implicit ordering applies, evaluation of segments with equivalent label priority begins from a 12 o'clock position on the connective junction and progresses clockwise. The first transition segment, labeled with event E\_one, is not valid. The next transition segment, labeled with event E\_two, is valid. The complete transition from state A to state C is valid.
- 2 State A exit actions (exitA()) execute and complete.
- 3 State A is marked inactive.
- 4 State C is marked active.
- 5 State C entry actions (entC()) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_two.

## Resolve Equally Valid Transition Paths

### What Are Conflicting Transitions?

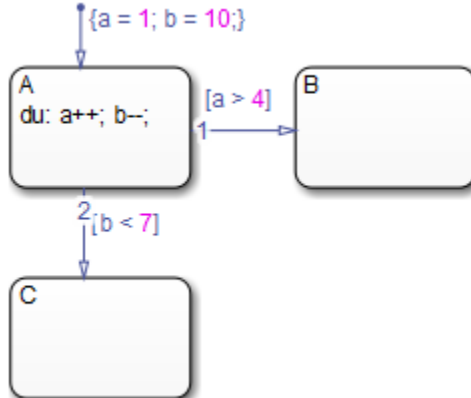
Conflicting transitions are two equally valid paths from the same source in a Stateflow chart during simulation. In the case of a conflict, the chart evaluates equally valid transitions based on ordering mode in the chart: explicit or implicit.

- For explicit ordering (the default mode), evaluation of conflicting transitions occurs based on the order you specify for each transition. For details, see “Explicit Ordering” on page 3-39.
- For implicit ordering in C charts, evaluation of conflicting transitions occurs based on internal rules described in “Implicit Ordering” on page 3-39.

### Example of Conflicting Transitions

The following chart has two equally valid transition paths:





### Conflict Resolution for Implicit Ordering

For implicit ordering, the chart evaluates multiple outgoing transitions with equal label priority in a clockwise progression starting from the twelve o'clock position on the state. In this case, the transition from state A to state B occurs.

### Conflict Resolution for Explicit Ordering

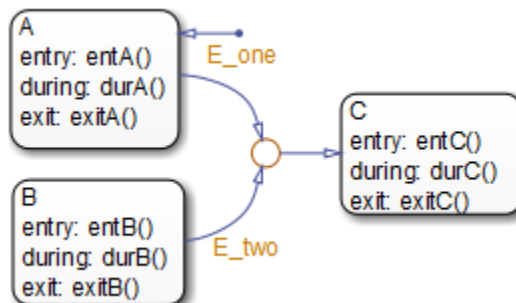
For explicit ordering, the chart resolves the conflict by evaluating outgoing transitions in the order that you specify explicitly. For example, if you right-click the transition from state A to state C and select **Execution Order** > **1** from the context menu, the chart evaluates that transition first. In this case, the transition from state A to state C occurs.

### How the Transition Conflict Occurs

The default transition to state A assigns data a equal to 1 and data b equal to 10. The during action of state A increments a and decrements b during each time step. The transition from state A to state B is valid if the condition  $[a > 4]$  is true. The transition from state A to state C is valid if the condition  $[b < 7]$  is true. During simulation, there is a time step where state A is active and both conditions are true. This issue is a transition conflict.

### Transition from Multiple Sources to a Common Destination

This example shows the behavior of transitions from multiple sources to a single destination using a connective junction.



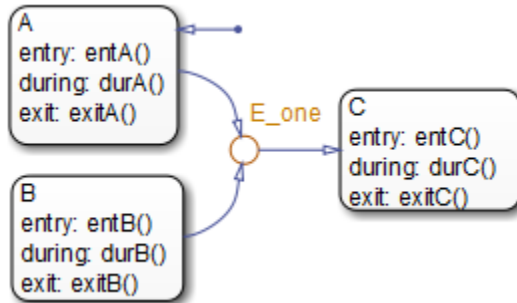
Initially, the chart is asleep. State A is active. Event  $E\_one$  occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. A valid transition segment exists from state A to the connective junction and from the junction to state C.
- 2 State A exit actions (`exitA()`) execute and complete.
- 3 State A is marked inactive.
- 4 State C is marked active.
- 5 State C entry actions (`entC()`) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

## Transition from a Source to a Destination Based on a Common Event

This example shows the behavior of transitions from multiple sources to a single destination based on the same event using a connective junction.



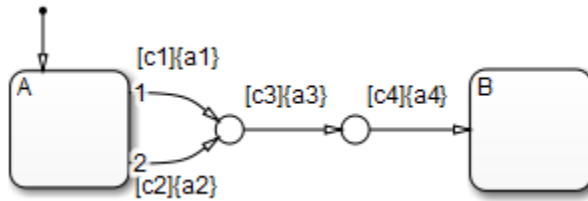
Initially, the chart is asleep. State B is active. Event `E_one` occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of `E_one`. A valid transition segment exists from state B to the connective junction and from the junction to state C.
- 2 State B exit actions (`exitB()`) execute and complete.
- 3 State B is marked inactive.
- 4 State C is marked active.
- 5 State C entry actions (`entC()`) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one`.

## Backtrack in Flow Charts

This example shows the behavior of transitions with junctions that force backtracking behavior in flow charts. The chart uses implicit ordering of outgoing transitions (see “Implicit Ordering” on page 3-39).



Initially, state A is active and conditions c1, c2, and c3 are true:

- 1 The chart root checks to see if there is a valid transition from state A.

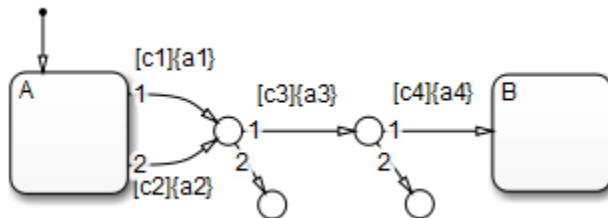
There is a valid transition segment marked with the condition c1 from state A to a connective junction.

- 2 Condition c1 is true and action a1 executes.
- 3 Condition c3 is true and action a3 executes.
- 4 Condition c4 is not true and control flow backtracks to state A.
- 5 The chart root checks to see if there is another valid transition from state A.

There is a valid transition segment marked with the condition c2 from state A to a connective junction.

- 6 Condition c2 is true and action a2 executes.
- 7 Condition c3 is true and action a3 executes.
- 8 Condition c4 is not true and control flow backtracks to state A.
- 9 The chart goes to sleep.

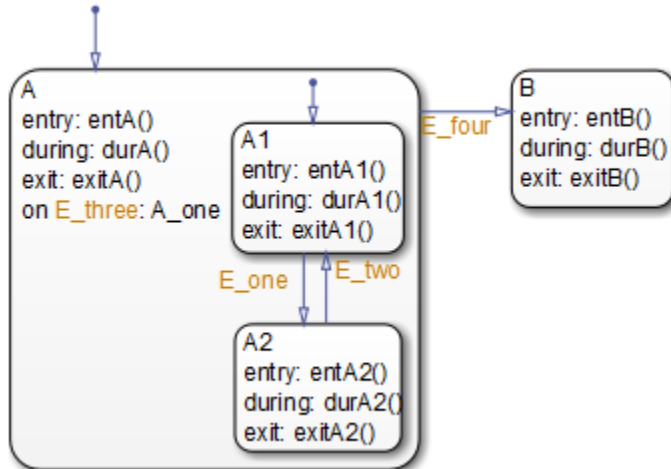
The preceding example shows the expected behavior of executing both actions a1 and a2. Another unexpected behavior is the execution of action a3 twice. To resolve this problem, consider adding unconditional transitions to terminating junctions.



The terminating junctions allow flow to end if either c3 or c4 is not true. This design leaves state A active without executing unnecessary actions.

## Control Chart Execution by Using Event Actions in a Superstate

The following example shows the use of event actions in a superstate.



Initially, the chart is asleep. State A.A1 is active. Event E\_three occurs and awakens the chart, which processes the event from the root down through the hierarchy:

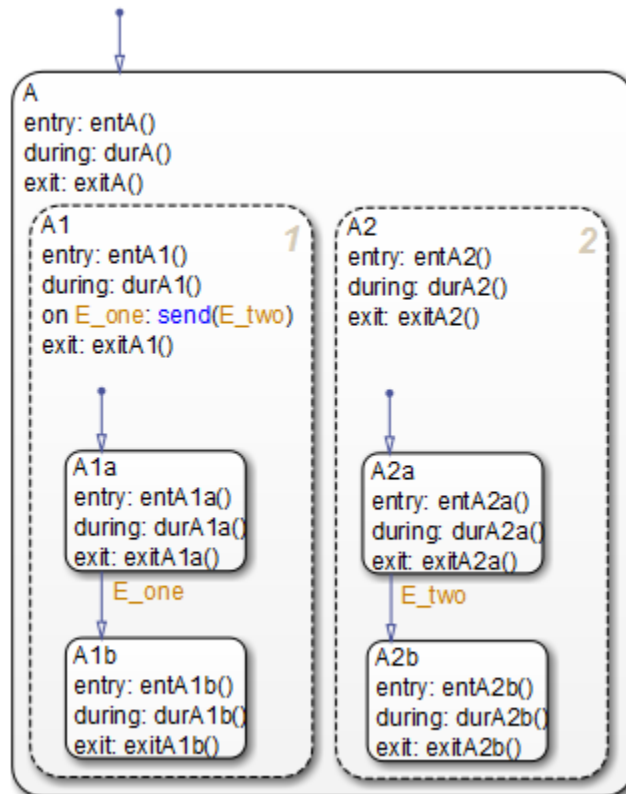
- 1 The chart root checks to see if there is a valid transition as a result of E\_three. No valid transition exists.
- 2 State A during actions (durA()) execute and complete.
- 3 State A executes and completes the on event E\_three action (A\_one).
- 4 State A checks its children for valid transitions. No valid transitions exist.
- 5 State A1 during actions (durA1()) execute and complete.
- 6 The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_three.

## Undirected Broadcast Events in Parallel States

### Broadcast Events in State Actions

This example shows the behavior of event broadcast actions in parallel states. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).



Initially, the chart is asleep. Parallel substates A.A1.A1a and A.A2.A2a are active. Event *E\_one* occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition at the root level as a result of *E\_one*. No valid transition exists.
- 2 State A during actions (*durA()*) execute and complete.
- 3 The children of state A are parallel (AND) states. Because implicit ordering applies, the states are evaluated and executed from left to right and top to bottom. State A.A1 is evaluated first. State A.A1 during actions (*durA1()*) execute and complete. State A.A1 executes and completes the on *E\_one* action and broadcasts event *E\_two*. The during and on *event\_name* actions are processed based on their order of appearance in the state label:
  - a The broadcast of event *E\_two* awakens the chart a second time. The chart root checks to see if there is a valid transition as a result of *E\_two*. No valid transition exists.
  - b State A during actions (*durA()*) execute and complete.
  - c State A checks its children for valid transitions. No valid transitions exist.

- d** State A's children are evaluated starting with state A.A1. State A.A1 during actions (durA1()) execute and complete. State A.A1 is evaluated for valid transitions. There are no valid transitions as a result of E\_two within state A1.
  - e** State A1a's during actions (durA1a()) execute.
  - f** State A.A2 is evaluated. State A.A2 during actions (durA2()) execute and complete. State A.A2 checks for valid transitions. State A.A2 has a valid transition as a result of E\_two from state A.A2.A2a to state A.A2.A2b.
  - g** State A.A2.A2a exit actions (exitA2a()) execute and complete.
  - h** State A.A2.A2a is marked inactive.
  - i** State A.A2.A2b is marked active.
  - j** State A.A2.A2b entry actions (entA2b()) execute and complete.
- 4** The processing of E\_one continues once the on event broadcast of E\_two has been processed. State A.A1 checks for any valid transitions as a result of event E\_one. A valid transition exists from state A.A1.A1a to state A.A1.A1b.
  - 5** State A.A1.A1a executes and completes exit actions (exitA1a).
  - 6** State A.A1.A1a is marked inactive.
  - 7** State A.A1.A1b is marked active.
  - 8** State A.A1.A1b entry actions (entA1b()) execute and complete.
  - 9** Parallel state A.A2 is evaluated next. State A.A2 during actions (durA2()) execute and complete. There are no valid transitions as a result of E\_one.
  - 10** State A.A2.A2b during actions (durA2b()) execute and complete.
- State A.A2.A2b is now active as a result of the processing of the on event broadcast of E\_two.
- 11** The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one and the on event broadcast to a parallel state of event E\_two. The final chart activity is that parallel substates A.A1.A1b and A.A2.A2b are active.

---

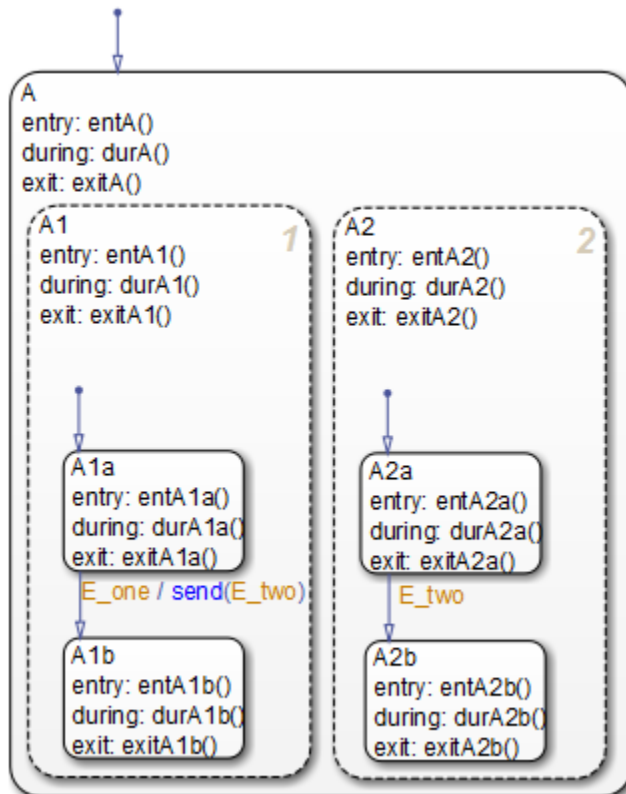
**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

---

## Broadcast Events in Transition Actions

This example shows the behavior of an event broadcast transition action that includes a nested event broadcast in a parallel state. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).



### Start of Event E\_one Processing

Initially, the chart is asleep. Parallel substates A.A1.A1a and A.A2.A2a are active. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. There is no valid transition.
- 2 State A during actions (durA()) execute and complete.
- 3 State A's children are parallel (AND) states. Because implicit ordering applies, the states are evaluated and executed from left to right and top to bottom. State A.A1 is evaluated first. State A.A1 during actions (durA1()) execute and complete.
- 4 State A.A1 checks for any valid transitions as a result of event E\_one. There is a valid transition from state A.A1.A1a to state A.A1.A1b.
- 5 State A.A1.A1a executes and completes exit actions (exitA1a).
- 6 State A.A1.A1a is marked inactive.

### Event E\_two Preempts E\_one

- 1 The transition action that broadcasts event E\_two executes and completes:
  - a The broadcast of event E\_two now preempts the transition from state A1a to state A1b that event E\_one triggers.
  - b The broadcast of event E\_two awakens the chart a second time. The chart root checks to see if there is a valid transition as a result of E\_two. No valid transition exists.

- c** State A during actions (`durA()`) execute and complete.
- d** State A's children are evaluated starting with state A.A1. State A.A1 during actions (`durA1()`) execute and complete. State A.A1 is evaluated for valid transitions. There are no valid transitions as a result of `E_two` within state A1.
- e** State A.A2 is evaluated. State A.A2 during actions (`durA2()`) execute and complete. State A.A2 checks for valid transitions. State A.A2 has a valid transition as a result of `E_two` from state A.A2.A2a to state A.A2.A2b.
- f** State A.A2.A2a exit actions (`exitA2a()`) execute and complete.
- g** State A.A2.A2a is marked inactive.
- h** State A.A2.A2b is marked active.
- i** State A.A2.A2b entry actions (`entA2b()`) execute and complete.

### Event `E_one` Processing Resumes

- 1** State A.A1.A1b is marked active.
- 2** State A.A1.A1b entry actions (`entA1b()`) execute and complete.
- 3** Parallel state A.A2 is evaluated next. State A.A2 during actions (`durA2()`) execute and complete. There are no valid transitions as a result of `E_one`.
- 4** State A.A2.A2b during actions (`durA2b()`) execute and complete.

State A.A2.A2b is now active as a result of the processing of event broadcast `E_two`.

- 5** The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event `E_one` and the event broadcast on a transition action to a parallel state of event `E_two`. The final chart activity is that parallel substates A.A1.A1b and A.A2.A2b are active.

---

**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

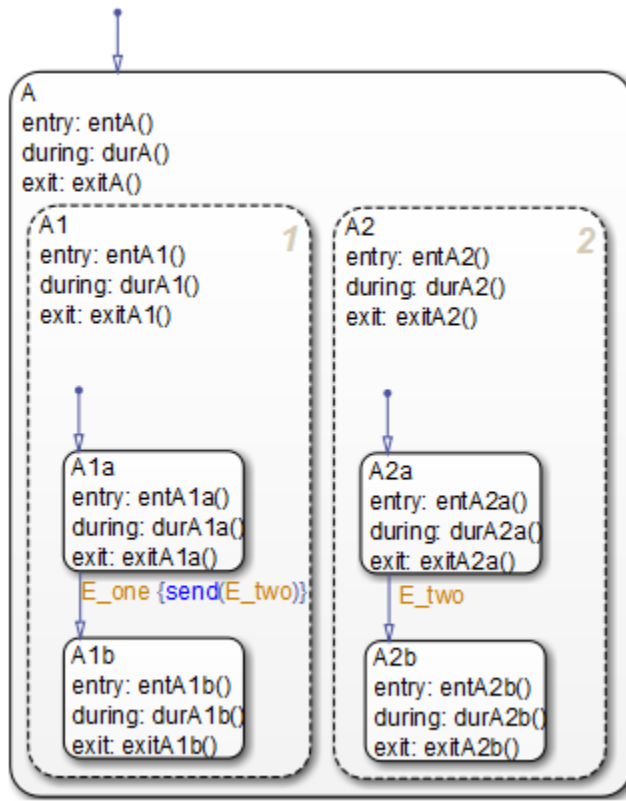
You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

---

## Broadcast Events in Condition Actions

This example shows the behavior of a condition action event broadcast in a parallel (AND) state. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).





Initially, the chart is asleep. Parallel substates A.A1.A1a and A.A2.A2a are active. Event E\_one occurs and awakens the chart, which processes the event from the root down through the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of E\_one. No valid transition exists.
- 2 State A during actions (durA()) execute and complete.
- 3 State A's children are parallel (AND) states. Because implicit ordering applies, the states are evaluated and executed from top to bottom, and from left to right. State A.A1 is evaluated first. State A.A1 during actions (durA1()) execute and complete.
- 4 State A.A1 checks for any valid transitions as a result of event E\_one. A valid transition from state A.A1.A1a to state A.A1.A1b exists. A valid condition action also exists. The condition action event broadcast of E\_two executes and completes. State A.A1.A1a is still active:
  - a The broadcast of event E\_two awakens the Stateflow chart a second time. The chart root checks to see if there is a valid transition as a result of E\_two. There is no valid transition.
  - b State A during actions (durA()) execute and complete.
  - c State A's children are evaluated starting with state A.A1. State A.A1 during actions (durA1()) execute and complete. State A.A1 is evaluated for valid transitions. There are no valid transitions as a result of E\_two within state A1.
  - d State A1a during actions (durA1a()) execute.
  - e State A.A2 is evaluated. State A.A2 during actions (durA2()) execute and complete. State A.A2 checks for valid transitions. State A.A2 has a valid transition as a result of E\_two from state A.A2.A2a to state A.A2.A2b.

- f** State A.A2.A2a exit actions (`exitA2a()`) execute and complete.
- g** State A.A2.A2a is marked inactive.
- h** State A.A2.A2b is marked active.
- i** State A.A2.A2b entry actions (`entA2b()`) execute and complete.
- 5** State A.A1.A1a executes and completes exit actions (`exitA1a`).
- 6** State A.A1.A1a is marked inactive.
- 7** State A.A1.A1b is marked active.
- 8** State A.A1.A1b entry actions (`entA1b()`) execute and complete.
- 9** Parallel state A.A2 is evaluated next. State A.A2 during actions (`durA2()`) execute and complete. There are no valid transitions as a result of E\_one.
- 10** State A.A2.A2b during actions (`durA2b()`) execute and complete.  
  
State A.A2.A2b is now active as a result of the processing of the condition action event broadcast of E\_two.
- 11** The chart goes back to sleep.

This sequence completes the execution of this Stateflow chart associated with event E\_one and the event broadcast on a condition action to a parallel state of event E\_two. The final chart activity is that parallel substates A.A1.A1b and A.A2.A2b are active.

---

**Tip** Avoid using undirected local event broadcasts. Undirected local event broadcasts can cause unwanted recursive behavior in your chart. Instead, send local events by using directed broadcasts. For more information, see “Broadcast Local Events to Synchronize Parallel States” on page 14-23.

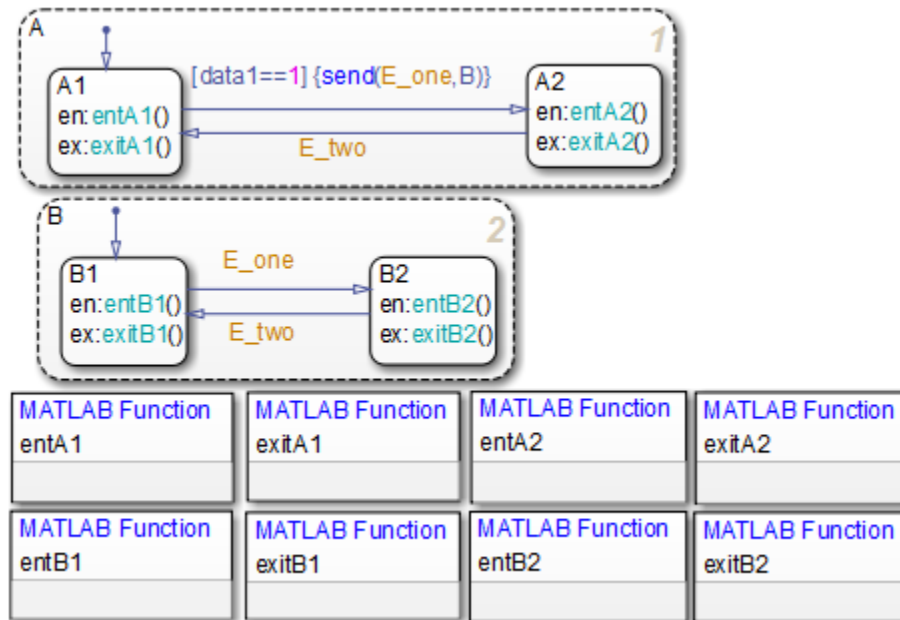
You can set the diagnostic level for detecting undirected local event broadcasts. In the Configuration Parameters dialog box, open the **Diagnostics > Stateflow** pane and set the **Undirected event broadcasts** parameter to none, warning, or error. The default setting is warning.

---

## Broadcast Local Events in Parallel States

### Directed Event Broadcast Using Send

This example shows the behavior of directed event broadcast using the `send(event_name, state_name)` syntax on a transition. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).



Initially, the chart is asleep. Parallel substates A.A1 and B.B1 are active, which implies that parallel (AND) superstates A and B are also active. The condition `[data1==1]` is true. The event `E_one` belongs to the chart and is visible to both A and B.

After waking up, the chart checks for valid transitions at every level of the hierarchy:

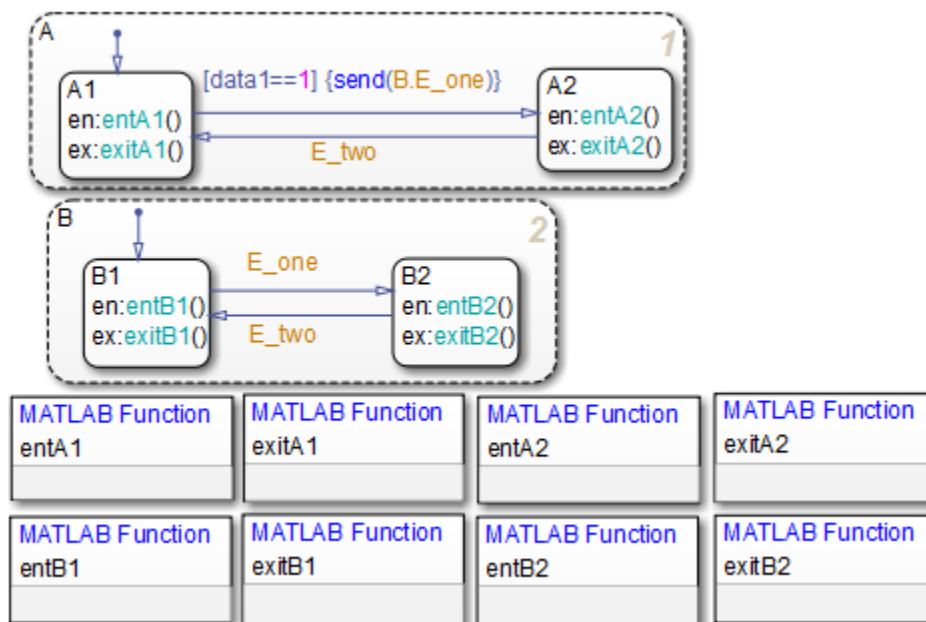
- 1 The chart root checks to see if there is a valid transition as a result of the event. There is no valid transition.
- 2 State A checks for any valid transitions as a result of the event. Because the condition `[data1==1]` is true, there is a valid transition from state A.A1 to state A.A2.
- 3 The action `send(E_one, B)` executes:
  - a The broadcast of event `E_one` reaches state B. Because state B is active, that state receives the event broadcast and checks to see if there is a valid transition. There is a valid transition from B.B1 to B.B2.
  - b State B.B1 exit actions (`exitB1()`) execute and complete.
  - c State B.B1 becomes inactive.
  - d State B.B2 becomes active.
  - e State B.B2 entry actions (`entB2()`) execute and complete.
- 4 State A.A1 exit actions (`exitA1()`) execute and complete.

- 5 State A.A1 becomes inactive.
- 6 State A.A2 becomes active.
- 7 State A.A2 entry actions (entA2()) execute and complete.

This sequence completes execution of a chart with a directed event broadcast to a parallel state.

## Directed Event Broadcast Using Qualified Event Name

This example shows the behavior of directed event broadcast using a qualified event name on a transition. The chart uses implicit ordering of parallel states (see “Implicit Ordering of Parallel States” on page 3-61).



The only differences from the chart in “Directed Event Broadcast Using Send” on page B-39 are:

- The event E\_one belongs to state B and is visible only to that state.
- The action send(E\_one, B) is now send(B.E\_one).

Using a qualified event name is necessary because E\_one is not visible to state A.

After waking up, the chart checks for valid transitions at every level of the hierarchy:

- 1 The chart root checks to see if there is a valid transition as a result of the event. There is no valid transition.
- 2 State A checks for any valid transitions as a result of the event. Because the condition [data1==1] is true, there is a valid transition from state A.A1 to state A.A2.
- 3 The action send(B.E\_one) executes and completes:
  - a The broadcast of event E\_one reaches state B. Because state B is active, that state receives the event broadcast and checks to see if there is a valid transition. There is a valid transition from B.B1 to B.B2.

- b** State B.B1 exit actions (`exitB1()`) execute and complete.
- c** State B.B1 becomes inactive.
- d** State B.B2 becomes active.
- e** State B.B2 entry actions (`entB2()`) execute and complete.
- 4** State A.A1 exit actions (`exitA1()`) execute and complete.
- 5** State A.A1 becomes inactive.
- 6** State A.A2 becomes active.
- 7** State A.A2 entry actions (`entA2()`) execute and complete.

This sequence completes execution of a chart with a directed event broadcast using a qualified event name to a parallel state.

### **See Also**

send

### **More About**

- “Broadcast Local Events to Synchronize Parallel States” on page 14-23



# Simulation Data Inspector

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- “View Data in the Simulation Data Inspector” on page 36-2
- “Import Data from a CSV File into the Simulation Data Inspector” on page 36-11
- “Microsoft Excel Import, Export, and Logging Format” on page 36-16
- “Configure the Simulation Data Inspector” on page 36-24
- “How the Simulation Data Inspector Compares Data” on page 36-32
- “Save and Share Simulation Data Inspector Data and Views” on page 36-37
- “Inspect and Compare Data Programmatically” on page 36-42
- “Limit the Size of Logged Data” on page 36-47

## View Data in the Simulation Data Inspector

You can use the Simulation Data Inspector to visualize the data you generate throughout the design process. Simulation data that you log in a Simulink model logs to the Simulation Data Inspector. You can also import test data and other recorded data into the Simulation Data Inspector to inspect and analyze it alongside the logged simulation data. The Simulation Data Inspector offers several types of plots, which allow you to easily create complex visualizations of your data.

### View Logged Data

Logged signals as well as outputs and states logged using the `Dataset` format automatically log to the Simulation Data Inspector when you simulate a model. You can also record other kinds of simulation data so the data appears in the Simulation Data Inspector at the end of the simulation. To see states and output data logged using a format other than `Dataset` in the Simulation Data Inspector, in the **Model Configuration Parameters Data Import/Export** pane, select the **Record logged workspace data in Simulation Data Inspector** option.

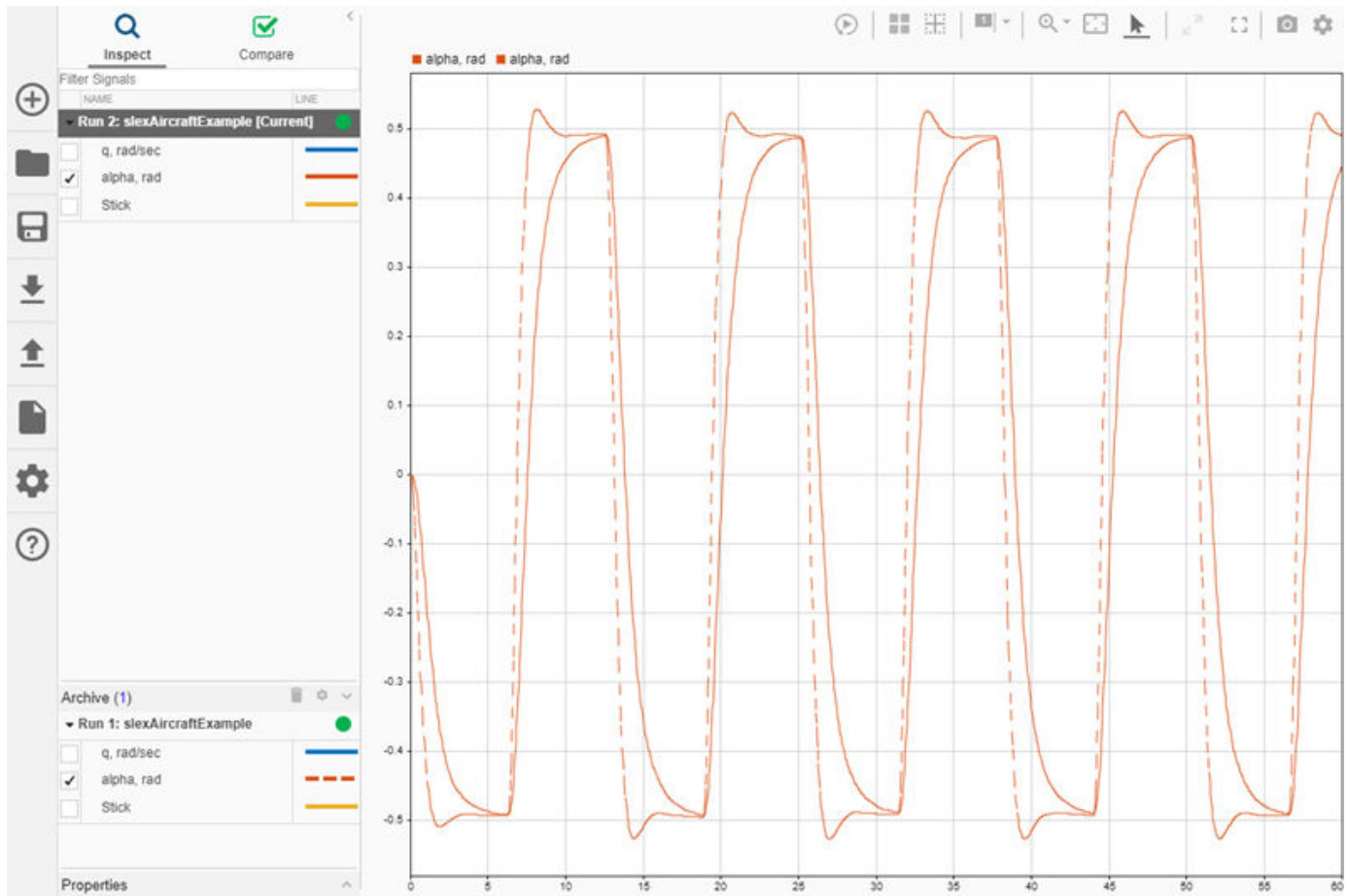
---

**Note** When you log states and outputs using the `Structure` or `Array` format, you must also log time for the data to record to the Simulation Data Inspector.

---

The Simulation Data Inspector displays available data in the table in the **Inspect** pane. To plot a signal, select the check box next to the signal. You can modify the layout and add different visualizations to analyze the simulation data. For more information, see “Create Plots Using the Simulation Data Inspector” (Simulink).





The Simulation Data Inspector manages incoming simulation data using the archive. By default, the previous run moves to the archive when you start a new simulation. You can plot signals from the archive, or you can drag runs of interest back into the work area.

## Import Data from the Workspace or a File

You can import data from the base workspace or from a file to view on its own or alongside simulation data. The Simulation Data Inspector supports all built-in data types and many data formats for importing data from the workspace. In general, whatever the format, sample values must be paired with sample times. The Simulation Data Inspector allows up to 8000 channels per signal in a run created from imported workspace data.

You can also import data from these types of files:

- MAT file
- CSV file — Format data as shown in “Import Data from a CSV File into the Simulation Data Inspector” (Simulink).
- Microsoft® Excel file — Format data as described in “Microsoft Excel Import, Export, and Logging Format” (Simulink).
- MDF file — MDF file import is supported for Linux® and Windows operating systems. The MDF file must have a .mdf, .mf4, .mf3, .data, or .dat file extension and contain data with only integer and floating data types.

- ULG file — Flight log data import requires a UAV Toolbox license.

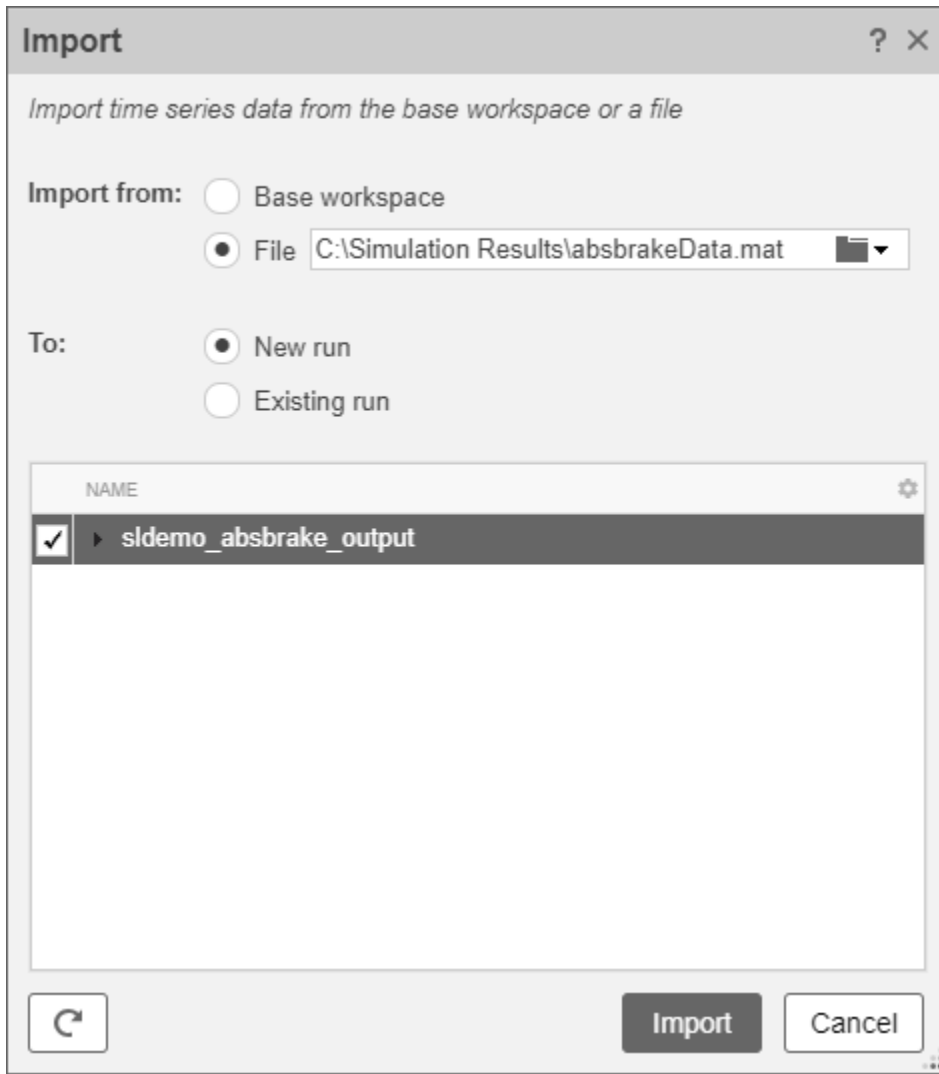
To import data from the workspace or from a file that is saved in a data or file format that the Simulation Data Inspector does not support, you can write your own workspace data or file reader to import the data using the `io.reader` class. You can also write a custom reader to use instead of the built-in reader for supported file types. For examples, see:

- “Import Data Using a Custom File Reader” (Simulink)
- “Import Workspace Variables Using a Custom Data Reader” (Simulink)



To import data, select the **Import** button in the Simulation Data Inspector.

In the Import dialog, you can choose to import data from the workspace or from a file. The table below the options shows data available for import. If you do not see your workspace variable or file contents in the table, that means the Simulation Data Inspector does not have a built-in or registered reader that supports that data. You can select which data to import using the check boxes, and you can choose whether to import that data into an existing run or a new run.



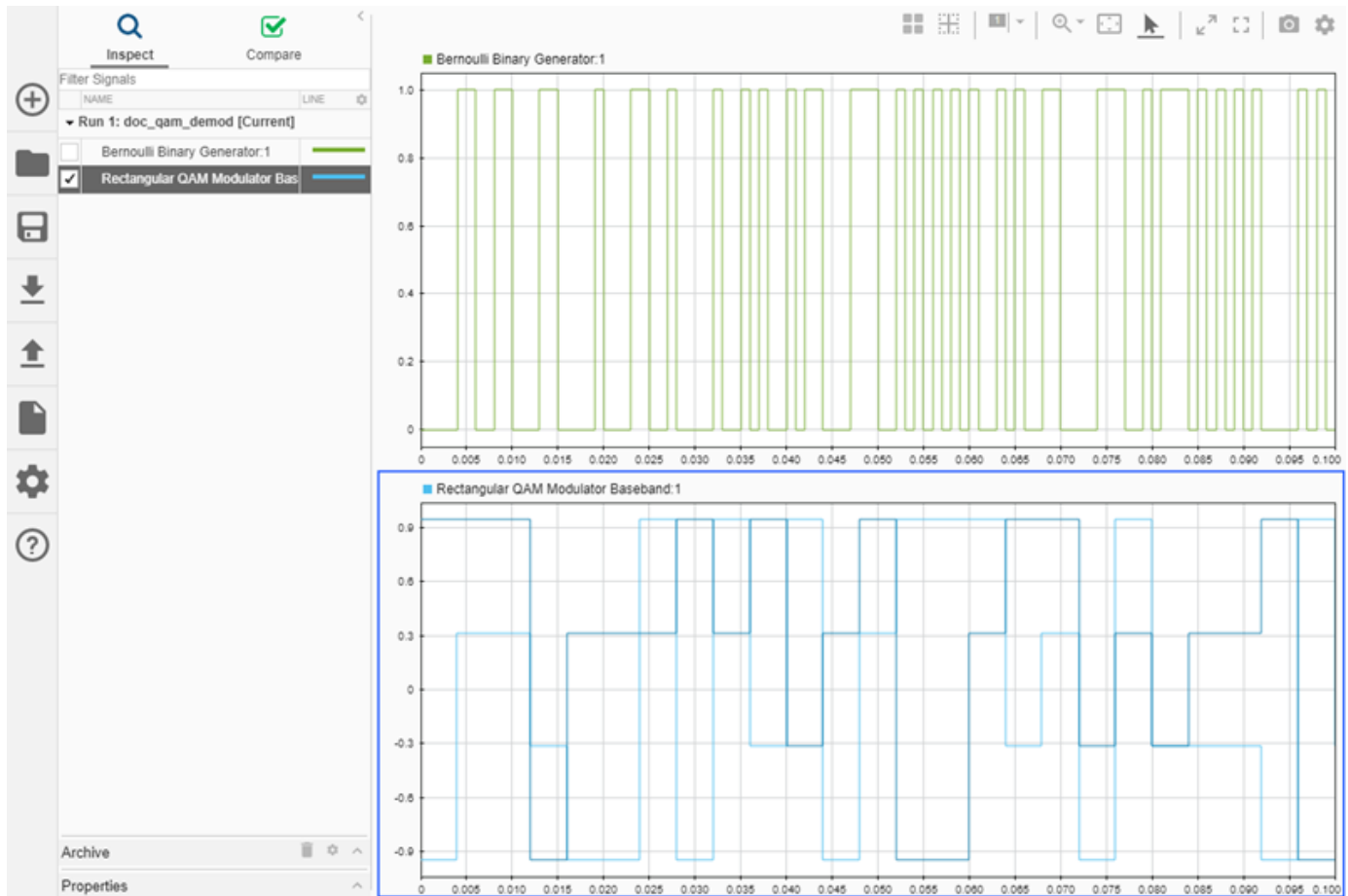
When you import data into a new run, the run always appears in the work area. You can manually move imported runs to the archive.

## View Complex Data

To view complex data in the Simulation Data Inspector, import the data or log the signals to the Simulation Data Inspector. You can control how to visualize the complex signal using the **Properties** pane in the Simulation Data Inspector and in the **Instrumentation Properties** for the signal in the model. To access the **Instrumentation Properties** for a signal, right-click the logging badge for the signal and select **Properties**.

You can specify the **Complex Format** as Magnitude, Magnitude-Phase, Phase, or Real-Imaginary. If you select Magnitude-Phase or Real-Imaginary for the **Complex Format**, the Simulation Data Inspector plots both components of the signal when you select the check box for the signal. For signals in Real-Imaginary format, the **Line Color** specifies the color of the real component of the signal, and the imaginary component is a different shade of the **Line Color**. For example, the Rectangular QAM Modular Baseband signal on the lower graph displays the real component of

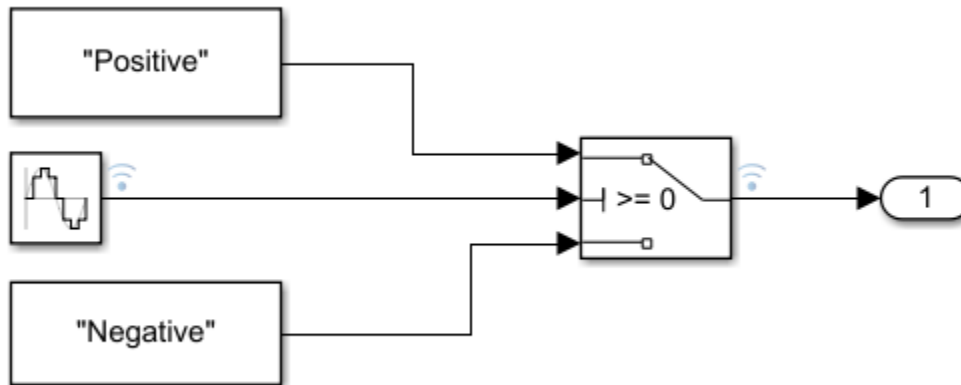
the signal in light blue, matching the **Line Color** parameter, and the imaginary component is shown in a darker shade of blue.



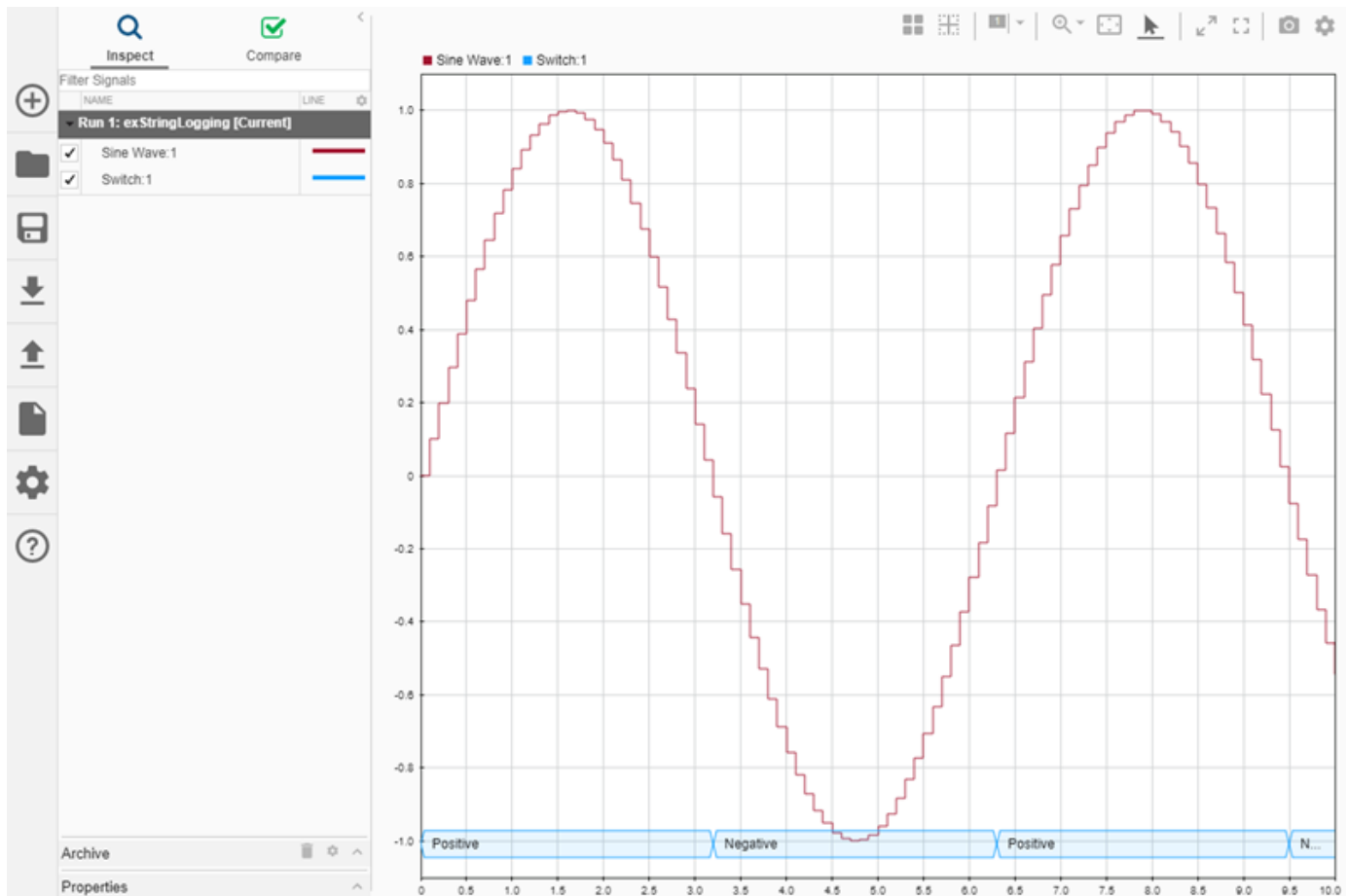
For signals in Magnitude-Phase format, the **Line Color** specifies the color of the magnitude component, and the phase is displayed in a different shade of the **Line Color**.

## View String Data

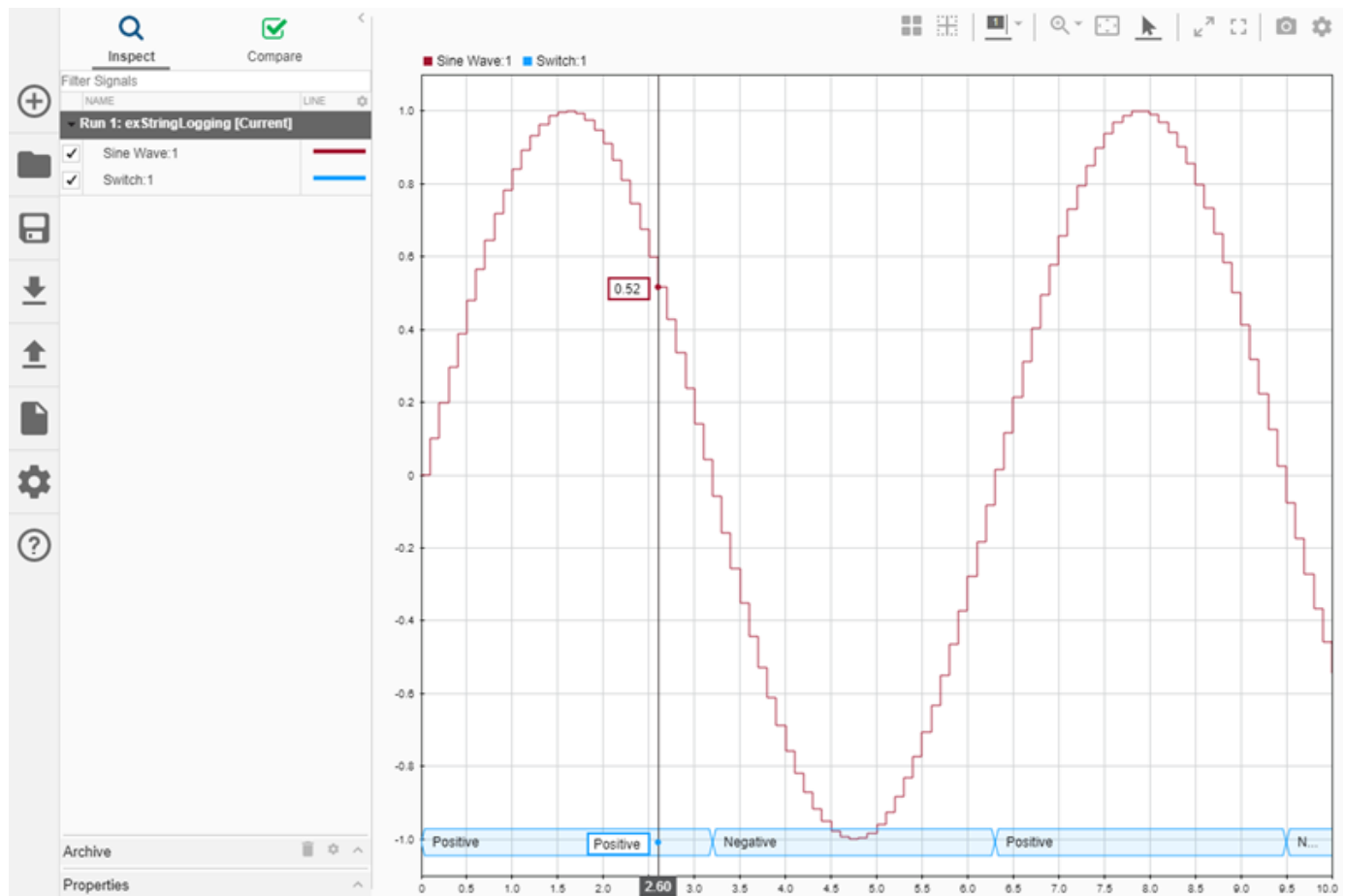
You can log and view string data with your signal data in the Simulation Data Inspector. For example, consider this simple model. The value of the sine wave block controls whether the switch sends a string reading Positive or Negative to the output.



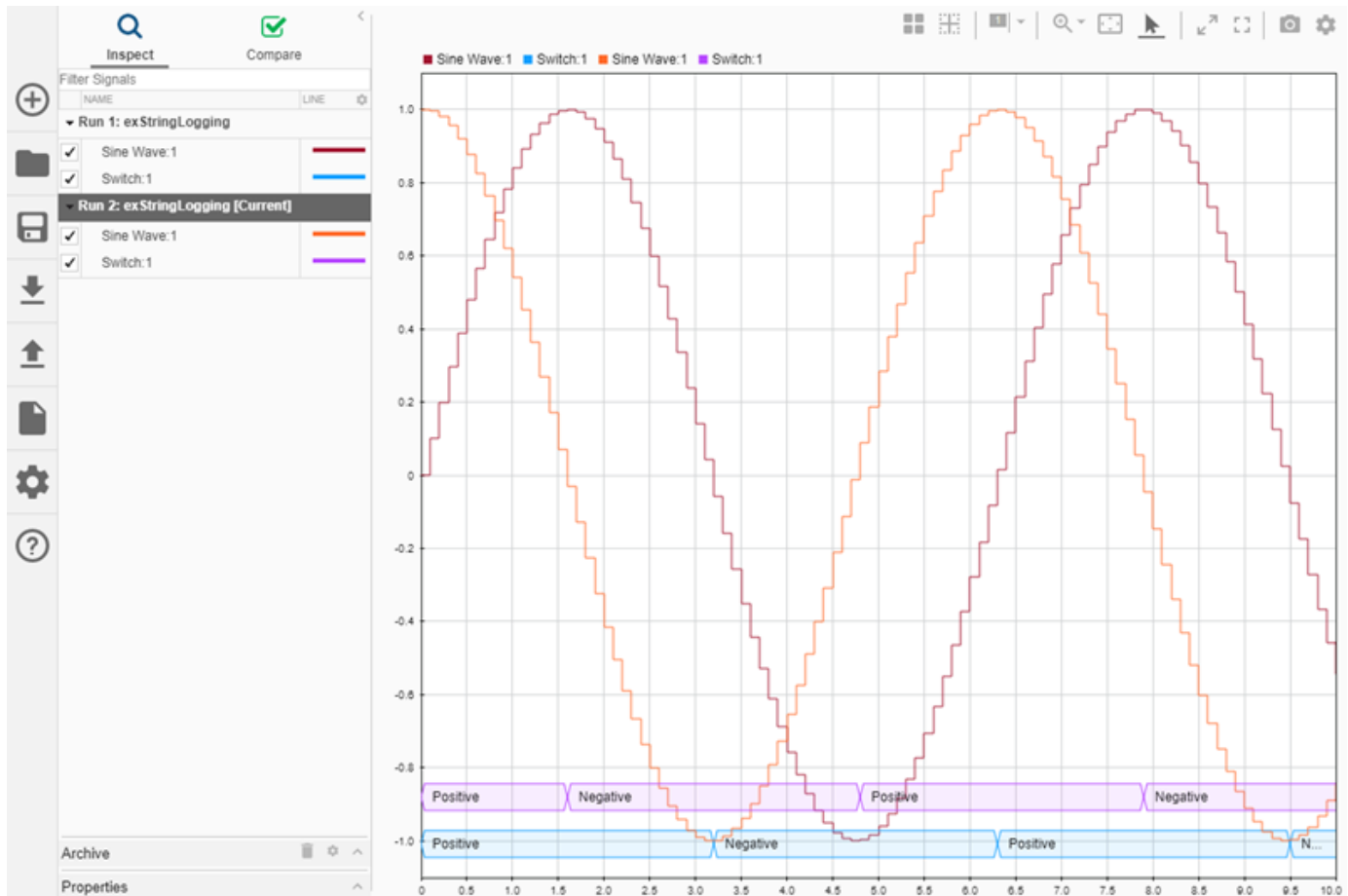
The plot shows the results of simulating the model. The string signal is shown at the bottom of the graphical viewing area. The value of the signal is displayed inside a band, and transitions in the string signal's value are marked with criss-crossed lines.



You can use cursors to inspect how the string signal values correspond with the sine signal's values.



When you plot multiple string signals on a plot, the signals stack in the order they were simulated or imported, with the most recent signal positioned at the top. For example, you might consider the effect of changing the phase of the sine wave controlling the switch.

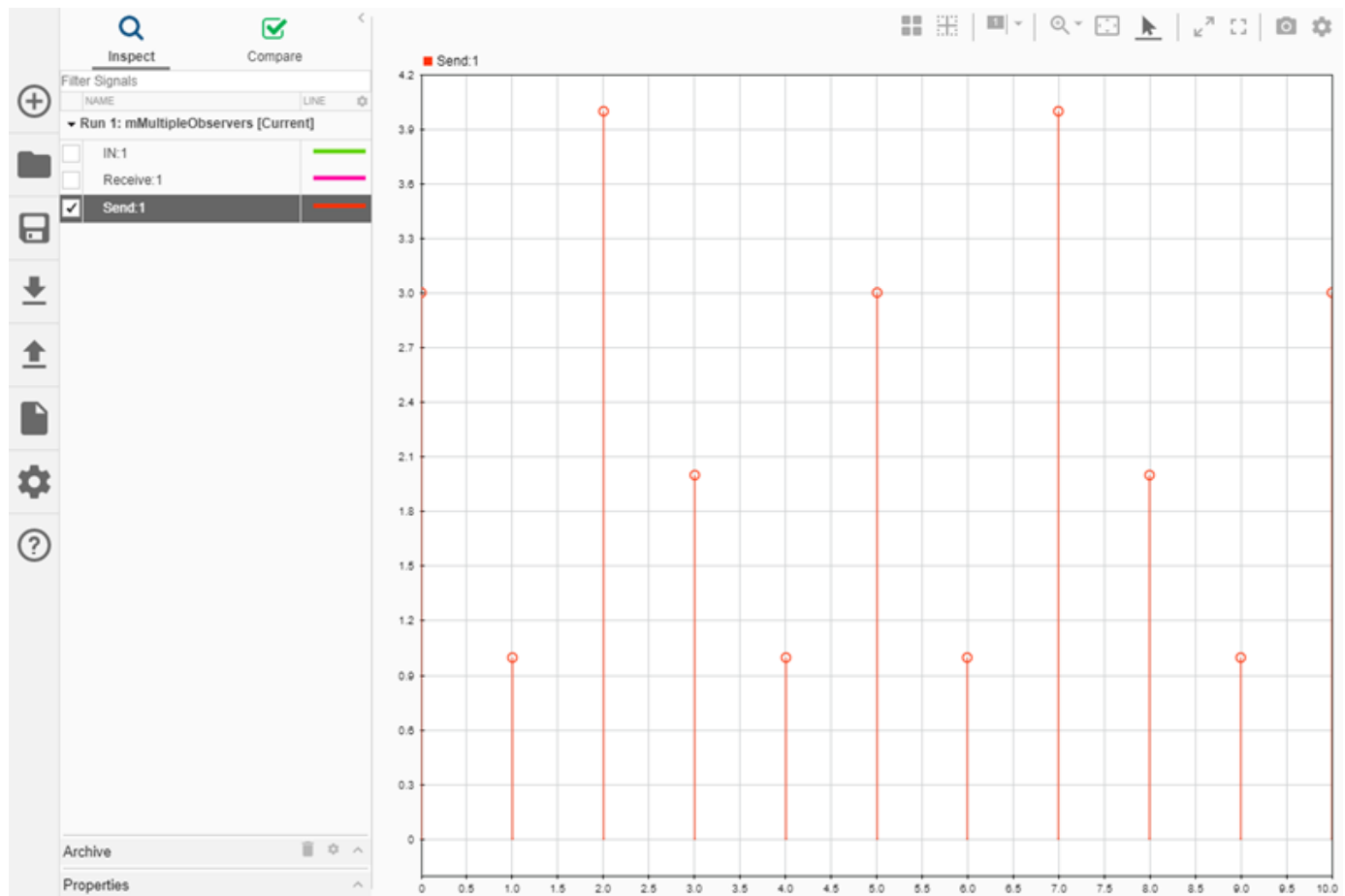


## View Frame-Based Data

Processing data in frames rather than point by point provides a performance boost needed in some applications. To view frame-based data in the Simulation Data Inspector, you have to specify that the signal is frame-based in the **Instrumentation Properties** for the signal. To access the **Instrumentation Properties** dialog for a signal, right-click the signal's logging badge and select **Properties**. To specify a signal as frame-based, select **Columns as channels (frame based)** for **Input processing**.

## View Event-Based Data

You can log or import event data to the Simulation Data Inspector. To view the logged event-based data, select the check box next to **Send: 1**. The Simulation Data Inspector displays the data as a stem plot, with each stem representing the number of events that occurred for a given sample time.



## See Also

### More About

- [Inspect Simulation Data \(Simulink\)](#)
- [Compare Simulation Data \(Simulink\)](#)
- [Share Simulation Data Inspector Data and Views on page 36-37](#)
- [Decide How to Visualize Data \(Simulink\)](#)
- [Dataset Conversion for Logged Data \(Simulink\)](#)



## Import Data from a CSV File into the Simulation Data Inspector

To import data into the Simulation Data Inspector from a CSV file, format the data in the CSV file. Then, you can import the data using the Simulation Data Inspector UI or the `Simulink.sdi.createRun` function.

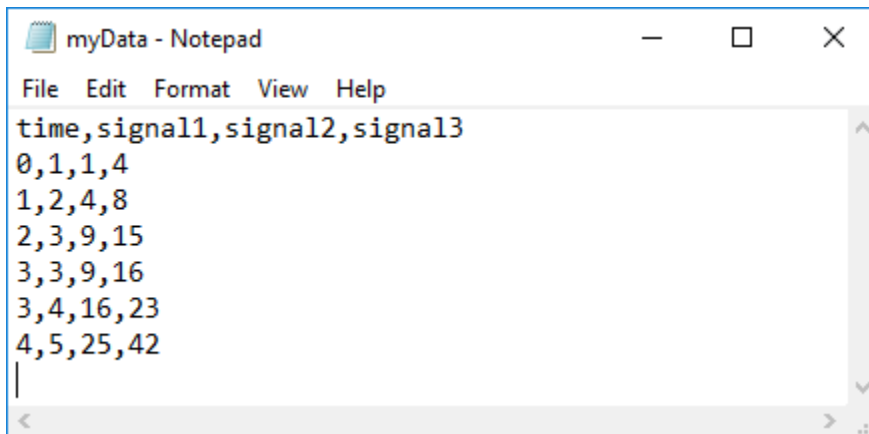
---

**Tip** When you want to import data from a CSV file where the data is formatted differently from the specification in this topic, you can write your own file reader for the Simulation Data Inspector using the `io.reader` class.

---

### Basic File Format

In the simplest format, the first row in the CSV file is a header that lists the names of the signals in the file. The first column is time. The name for the time column must be `time`, and the time values must increase monotonically. The rows below the signal names list the signal values that correspond to each time step.



```
myData - Notepad
File Edit Format View Help
time,signal1,signal2,signal3
0,1,1,4
1,2,4,8
2,3,9,15
3,3,9,16
3,4,16,23
4,5,25,42
```

The import operation does not support time data that includes `Inf` or `NaN` values or signal data that includes `Inf` values. Empty or `NaN` signal values render as missing data. All built-in data types are supported.

### Multiple Time Vectors

When your data includes signals with different time vectors, the file can include more than one time vector. Every time column must be named `time`. Time columns specify the sample times for signals to the right, up to the next time vector. For example, the first time column defines the time for `signal1` and `signal2`, and the second time column defines the time steps for `signal3`.

```

myData - Notepad
File Edit Format View Help
time,signal1,signal2,time,signal3
0,1,1,0,4
1,2,4,2,8
2,3,9,3,15
3,3,9,5,16
3,4,16
4,5,25

```

Signal columns must have the same number of data points as the associated time vector.

## Signal Metadata

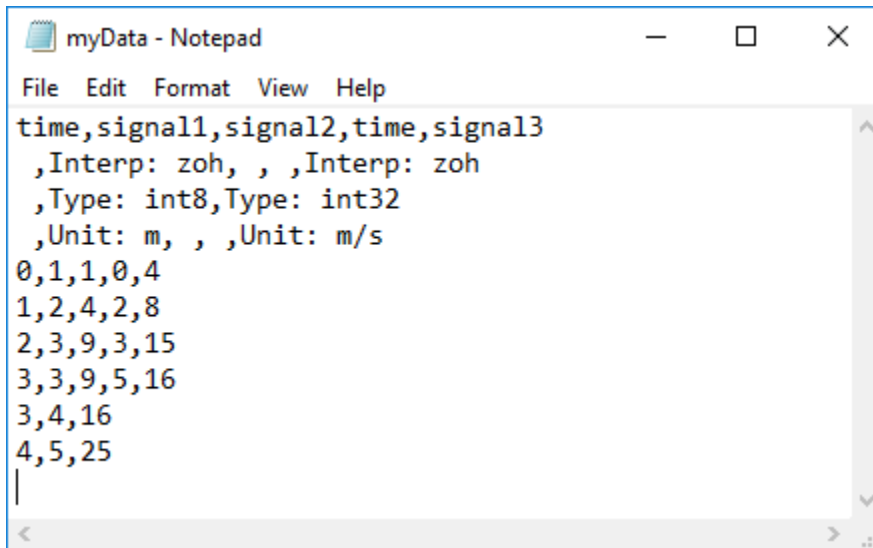
You can specify signal metadata in the CSV file to indicate the signal data type, units, interpolation method, block path, and port index. List metadata for each signal in rows between the signal name and the signal data. Label metadata according to this table.

Signal Property	Label	Value
Data type	Type:	Built-in data type.
Units	Unit:	Supported unit. For example, Unit: m/s specifies units of meters per second.  For a list of supported units, enter <code>showunitslist</code> in the MATLAB Command Window.
Interpolation method	Interp:	linear, zoh for zero order hold, or none.
Block Path	BlockPath:	Path to the block that generated the signal.
Port Index	PortIndex:	Integer.

You can also import a signal with a data type defined by an enumeration class. Instead of using the Type: label, use the Enum: label and specify the value as the name of the enumeration class. The definition for the enumeration class must be saved on the MATLAB path.

When an imported file does not specify signal metadata, the Simulation Data Inspector assumes double data type and linear interpolation. You can specify the interpolation method as linear, zoh (zero-order hold), or none. If you do not specify units for the signals in your file, you can assign units to the signals in the Simulation Data Inspector after you import the file.

You can specify any combination of metadata for each signal. Leave a blank cell for signals with less specified metadata.



```

myData - Notepad
File Edit Format View Help
time,signal1,signal2,time,signal3
,Interp: zoh, , ,Interp: zoh
,Type: int8,Type: int32
,Unit: m, , ,Unit: m/s
0,1,1,0,4
1,2,4,2,8
2,3,9,3,15
3,3,9,5,16
3,4,16
4,5,25
|

```

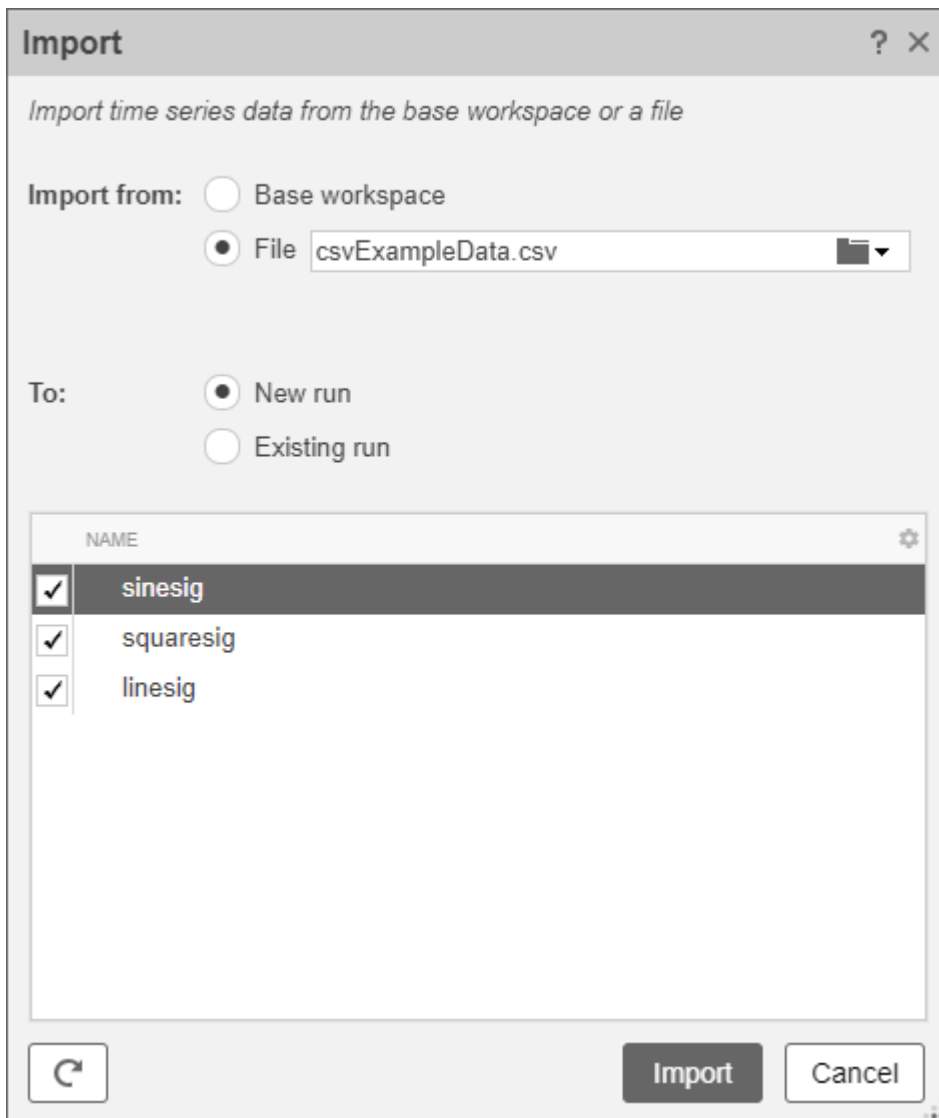
## Import Data from a CSV File

You can import data from a CSV file using the Simulation Data Inspector UI or using the `Simulink.sdi.createRun` function.

To import data using the UI, open the Simulation Data Inspector using the `Simulink.sdi.view` function or the **Data Inspector** button in the Simulink™ toolstrip. Then, click the **Import** button.



In the Import dialog, select the option to import data from a file and navigate in the file system to select the file. After you select the file, data available for import shows in the table. You can choose which signals to import and whether to import them to a new or existing run. This example imports all available signals to a new run. After selecting the options, click the **Import** button.



When you import data into a new run using the UI, the new run name includes the run number followed by `Imported_Data`.

When you import data programmatically, you can specify the name of the imported run.

```
csvRunID = Simulink.sdi.createRun('CSV File Run', 'file', 'csvExampleData.csv');
```

## See Also

### Functions

`Simulink.sdi.createRun`

## More About

- “View Data in the Simulation Data Inspector” (Simulink)

- “Microsoft Excel Import, Export, and Logging Format” (Simulink)
- “Import Data Using a Custom File Reader” (Simulink)

## Microsoft Excel Import, Export, and Logging Format

Using the Simulation Data Inspector or Simulink Test, you can import data from a Microsoft Excel file or export data to a Microsoft Excel file. You can also log data to an Excel file using the Record block. The Simulation Data Inspector, Simulink Test, and the Record block all use the same file format, so you can use the same Microsoft Excel file with multiple applications.

---

**Tip** When the format of the data in your Excel file does not match the specification in this topic, you can write your own file reader to import the data using the `io.reader` class.

---

### Basic File Format

In the simplest format, the first row in the Excel file is a header that lists the names of the signals in the file. The first column is time. The name for the time column must be `time`, and the time values must increase monotonically. The rows below the signal names list the signal values that correspond to each time step.

	A	B	C	D
1	<code>time</code>	<code>signal1</code>	<code>signal2</code>	<code>signal3</code>
2	0	1	1	4
3	1	2	4	8
4	2	3	9	15
5	3	3	9	16
6	3	4	16	23
7	4	5	25	42

The import operation does not support time data that includes `Inf` or `NaN` values or signal data that includes `Inf` values. Empty or `NaN` signal values imported from the Excel file render as missing data in the Simulation Data Inspector. All built-in data types are supported.

### Multiple Time Vectors

When your data includes signals with different time vectors, the file can include more than one time vector. Every time column must be named `time`. Time columns specify the sample times for signals to the right, up to the next time vector. For example, the first time column defines the time for `signal1` and `signal2`, and the second time column defines the time steps for `signal3`.

	A	B	C	D	E
1	<code>time</code>	<code>signal1</code>	<code>signal2</code>	<code>time</code>	<code>signal3</code>
2	0	1	1	0	4
3	1	2	4	2	8
4	2	3	9	3	15
5	3	3	9	5	16
6	3	4	16		
7	4	5	25		

Signal columns must have the same number of data points as the associated time vector.

## Signal Metadata

The file can include metadata for signals such as data type, units, and interpolation method. Metadata for each signal is listed in rows between the signal names and the signal data. You can specify any combination of metadata for each signal. Leave a blank cell for signals with less specified metadata.

	A	B	C	D	E
1	time	signal1	signal2	time	signal3
2		Interp: zoh			Interp: zoh
3		Type: int8	Type: int32		
4		Unit: m			Unit: m/s
5	0	1	1	0	4
6	1	2	4	2	8
7	2	3	9	3	15
8	3	3	9	5	16
9	3	4	16		
10	4	5	25		

Label each piece of metadata according to this table. The table also indicates which tools and operations support each piece of metadata.

## Property Descriptions

Signal Property	Label	Values	Simulation Data Inspector Import	Record Block Logging and Simulation Data Inspector Export	Simulink Test Import and Export
Data type	Type:	Built-in data type.	<b>Supported</b>	<b>Supported</b>	<b>Supported</b>
Units	Unit:	Supported unit. For example, Unit: m/s specifies units of meters per second.  For a list of supported units, enter showunitslist in the MATLAB Command Window.	<b>Supported</b>	<b>Supported</b>	<b>Supported</b>
Interpolation method	Interp:	linear, zoh for zero order hold, or none.	<b>Supported</b>	<b>Supported</b>	<b>Supported</b>
Synchronization method	Sync:	union or intersection.	<b>Supported</b>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>
Relative tolerance	RelTol:	Percentage, represented as a decimal. For example, RelTol: 0.1 specifies a 10% relative tolerance.	<b>Supported</b>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>
Absolute tolerance	AbsTol:	Numeric value.	<b>Supported</b>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>
Time tolerance	TimeTol:	Numeric value, in seconds.	<b>Supported</b>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>



<b>Signal Property</b>	<b>Label</b>	<b>Values</b>	<b>Simulation Data Inspector Import</b>	<b>Record Block Logging and Simulation Data Inspector Export</b>	<b>Simulink Test Import and Export</b>
Leading tolerance	LeadingTol :	Numeric value, in seconds.	<b>Supported</b> <i>Only visible in Simulink Test.</i>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>
Lagging tolerance	LaggingTol :	Numeric Value, in seconds.	<b>Supported</b> <i>Only visible in Simulink Test.</i>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>
Block Path	BlockPath :	Path to the block that generated the signal.	<b>Supported</b>	<b>Supported</b>	<b>Supported</b>
Port Index	PortIndex :	Integer.	<b>Supported</b>	<b>Supported</b>	<b>Supported</b>
Name	Name :	Signal name	<b>Supported</b>	<b>Not Supported</b> <i>Metadata not included in exported file.</i>	<b>Supported</b>

When an imported file does not specify signal metadata, double data type, linear interpolation, and union synchronization are used.

## User-Defined Data Types

In addition to built-in data types, you can use other labels in place of the DataType: label to specify fixed-point, enumerated, alias, and bus data types.

## Property Descriptions

Data Type	Label	Values	Simulation Data Inspector Import	Record Block Logging and Simulation Data Inspector Export	Simulink Test Import and Export
Enumeration	Enum:	Name of the enumeration class.	<b>Supported</b> <i>Enumeration class definition must be saved on the MATLAB path.</i>	<b>Supported</b> <i>Enumeration class definition must be saved on the MATLAB path.</i>	<b>Supported</b> <i>Enumeration class definition must be saved on the MATLAB path.</i>
Alias	Alias:	Name of a Simulink.AliasType object in the MATLAB workspace.	<b>Supported</b> <i>For matrix and complex signals, specify the alias data type on the first channel.</i>	<b>Not Supported</b>	<b>Supported</b> <i>For matrix and complex signals, specify the alias data type on the first channel.</i>
Fixed-point	Fixdt:	<ul style="list-style-type: none"> <li>fixdt constructor.</li> <li>Name of a Simulink.NumericType object in the MATLAB workspace.</li> <li>Name of a fixed-point data type as described in “Fixed-Point Numbers in Simulink” (Fixed-Point Designer).</li> </ul>	<b>Supported</b>	<b>Not Supported</b>	<b>Supported</b>
Bus	Bus:	Name of a Simulink.Bus object in the MATLAB workspace.	<b>Supported</b>	<b>Not Supported</b>	<b>Supported</b>

When you specify the type using the name of a Simulink.Bus object and the object is not in the MATLAB workspace, the data still imports from the file. However, individual signals in the bus use data types described in the file rather than data types defined in the Simulink.Bus object.

## Complex, Multidimensional, and Bus Signals

You can import and export complex, multidimensional, and bus signals using an Excel file. The signal name for a column of data indicates whether that data is part of a complex, multidimensional, or bus signal. Excel file import and export do not support array of bus signals.

Multidimensional signal names include index information in parentheses. For example, the signal name for a column might be `signal1(2,3)`. When you import data from a file that includes multidimensional signal data, elements in the data not included in the file take zero sample values with the same data type and complexity as the other elements.

Complex signal data is always in real-imaginary format. Signal names for columns containing complex signal data include `(real)` and `(imag)` to indicate which data each column contains. When you import data from a file that includes imaginary signal data without specifying values for the real component of that signal, the signal values for the real component default to zero.

Multidimensional signals can contain complex data. The signal name includes the indication for the index within the multidimensional signal and the real or imaginary tag. For example, `signal1(1,3) (real)`.

Dots in signal names specify the hierarchy for bus signals. For example:

- `bus.y.a`
- `bus.y.b`
- `bus.x`

	A	B	C	D	E
1	time	bus.y.a	bus.y.b	time	bus.x
2		Interp: zoh			Interp: zoh
3		Type: int8	Type: int32		
4		Unit: m			Unit: m/s
5	0	1	1	0	4
6	1	2	4	2	8
7	2	3	9	3	15
8	3	3	9	5	16
9	3	4	16		
10	4	5	25		

---

**Tip** When the name of your signal includes characters that could make it appear as though it were part of a matrix, complex signal, or bus, use the **Name** metadata option to specify the name you want the imported signal to use in the Simulation Data Inspector and Simulink Test.

---

## Function-Call Signals

Signal data specified in columns before the first time column is imported as one or more function-call signals. The data in the column specifies the times at which the function-call signal was enabled. The imported signals have a value of 1 for the times specified in the column. The time values for function-call signals must be double, scalar, and real, and must increase monotonically.

When you export data from the Simulation Data Inspector, function-call signals are formatted the same as other signals, with a time column and a column for signal values.

## Simulation Parameters

You can import data for parameter values used in simulation. In the Simulation Data Inspector, the parameter values are shown as signals. Simulink Test uses imported parameter values to specify values for those parameters in the tests it runs based on imported data.

Parameter data is specified using two or three columns. The first column specifies the parameter names, with the cell in the header row for that column labeled `Parameter:`. The second column specifies the value used for each parameter, with the cell in the header row labeled `Value:`. Parameter data may also include a third column that contains the block path associated with each parameter, with the cell in the header row labeled `BlockPath:`. Specify names, values, and block paths for parameters starting in the first row that contains signal data, below rows used to specify signal metadata. For example, this file specifies values for two parameters, X and Y.

	A	B	C	D	E	F	G
1	time	signal1	signal2	time	signal3	Parameter: Value:	
2		Interp: zoh			Interp: zoh		
3		Type: int8	Type: int32				
4		Unit: m			Unit: m/s		
5	0	1	1	0	4 X		2
6	1	2	4	2	8 Y		1.2
7	2	3	9	3	15		
8	3	3	9	5	16		
9	3	4	16				
10	4	5	25				

## Multiple Runs

You can include data for multiple runs in a single file. Within a sheet, you can divide data into runs by labeling data with a simulation number and a source type, such as `Input` or `Output`. Specify the simulation number and source type as additional signal metadata, using the label `Simulation:` for the simulation number and the label `Source:` for the source type. The Simulation Data Inspector uses the simulation number and source type only to determine which signals belong in each run. Simulink Test uses the information to define inputs, parameters, and acceptance criteria for tests to run based on imported data.

You do not need to specify the simulation number and output type for every signal. Signals to the right of a signal with a simulation number and source use the same simulation number and source until the next signal with a different source or simulation number. For example, this file defines data for two simulations and imports into four runs in the Simulation Data Inspector:

- **Run 1** contains `signal1` and `signal2`.
- **Run 2** contains `signal3`, X, and Y.
- **Run 3** contains `signal4`.

- **Run 4** contains signal5.

	A	B	C	D	E	F	G	H	I	J
1	time	signal1	signal2	time	signal3	Parameter:	Values:	time	signal4	signal5
2		Interp: zoh			Interp: zoh					
3		Type: int8	Type: int32							
4		Unit: m			Unit: m/s					
5		Simulation: 1							Simulation: 2	
6		Source: Input			Source: Output				Source: Input	Source: Output
7	0	1	1	0	4 X		2	1	2	1
8	1	2	4	2	8 Y		1.2	2	6	3
9	2	3	9	3	15			3	4	5
10	3	3	9	5	16			4	8	7
11	3	4	16					5	10	2
12	4	5	25							

You can also use sheets within the Microsoft Excel file to divide the data into runs and tests. When you do not specify simulation number and source information, the data on each sheet is imported into a separate run in the Simulation Data Inspector. When you export multiple runs from the Simulation Data Inspector, the data for each run is saved on a separate sheet. When you import a Microsoft Excel file that contains data on multiple sheets into Simulink Test, you are prompted to specify how to import the data.

## See Also

`Simulink.sdi.createRun` | `Simulink.sdi.exportRun`

## More About

- “View Data in the Simulation Data Inspector” (Simulink)
- “Import Data from a CSV File into the Simulation Data Inspector” (Simulink)
- “Import Data Using a Custom File Reader” (Simulink)

## Configure the Simulation Data Inspector

The Simulation Data Inspector supports a wide range of use cases for analyzing and visualizing data. You can modify preferences in the Simulation Data Inspector to match your visualization and analysis requirements. The preferences that you specify persist between MATLAB sessions.

By specifying preferences in the Simulation Data Inspector, you can configure options such as:

- How signals and metadata are displayed.
- Which data automatically imports from parallel simulations.
- Where prior run data is retained and how much prior data to store.
- How much memory is used during save operations.
- The system of units used to display signals.



Open the Simulation Data Inspector preferences by selecting the **Preferences** button.

---

**Note** You can restore all preferences in the Simulation Data Inspector to default values by clicking **Restore Defaults** in the dialog or by using the `Simulink.sdi.clearPreferences` function.

---

### Logged Data Size and Location

By default, simulation data logs to disk with data loaded into memory on demand, and the maximum size of logged data is constrained only by available disk space. You can use the **Disk Management** settings in the Simulation Data Inspector to directly control the size and location of logged data.

The **Record mode** setting specifies whether logged data is retained after simulation. When you change the **Record mode** setting to **View during simulation only**, no logged data is available in the Simulation Data Inspector or the workspace after the simulation completes. Only use this mode when you do not want to save logged data. The **Record mode** setting reverts to **View and record data** each time you start MATLAB. Changing the **Record mode** setting can affect other applications, such as visualization tools. For details, see “View Data Only During Simulation” (Simulink).

To directly limit the size of logged data, you can specify a minimum amount of free disk space or a maximum size for the logged data. By default, logged data must leave at least 100 MB of free disk space with no maximum size limit. Specify the required disk space and maximum size in GB, and specify 0 to apply no disk space requirement or no maximum size limit.

When you specify a minimum disk space requirement or a maximum size for logged data, you can also specify whether to prioritize retaining data from the current simulation or data from prior simulations when approaching the limit. By default, the Simulation Data Inspector prioritizes retaining data for the current run by deleting data for prior runs. To prioritize retaining prior data, change the **When low on disk space** setting to **Keep prior runs and stop recording**. You see a warning message when prior runs are deleted and when recording is disabled. If recording is disabled due to the size of logged data, you need to change the **Record Mode** back to **View and record data** to continue logging data, after you have freed up disk space. For more information, see “Specify a Minimum Disk Space Requirement or Maximum Size for Logged Data” (Simulink).

The **Storage Mode** setting specifies whether to log data to disk or to memory. By default, data logs to disk. When you configure a parallel worker to log data to memory, data transfer back to the host is not supported.

You can also specify the location of the temporary file that stores logged data. By default, data logs to the temporary files directory on your computer. You may change the file location when you need to log large amounts of data and a secondary drive provides more storage capacity. Logging data to a network location can degrade performance.

### Programmatic Use

You can programmatically configure and check each preference value.

Preference	Functions
<b>Record mode</b>	Simulink.sdi.setRecordData Simulink.sdi.getRecordData
<b>Required Free Space</b>	Simulink.sdi.setRequiredFreeSpace Simulink.sdi.getRequiredFreeSpace
<b>Max Disk Usage</b>	Simulink.sdi.setMaxDiskUsage Simulink.sdi.getMaxDiskUsage
<b>When low on disk space</b>	Simulink.sdi.setDeleteRunsOnLowSpace Simulink.sdi.getDeleteRunsOnLowSpace
<b>Storage Mode</b>	Simulink.sdi.setStorageMode Simulink.sdi.getStorageMode
<b>Storage Location</b>	Simulink.sdi.setStorageLocation Simulink.sdi.getStorageLocation

## Archive Behavior and Run Limit

The Simulation Data Inspector archive stores runs in a collapsible pane, allowing you to manage the contents of the work area without deleting run data. You can configure whether the Simulation Data Inspector automatically moves prior simulation runs to the archive. You can also limit the number of runs stored in the archive.


### Manage Runs in the Archive

By default, the Simulation Data Inspector automatically archives simulation runs. When you simulate a model, the prior simulation run moves to the archive, and the Simulation Data Inspector updates the view to show the data for aligned signals in the current run.

The archive does not impose functional limitations on the runs and signals it contains. You can plot signals from the archive, and you can use runs and signals in the archive in comparisons. You can drag runs of interest from the archive to the work area and vice versa whether the **Automatically Archive** setting is enabled or disabled. To prevent the Simulation Data Inspector from automatically moving prior simulations runs to the archive, clear the **Automatically archive** setting.

When you import runs into the Simulation Data Inspector, the imported runs appear in the work area, and the **Current** tag remains on the most recent simulation run. You can import signals to existing runs in the work area and in the archive.

---

**Tip** You can delete the contents of the archive manually using the trash  icon.

---

### Limit Data Retention

To reduce the amount of data the Simulation Data Inspector retains, you can configure a limit for the number of runs stored in the archive. When the number of runs in the archive reaches the size limit, the Simulation Data Inspector starts to delete runs on a first-in, first-out basis.

The size limit applies only to runs in the archive. For the Simulation Data Inspector to automatically limit the data it retains by deleting old runs, select **Automatically archive** and specify a size limit.

By default, the Simulation Data Inspector retains the last 20 runs moved to the archive. To remove the limit, select **No limit**. To specify the maximum number of runs to store in the archive, select **Last n runs** and enter the desired limit. The Simulation Data Inspector warns you when you specify a limit that would delete runs already in the archive.

### Programmatic Use

Configure the **Automatically archive** setting programmatically using the `Simulink.sdi.setAutoArchiveMode` function.

Specify the number of runs to retain in the archive using the `Simulink.sdi.setArchiveRunLimit` function.

### Incoming Run Names and Location

You can configure how the Simulation Data Inspector handles incoming runs from import or simulation. You can choose whether new runs are added at the top of the work area or the bottom and specify a naming rule to use for runs created from simulation.

By default, the Simulation Data Inspector adds new runs below prior runs in the work area. The **Archive** settings also affect the location of runs. By default, prior runs are moved to the archive when a new simulation run is created.

The run naming rule is used to name runs created from simulation. You can create the run naming rule using a mix of literal text that is used in the run name as-is and one or more tokens that represent metadata about the run. By default, the Simulation Data Inspector names runs using the run index and model name: `Run <run_index>: <model_name>`.

---

**Tip** To rename an existing run, double-click the name in the work area and enter the new name, or modify the run name in the **Properties** pane.

---

### Programmatic Use

You can programmatically check and modify the naming rule using the `Simulink.sdi.getRunNamingRule` and `Simulink.sdi.setRunNamingRule` functions. Restore



the naming rule to its default programmatically using the `Simulink.sdi.resetRunNamingRule` function.

## Signal Metadata to Display

You can control which signal metadata is displayed in the work area of the **Inspect** pane and in the results section on the **Compare** pane in the Simulation Data Inspector. You specify the metadata to display separately for each pane using the **Table Columns** preferences in the **Inspect** and **Compare** sections of the Preferences dialog, respectively.

### Inspect Pane

By default, the signal name and the line style and color used to plot the signal are displayed on the **Inspect** pane. To display different or additional metadata in the work area on the **Inspect** pane, select the check box next to each piece of metadata you want to display in the **Table Columns** preference in the **Inspect** section. You can always view complete metadata for the selected signal in the **Inspect** pane using the **Properties** pane.

---

**Note** Metadata displayed in the work area on **Inspect** pane is included when you generate a report of plotted signals. You can also specify metadata to include in the report regardless of what is displayed in the work area when you create the report programmatically using the `Simulink.sdi.report` function.

---

### Compare Pane

By default, the **Compare** pane shows the signal name, the absolute and relative tolerances used in the signal comparison, and the maximum difference from the comparison result. To display different or additional metadata in the results on the **Compare** pane, select the check box next to each piece of metadata you want to display in the **Table Columns** preference in the **Compare** section. You can always view complete metadata for the signals compared for a selected signal result using the **Properties** pane, where metadata that differs between the compared signals is highlighted. Signal metadata displayed on the **Compare** pane does not affect the contents of comparison reports.

## Signal Selection on the Inspect Pane

You can configure how you select signals to plot on the selected subplot in the Simulation Data Inspector. By default, you use check boxes next to each signal to plot. You can also choose to plot signals based on selection in the work area. Use **Check Mode** when creating views and visualizations that represent findings and analysis of a data set. Use **Browse Mode** to quickly view and analyze data sets with a large number of signals.

For more information about creating visualizations using **Check Mode**, see “Create Plots Using the Simulation Data Inspector” (Simulink).

For more information about using **Browse Mode**, see “Visualize Many Logged Signals” (Simulink).

---

**Note** To use **Browse Mode**, your layout must include only **Time Plot** visualizations.

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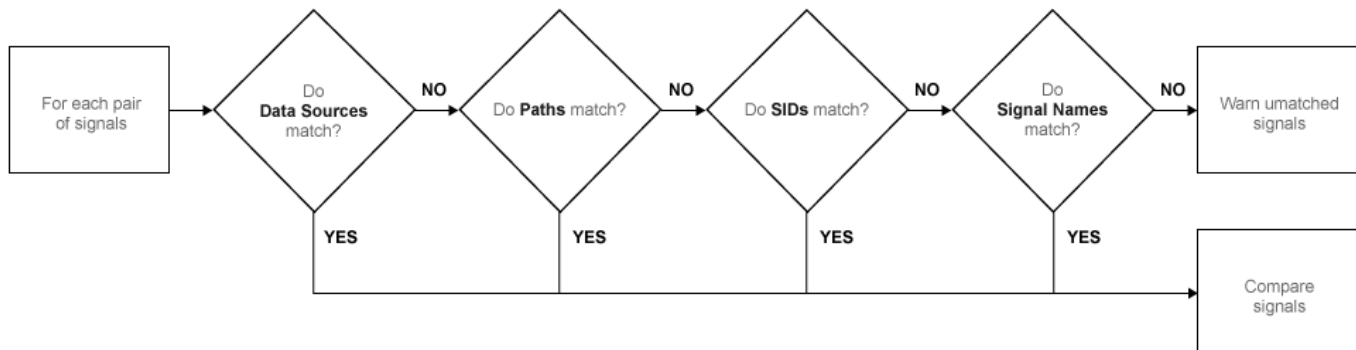
## How Signals Are Aligned for Comparison

When you compare runs using the Simulation Data Inspector, the comparison algorithm pairs signals for signal comparison through a process called alignment. You can align signals between the compared runs using one or more of the signal properties shown in the table.

Property	Description
Data Source	Path of the variable in the MATLAB workspace for data imported from the workspace
Path	Block path for the source of the data in its model
SID	Simulink identifier  For more information about SIDs, see “Simulink Identifiers” (Simulink)
Signal Name	Name of the signal

You can specify the priority for each piece of metadata used for alignment. The **Align By** field specifies the highest priority property used to align signals. The priority drops with each subsequent **Then By** field. You must specify a primary alignment property in the **Align By** field, but you can leave any number of **Then By** fields blank.

By default, the Simulation Data Inspector aligns signals between runs according to this flow chart.



For more information about configuring comparisons in the Simulation Data Inspector, see “How the Simulation Data Inspector Compares Data” (Simulink).

## Colors Used to Display Comparison Results

You can configure the colors used to display comparison results using the Simulation Data Inspector preferences. You can specify whether to use the signal color from the **Inspect** pane or a fixed color for the baseline and compared signals. You can also choose colors for the tolerance and the difference signal.

By default, the Simulation Data Inspector displays comparison results using fixed colors for the baseline and compared signals. Using a fixed color allows you to avoid the baseline signal color and compared signal color being either the same or too similar to distinguish.

## Signal Grouping

You can specify how to group signals within a run in the Simulation Data Inspector. The preferences apply to both the **Inspect** and **Compare** panes. You can group signals by:

- Domain — Signal type. For example, signals created by signal logging have a domain of **Signal**, while signals created from logging model outputs have a domain of **Outputs**.
- Physical System Hierarchy — Signal Simscape™ physical system hierarchy. The option to group by physical system hierarchy is available when you have a Simscape license.
- Data Hierarchy — Signal location within structured data. For example, data hierarchy grouping reflects the hierarchy of a bus.
- Model Hierarchy — Signal location within model hierarchy. Grouping by model hierarchy can be helpful when you log data from a model that includes model or subsystem references.

Grouping signals adds rows for the hierarchical nodes, which you can expand to show the signals within that node. By default, the Simulation Data Inspector groups signals by domain, then by physical system hierarchy (if you have a Simscape license), and then by data hierarchy.

To remove grouping and display a flat list of signals in each run, select **None** for all grouping options.

### Programmatic Use

To specify how to group signals programmatically, use the `Simulink.sdi.setTableGrouping` function.

## Data to Stream from Parallel Simulations

When you run parallel simulations using the `parsim` function, you can stream logged simulation data to the Simulation Data Inspector. A dot next to the run name in the **Inspect** pane indicates the status of the simulation that corresponds to the run, so you can monitor simulation progress while visualizing the streamed data. You can control whether data streams from a parallel simulation based on the type of worker the data comes from.

By default, the Simulation Data Inspector is configured for manual import of data from parallel workers. You can use the Simulation Data Inspector programmatic interface to inspect the data on the worker and decide whether to send it to the client Simulation Data Inspector for further analysis. To manually move data from a parallel worker to the Simulation Data Inspector, use the `Simulink.sdi.sendWorkerRunToClient` function.

You may want to automatically stream data from parallel simulations that run on local workers or on local and remote workers. Streaming data from both local and remote workers may affect simulation performance, depending on how many simulations you run and how much data you log. When you choose to stream data from local workers or all parallel workers, all logged simulation data automatically shows in the Simulation Data Inspector.

### Programmatic Use

You can configure Simulation Data Inspector support for parallel worker data programmatically using the `Simulink.sdi.enablePCTSupport` function.

## Options for Saving and Loading Session Files

You can specify a maximum amount of memory to use while loading or saving a session file. By default, the Simulation Data Inspector uses a maximum of 100 MB of memory when you load or save a session file. You can specify a memory use limit as low as 50 MB.

To reduce the size of the saved session file, you can specify a compression option.

- **None** — Do not compress saved data.
- **Normal** — Compress the saved file as much as possible.
- **Fastest** — Compress the saved file less than **Normal** compression for faster save time.

## Signal Display Units

Signals in the Simulation Data Inspector have two units properties: stored units and display units. The stored units represent the units of the data saved to disk. The display units specify how the Simulation Data Inspector displays the data. You can configure the Simulation Data Inspector to use a system of units to define the display units for all signals. You can choose either the **SI** or **US Customary** system of units, or you can display data using its stored units.

When you use a system of units to define display units for signals in the Simulation Data Inspector, the display units update for any signal with display units that are not valid for that unit system. For example, if you select **SI** units, the display units for a signal may update from **ft** to **m**.

---

**Note** The system of units you choose to use in the Simulation Data Inspector does not affect the stored units for any signal. You can convert the stored units for a signal using the `convertUnits` function. Conversion may result in loss of precision.

---

In addition to selecting a system of units, you can specify override units so that all signals of a given measurement type are displayed using consistent units. For example, if you want to visualize all signals that represent weight using units of **kg**, specify **kg** as an override unit.

---

**Tip** For a list of units supported by Simulink, enter `showunitslist` in the MATLAB Command Window.

---

You can also modify the display units for a specific signal using the **Properties** pane. For more information, see “Modify Signal Properties in the Simulation Data Inspector” (Simulink).

### Programmatic Use

Configure the unit system and override units using the `Simulink.sdi.setUnitSystem` function. You can check the current units preferences using the `Simulink.sdi.getUnitSystem` function.

## See Also

### Functions

`Simulink.sdi.clearPreferences` | `Simulink.sdi.enablePCTSupport` |  
`Simulink.sdi.setArchiveRunLimit` | `Simulink.sdi.setAutoArchiveMode` |  
`Simulink.sdi.setRunNamingRule` | `Simulink.sdi.setTableGrouping`

## **More About**

- [“Iterate Model Design Using the Simulation Data Inspector” \(Simulink\)](#)
- [“How the Simulation Data Inspector Compares Data” \(Simulink\)](#)
- [“Compare Simulation Data” \(Simulink\)](#)
- [“Create Plots Using the Simulation Data Inspector” \(Simulink\)](#)
- [“Modify Signal Properties in the Simulation Data Inspector” \(Simulink\)](#)

## How the Simulation Data Inspector Compares Data

You can tailor the Simulation Data Inspector comparison process to fit your requirements in multiple ways. When comparing runs, the Simulation Data Inspector:

- 1 Aligns signal pairs in the **Baseline** and **Compare To** runs based on the **Alignment** settings.




The Simulation Data Inspector does not compare signals that it cannot align.

- 2 Synchronizes aligned signal pairs according to the specified **Sync Method**.

Values for time points added in synchronization are interpolated according to the specified **Interpolation Method**.

- 3 Computes the difference of the signal pairs.
- 4 Compares the difference result against specified tolerances.

When the comparison run completes, the results of the comparison are displayed in the navigation pane.

Status	Comparison Result
	Difference falls within the specified tolerance.
	Difference violates specified tolerance.
	The signal does not align with a signal from the <b>Compare To</b> run.

When you compare signals with differing time intervals, the Simulation Data Inspector compares the signals on their overlapping interval.

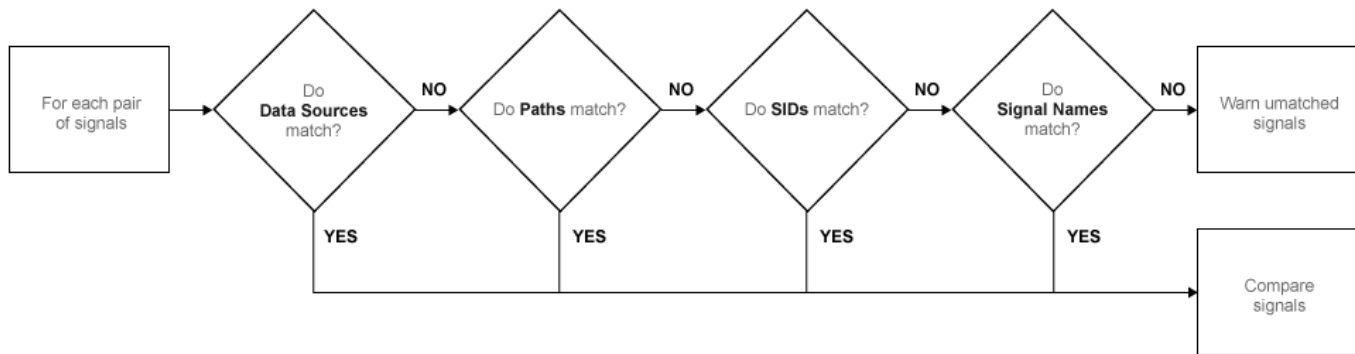
### Signal Alignment

In the alignment step, the Simulation Data Inspector decides which signal from the **Compare To** run pairs with a given signal in the **Baseline** run. When you compare signals with the Simulation Data Inspector, you complete the alignment step by selecting the **Baseline** and **Compare To** signals.

The Simulation Data Inspector aligns signals using a combination of their Data Source, Path, SID, and Signal Name properties.

Property	Description
Data Source	Path of the variable in the MATLAB workspace for data imported from the workspace
Path	Block path for the source of the data in its model
SID	Simulink identifier  For more information about SIDs, see “Simulink Identifiers” (Simulink)
Signal Name	Name of the signal in the model

With the default alignment settings, the Simulation Data Inspector aligns signals between runs according to this flow chart.

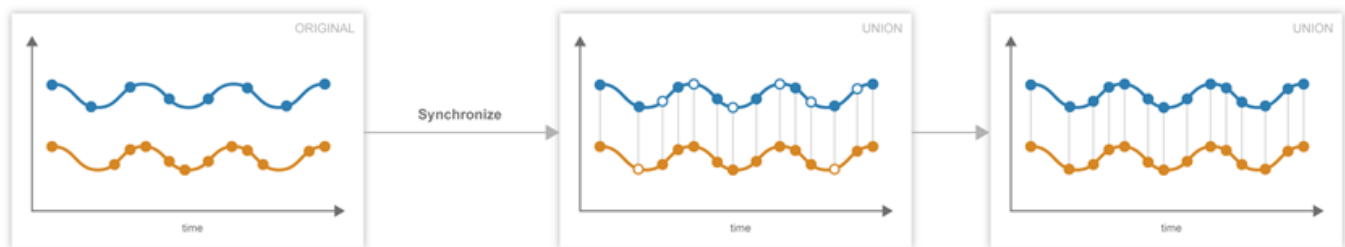


You can specify the priority for each of the signal properties used for alignment in the Simulation Data Inspector **Preferences**. The **Align By** field specifies the highest priority property used to align signals. The priority drops with each subsequent **Then By** field. You must specify a primary alignment property in the **Align By** field, but you can leave any number of the **Then By** fields blank.

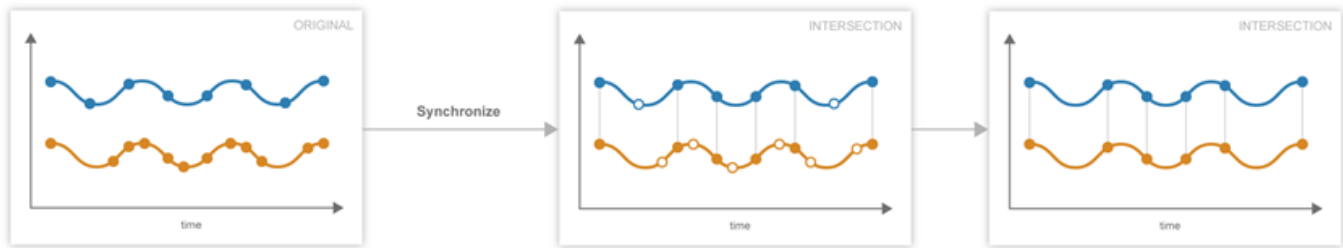
## Synchronization

Often, signals that you want to compare don't contain the exact same set of time points. The synchronization step in Simulation Data Inspector comparisons resolves discrepancies in signals' time vectors. You can choose **union** or **intersection** as the synchronization method.

When you specify **union** synchronization, the Simulation Data Inspector builds a time vector that includes every sample time between the two signals. For each sample time not originally present in either signal, the Simulation Data Inspector interpolates the value. The second graph in the illustration shows the union synchronization process, where the Simulation Data Inspector identifies samples to add in each signal, represented by the unfilled circles. The final plot shows the signals after the Simulation Data Inspector has interpolated values for the added time points. The Simulation Data Inspector computes the difference using the signals in the final graph, so that the computed difference signal contains all the data points between the signals.



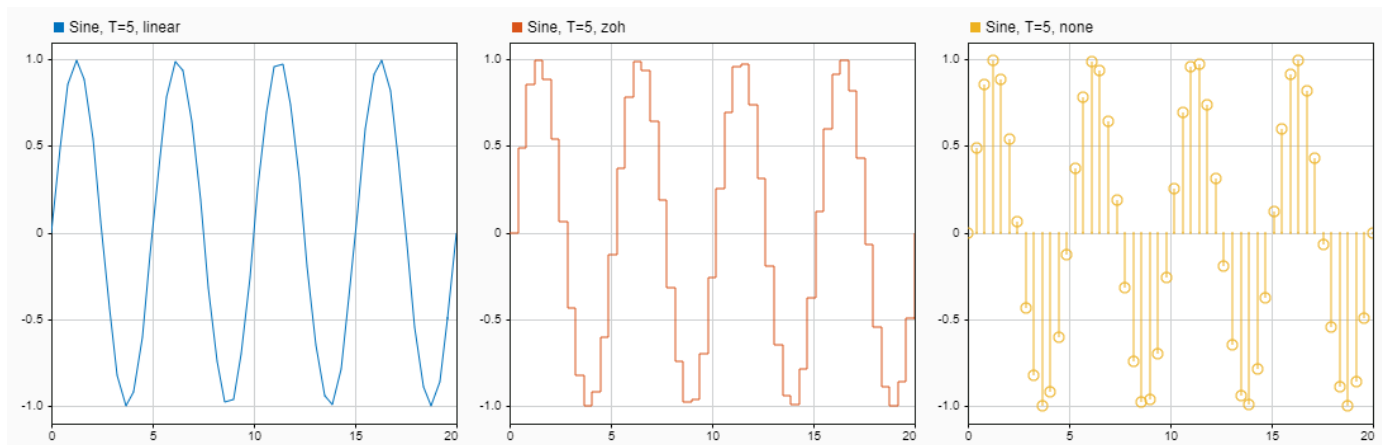
When you specify **intersection** synchronization, the Simulation Data Inspector uses only the sample times present in both signals in the comparison. In the second graph, the Simulation Data Inspector identifies samples that do not have a corresponding sample for comparison, shown as unfilled circles. The final graph shows the signals used for the comparison, without the samples identified in the second graph.



The choice between the synchronization options involves a trade off between speed and accuracy. The interpolation required by `union` synchronization takes time, but provides a more precise result. When you use `intersection` synchronization, the comparison finishes quickly because the Simulation Data Inspector computes the difference for fewer data points and does not interpolate. However, some data is discarded and precision is lost with `intersection` synchronization.

## Interpolation

The interpolation property of a signal determines how the Simulation Data Inspector displays the signal and how additional data values are computed in synchronization. You can choose to interpolate your data with a zero-order hold (`zoh`) or a linear approximation. You can also specify no interpolation.



When you specify `zoh` or `none` for the **Interpolation Method**, the Simulation Data Inspector replicates the data of the previous sample for interpolated sample times. When you specify `linear` interpolation, the Simulation Data Inspector uses samples on either side of the interpolated point to linearly approximate the interpolated value. Typically, discrete signals use `zoh` interpolation and continuous signals use `linear` interpolation. You can specify the **Interpolation Method** for your signals in the signal properties.

## Tolerance Specification

The Simulation Data Inspector allows you to specify the scope and value of the tolerance for your signal. You can define a tolerance band using any combination of absolute, relative, and time tolerance values, and you can specify whether the specified tolerance applies to an individual signal or to all the signals in a run.



## Tolerance Scope

In the Simulation Data Inspector, you can specify the tolerance for your data globally or for an individual signal. Global tolerance values apply to all signals in a run that do not have **Override Global Tol** set to yes. You can specify global tolerance values for your data at the top of the graphical viewing area in the **Compare** view. To specify signal specific tolerance values, edit the signal properties and ensure the **Override Global Tol** property is set to yes.

## Tolerance Computation

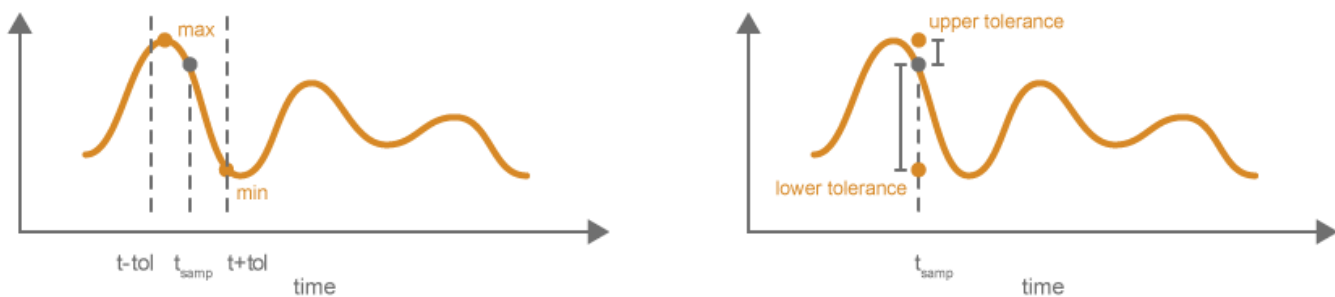
In the Simulation Data Inspector, you can specify a tolerance band for your run or signal using a combination of absolute, relative, and time tolerance values. When you specify the tolerance for your run or signal using multiple types of tolerances, each tolerance can yield a different answer for the tolerance at each point. The Simulation Data Inspector computes the overall tolerance band by selecting the most lenient tolerance result for each data point.

When you define your tolerance using only the absolute and relative tolerance properties, the Simulation Data Inspector computes the tolerance for each point as a simple maximum.

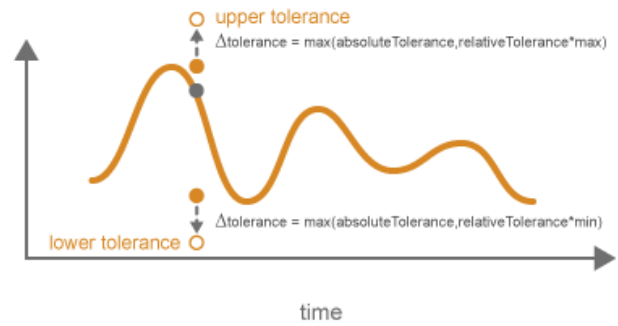
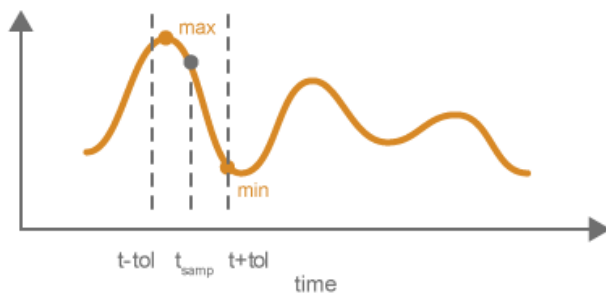
```
tolerance = max(absoluteTolerance, relativeTolerance*abs(baselineData));
```

The upper boundary of the tolerance band is formed by adding **tolerance** to the **Baseline** signal. Similarly, the Simulation Data Inspector computes the lower boundary of the tolerance band by subtracting **tolerance** from the **Baseline** signal.

When you specify a time tolerance, the Simulation Data Inspector evaluates the time tolerance first, over a time interval defined as  $[(t_{\text{samp}} - \text{tol}), (t_{\text{samp}} + \text{tol})]$  for each sample. The Simulation Data Inspector builds the lower tolerance band by selecting the minimum point on the interval for each sample. Similarly, the maximum point on the interval defines the upper tolerance for each sample.



If you specify a tolerance band using an absolute or relative tolerance in addition to a time tolerance, the Simulation Data Inspector applies the time tolerance first, and then applies the absolute and relative tolerances to the maximum and minimum points selected with the time tolerance.



`upperTolerance = max + max(absoluteTolerance, relativeTolerance*max)`

`lowerTolerance = min - max(absoluteTolerance, relativeTolerance*min)`

## Limitations

The Simulation Data Inspector does not support comparing:

- Signals of data types `int64` or `uint64`.
- Variable-size signals.

## See Also

### Related Examples

- “Compare Simulation Data” (Simulink)

## Save and Share Simulation Data Inspector Data and Views

After you inspect, analyze, or compare your data in the Simulation Data Inspector, you can share your results with others. The Simulation Data Inspector provides several options for sharing and saving your data and results, depending on your needs. With the Simulation Data Inspector, you can:

- Save your data and layout modifications in a Simulation Data Inspector session.
- Share your layout modifications in a Simulation Data Inspector view.
- Share images and figures of plots you create in the Simulation Data Inspector.
- Create a Simulation Data Inspector report.
- Export your data from the Simulation Data Inspector.

### Save and Load Simulation Data Inspector Sessions

If you want to save or share data along with a configured view in the Simulation Data Inspector, save your data and settings in a Simulation Data Inspector session. You can save sessions as MAT- or MLDATX-files. The default format is MLDATX. When you save a Simulation Data Inspector session, the session file contains:

- All runs, data, and properties from the **Inspect** pane, including which run is the current run and which runs are in the archive.
- Plot display selection for signals in the **Inspect** pane.
- Subplot layout and line style and color selections.

---

**Note** Comparison results and global tolerances are not saved in Simulation Data Inspector sessions.

---

To save a Simulation Data Inspector session:

- 1 Hover over the save icon on the left side bar. Then, click **Save As**.




- 2 Name the file.
- 3 Browse to the location where you want to save the session, and click **Save**.

For large datasets, a status overlay in the bottom right of the graphical viewing area displays information about the progress of the save operation and allows you to cancel the save operation.

The **Save** tab of the Simulation Data Inspector preferences menu on the left side bar allows you to configure options related to save operations for MLDATX-files. You can set a limit as low as 50MB on the amount of memory used for the save operation. You can also select one of three **Compression** options:

- **None**, the default, applies no compression during the save operation.
- **Normal** creates the smallest file size.
- **Fastest** creates a smaller file size than you would get by selecting **None**, but provides a faster save time than **Normal**.



To load a Simulation Data Inspector session, click the open icon  on the left side bar. Then, browse to select the MLDATX-file you want to open, and click **Open**.

Alternatively, you can double-click the MLDATX-file. MATLAB and the Simulation Data Inspector open if they are not already open.

When the Simulation Data Inspector already contains runs and you open a session, all of the runs in the session move to the archive. The view updates to reflect show plotted signals from the session file. You can drag runs between the work area and archive as desired.


When the Simulation Data Inspector does not contain runs and you open a session, the Simulation Data Inspector puts runs in the work area and archive as specified in the file.

## Share Simulation Data Inspector Views


When you have different sets of data that you want to visualize the same way, you can save a view. A view saves the layout and appearance characteristics of the Simulation Data Inspector without saving the data. Specifically, a view saves:

- Plot layout, axis ranges, linking characteristics, and normalized axes.
- Location of signals in the plots, including plotted signals in the archive.
- Signal grouping and columns on display in the **Inspect** pane.
- Signal color and line styling.

To save a view:


- 1 Click the layout button .
- 2 Click **Save current view**.
- 3 In the dialog box, specify a name for the view and browse to the location where you want to save the MLDATX-file.
- 4 Click **Save**.

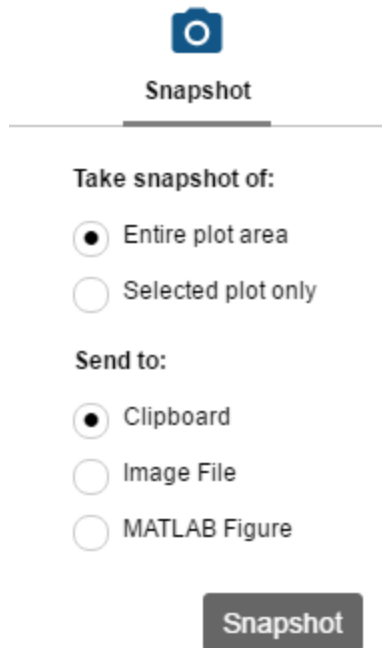
To load a view:

- 1 Click the layout button .
- 2 Click **Open saved view**.
- 3 Browse to the view you would like to load, and click **Open**.

## Share Simulation Data Inspector Plots

Use the snapshot feature to share the plots you generate in the Simulation Data Inspector. You can export your plots to the clipboard to paste into a document, as an image file, or to a MATLAB figure. You can choose to capture the entire plot area, including all subplots in the plot area, or to capture only the selected subplot.

Click the camera icon  on the toolbar to access the snapshot menu. Use the radio buttons to select the area you want to share and how you want to share the plot. After you make your selections, click **Snapshot** to export the plot.



If you create an image, select where you would like to save the image in the file browser.

You can create snapshots of your plots in the Simulation Data Inspector programmatically using `Simulink.sdi.snapshot`.

## Create a Simulation Data Inspector Report

To generate documentation of your results quickly, create a Simulation Data Inspector report. You can create a report of your data in either the **Inspect** or the **Compare** pane. The report is an HTML file that includes information about all the signals and plots in the active pane. The report includes all signal information displayed in the signal table in the navigation pane. For more information about configuring the table, see “Inspect Metadata” (Simulink).

To generate a Simulation Data Inspector Report:

1

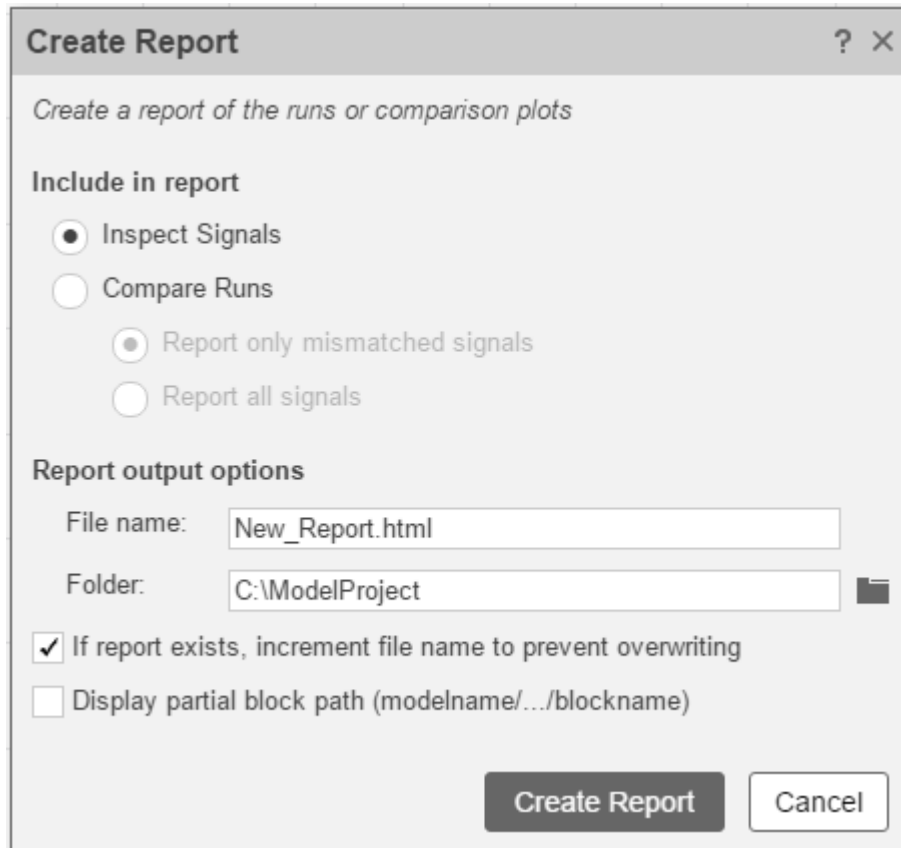


Click the create report icon on the left side bar.

2 Under **Include in report**, specify the type of report you want to create.

- Select **Inspect Signals** to include the plots and signals from the **Inspect** pane.
- Select **Compare Runs** to include the data and plots from the **Compare** pane. When you generate a **Compare Runs** report, you can choose to **Report only mismatched signals** or

to **Report all signals**. If you select **Report only mismatched signals**, the report shows only signal comparisons that are not within the specified tolerances.



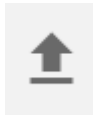
- 3 Specify a **File name** for the report, and navigate to the **Folder** where you want to save the report.
- 4 Click **Create Report**.

The generated report automatically opens in your default browser.

## Export Data from the Simulation Data Inspector

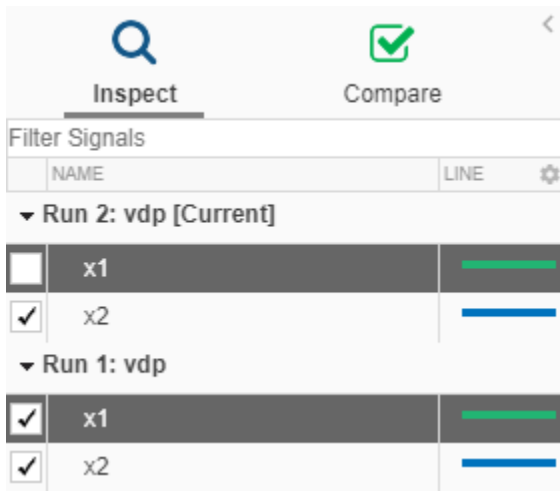
You can use the Simulation Data Inspector to export data to the base workspace, a MAT-file, or a Microsoft Excel file. You can export a selection of runs and signals, runs in the work area, or all runs in the **Inspect** pane, including the **Archive**.

When you export a selection of runs and signals, make the selection of data to export before clicking



the export button.

Only the selected runs and signals are exported. In this example, only the x1 signals from Run 1 and Run 2 are exported. The check box selections for the plotting area do not affect whether a signal is exported.



When you export a single signal, the signal is stored in `timeseries` format in the workspace variable or MAT-file. Exported data for a run or multiple signals is stored in `Simulink.SimulationData.Dataset` format.

---

**Note** When you export a run that contains logged parameter data, the exported `Simulink.SimulationData.Dataset` contains a `Simulink.SimulationData.Parameter` element for each logged parameter.

---

To export data to a file, select the **File** option in the **Export** dialog. You can specify a file name and browse to the location where you want to save the exported file. When you export data to a MAT-file, a single exported signal is stored in `timeseries` format, and runs or multiple signals are stored in `Simulink.SimulationData.Dataset` format. When you export data to a Microsoft Excel file, the data is stored in the format described in “Microsoft Excel Import, Export, and Logging Format” (Simulink).

To export to a Microsoft Excel file, select the XLSX extension from the drop-down. When you export data to a Microsoft Excel file, you can specify additional options for the format of the data in the exported file. If the file name you provided already exists, you can choose to overwrite the entire file or to only overwrite sheets containing data that corresponds to the exported data. You can also choose which metadata to include and whether signals with identical time data share a time column in the exported file.

## See Also

### Related Examples

- “View Data in the Simulation Data Inspector” (Simulink)
- “Inspect Simulation Data” (Simulink)
- “Compare Simulation Data” (Simulink)

## Inspect and Compare Data Programmatically

You can harness the capabilities of the Simulation Data Inspector from the MATLAB command line using the Simulation Data Inspector API.

The Simulation Data Inspector organizes data in runs and signals, assigning a unique numeric identification to each run and signal. Some Simulation Data Inspector API functions use the run and signal IDs to reference data, rather than accepting the run or signal itself as an input. To access the run IDs in the workspace, you can use `Simulink.sdi.getAllRunIDs` or `Simulink.sdi.getRunIDByIndex`. You can access signal IDs through a `Simulink.sdi.Run` object using the `getSignalIDByIndex` method.

The `Simulink.sdi.Run` and `Simulink.sdi.Signal` classes provide access to your data and allow you to view and modify run and signal metadata. You can modify the Simulation Data Inspector preferences using functions like `Simulink.sdi.setSubPlotLayout`, `Simulink.sdi.setRunNamingRule`, and `Simulink.sdi.setMarkersOn`. To restore the Simulation Data Inspector's default settings, use `Simulink.sdi.clearPreferences`.

### Create a Run and View the Data

This example shows how to create a run, add data to it, and then view the data in the Simulation Data Inspector.

#### Create Data for the Run

Create `timeseries` objects to contain data for a sine signal and a cosine signal. Give each `timeseries` object a descriptive name.

```
time = linspace(0,20,100);

sine_vals = sin(2*pi/5*time);
sine_ts = timeseries(sine_vals,time);
sine_ts.Name = 'Sine, T=5';

cos_vals = cos(2*pi/8*time);
cos_ts = timeseries(cos_vals,time);
cos_ts.Name = 'Cosine, T=8';
```

#### Create a Run and Add Data

Use the `Simulink.sdi.view` function to open the Simulation Data Inspector.

```
Simulink.sdi.view
```

To import data into the Simulation Data Inspector from the workspace, create a `Simulink.sdi.Run` object using the `Simulink.sdi.Run.create` function. Add information about the run to its metadata using the `Name` and `Description` properties of the `Run` object.

```
sinusoidsRun = Simulink.sdi.Run.create;
sinusoidsRun.Name = 'Sinusoids';
sinusoidsRun.Description = 'Sine and cosine signals with different frequencies';
```

Use the `add` function to add the data you created in the workspace to the empty run.

```
add(sinusoidsRun,'vars',sine_ts,cos_ts);
```



## Plot the Data in the Simulation Data Inspector

Use the `getSignalByIndex` function to access `Simulink.sdi.Signal` objects that contain the signal data. You can use the `Simulink.sdi.Signal` object properties to specify the line style and color for the signal and plot it in the Simulation Data Inspector. Specify the `LineColor` and `LineDashed` properties for each signal.

```
sine_sig = getSignalByIndex(sinusoidsRun,1);
sine_sig.LineColor = [0 0 1];
sine_sig.LineDashed = '-.';

cos_sig = sinusoidsRun.getSignalByIndex(2);
cos_sig.LineColor = [0 1 0];
cos_sig.LineDashed = '--';
```

Use the `Simulink.sdi.setSubPlotLayout` function to configure a 2-by-1 subplot layout in the Simulation Data Inspector plotting area. Then use the `plotOnSubplot` function to plot the sine signal on the top subplot and the cosine signal on the lower subplot.

```
Simulink.sdi.setSubPlotLayout(2,1);

plotOnSubPlot(sine_sig,1,1,true);
plotOnSubPlot(cos_sig,2,1,true);
```

## Close the Simulation Data Inspector and Save Your Data

When you have finished inspecting the plotted signal data, you can close the Simulation Data Inspector and save the session to an MLDATX file.

```
Simulink.sdi.close('sinusoids.mldatx')
```

## Compare Two Signals in the Same Run

You can use the Simulation Data Inspector programmatic interface to compare signals within a single run. This example compares the input and output signals of an aircraft longitudinal controller.

First, load the session that contains the data.

```
Simulink.sdi.load('AircraftExample.mldatx');
```

Use the `Simulink.sdi.Run.getLatest` function to access the latest run in the data.

```
aircraftRun = Simulink.sdi.Run.getLatest;
```

Then, you can use the `Simulink.sdi.getSignalsByName` function to access the `Stick` signal, which represents the input to the controller, and the `alpha, rad` signal that represents the output.

```
stick = getSignalsByName(aircraftRun,'Stick');
alpha = getSignalsByName(aircraftRun,'alpha, rad');
```

Before you compare the signals, you can specify a tolerance value to use for the comparison. Comparisons use tolerance values specified for the baseline signal in the comparison, so set an absolute tolerance value of 0.1 on the `Stick` signal.

```
stick.AbsTol = 0.1;
```

Now, compare the signals using the `Simulink.sdi.compareSignals` function. The `Stick` signal is the baseline, and the `alpha, rad` signal is the signal to compare against the baseline.

```
comparisonResults = Simulink.sdi.compareSignals(stick.ID,alpha.ID);
match = comparisonResults.Status

match =
OutOfTolerance
```

The comparison result is out of tolerance. You can use the `Simulink.sdi.view` function to open the Simulation Data Inspector to view and analyze the comparison results.

## Compare Runs with Global Tolerance

You can specify global tolerance values to use when comparing two simulation runs. Global tolerance values are applied to all signals within the run. This example shows how to specify global tolerance values for a run comparison and how to analyze and save the comparison results.

First, load the session file that contains the data to compare. The session file contains data for four simulations of an aircraft longitudinal controller. This example compares data from two runs that use different input filter time constants.

```
Simulink.sdi.load('AircraftExample.mldatx');
```

To access the run data to compare, use the `Simulink.sdi.getAllRunIDs` (Simulink) function to get the run IDs that correspond to the last two simulation runs.

```
runIDs = Simulink.sdi.getAllRunIDs;
runID1 = runIDs(end - 1);
runID2 = runIDs(end);
```

Use the `Simulink.sdi.compareRuns` (Simulink) function to compare the runs. Specify a global relative tolerance value of `0.2` and a global time tolerance value of `0.5`.

```
runResult = Simulink.sdi.compareRuns(runID1,runID2,'reltol',0.2,'timetol',0.5);
```

Check the `Summary` property of the returned `Simulink.sdi.DiffRunResult` object to see whether signals were within the tolerance values or out of tolerance.

```
runResult.Summary

ans = struct with fields:
    OutOfTolerance: 0
    WithinTolerance: 3
    Unaligned: 0
    UnitsMismatch: 0
    Empty: 0
    Canceled: 0
    EmptySynced: 0
    DataTypeMismatch: 0
    TimeMismatch: 0
    StartStopMismatch: 0
    Unsupported: 0
```

All three signal comparison results fell within the specified global tolerance.

You can save the comparison results to an MLDATX file using the `saveResult` (Simulink) function.

```
saveResult(runResult, 'InputFilterComparison');
```

## Analyze Simulation Data Using Signal Tolerances

You can programmatically specify signal tolerance values to use in comparisons performed using the Simulation Data Inspector. In this example, you compare data collected by simulating a model of an aircraft longitudinal flight control system. Each simulation uses a different value for the input filter time constant and logs the input and output signals. You analyze the effect of the time constant change by comparing results using the Simulation Data Inspector and signal tolerances.

First, load the session file that contains the simulation data.

```
Simulink.sdi.load('AircraftExample.mldatx');
```

The session file contains four runs. In this example, you compare data from the first two runs in the file. Access the `Simulink.sdi.Run` objects for the first two runs loaded from the file.

```
runIDs = Simulink.sdi.getAllRunIDs;
runIDs1 = runIDs(end-3);
runIDs2 = runIDs(end-2);
```

Now, compare the two runs without specifying any tolerances.

```
noTolDiffResult = Simulink.sdi.compareRuns(runIDs1, runIDs2);
```

Use the `getResultByIndex` function to access the comparison results for the `q` and `alpha` signals.

```
qResult = getResultByIndex(noTolDiffResult, 1);
alphaResult = getResultByIndex(noTolDiffResult, 2);
```

Check the `Status` of each signal result to see whether the comparison result fell within our out of tolerance.

```
qResult.Status
```

```
ans =
OutOfTolerance
```

```
alphaResult.Status
```

```
ans =
OutOfTolerance
```

The comparison used a value of `0` for all tolerances, so the `OutOfTolerance` result means the signals are not identical.

You can further analyze the effect of the time constant by specifying tolerance values for the signals. Specify the tolerances by setting the properties for the `Simulink.sdi.Signal` objects that correspond to the signals being compared. Comparisons use tolerances specified for the baseline signals. This example specifies a time tolerance and an absolute tolerance.

To specify a tolerance, first access the `Signal` objects from the baseline run.

```
runTs1 = Simulink.sdi.getRun(runIDTs1);  
qSig = getSignalsByName(runTs1, 'q, rad/sec');  
alphaSig = getSignalsByName(runTs1, 'alpha, rad');
```

Specify an absolute tolerance of 0.1 and a time tolerance of 0.6 for the q signal using the `AbsTol` and `TimeTol` properties.

```
qSig.AbsTol = 0.1;  
qSig.TimeTol = 0.6;
```

Specify an absolute tolerance of 0.2 and a time tolerance of 0.8 for the alpha signal.

```
alphaSig.AbsTol = 0.2;  
alphaSig.TimeTol = 0.8;
```

Compare the results again. Access the results from the comparison and check the `Status` property for each signal.

```
tolDiffResult = Simulink.sdi.compareRuns(runIDTs1, runIDTs2);  
qResult2 = getResultByIndex(tolDiffResult, 1);  
alphaResult2 = getResultByIndex(tolDiffResult, 2);
```

```
qResult2.Status
```

```
ans =  
WithinTolerance
```

```
alphaResult2.Status
```

```
ans =  
WithinTolerance
```

## See Also

**Simulation Data Inspector**

## Related Examples

- “Compare Simulation Data” (Simulink)
- “How the Simulation Data Inspector Compares Data” (Simulink)
- “Create Plots Using the Simulation Data Inspector” (Simulink)

## Limit the Size of Logged Data

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Logging simulation data can produce large amounts of data that fill up disk space. Such situations include logging many signals, logging data for long simulations, and running many simulations without deleting run data from the Simulation Data Inspector. You can choose among several options to limit the size of logged simulation data. You can:

- Limit the number of runs retained in the Simulation Data Inspector archive.
- Reduce the number of data points logged in each simulation.
- Specify a minimum disk space requirement or maximum size for logged data.
- Configure logging for only viewing data during simulation.

Depending on your requirements, you can use more than one strategy to limit the size of logged data.

### Limit the Number of Runs Retained in the Simulation Data Inspector Archive

When you run multiple simulations in a single MATLAB session, logged simulation data accumulates in the Simulation Data Inspector even if you overwrite the logging data in the MATLAB workspace. To reduce the amount of data the Simulation Data Inspector retains, you can configure a limit for the number of runs stored in the archive. When the number of runs in the archive reaches the size limit, the Simulation Data Inspector starts to delete runs from the archive on a first-in, first-out basis.

Configure the archive **Size** setting in the Simulation Data Inspector preferences. The size limit only applies to runs in the archive. For the Simulation Data Inspector to automatically limit data retention, select **Automatically archive** and specify the maximum number of runs to retain in the archive. By default, **Automatically archive** is enabled with an archive size limit of twenty runs. If you experience issues with logged data consuming too much disk space, consider adjusting the size limit for the archive in the Simulation Data Inspector preferences.

### Specify a Minimum Disk Space Requirement or Maximum Size for Logged Data

You can use preferences in the Simulation Data Inspector to directly limit the size of logged data by specifying a minimum amount of disk space to leave free or by specifying a maximum size for logged data on disk. Each setting accounts for all kinds of logged data. By default, logged data must leave at least 100 MB of free disk space with no maximum size limit. Specify the required disk space and maximum size in GB, and specify 0 to apply no disk space requirement or no maximum size limit.

When you specify a minimum disk space requirement or a maximum size for logged data, you can also specify whether to prioritize retaining data from the current simulation or data from prior simulations when approaching the limit. By default, the Simulation Data Inspector prioritizes

retaining data for the current run. As the free disk space or logged data size approaches the limit, prior runs are deleted first to free up space for data being logged in the current run. If deleting runs does not free up enough space, recording is disabled. To prioritize retaining prior data, change the **When low on disk space** setting to **Keep prior runs and stop recording**. You see a warning message when prior runs are deleted and when recording is disabled. If recording is disabled due to the size of logged data, you need to change the **Record Mode** back to **View and record data** to continue logging data, after you have freed up disk space.

## View Data Only During Simulation

In some situations, you may want to only view the data for logged signals and not save the values. For example, when using the Simulation Data Inspector to visualize data streaming from hardware, you may only want to view the data live and not record it. You can change the **Record mode** in the Simulation Data Inspector preferences to **View during simulation only** so that logged data is not saved and you can still view the data during simulation. The **Record mode** is reset to **View and record data** at the start of each MATLAB session.

When you change the **Record mode** to **View during simulation only**:

- Logged data is not available in the Simulation Data Inspector or workspace after simulation.
- You can view data using dashboard blocks, scopes, and the Simulation Data Inspector, but plots clear when you pan or zoom.
- You cannot access logged data during simulation using the Simulation Data Inspector programmatic interface.

## Reduce the Number of Data Points Logged from Simulation

Model configuration parameters and signal properties allow you to limit the number of data points logged in a simulation. Be sure to carefully consider data requirements when limiting logged data points. Limiting data can skip critical time points, and can lead to aliasing, if your effective sample rate is too low.

You can reduce the number of data points using:

- Decimation — Log every  $n$ th signal value.
- Limit data points to last — Only log the last  $n$  signal values.
- Logging intervals — Specify specific time intervals in which to log data.

For details, see “Specify Signal Values to Log” (Simulink).

## See Also

### Tools

**Simulation Data Inspector**

## Related Examples

- “Specify Signal Values to Log” (Simulink)
- “Configure the Simulation Data Inspector” (Simulink)