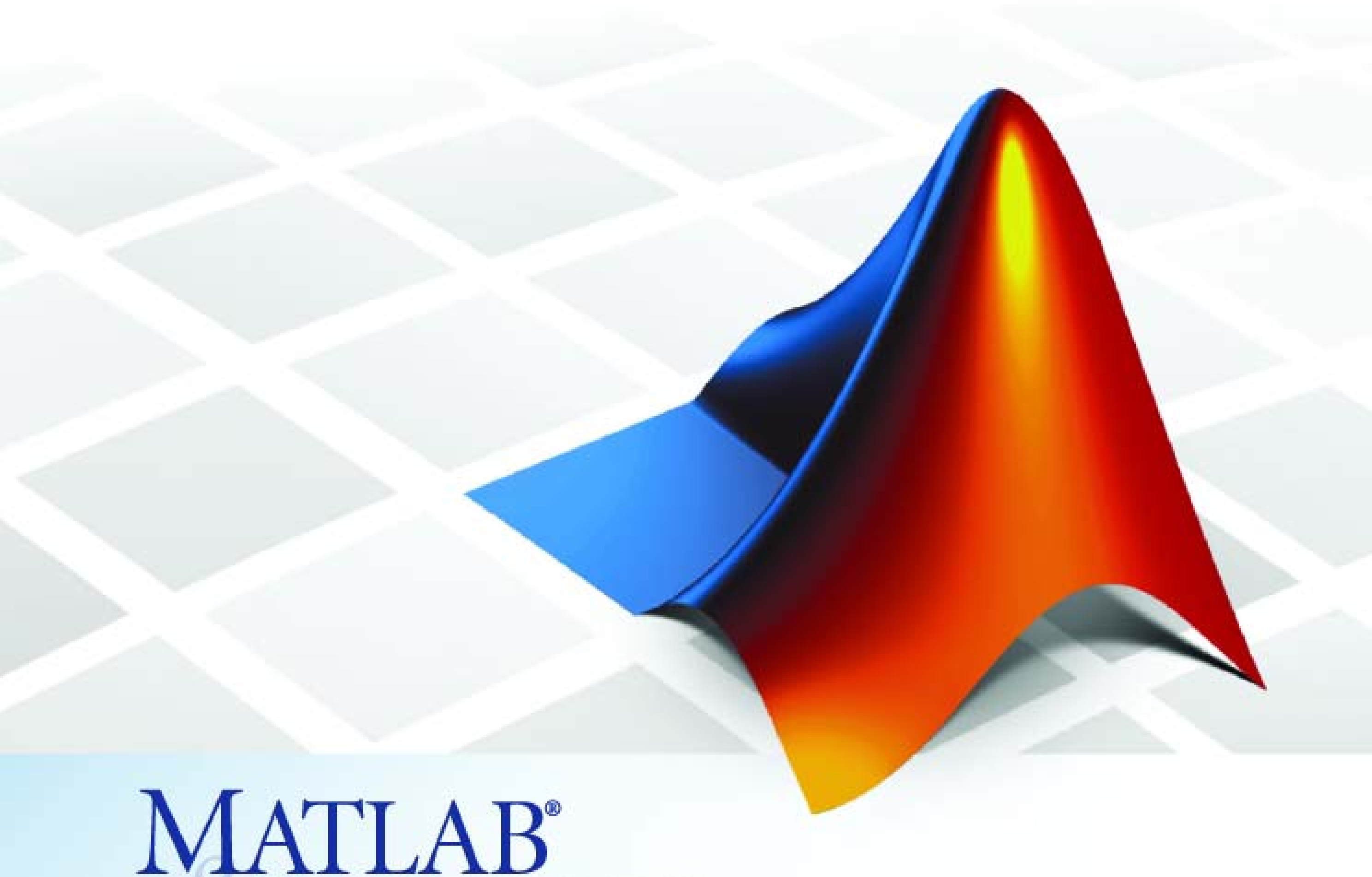
Stateflow® and Stateflow® Coder 6

User's Guide



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Stateflow and Stateflow Coder User's Guide

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A Semantic Rules Summary

Stateflow Concepts

This chapter acquaints you with the concepts involved in defining a finite state machine and follows this with a look at the hierarchical organization of Stateflow® objects. Later, it introduces you to a real-world Stateflow example. The sections in this chapter are as follows:

Stateflow Hierarchy of Objects (p. 1-21)	Stateflow supports a containment hierarchy for both charts and states. Charts can contain states, transitions, and the other Stateflow objects. States can contain other states, transitions, and so on as if they were charts themselves. This containment hierarchy applies to all Stateflow objects except targets, which are the sole possession of the Stateflow machine.
Exploring a Real-World Stateflow Application (p. 1-24)	The modeling of a real-world fault-tolerant fuel control system demonstrates how Simulink and Stateflow can be used to efficiently model hybrid systems containing both continuous dynamics and complex logical behavior.

Finite State Machine Concepts

Stateflow is an example of a finite state machine. The following topics examine what it means to be a finite state machine and what that designation requires from Stateflow:

- "What Is a Finite State Machine?" on page 1-3
- "Finite State Machine Representations" on page 1-3
- "Stateflow Representations" on page 1-4
- "Notation" on page 1-4
- "Semantics" on page 1-4
- "References" on page 1-5

What Is a Finite State Machine?

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 prescribed state, provided that the condition defining the change is true.

For example, you can use a state machine to represent a car's automatic transmission. The transmission has a number of 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 state that is active is determined based on the occurrence of events under certain conditions. State-transition diagrams and bubble diagrams are graphical representations based on this approach.

Stateflow Representations

Stateflow uses a variant of the finite state machine notation established by Harel [1]. Using Stateflow, you create Stateflow diagrams. A Stateflow diagram is a graphical representation of a finite state machine, where *states* and *transitions* form the basic building blocks of the system. You can also represent flow (stateless) diagrams using Stateflow. Stateflow provides a block that you include in a Simulink model. The collection of Stateflow blocks in a Simulink model is the Stateflow machine.

Additionally, Stateflow enables the representation of hierarchy, parallelism, and history. Hierarchy enables you to organize complex systems by defining a parent/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. History provides the means to specify the destination state of a transition based on historical information. These characteristics enhance the usefulness of this approach and go beyond what state-transition diagrams and bubble diagrams provide.

Notation

Notation defines a set of objects and the rules that govern the relationships between those objects. Stateflow notation provides a common language to communicate the design information conveyed by a Stateflow diagram.

Stateflow notation consists of the following:

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

See Chapter 2, “Stateflow Notation”, for detailed information on Stateflow notations.

Semantics

Semantics describe how the notation is interpreted and implemented. A completed Stateflow diagram illustrates how the system will behave. A Stateflow diagram contains actions associated with transitions and states.

The semantics describe in what sequence these actions take place during Stateflow diagram execution.

Knowledge of the semantics is important to make sound Stateflow diagram design decisions for code generation. Different use of notations results in different ordering of simulation and generated code execution.

The default semantics provided with the product are described in Chapter 3, "Stateflow Semantics".

References

For more information on finite state machine theory, consult these sources:

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

[2] Hatley, Derek J., and Imtiaz A. Pirbhai, *Strategies for Real-Time System Specification*, Dorset House Publishing Co., Inc., NY, 1988.

Stateflow and Simulink

Stateflow functions as a finite state machine within a Simulink model. The following topics examine how Stateflow functions in this environment and how Simulink and Stateflow communicate with each other:

- "The Simulink Model and the Stateflow Machine" on page 1-6
- "Stateflow Data Dictionary of Objects" on page 1-6
- "Defining Stateflow Interfaces to Simulink" on page 1-8

The Simulink Model and the Stateflow Machine

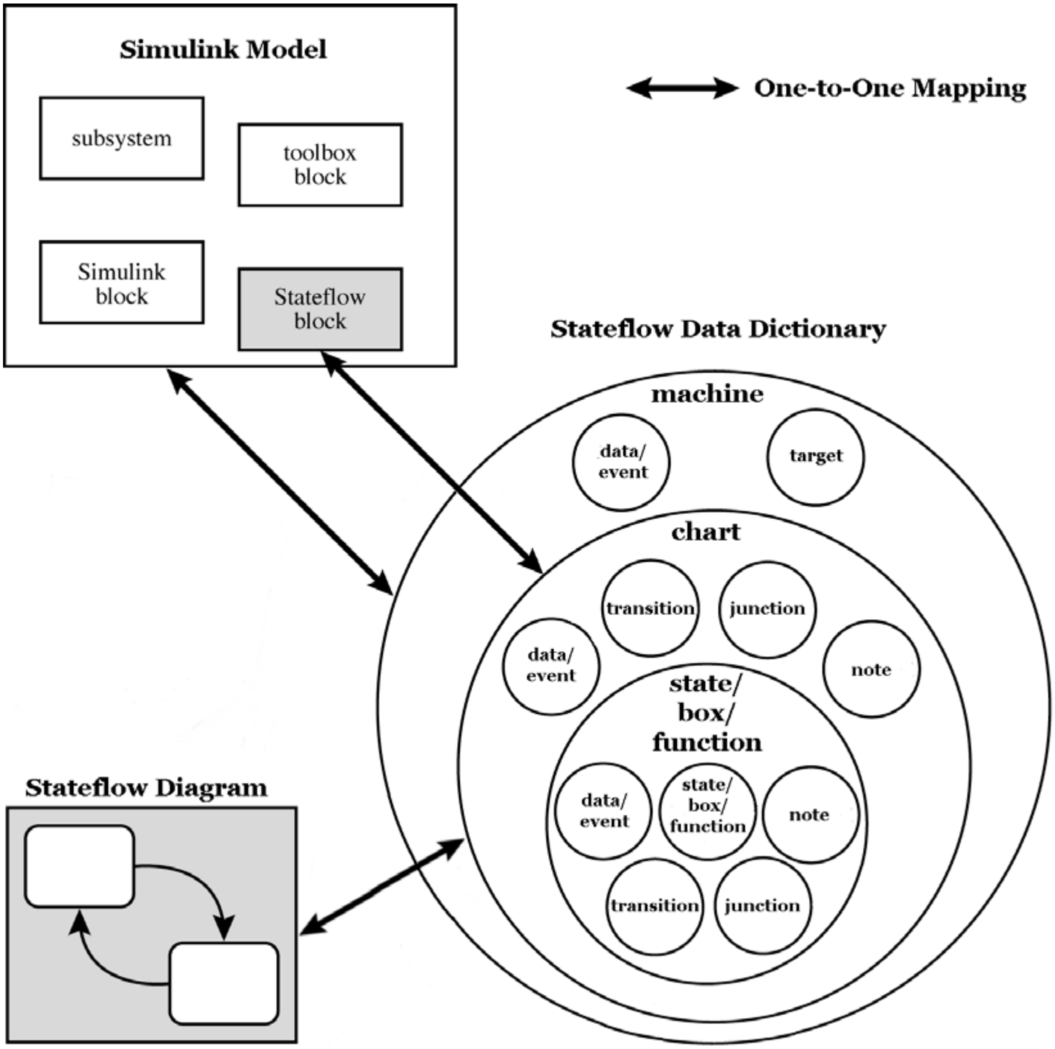
The Stateflow machine is the collection of Stateflow blocks in a Simulink model. The Simulink model and Stateflow machine work seamlessly together. Running a simulation automatically executes both the Simulink and Stateflow portions of the model.

A Simulink model can consist of combinations of Simulink blocks, toolbox blocks, and Stateflow blocks (Stateflow diagrams). In Stateflow, the chart (Stateflow diagram) consists of a set of graphical objects (states, boxes, functions, notes, transitions, connective junctions, and history junctions) and nongraphical objects (events, data, and targets).

There is a one-to-one correspondence between the Simulink model and the Stateflow machine. Each Stateflow block in the Simulink model is represented in Stateflow by a single chart (Stateflow diagram). Each Stateflow machine has its own object hierarchy. The Stateflow machine is the highest level in the Stateflow hierarchy. The object hierarchy beneath the Stateflow machine consists of combinations of graphical and nongraphical objects.

Stateflow Data Dictionary of Objects

The Stateflow data dictionary is the internal representation for the hierarchy of all Stateflow objects, graphical and nongraphical, that reside in a Simulink model. It is represented by the following diagram:



Stateflow scoping rules dictate where different nongraphical objects can exist in the hierarchy. For example, data and events can be parented by the machine, the chart (Stateflow diagram), or by a state. Targets can only be parented by the machine. Once a parent is chosen, that object is known in the hierarchy from the parent downward (including the parent's offspring). For example, a data object parented by the machine is accessible by that machine, by any charts within that machine, and by any states within that machine.

The hierarchy of the graphical objects is easily and automatically handled for you by the graphics editor. You manage the hierarchy of nongraphical objects through the Explorer or the graphics editor **Add** menu. See “Stateflow Hierarchy of Objects” on page 1-21.

Defining Stateflow Interfaces to Simulink

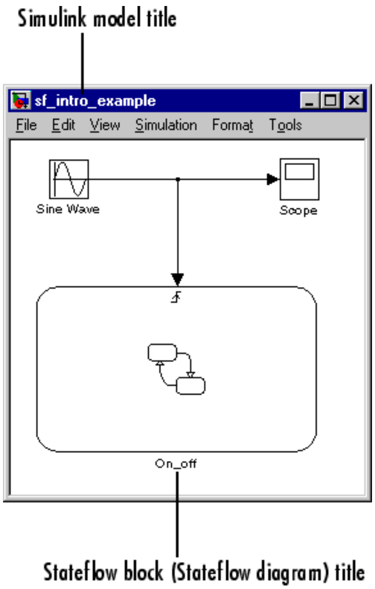
Each Stateflow block corresponds to a single Stateflow diagram. The Stateflow block interfaces to its Simulink model. The Stateflow block can interface to code sources external to the Simulink model (data, events, custom code).

Stateflow diagrams are event driven. Events can be local to the Stateflow block or can be propagated to and from Simulink and code sources external to Simulink. Data can be local to the Stateflow block or can be shared with and passed to the Simulink model and to code sources external to the Simulink model.

You must define the interface to each Stateflow block. Defining the interface for a Stateflow block can involve some or all of these tasks:

- Defining the Stateflow block update method
- Defining **Output to Simulink** events
- Adding and defining nonlocal events and nonlocal data within the Stateflow diagram
- Defining relationships with any external sources

In the following example, the Simulink model titled `sf_intro_example` consists of a Simulink Sine Wave source block, a Simulink Scope sink block, and a single Stateflow block, titled `On_off`.

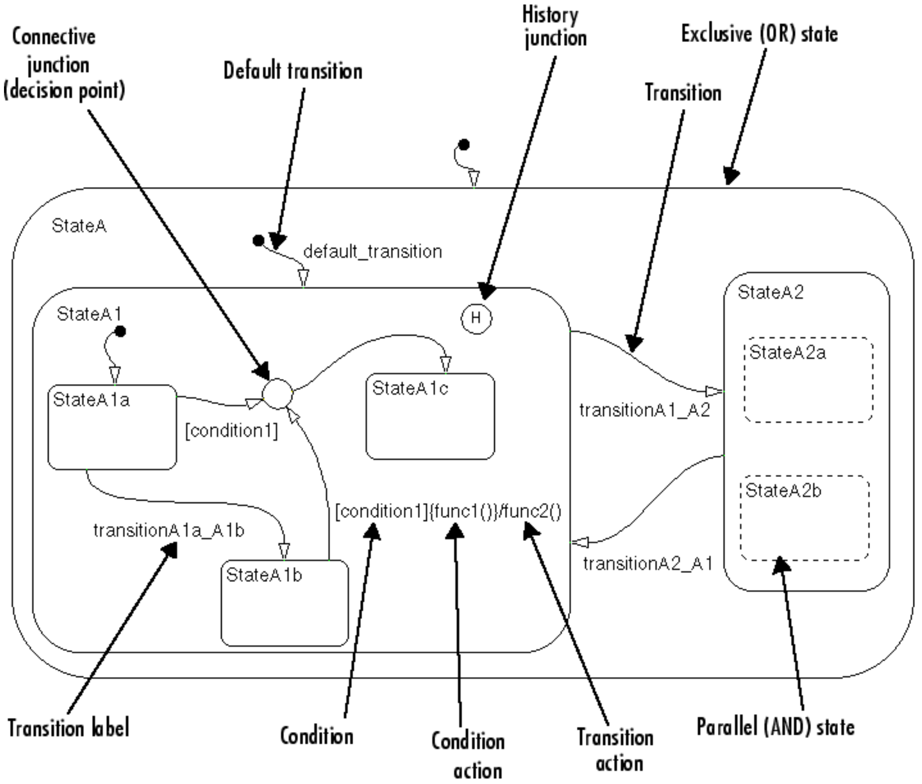


See “Defining Input Events” on page 7-13 and Chapter 10, “Defining Interfaces to Simulink and MATLAB” for more information.

Stateflow Diagram Objects

Stateflow diagrams are made of objects. Some of these objects graphical, that is, you draw them in a Stateflow diagram. Some of these objects are nongraphical, that is, they do not have a graphical appearance, but are referred to in the Stateflow diagram.

The following sample Stateflow diagram displays some of the key graphical objects of a Stateflow diagram.



Stateflow Diagram of Graphical Objects

This section introduces you to the graphical and nongraphical objects in a Stateflow diagram in the following topics:

- “States” on page 1-11
- “Transitions” on page 1-13
- “Default Transitions” on page 1-14
- “Events” on page 1-15
- “Data” on page 1-15
- “Conditions” on page 1-16
- “History Junction” on page 1-16
- “Actions” on page 1-17
- “Connective Junctions” on page 1-19

All Stateflow objects are arranged in a hierarchy of objects. See “Stateflow Hierarchy of Objects” on page 1-21.

States

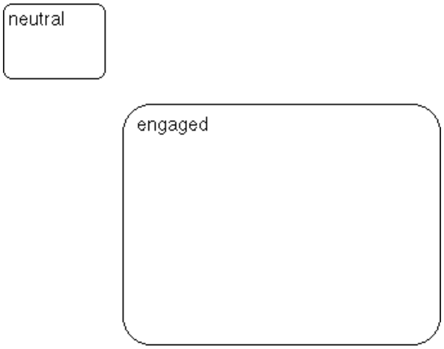
A *state* describes a mode of an event-driven system. The activity or inactivity of the states dynamically changes based on events and conditions.

Every state has a parent. In a Stateflow diagram consisting of a single state, that state’s parent is the Stateflow diagram itself (also called the Stateflow diagram root). You can place states within other higher-level states. In the preceding figure, `StateA1` is a child of `StateA`.

A state can have its activity history recorded in a *history junction*. History provides an efficient means of basing future activity on past activity. See “History Junction” on page 1-16.

States have labels that can specify actions executed in a sequence based upon action type. The action types are `entry`, `during`, `exit`, and `on`. See “Actions” on page 1-17.

The *decomposition* of a state defines the kind of state that a state can contain and the next level of containment. Stateflow provides two types of states: exclusive (OR) and parallel (AND) states. Exclusive (OR) states are used to describe modes that are mutually exclusive. A chart or state that contains exclusive (OR) states is said to have exclusive decomposition. The following transmission example has exclusive (OR) states.

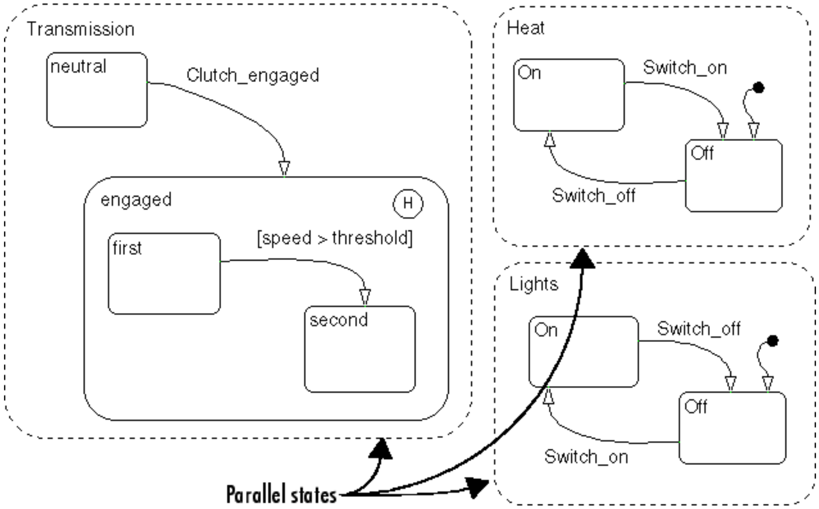


An automatic transmission can be set to either neutral or engaged. In this example either the `neutral` state or the `engaged` state is active at any one time. Both cannot be active at the same time.

A chart or state with *parallel* states has two or more states that can be active at the same time. A chart or state that contains parallel (AND) states is said to have parallel decomposition.

Parallel (AND) states are displayed as dashed rectangles. The activity of each parallel state is essentially independent of other states. In the diagram in Stateflow Diagram of Graphical Objects on page 1-10, `StateA2` has parallel (AND) state decomposition. Its states, `StateA2a` and `StateA2b,` are parallel (AND) states.

The following Stateflow diagram has parallel superstate decomposition.

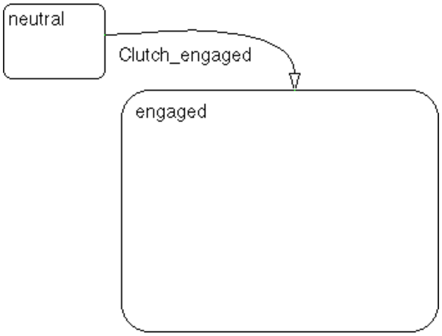


In this example, the transmission, heating, and light systems are parallel subsystems in a car. They are active at the same time and are physically independent of each other. There are many other parallel components in a car, such as the braking and windshield wiper subsystems.

Transitions

A *transition* is a graphical object that, in most cases, links one object to another. One end of a transition is attached to a source object and the other end to a destination object. The *source* is where the transition begins and the *destination* is where the transition ends. A *transition label* describes the circumstances under which the system moves from one state to another. It is always the occurrence of some event that causes a transition to take place. In the diagram in Stateflow Diagram of Graphical Objects on page 1-10, the transition from `StateA1` to `StateA2` is labeled with the event `transitionA1_A2` that triggers the transition to occur.

Consider again the automatic transmission system. `clutch_engaged` is the event required to trigger the transition from `neutral` to `engaged`.

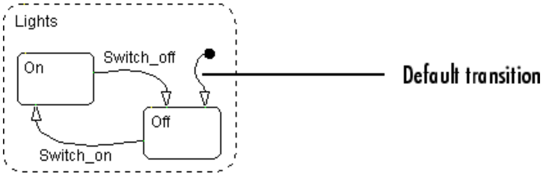


Default Transitions

Default transitions 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.

For example, in the diagram in Stateflow Diagram of Graphical Objects on page 1-10, the default transition to `StateA1` resolves the ambiguity that exists with regard to whether `StateA1` or `StateA2` should be active when State A becomes active. In this case, when `StateA` is active, by default `StateA1` is also active.

In the following `Lights` subsystem, the default transition to the `Lights.Off` substate indicates that when the `Lights` superstate becomes active, the `Off` substate becomes active by default.



Note History junctions override default transition paths in superstates with exclusive (OR) decomposition. In parallel (AND) states, a default transition must always be present to indicate which of its exclusive (OR) states is active when the parallel state becomes active.

Events

Events drive the Stateflow diagram execution but are nongraphical objects and are thus not represented directly in a Stateflow chart. All events that affect the Stateflow diagram must be defined. The occurrence of an event causes the status of the states in the Stateflow diagram to be evaluated. The broadcast of an event can trigger a transition to occur or can trigger an action to be executed. Events are broadcast in a top-down manner starting from the event's parent in the hierarchy.

Events are created and modified using the Stateflow Explorer. Events can be created at any level in the hierarchy. Events have properties such as a `scope`. The `scope` defines whether the event is

- Local to the Stateflow diagram
- An input to the Stateflow diagram from its Simulink model
- An output from the Stateflow diagram to its Simulink model
- Exported to a (code) destination external to the Stateflow diagram and Simulink model
- Imported from a code source external to the Stateflow diagram and Simulink model

Data

Data objects are used to store numerical values for reference in the Stateflow diagram. They are nongraphical objects and are thus not represented directly in a Stateflow chart.

You create and modify data objects for Stateflow diagrams in Stateflow Explorer. Data objects have a property called `scope` that defines whether the data object is

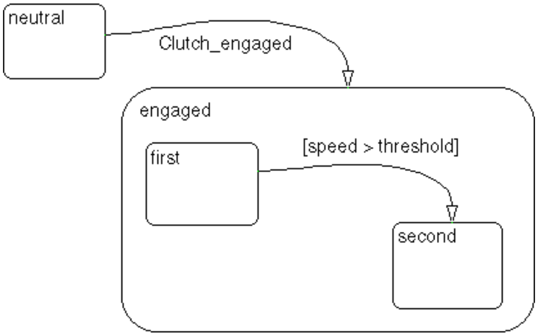
- Local to the Stateflow diagram
- An input to the Stateflow diagram from its Simulink model
- An output from the Stateflow diagram to its Simulink model
- Nonpersistent temporary data
- Defined in the MATLAB® workspace

- A constant
- Exported to a (code) destination external to the Stateflow diagram and Simulink model
- Imported from a code source external to the Stateflow diagram and Simulink model

Conditions

A *condition* is a Boolean expression specifying that a transition occurs, given that the specified expression is true. In the component summary Stateflow diagram, `[condition1]` represents a Boolean expression that must be true for the transition to occur.

In the automatic transmission system, the transition from `first` to `second` occurs if the transition condition `[speed > threshold]` is true.

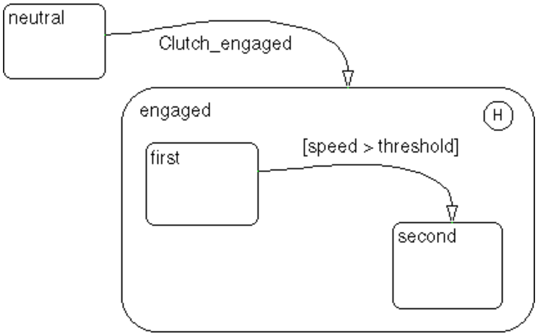


History Junction

A *history junction* records the most recently active state of a chart or superstate.

If a superstate with exclusive (OR) decomposition has a history junction, the destination substate is defined to be the substate that was most recently visited. A history junction applies to the level of the hierarchy in which it appears. The history junction overrides any default transitions. In the component summary Stateflow diagram, the history junction in `StateA1` indicates that when a transition to `StateA1` occurs, the substate that becomes active (StateA1a, StateA1b, or StateA1c) is based on which of those substates was most recently active.

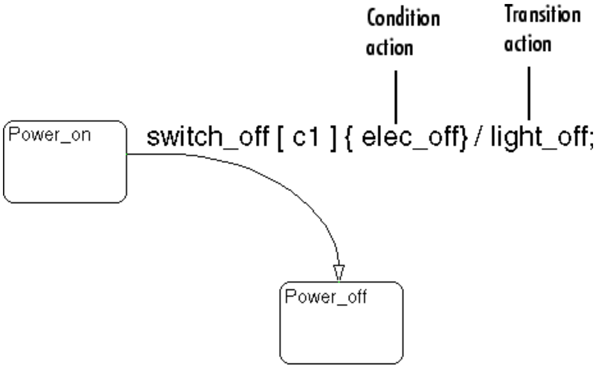
In the automatic transmission system, history indicates that when clutch_engaged causes a transition from neutral to the engaged superstate, the substate that becomes active, either first or second, is based on which of those substates was most recently active.



Actions

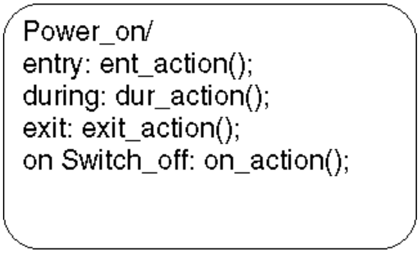
Actions take place as part of Stateflow diagram execution. The action can be executed either as part of a transition from one state to another or based on the activity status of a state.

Transitions ending in a state can have *condition* actions and *transition* actions, as shown in the following example:



In the diagram in Stateflow Diagram of Graphical Objects on page 1-10, the transition segment from `StateA1b` to the connective junction is labeled with the condition action `func1()` and the transition action `func2()`. The semantics of how and why actions take place are discussed throughout the examples listed in “Semantic Examples” on page 3-42.

States can have `entry`, `during`, `exit`, and `on` *`event_name`* actions. For example,



```
Power_on/
entry: ent_action();
during: dur_action();
exit: exit_action();
on Switch_off: on_action();
```

Action language defines the types of actions you can specify and their associated notations. An action can be a function call, the broadcast of an event, the assignment of a value to a variable, and so on.

Stateflow supports both Mealy and Moore finite state machine modeling paradigms. In the Mealy model, actions are associated with transitions, whereas in the Moore model they are associated with states. For more information, see Chapter 5, “Building Mealy and Moore Charts in Stateflow”.

Stateflow supports state actions, transition actions, and condition actions. For more information, see the following:

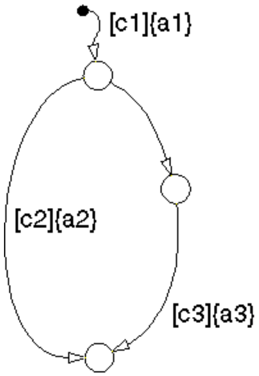
- “State Labels” on page 2-9 — Describes action language for states, which is included in the label for a state
- “Transition Label Notation” on page 2-15 — Describes action language for transitions which is included in the label of a transition.
- “Labeling States” on page 4-11 — Shows you to label states with its name and actions in the Stateflow diagram editor.
- “Labeling Transitions” on page 4-17 — Shows you how to label transitions with actions in the Stateflow diagram editor.

Connective Junctions

Connective junctions are decision points in the system. A connective junction is a graphical object that simplifies Stateflow diagram representations and facilitates generation of efficient code. Connective junctions provide alternative ways to represent desired system behavior. In the diagram in "Stateflow Diagram Objects" on page 1-10, the connective junction is used as a decision point for two transition segments that complete at `StateA1c`.

Transitions connected to junctions are called *transition segments*. Transitions, apart from default transitions, must go state to state. However, once the transition segments taken complete a state to state transition, the accumulation of the transition segments taken forms a complete transition.

The following example shows how connective junctions (displayed as small circles) are used to represent the flow of an `if-else` code structure shown in accompanying pseudocode.



```
if [c1]{
    a1
    if [c2]{
        a2
    }else if [c3]{
      a3
    }
}
```

This example executes as follows:

1. If condition `[c1]` is true, condition action `a1` is executed and the default transition to the top junction is taken.

2. Stateflow now considers which transition segment to take out of the top junction (it can take only one). Junctions with conditions have priority over junctions without conditions, so the transition with the condition `[c2]` is considered first.

3 If condition [c2] is true, action a2 is executed and the transition segment to the bottom junction is taken. Because there are no outgoing transition segments from the bottom junction, the diagram is finished executing.

4 If condition [c2] is false, the empty transition segment on the right is taken (because it has no condition at all).

5 If condition [c3] is true, condition action a3 is executed and the transition segment from the middle to the bottom junction is taken. Because there are no outgoing transition segments from the bottom junction, the diagram is finished executing.

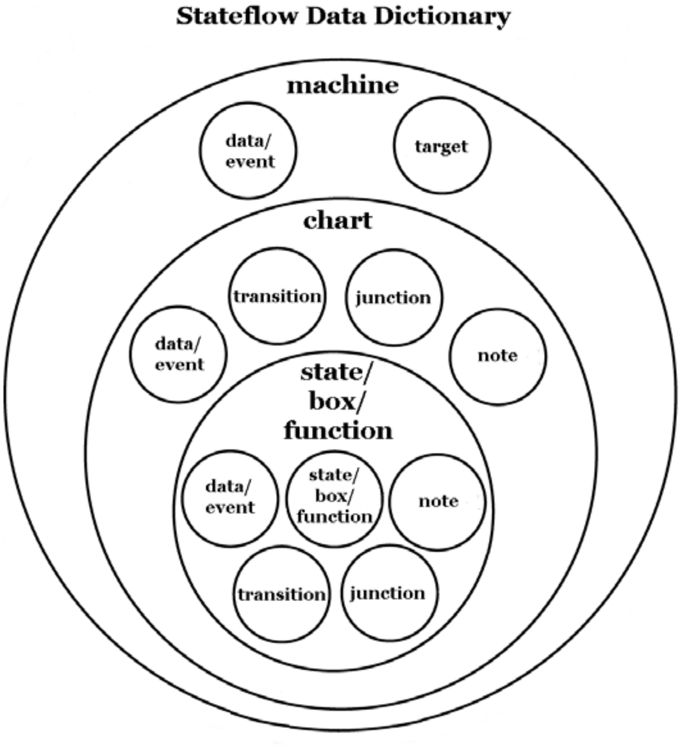
6 If condition [c3] is false, execution is finished at the middle junction.

The above steps describe the execution of the example diagram for connective junctions with Stateflow semantics. Stateflow semantics describe how objects in diagrams relate to each other during execution. See Chapter 3, “Stateflow Semantics”.

Stateflow Hierarchy of Objects

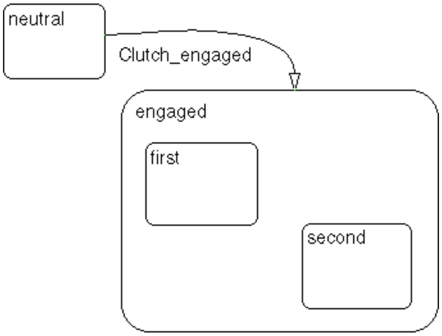
Stateflow diagrams arrange Stateflow objects in a hierarchy of objects. This hierarchy is based on containment. That is, one Stateflow object can contain other Stateflow objects.

The object hierarchy for all Stateflow objects in a Simulink model is referred to as the Stateflow Data Dictionary. This dictionary defines which objects a particular object can contain in a Stateflow diagram. The Stateflow Data Dictionary is depicted in the following diagram.



The highest object in Stateflow hierarchy is the Stateflow machine. It is defined as an object that contains all other Stateflow objects in a Simulink model. This means that the Stateflow machine contains all the Stateflow charts (diagrams) in a Simulink model. In addition, the Stateflow machine for a model can also contain its own data, event, and target objects. Only a simulation target (named `sfun`) is added to the Stateflow machine by default when the model is created. All other data, event, and target objects must be added to the machine.

Similarly, charts can contain state, box, function, data, event, transition, junction, and note events. You use all of these objects to create a Stateflow diagram. Continuing with the Stateflow hierarchy, states can contain all of these objects as well, including other states. Stateflow represents state hierarchy with superstates and substates. For example, this Stateflow diagram has a superstate that contains two substates.



In the preceding Stateflow diagram, the `engaged` superstate contains the `first` and `second` substates. The `engaged` superstate is the parent in the hierarchy to the states `first` and `second`. When the event `clutch_engaged` occurs, the system transitions out of the `neutral` state to the `engaged` superstate. Transitions within the `engaged` superstate are intentionally omitted from this example for simplicity.

A transition out of a superstate implies transitions out of any of its active substates. Transitions can cross superstate boundaries to specify a substate destination. If a substate is made active its parent superstate is also made active.

The Stateflow hierarchy of objects lets you organize complex Stateflow diagrams by defining a containment structure. A hierarchical design usually reduces the number of transitions and produces neat, manageable diagrams. Stateflow supports a hierarchical organization of both charts and states.

Exploring a Real-World Stateflow Application

The modeling of a fault-tolerant fuel control system demonstrates how Simulink and Stateflow can be used to efficiently model hybrid systems containing both continuous dynamics and complex logical behavior.

Simulink elements model behavior based on a given sample time. Each loop of its block diagram is assigned an increment of sample time. Stateflow execution makes no consideration for sample time. Internally, its application might take many cycles of execution, which are assumed to take place during the sample time assigned in Simulink.

The model described represents a fuel control system for a gasoline engine. This robust control system reacts to the detection of individual sensor failures and is dynamically reconfigured for uninterrupted operation. This section describes how Stateflow is used to implement supervisory logic control system to deal with the sensor failures and contains the following topics:

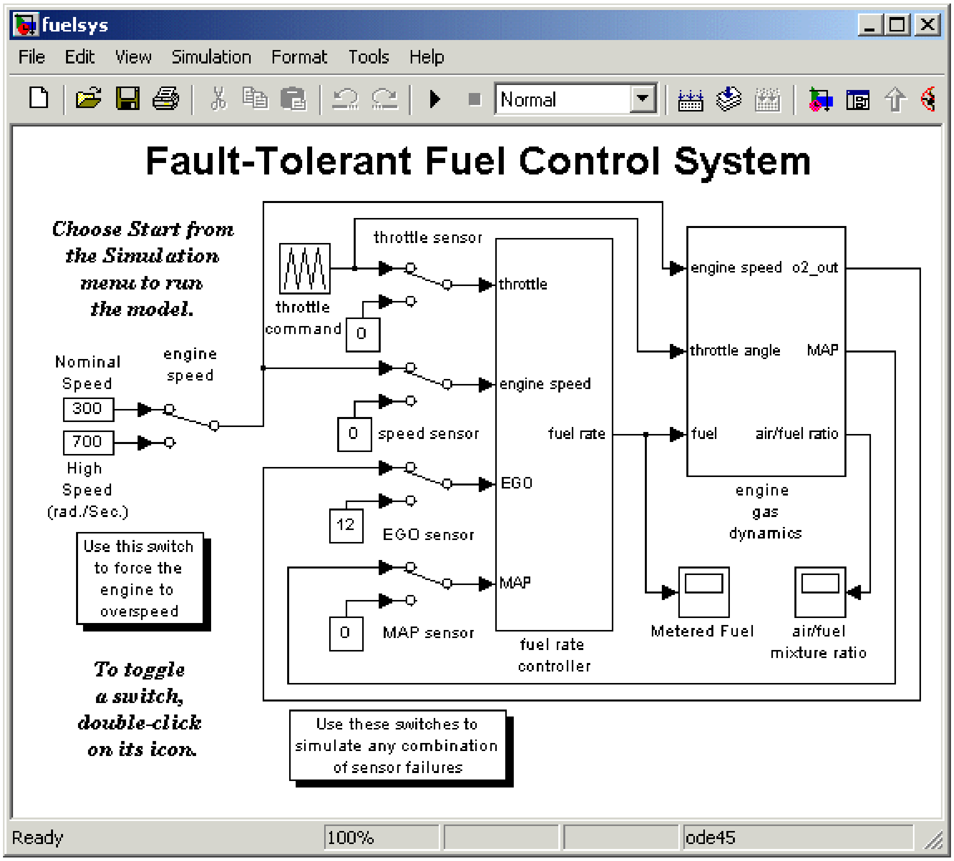
- “Overview of the "fuel rate controller" Model” on page 1-24
- “Control Logic of the "fuel rate controller" Model” on page 1-28
- “Simulating the "fuel rate controller" Model” on page 1-30

Overview of the "fuel rate controller" Model

The mass flow rate of air pumped from the intake manifold, divided by the fuel rate, which is injected at the valves, gives the air/fuel ratio. The ideal mixture ratio provides a good compromise between power, fuel economy, and emissions. A target air/fuel ratio of 14.6 is assumed in this system.

A sensor (EGO) determines the amount of residual oxygen present in the exhaust gas. This gives a good indication of the air/fuel ratio and provides a feedback measurement for closed-loop control. If the sensor indicates a high oxygen level, the controller increases the fuel rate. If the sensor detects a fuel-rich mixture (corresponding to a very low level of residual oxygen), the controller decreases the fuel rate.

The following figure shows the top level of the Simulink model (`fuelsys.mdl`). The model is modularized into a fuel rate controller and a subsystem to simulate engine gas dynamics.



Choose Start from the Simulation menu to run the model.

Use this switch to force the engine to overspeed

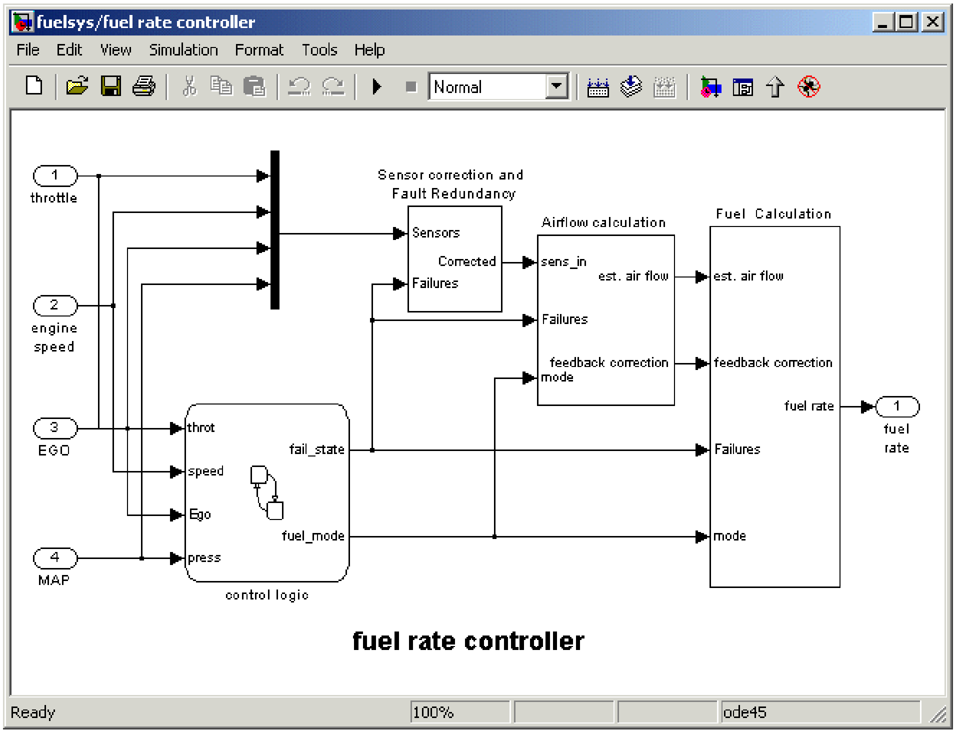
To toggle a switch, double-click on its icon.

Use these switches to simulate any combination of sensor failures

The fuel rate controller uses signals from the system's sensors to determine the fuel rate that gives an ideal 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.

To simulate failures in the system, the user can selectively disable each of the four sensors: throttle angle, speed, exhaust gas (EGO), and manifold absolute pressure (MAP). Simulink accomplishes this with Manual Switch blocks. The user can toggle the position of a switch by double-clicking its icon prior to or during a simulation. Similarly, the user can induce the failure condition of a high engine speed by toggling the switch on the far left.

The controller uses the sensor input and feedback signals to adjust the fuel rate to provide an ideal ratio. The model uses four subsystems to implement this strategy: control logic, sensor correction, 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.



A detailed explanation of the Simulink part of the fault-tolerant control system is given in *Using Simulink and Stateflow in Automotive Applications*, a Simulink-Stateflow Technical Examples booklet published by The MathWorks. This section concentrates on the supervisory logic part of the system that is implemented in Stateflow, but the following points are crucial to the interaction between Simulink and Stateflow:

- The supervisory logic monitors the input data readings from the sensors.
- The logic determines from these readings the sensors that have failed and outputs a failure state Boolean array as `fail_state`.
- Given the current failure state, the logic determines in which fueling mode the engine should be run.

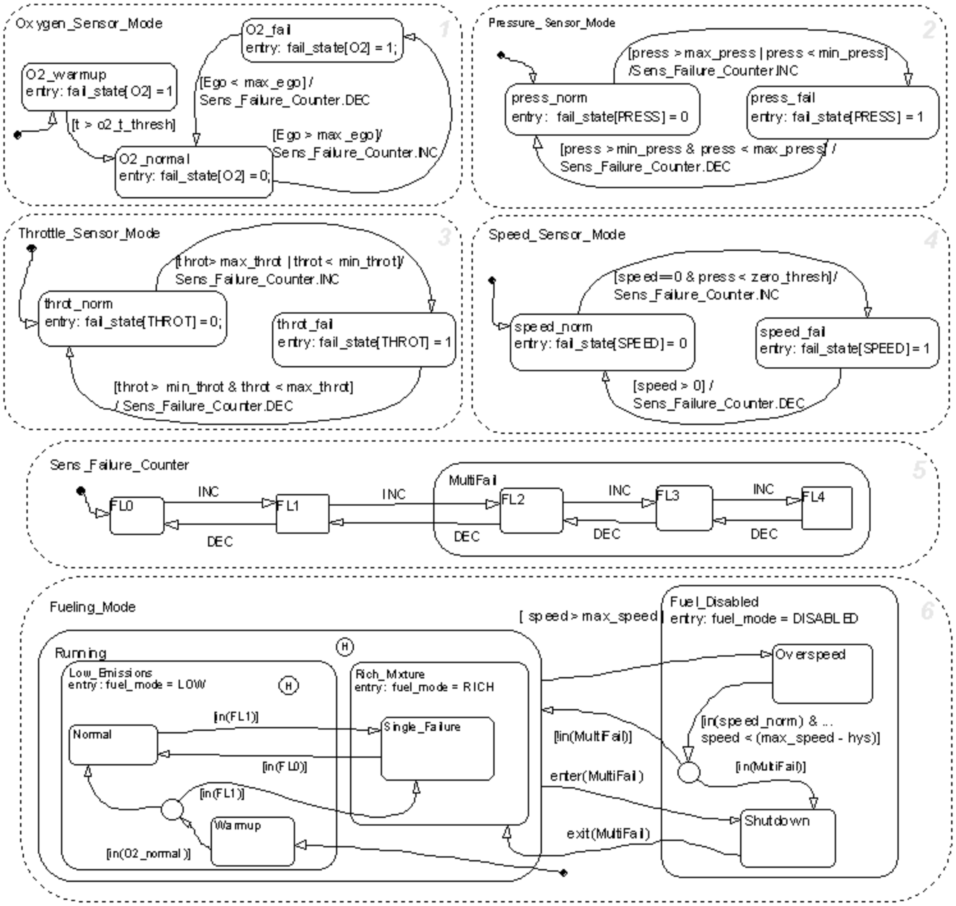
The fueling mode can be one of the following modes:

- **Low emissions mode** is the normal mode of operation where no sensors have failed.
- **Rich mixture mode** occurs when a sensor has failed, to ensure smooth running of the engine.
- **Shutdown mode** occurs when more than one sensor has failed, rendering the engine inoperable.

The fueling mode and failure state are output from Stateflow as `fuel_mode` and `fail_state` respectively into the algorithmic part of the model, where they determine the fueling calculations.

Control Logic of the "fuel rate controller" Model

The single Stateflow chart that implements the entire control logic for the `fuelsys` model is shown in the following diagram:



The chart consists of six parallel states with dashed boundaries that represent concurrent modes of operation.

The four parallel states at the top of the diagram correspond to the four individual sensors. Each of these states has a substate that represents the functioning or failing status of that sensor. These substates are mutually exclusive. For example, if the throttle sensor fails then the lone active substate of the `Throttle_Sensor_Mode` state is `throt_fail`.

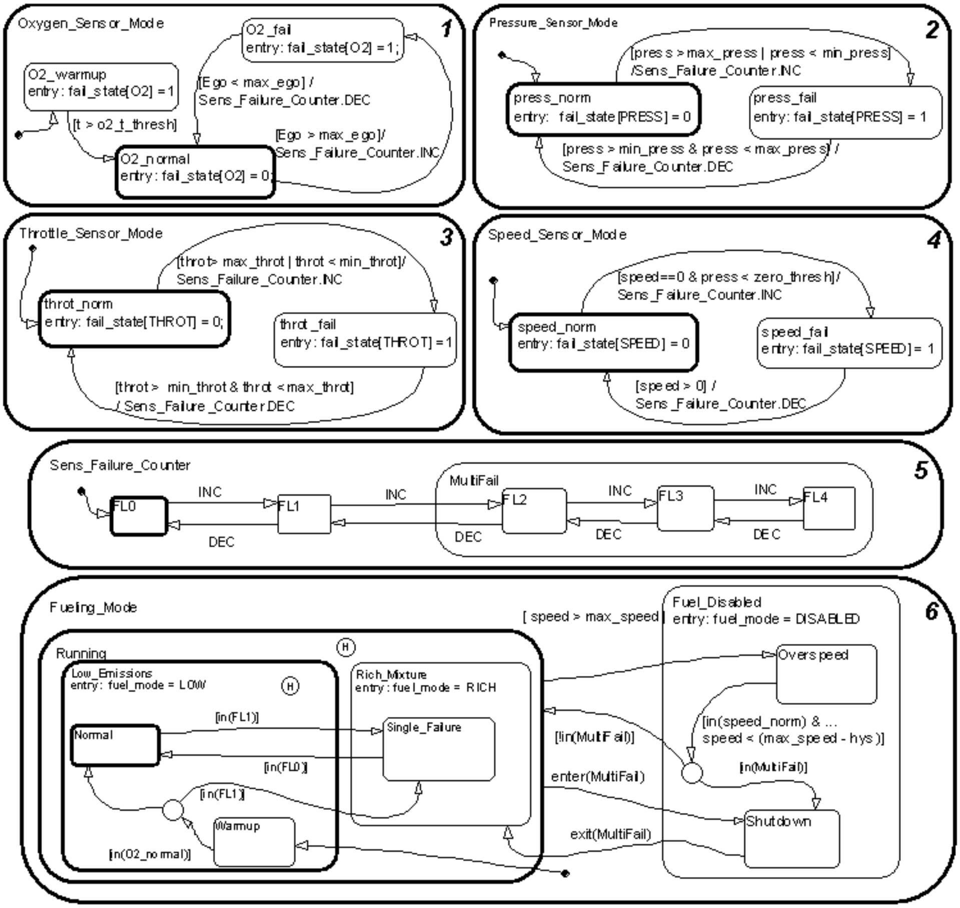
Transitions determine how states can change and can be guarded by conditions. For example, the active state can change from the `throt_norm` state to the `throt_fail` state when the measurement from the throttle sensor exceeds `max_throt` or is below `min_throt`.

The remaining two parallel states at the bottom consider the status of the four sensors simultaneously and determine the overall system operating mode. The `Sens_Failure_Counter` superstate acts as a store for the resultant number of sensor failures. This state is polled by the `Fueling_Mode` state that determines 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, because the air/fuel ratio cannot be controlled reliably.

Although it is possible to run Stateflow charts asynchronously by injecting events from Simulink when required, the fueling control logic is polled synchronously at a rate of 100 Hz. Consequently, the sensors are checked every 1/100 second to see if they have changed status, and the fueling mode is adjusted accordingly.

Simulating the "fuel rate controller" Model

On starting the simulation, and assuming no sensors have failed, the Stateflow diagram initializes in the `Warmup` mode in which the oxygen sensor is deemed to be in a warm-up phase. If Stateflow is placed into animation mode, the current state of the system can clearly be seen highlighted on the Stateflow diagram, as shown.



After a given time period, defined by o2_t_thresh, the sensor is deemed to have reached operating temperature and the system settles into the normal mode of operation, shown above, in which the fueling mode is set to NORMAL.

As the simulation progresses, the chart is woken up synchronously every 0.01 second. The events and conditions that guard the transitions are evaluated and if a transition is valid, it is taken and animated on the Stateflow diagram.

To illustrate this, you can provoke a transition by switching one of the sensors to a failure value on the top-level Simulink model. 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.

Switch the Simulink switch for the manifold air pressure sensor to the off position to witness the following sequence of transitions (note the diagram that follows).

1 Switching the Simulink manifold air pressure sensor switch causes a value of zero to be read by the fuel rate controller.

2 When the chart is next woken up, the transition from the `press_norm` state becomes valid as the reading is now out of bounds and the transition is taken to the `press_fail` state, as shown.

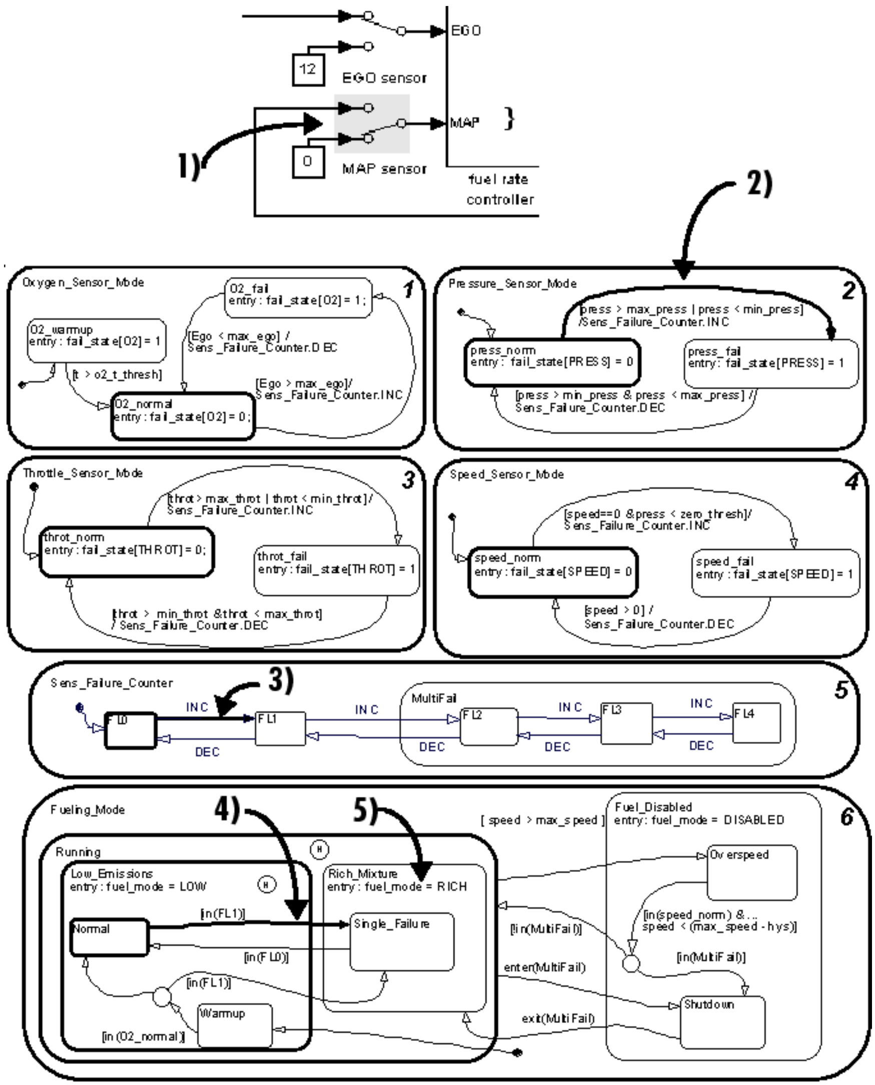
3 Regardless of which sensor fails, the model always generates the directed event broadcast `Sens_Failure_Counter.INC`, which makes the triggering of the universal sensor failure logic independent of the sensor.

   This event causes a second transition from `FL0` to `FL1` in the `Sens_Failure_Counter` superstate. Both transitions are animated on the Stateflow diagram.

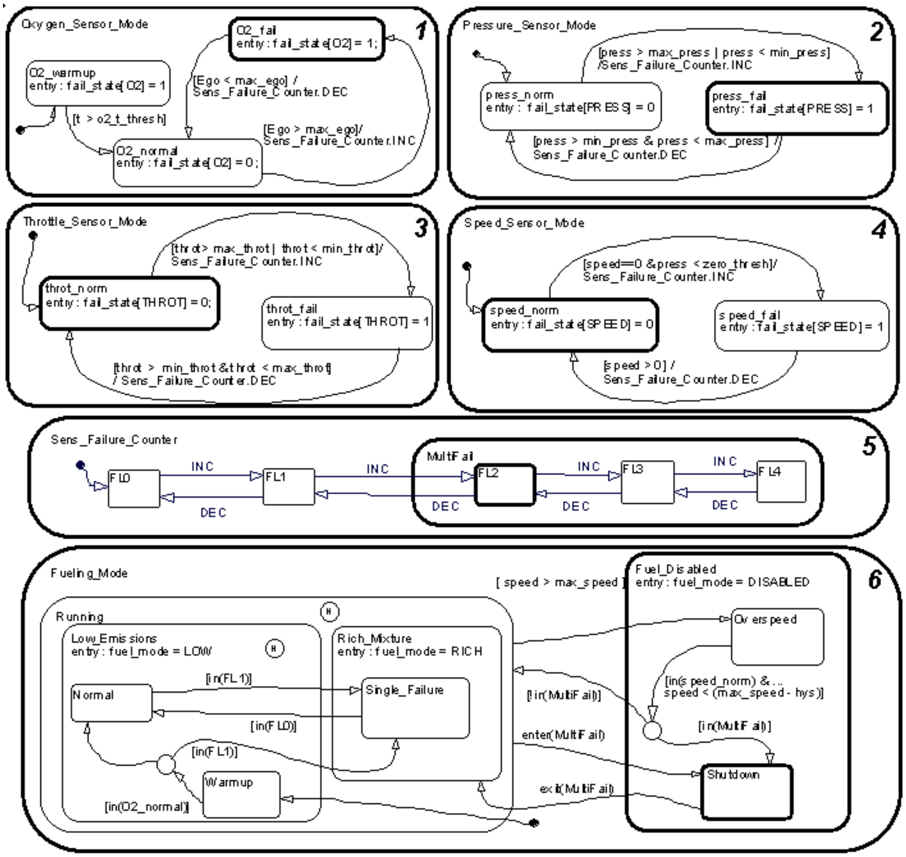
4 With the `Sens_Failure_Counter` state showing one failure, the condition that guards the transition from the `Low_Emissions.Normal` state to the `Rich_Mixture.Single_Failure` state is now valid and is therefore taken.

5 As the `Fuel_Disabled` state is entered, the data `fuel_mode` is set to `RICH`, as shown.

The transitions taken in the preceding steps are depicted in the following simulation diagram. Step numbers appear next to the dashed indicator line.



A second sensor failure causes the `Sens_Failure_Counter` to enter the `Multifail` state, broadcasting an implicit event that immediately triggers the transition from the `Running` state to the `Shutdown` state. On entering the `Fuel_Disabled` superstate the Stateflow data `fuel_mode` is set to `DISABLED`.

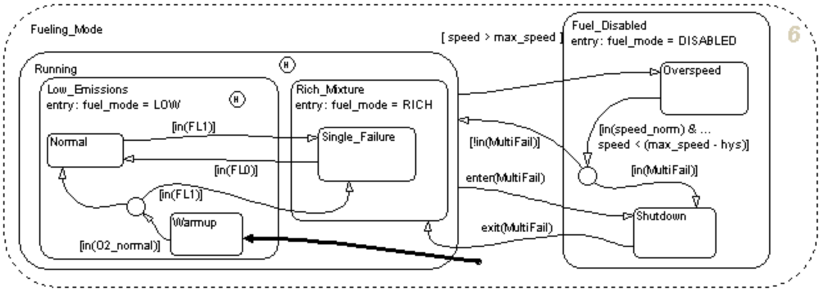


Implicit Event Broadcasts

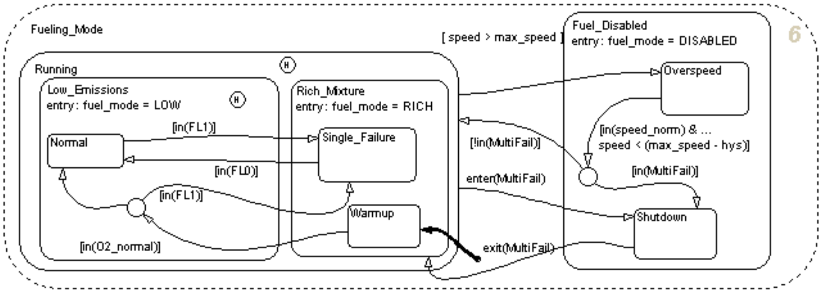
The preceding example shows how the control logic can be represented in a clear and intuitive manner. The Stateflow diagram (or chart) has been developed in a way that allows the user, or a reviewer, to easily understand how the logic is structured. Implicit event broadcasts (such as `enter(multifail)`) and implicit conditions (`in(FL0)`) make the diagram easy to read and the generated code more efficient.

Modifying the Model

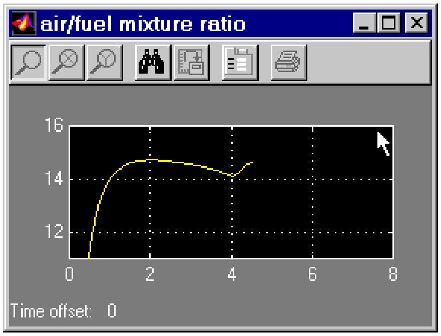
To illustrate how easy it is to modify the model, consider the `Warmup` fueling state in the fuel control logic. At the moment the fueling is set to the low emissions mode (note the highlighted default transition at the bottom).



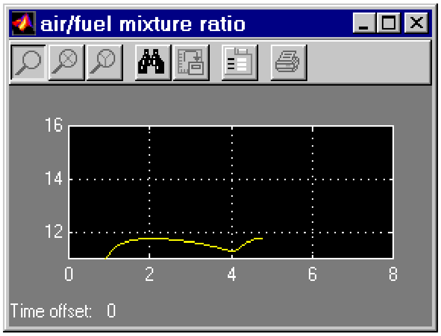
You might decide that when the oxygen sensor is warming up, changing the warm-up fueling mode to a rich mixture would be beneficial. In the Stateflow chart you can easily achieve this by changing the parent of the `Warmup` state to the `Rich_Mixture` state. This is accomplished by enlarging the `Rich_Mixture` state and moving the `Warmup` state into it from the `Low_Emissions` state. This alteration is obvious to all who need to inspect or maintain the code as shown in the following result (note the highlighted default transition at the bottom):



The results of changing the algorithm can be seen in the following graphs of air/fuel mixture ratio for the first few seconds of engine operation after startup. The left graph shows the air/fuel ratio for the unaltered system. The right graph for the altered system shows how the air/fuel ratio stays low in the warming up phase indicating a rich mixture.



Time offset: 0



Time offset: 0

2

Stateflow Notation

You compose Stateflow diagrams with the symbolic objects of Stateflow notation. Learning Stateflow notation is the first step to designing and implementing efficient Stateflow diagrams. Use the following sections to introduce yourself to the objects of Stateflow diagrams:

Overview of Stateflow Objects

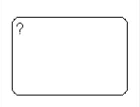
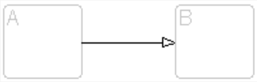
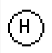
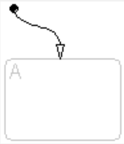
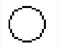
This section describes the different types of available Stateflow objects. Its topics are as follows:

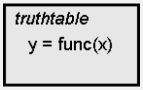
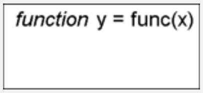
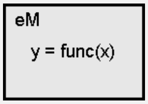
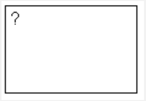
- “Graphical Objects” on page 2-3
- “Nongraphical Objects” on page 2-4
- “The Stateflow Data Dictionary of Objects” on page 2-5

While this chapter defines most of these relationships, they are dealt with in more detail in Chapter 3, “Stateflow Semantics” which describes the behavior of Stateflow charts.

Graphical Objects

The following table gives the name of each graphical object in Stateflow, its appearance when drawn in the diagram editor (Notation), and the toolbar icon used in drawing the object:

Name	Notation	Toolbar Icon
State		
Transition		NA
History Junction		H
Default Transition		
Connective Junction		

Name	Notation	Toolbar Icon
Truth Table Function		
Graphical Function		
Embedded MATLAB Function		
Box		

Nongraphical Objects

Stateflow defines event, data, and target objects that do not have graphical representations in the Stateflow diagram editor. However, you can see them in the Stateflow Explorer. See "Using the Model Explorer with Stateflow Objects" on page 16-2.

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 a full description of events, see "Adding Events" on page 7-4.

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. When creating a Stateflow model, you must define any internal or external data that you use in the action language of a Stateflow chart. For a full description of data objects, see “Adding Data” on page 7-27.

Target Objects

You build targets in Stateflow to execute the application you program in Stateflow charts and the Simulink model that contains them. A target is a program that executes a Stateflow model or a Simulink model containing a Stateflow machine. You build a simulation target (named `sfun`) to execute a simulation of your model. You build a Real-Time Workshop® target (named `rtw`) to execute the Simulink model on a supported processor environment. You build custom targets (with names other than `sfun` or `rtw`) to pinpoint your application to a specific environment. For a full description of target objects in Stateflow and Simulink, see “Overview of Stateflow Targets” on page 14-3.

The Stateflow Data Dictionary of Objects

The data dictionary is a database containing all the information about the graphical and nongraphical objects. Data dictionary entries for graphical objects are created automatically as the objects are added and labeled. You explicitly define nongraphical objects in the data dictionary by using the Stateflow Explorer. The parser evaluates entries and relationships between entries in the data dictionary to verify that the notation is correct.

States

This topic describes Stateflow's primary object, the state. States represent modes of a reactive system. See the following topics for information about states and their properties:

- "What Is a State?" on page 2-6
- "State Hierarchy" on page 2-6
- "State Decomposition" on page 2-8
- "State Labels" on page 2-9

What Is a State?

A *state* describes a mode of a reactive Stateflow chart. States in a Stateflow chart represent these modes. The following table shows the button icon for a drawing a state in the Stateflow diagram editor and a short description.

Name	Button Icon	Description
State	▣	Use a state to depict a mode of the system.

States can be active or inactive. When a state is active, the chart takes on that mode. When a state is inactive, the chart is not in that mode. The activity or inactivity of a chart's states dynamically changes based on events and conditions. The occurrence of events drives the execution of the Stateflow diagram by making states become active or inactive. At any point in the execution of a Stateflow diagram, there is a combination of active and inactive states.

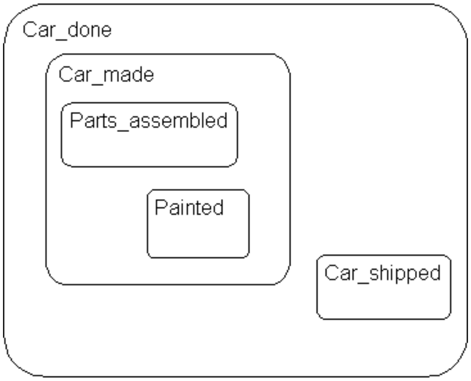
State Hierarchy

States can contain all other Stateflow objects except targets. Stateflow notation supports the representation of graphical object hierarchy in Stateflow diagrams 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 diagram itself.

States can also contain nongraphical data and event objects. The hierarchy of this containment is represented in the Explorer tool. Data and event containment is defined by specifying the parent object when you create it. See Chapter 7, “Defining Events and Data” and Chapter 10, “Defining Interfaces to Simulink and MATLAB” for information and examples on representing data and event objects in the Explorer tool.

Representing State Hierarchy Example

In the following example, 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 and the outer state is the parent of the inner state:



In this example, the Stateflow diagram 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.

Stateflow hierarchy can also be represented textually, in which the Stateflow diagram is represented by the slash (`/`) character and each level in the hierarchy of states is separated by the period (`.`) character. The following 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

State Decomposition

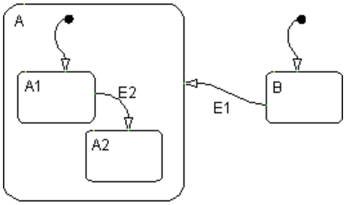
Every state (and chart) has a *decomposition* that dictates what kind of substates it can contain. All substates of a superstate must be of the same type as the superstate's decomposition. Decomposition for a state can be exclusive (OR) or parallel (AND). These types of decomposition are described in the following topics:

- "Exclusive (OR) State Decomposition" on page 2-8
- "Parallel (AND) State Decomposition" on page 2-8

Exclusive (OR) State Decomposition

Exclusive (OR) state decomposition for a superstate (or chart) is indicated when its substates have solid borders. Exclusive (OR) decomposition is used to describe system modes that are mutually exclusive. When a state has exclusive (OR) decomposition, only one substate can be active at a time. The children of exclusive (OR) decomposition parents are OR states.

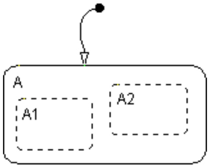
In the following example, either state A or state B can be active. If state A is active, either state A1 or state A2 can be active at any one time.



Parallel (AND) State Decomposition

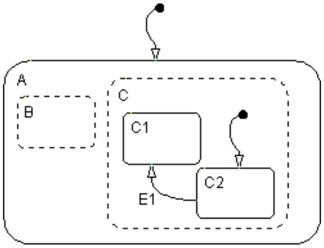
The children of parallel (AND) decomposition parents are parallel (AND) states. Parallel (AND) state decomposition for a superstate (or chart) is indicated when its substates have dashed borders. This representation is appropriate if all states at that same level in the hierarchy are always active at 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.

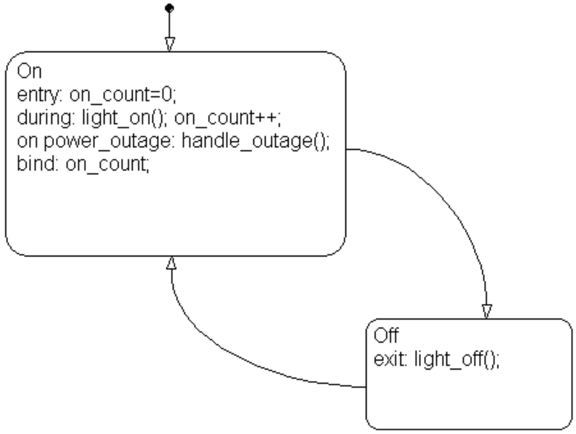


State Labels

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
bind:events, data
on event_name:on event_name actions
```

The following example demonstrates the components of a state label.


On
entry: on_count=0;
during: light_on(); on_count++;
on power_outage: handle_outage();
bind: on_count;
Off
exit: light_off();

Each of the above actions is described in the subtopics that follow. For more information on state actions, see the following topics:

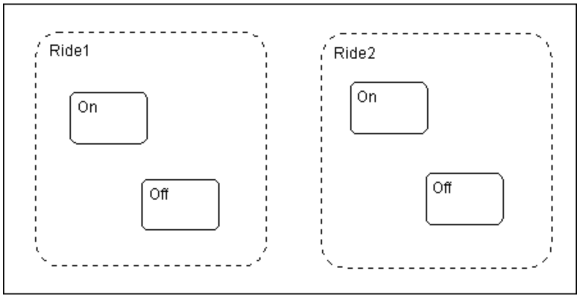
- "Entering, Executing, and Exiting a State" on page 3-21 — Describes how and when `entry`, `during`, `exit`, and `on` *`event_name`* actions are taken.
- "State Action Types" on page 8-3— Gives more detailed descriptions of each type of state action.

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 example, `Transmission` or `Green_on`.

The use of hierarchy provides some flexibility in the naming of states. The name that you enter as part of the label must be unique when preceded by the hierarchy of its ancestor states. The name stored in the data dictionary is the text you enter as the label on the state, preceded by the hierarchy of its parent states separated by periods. Each state can have the same name appear in the label of the state, as long as their full names within the data dictionary are unique. Otherwise, the parser indicates an error.

The following example shows how hierarchy supports unique naming of states.



Each of these states has a unique name because of its location in the hierarchy of the Stateflow diagram. Although the name portion of the label on these states is not unique, when the hierarchy is prefixed to the name in the data dictionary, the result is unique. The full names for these states as seen in the data dictionary are as follows:

- `Ride1.On`
- `Ride1.Off`
- `Ride2.On`
- `Ride2.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 by adding additional `on` *`event_name`* lines for different events.

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 only specifying `entry` actions.

Entry Action. Preceded by the prefix `entry` or `en` for short. In the preceding example, state `On` has `entry` action `on_count=0`. This means that the value of `on_count` is reset to 0 whenever state `On` becomes active (entered).

During Action. Preceded by the prefix `during` or `du` for short. In the preceding label example, state `On` has two `during` actions, `light_on()` and `on_count++.` These actions are executed whenever state `On` is already active and any event occurs.

Exit Action. Preceded by the prefix `exit` or `ex` for short. In the preceding label example, state `Off` has the `exit` action `light_off()`. If the state Off is active, but becomes inactive (exited), this action is executed.

On Event_Name Action. Preceded by the prefix `on` *`event_name`*, where *`event_name`* is a unique event. In the preceding label example, state `On` has an `on power_outage` action. If state `On` is active and the event `power_outage` occurs, the action `handle_outage()` is executed.

Bind Action. Preceded by the prefix `bind`. In the preceding label example, the data `on_count` is bound to the state `On`. This means that only the state `On` or a child of `On` can change the value of `on_count`. Other states, such as the state Off, can use `on_count` in its actions, but it cannot change its value in doing so.

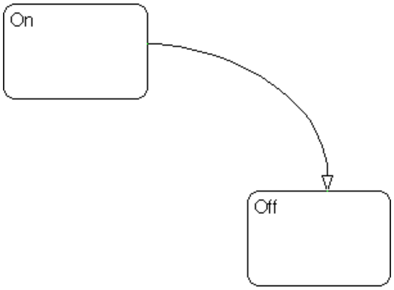
Transitions

You model the behavior of reactive systems by changing from one state to another through an object called a transition. This section contains the following topics on the transitions in Stateflow diagrams:

- "What Is a Transition?" on page 2-13
- "Transition Hierarchy" on page 2-14
- "Transition Label Notation" on page 2-15
- "Valid Transitions" on page 2-16

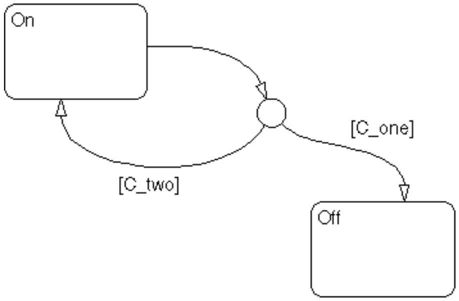
What Is a Transition?

A *transition* is a curved 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) object to another. A transition is attached to a source and a destination object. The *source* object is where the transition begins and the *destination* object is where the transition ends. This is an example of a transition from a source state, `On`, to a destination state, `Off`.



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.

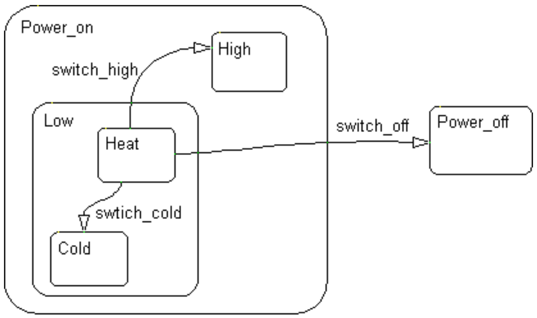
The following example has two segmented transitions: one from state On to state Off, and the other from state On to itself:



A default transition is a special type of transition that has no source object. See “Default Transitions” on page 2-26 for a description of a default transition.

Transition Hierarchy

Transitions cannot contain other objects like states can. However, transitions are contained by states. A transition’s hierarchy is described in terms of the transition’s parent, source, and destination. 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 Stateflow diagram is represented by the / character. 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 Label Notation

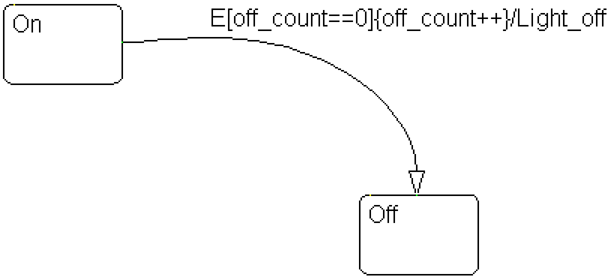
A transition is characterized by its *label*. The label can consist of an event, a condition, a condition action, and/or a transition action. The ? character is the default transition label. Transition labels have the following general format:

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

You replace the names for *event*, *condition*, *condition_action*, and *transition_action* with appropriate contents as shown in the example "Transition Label Example" on page 2-15. Each part of the label is optional.

Transition Label Example

Use the transition label in the following example to understand the parts of a transition label.



Event Trigger. specifies an event that causes the transition to be taken, provided the condition, if specified, is true. Specifying an event is optional. The absence of an event indicates that the transition is taken upon the occurrence of any event. Multiple events are specified using the OR logical operator (`|`).

In the preceding example, the broadcast of event `E` triggers the transition from `On` to `Off` provided the condition `[off_count==0]` is true.

Condition. specifies a boolean expression that, when true, validates a transition to be taken for the specified event trigger. Enclose the condition in square brackets ([]). See "Conditions" on page 8-8 for information on the condition notation.

In the preceding example, the condition `[off_count==0]` must evaluate as true for the condition action to be executed and for the transition from the source to the destination to be valid.

Condition Action. A *condition action* follows the condition for a transition and is enclosed in curly braces (`{}`). It is executed as soon as the condition is evaluated as true and 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.

In the preceding example, if the condition `[off_count==0]` is true, the condition action `off_count++` is immediately executed.

Transition Action. The transition action is executed after the transition destination has been determined to be valid provided the condition, if specified, is true. If the transition consists of multiple segments, the transition action is only executed when the entire transition path to the final destination is determined to be valid. Precede the transition action with a backslash.

In the preceding example, if the condition `[off_count==0]` is true, and the destination state `Off` is valid, the transition action `Light_off` is executed.

Valid Transitions

In most cases, a transition is valid when the source state of the transition is active and the transition label is valid. Default transitions are slightly 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 are 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
Condition only	Any event occurs and the condition is true
Action only	Any event occurs
Not specified	Any event occurs

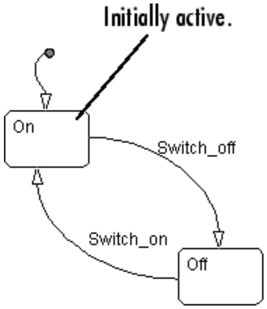
Transition Connections

Stateflow notation supports a wide variety of transition connections, which are demonstrated by the examples in the following topics:

- "Transitions to and from Exclusive (OR) States" on page 2-18
- "Transitions to and from Junctions" on page 2-18
- "Transitions to and from Exclusive (OR) Superstates" on page 2-19
- "Transitions to and from Substates" on page 2-20
- "Self-Loop Transitions" on page 2-21
- "Inner Transitions" on page 2-22

Transitions to and from Exclusive (OR) States

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

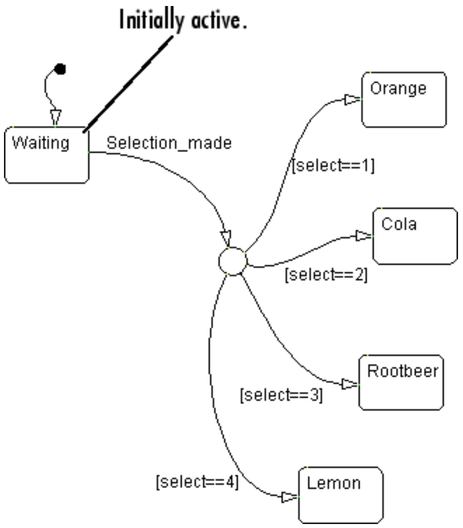


The transition `On`→`Off` is valid when state `On` is active and the event `Switch_off` occurs. The transition `Off`→`On` is valid when state `Off` is active and event `Switch_on` occurs.

See "Transitions to and from Exclusive (OR) States Examples" on page 3-44 for more information on the semantics of this notation.

Transitions to and from Junctions

This example shows transitions to and from a connective junction.

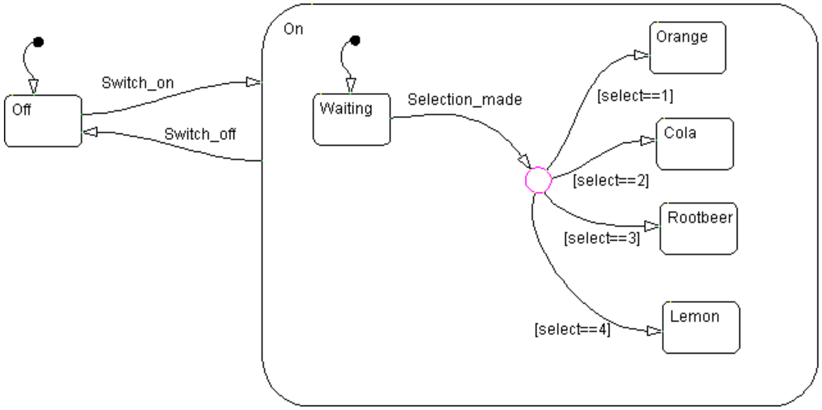


This is a Stateflow diagram of a soda machine. The Stateflow diagram is called when the external event `Selection_made` occurs. The Stateflow diagram awakens with the `Waiting` state active. The `Waiting` state is a common source state. When the event `Selection_made` occurs, the Stateflow diagram transitions from the `Waiting` state to one of the other states based on the value of the variable `select`. One transition is drawn from the `Waiting` state to the connective junction. Four additional transitions are drawn from the connective junction to the four possible destination states.

See "Transitions from a Common Source to Multiple Destinations Example" on page 3-77 for more information on the semantics of this notation.

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.



This is an expansion of the soda machine Stateflow diagram that includes the initial example of the On and Off exclusive (OR) states. On is now a superstate containing the Waiting and soda choices states. The transition Off→On is valid when state Off is active and event Switch_on occurs. Now that On is a superstate, this is an explicit transition to the On superstate.

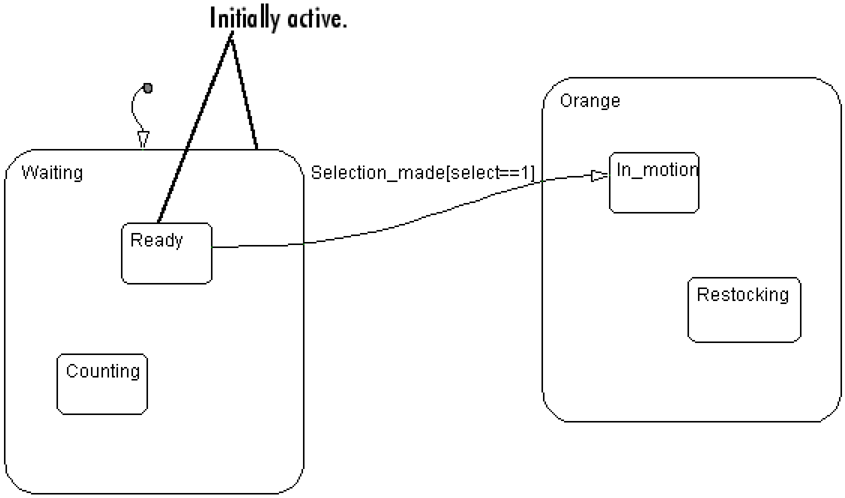
For a transition to a superstate to be a valid, the destination substate must be implicitly defined. The destination substate for On is implicitly defined by making the Waiting substate the destination state of a default transition. This notation defines that the resultant transition is made from the Off state to the state On.Waiting.

The transition from On to Off is valid when state On is active and event Switch_off occurs. However, when the Switch_off event occurs, a transition to the Off state must take place no matter which of the substates of On is active. This top-down approach simplifies the Stateflow diagram by looking at the transitions out of the superstate without considering all the details of states and transitions within the superstate.

See “Default Transition Examples” on page 3-56 for more information on the semantics of this notation.

Transitions to and from Substates

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

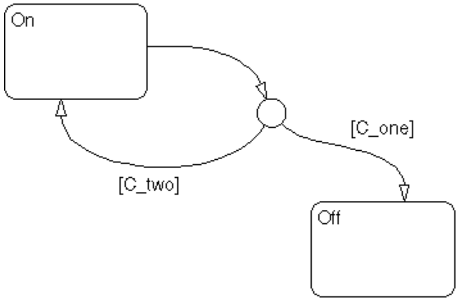


This Stateflow diagram shows a transition from one OR substate to another OR substate: the transition from `Waiting.Ready` to `Orange.`The transition to the state `In_motion` is valid when state `Waiting.Ready` is active and the event `Selection_made` occurs, providing that the variable `select` equals 1. This transition defines an explicit exit from the `Waiting.Ready` state and an implicit exit from the `Waiting` superstate. On the destination side, this transition defines an implicit `entry` into the `Orange` superstate and an explicit `entry` into the `Orange.In_motion` substate.

See "Transitioning from a Substate to a Substate with Events Example" on page 3-48 for more information on the semantics of this notation.

Self-Loop Transitions

A transition segment from a state to a connective junction that has an outgoing transition segment from the connective junction back to the state is a self-loop transition as shown in the following example:



See these sections for examples of self-loop transitions:

- “Connective Junction — Self-Loop Example” on page 2-33

  See “Self-Loop Transition Example” on page 3-73 for information on the semantics of this notation.

- “Connective Junction and For Loops Example” on page 2-34

  See “For Loop Construct Example” on page 3-74 for information on the semantics of this notation.

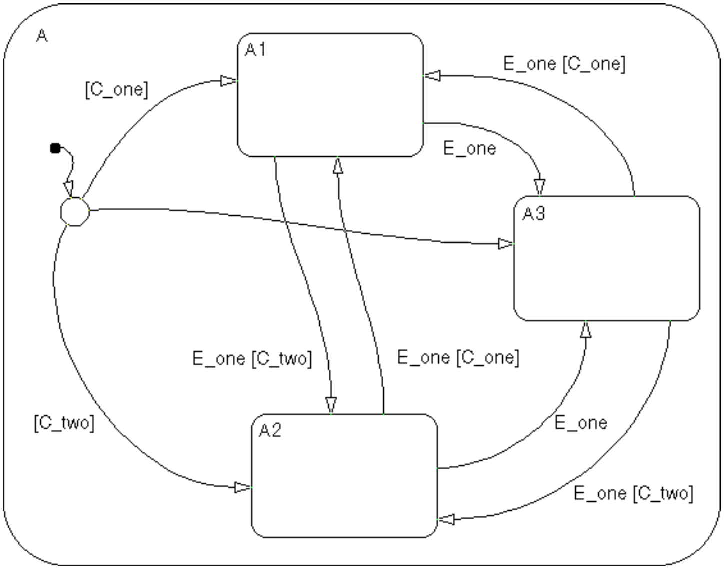
Inner Transitions

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

- “Before Using an Inner Transition” on page 2-22
- “After Using an Inner Transition to a Connective Junction” on page 2-23
- “Using an Inner Transition to a History Junction” on page 2-24

Before Using an Inner Transition

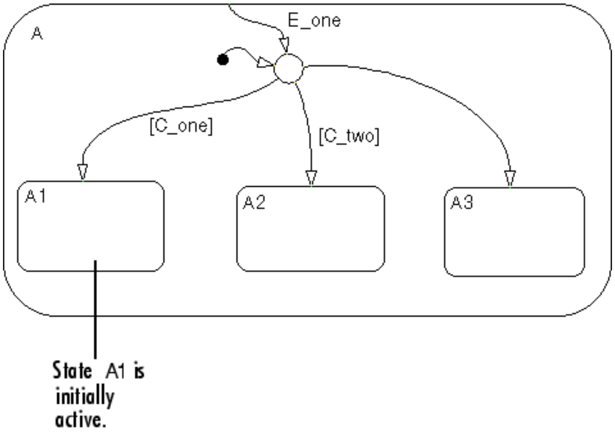
This is an example of a Stateflow diagram that could be simplified by using an inner transition.



Any event occurs and awakens the Stateflow diagram. The default transition to the connective junction is valid. The destination of the transition is determined by `[C_one]` and `[C_two]`. If `[C_one]` is true, the transition to `A1` is true. If `[C_two]` is true, the transition to `A2` is valid. If neither `[C_one]` nor `[C_two]` is true, the transition to `A3` is valid. The transitions among `A1`, `A2`, and `A3` are determined by `E_one`, `[C_one]`, and `[C_two]`.

After Using an Inner Transition to a Connective Junction

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



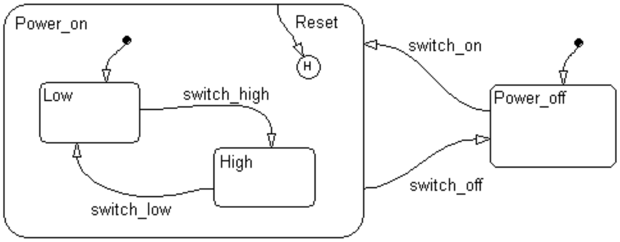
Any event occurs and awakens the Stateflow diagram. The default transition to the connective junction is valid. The destination of the transitions is determined by `[C_one]` and `[C_two]`.

The Stateflow diagram is simplified by using an inner transition in place of the many 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_one` occurs, the inner transition is potentially valid. If `[C_one]` is true, the transition to `A1` is valid. If `[C_two]` is true, the transition to `A2` is valid. If neither `[C_one]` nor `[C_two]` is true, the transition to `A3` is valid. This solution is much simpler than the previous one.

See “Processing the First Event with an Inner Transition to a Connective Junction” on page 3-65 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 “Use of History Junctions Example” on page 2-38 for another example using a history junction.

See “Inner Transition to a History Junction Example” on page 3-68 for more information on the semantics of this notation.

Default Transitions

You use default transitions to tell Stateflow which one of several states you enter when you first enter a chart or a state that has substates. See the following topics for information on default transitions:

- "What Is a Default Transition?" on page 2-26
- "Drawing Default Transitions" on page 2-26
- "Labeling Default Transitions" on page 2-27
- "Default Transition Examples" on page 2-27

What Is a Default Transition?

Default transitions are primarily used to specify which exclusive (OR) state is to be entered when there is ambiguity among two or more neighboring exclusive (OR) states. They have a destination but no source object. For example, default transitions specify 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. Default transitions are also used to 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.

One of the most common Stateflow programming mistakes 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 using the Debugger with the **State Inconsistencies** option enabled.

This table shows the button icon and briefly describes a default transition.

Name	Button Icon	Description
Default transition		Use a default transition to indicate, when entering this level in the hierarchy, which object becomes active by default.

Labeling Default Transitions

In some circumstances, you might want to 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.

Note When labeling default transitions, take care to ensure that there is always at least one valid default transition. Otherwise, a Stateflow chart can transition into an inconsistent state.

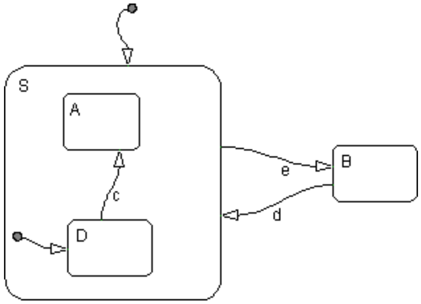
Default Transition Examples

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

- "Default Transition to a State Example" on page 2-27
- "Default Transition to a Junction Example" on page 2-28
- "Default Transition with a Label Example" on page 2-29

Default Transition to a State Example

This example shows a use of default transitions.



When the Stateflow diagram is first awakened, it must decide whether to activate state S or state B since they are exclusive (OR) states. The answer is given by the default transition to superstate S, which is taken if valid. Because there are no conditions on this default transition, it is taken.

State S, which is now active, has two substates, A and D. Which substate becomes active? Only one of them can be active because they are exclusive (OR) states. The answer is given by the default transition to substate D, which is taken if valid. Because there are no conditions on this default transition, it is taken.

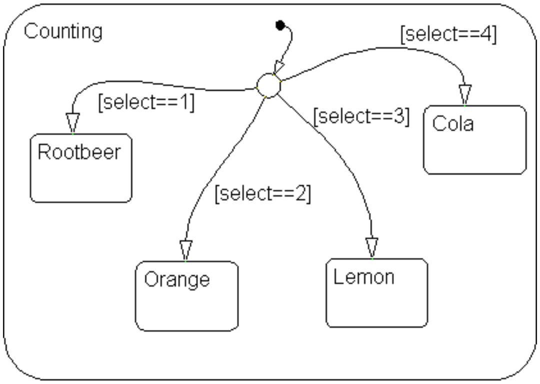
Suppose at a different execution point the Stateflow diagram is awakened by the occurrence of event d and state B is active. The transition from state B to state S is valid. When the system enters state S, it enters substate D because the default transition is defined.

See “Default Transition Examples” on page 3-56 for more information on the semantics of this notation.

The default transitions are required for the Stateflow diagram to execute. Without the default transition to state S, when the Stateflow diagram is awakened, none of the states becomes active. You can detect this situation at run-time by checking for state inconsistencies. See “Controlling Animation in the Debugging Window” on page 15-8 for more information.

Default Transition to a Junction Example

This example shows a default transition to a connective junction.

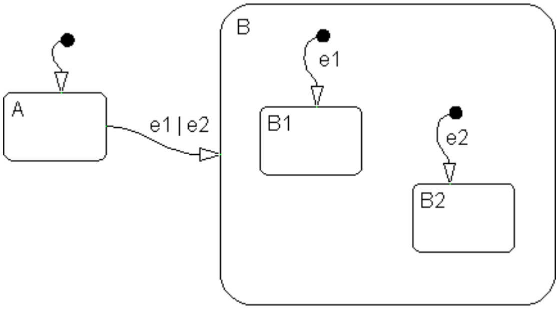


In this example, the default transition to the connective junction defines that upon entering the Counting state, the destination is determined by the condition on each transition segment.

See “Default Transition to a Junction Example” on page 3-57 for more information on the semantics of this notation.

Default Transition with a Label Example

The following example shows the labeling of default transitions.



If state A is initially active and either e1 or e2 occurs, the transition from state A to superstate B is valid. The substates B1 and B2 both have default transitions. The default transitions are labeled to specify the event that triggers the transition. If event e1 occurs, the transition A to B1 is valid. If event e2 occurs, the transition A to B2 is valid.

See “Labeled Default Transitions Example” on page 3-59 for more information on the semantics of this notation.

Connective Junctions

A connective junction represents a decision point between alternate transition paths taken for a single transition. See the following topics for more information on connective junctions:

- "What Is a Connective Junction?" on page 2-31
- "Flow Diagram Notation with Connective Junctions" on page 2-31

What Is a Connective Junction?

The connective junction enables representation of different possible transition paths for a single transition. Connective junctions are used to help represent the following:

- Variations of an `if-then-else` decision construct, by specifying conditions on some or all of the outgoing transitions from the connective junction
- A self-loop transition back to the source state if none of the outgoing transitions is valid
- Variations of a `for` loop construct, by having a self-loop transition from the connective junction back to itself
- Transitions from a common source to multiple destinations
- Transitions from multiple sources to a common destination
- Transitions from a source to a destination based on common events

Note An event cannot trigger a transition from a connective junction to a destination state.

See "Connective Junction Examples" on page 3-70 for a summary of the semantics of connective junctions.

Flow Diagram Notation with Connective Junctions

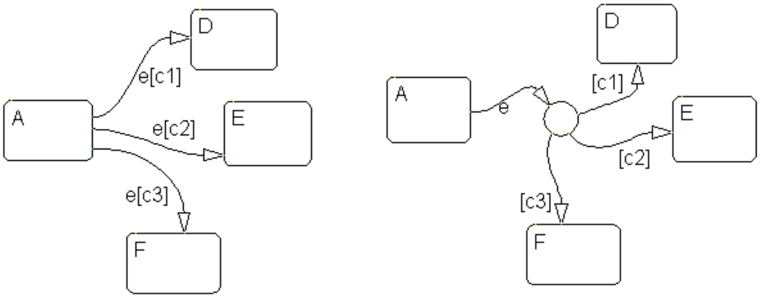
Flow diagram notation uses connective junctions to represent common code structures like `for` loops and `if-then-else` constructs without the use of states. And by reducing the number of states in your Stateflow diagrams, flow diagram notation produces more efficient generated code that helps optimize memory use.

Flow diagram notation employs combinations of the following:

- Transitions to and from connective junctions
- Self-loops to connective junctions
- Inner transitions to connective junctions

Flow diagram notation, states, and state-to-state transitions seamlessly coexist in the same Stateflow diagram. The key to representing flow diagram notation is in the labeling of the transitions (specifically the use of action language) as shown by the following examples.

Connective Junction with All Conditions Specified Example



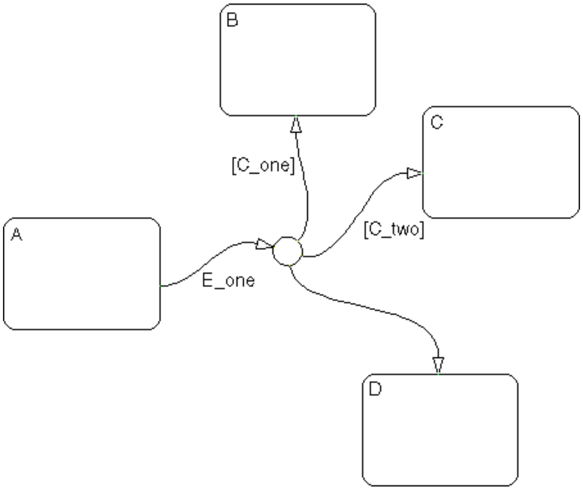
In the example on the left, if state A is active when event e occurs, the transition from state A to any of states D, E, or F takes place if one of the conditions [c1], [c2], or [c3] is met.

In the equivalent representation on the right, a transition from the source state to a connective junction is labeled by the event. Transitions from the connective junction to the destination states are labeled by the conditions. If state A is active when event e occurs, the transition from A to the connective junction occurs first. The transition from the connective junction to a destination state follows based on which of the conditions [c1], [c2], or [c3] is true. If none of the conditions is true, no transition occurs and state A remains active.

See “If-Then-Else Decision Construct Example” on page 3-71 for more information on the semantics of this notation.

Connective Junction with One Unconditional Transition Example

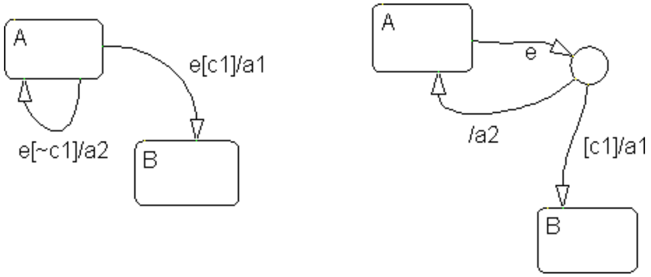
The transition A to B is valid when A is active, event E_one occurs, and [C_one] is true. The transition A to C is valid when A is active, event E_one occurs, and [C_two] is true. Otherwise, given A is active and event E_one occurs, the transition A to D is valid. If you do not explicitly specify condition [C_three], it is implicit that the transition condition is not [C_one] and not [C_two].



See “If-Then-Else Decision Construct Example” on page 3-71 for information on the semantics of this notation.

Connective Junction — Self-Loop Example

In some situations, the transition event occurs but a condition is not met. No transition is taken, but an action is generated. You can represent this situation by using a connective junction or a self-loop transition (transition from state to itself).



In the example on the left, if State A is active and event e occurs and the condition [c1] is met, the transition from A to B is taken, generating action a1. The transition from state A to state A is valid if event e occurs and [c1] is not true. In this self-loop transition, the system exits and reenters state A, and executes action a2.

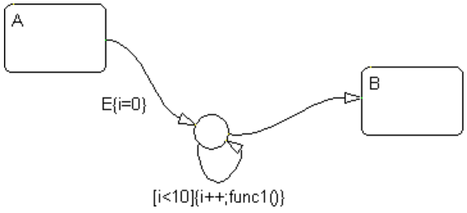
In the equivalent representation on the right, the use of a connective junction makes it unnecessary to specify the implied condition [~c1] explicitly.

See “Self-Loop Transition Example” on page 3-73 for more information on the semantics of this notation.

Connective Junction and For Loops Example

This example shows a combination of flow diagram notation and state transition notation. Self-loop transitions to connective junctions can be used to represent for loop constructs.

In state A, event E occurs. The transition from state A to state B is valid if the conditions along the transition path are true. The first segment of the transition does not have a condition, but does have a condition action. The condition action, {i=0}, is executed. The condition on the self-loop transition is evaluated as true and the condition actions {i++;func1()} execute. The condition actions execute until the condition [i<10] is false. The condition actions on both the first segment and the self-loop transition to the connective junction effectively execute a for loop (for i values 0 to 9 execute func1()). The for loop is executed outside the context of a state. The remainder of the path is evaluated. Because there are no conditions, the transition completes at the destination, state B.



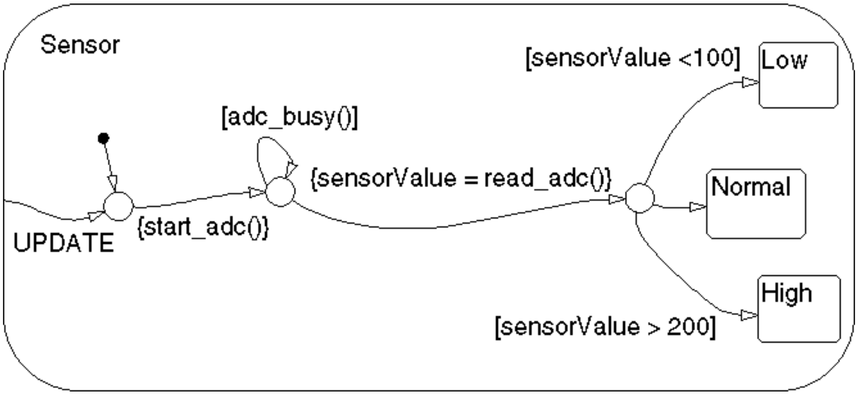
See “For Loop Construct Example” on page 3-74 for information on the semantics of this notation.

Flow Diagram Notation Example

This example shows a real-world use of flow diagram notation and state transition notation. This Stateflow diagram models an 8-bit analog-to-digital converter (ADC).

Consider the case when state `Sensor.Low` is active and event `UPDATE` occurs. The inner transition from `Sensor` to the connective junction is valid. The next transition segment has a condition action, `{start_adc()}`, which initiates a reading from the ADC. The self-loop on the second connective junction repeatedly tests the condition `[adc_busy()]`. This condition evaluates as true once the reading settles (stabilizes) and the loop completes. This self-loop transition is used to introduce the delay needed for the ADC reading to settle. The delay could have been represented by another state with some sort of counter. Using flow notation in this example avoids an unnecessary use of a state and produces more efficient code.

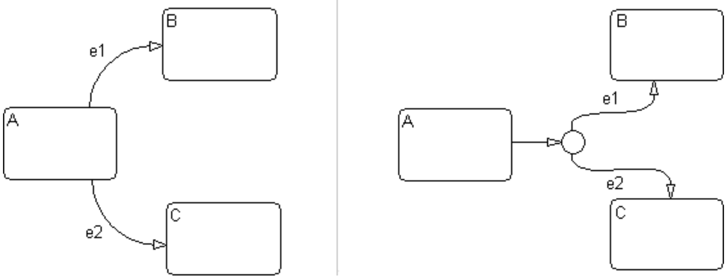
The next transition segment condition action, `{sensorValue=read_adc()}`, puts the new value read from the ADC in the data object `sensorValue`. The final transition segment is determined by the value of `sensorValue`. If `[sensorValue <100]` is true, the state `Sensor.Low` is the destination. If `[sensorValue >200]` is true, the state `Sensor.High` is the destination. Otherwise, state `Sensor.Normal` is the destination state.



See “Flow Diagram Notation Example” on page 3-75 for information on the semantics of this notation.

Connective Junction from a Common Source to Multiple Destinations Example

Transitions A to B and A to C share a common source state A. An alternative representation uses one arrow from A to a connective junction, and multiple arrows labeled by events from the junction to the destination states B and C.



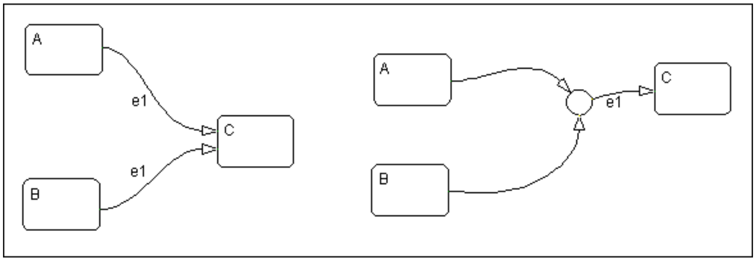
See “Transitions from a Common Source to Multiple Destinations Example” on page 3-77 for information on the semantics of this notation.

Connective Junction Common Events Example

Suppose, for example, that when event e1 occurs, the system, whether it is in state A or B, transfers to state C. Suppose that transitions A to C and B to C are triggered by the same event e1, so that both destination state and trigger event are common to the transitions. There are three ways to represent this:

- By drawing transitions from A and B to C, each labeled with e1
- By placing A and B in one superstate S, and drawing one transition from S to C, labeled with e1
- By drawing transitions from A and B to a connective junction, then drawing one transition from the junction to C, labeled with e1

This Stateflow diagram shows the simplification using a connective junction.



See “Transitions from a Source to a Destination Based on a Common Event Example” on page 3-79 for information on the semantics of this notation.

History Junctions

History junctions record the previously active state of the state in which they are resident. See the following sections for information on history junctions:

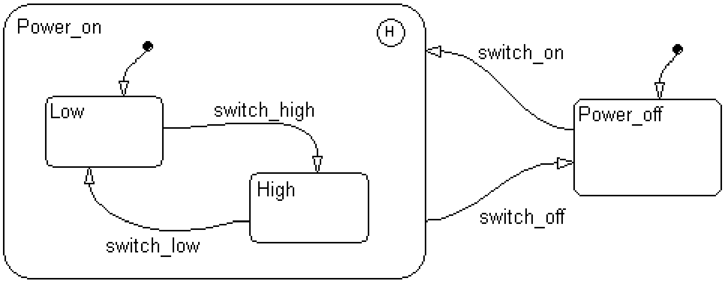
- “What Is a History Junction?” on page 2-38
- “History Junctions and Inner Transitions” on page 2-39

What Is a History Junction?

A history junction is used to represent historical decision points in the Stateflow diagram. 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.

Use of History Junctions Example

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 could enter either 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. Since Power_on.High was the last active state, it becomes active again. After the first time Power_on becomes active, the choice between entering `Power_on.Low` or `Power_on.High` is determined by the history junction.

See “Default Transition and a History Junction Example” on page 3-58 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 and/or condition, the active state is to be exited and then immediately reentered.

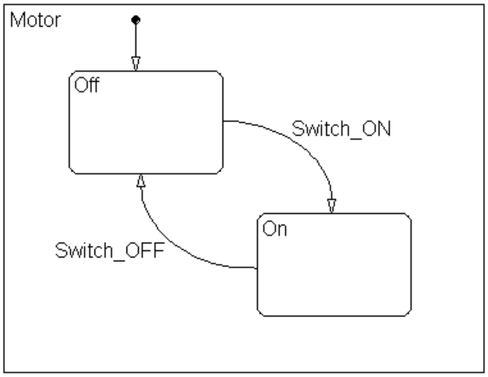
See “Using an Inner Transition to a History Junction” on page 2-24 for an example of this notation.

See “Inner Transition to a History Junction Example” on page 3-68 for more information on the semantics of this notation.

Boxes

You use boxes to graphically organize your diagram. Beyond this organizational use, boxes contribute little to how Stateflow diagrams execute.

The following is an example of a Stateflow Box object:

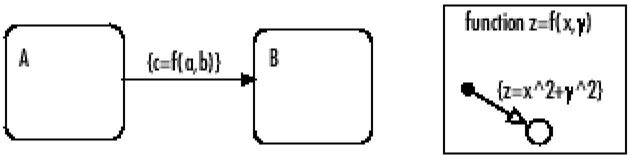


In this example, a box labeled `Motor` groups all the objects needed to control a simple motor. There can be many more objects displayed on the Stateflow chart along with this box, but now everything needed to control the motor is kept separate.

Graphical Functions

A *graphical function* is a function defined graphically by a flow diagram that provides convenience and power to Stateflow action language.

The following example shows a graphical function side by side in a Stateflow diagram with the transition that calls it:



In this example the function `z = f(x,y)` is called in the condition action of the transition from state A to state B. The function is defined using symbols that are valid only within the function itself. The function is called using data objects available to states A and B and their parent states (if any).

Graphical functions are similar to textual functions such as MATLAB and C functions in the following ways:

- Graphical functions can accept arguments and return results.
- You can invoke graphical functions in transition and state actions.

Unlike C and MATLAB functions, however, graphical functions are full-fledged Stateflow graphical objects. You use the Stateflow editor to create them and they reside in your Stateflow model along with the diagrams that invoke them. This makes graphical functions easier to create, access, and manage than textual custom code functions, whose creation requires external tools, and whose definition resides separately from the model.

3

Stateflow Semantics

Stateflow semantics describe how the notation in Stateflow charts is interpreted and implemented into a behavior. Knowledge of Stateflow semantics is important to make sound Stateflow diagram design decisions for code generation. Different notations result in different behavior during simulation and generated code execution.

This chapter explains the semantics of Classic Stateflow charts. You can also build Mealy and Moore charts, which use a subset of Classic Stateflow semantics (see Chapter 5, “Building Mealy and Moore Charts in Stateflow”).

The following sections describe Classic Stateflow semantics:

Executing an Event

A Stateflow chart executes only in response to an event. This occurs on two levels. First, Simulink updates the chart, which awakens it for execution. Second, once the chart is awakened, it continues to respond to events until there are no more events. The chart then goes to sleep. When another event occurs, the chart is awakened (from sleep) to respond to the event.

Because Stateflow runs on a single thread, actions that take place based on an event are atomic to that event. This means that all activity caused by the event in the chart is completed before returning to whatever activity was taking place prior to reception of the event. Once action is initiated by an event, it is completed unless interrupted by an early return.

See the following topics to continue with the behavior of events:

- "Sources for Stateflow Events" on page 3-3
- "Processing Events" on page 3-4

Sources for Stateflow Events

Stateflow charts are awakened by Simulink events. From the Stateflow perspective, this is an event like any other event, with the exception that it comes from Simulink. After the chart is made active, it can respond to the occurrence of this event in its action language.

You can also use events to control the processing of your Stateflow diagrams by broadcasting events in the action language associated with states and transitions in the chart itself. For the mechanics of broadcasting events in action language, see "Broadcasting Events in Actions" on page 8-46. For examples using event broadcasting and directed event broadcasting, see the following:

- "Condition Actions to Broadcast Events to Parallel (AND) States Example" on page 3-54
- "Cyclic Behavior to Avoid with Condition Actions Example" on page 3-54
- "Event Broadcast State Action Example" on page 3-84

- "Event Broadcast Transition Action with a Nested Event Broadcast Example" on page 3-87
- "Event Broadcast Condition Action Example" on page 3-91
- Directed Event Broadcasting

Before you can broadcast events in the action language of a Stateflow chart, you must first add them. You can do this in the **Add** menu of the Stateflow diagram editor or through the **Model Explorer**. See "Adding Data Using the Stateflow Editor" on page 7-27 for a description of the ways that you add events in Stateflow.

Events have hierarchy (a parent) and scope. The parent and scope together define a range of access to events. It is primarily the event's parent that determines who can trigger on the event (has receive rights). See the **Name** and **Parent** fields for an event in "Setting Event Properties in the Event Dialog" on page 7-8 for more information.

Processing Events

When an event occurs, it is processed from the top or root of the Stateflow diagram down through the hierarchy of the diagram. At each level in the hierarchy, any `during` and `on` *`event_name`* actions for the active state are executed and completed and then a check for the existence of a valid explicit or implicit transition among the children of the state is conducted. The examples in this chapter demonstrate the top-down processing of events.

All events, with the exception of the output edge trigger to Simulink (see the following note), have the following execution in a Stateflow diagram:

1. If the *receiver* of the event is active, then it is executed (see "Executing an Active Chart" on page 3-6 and "Executing an Active State" on page 3-23). (The event *receiver* is the parent of the event unless the event was explicitly directed to a *receiver* using the `send()` function.)
2. If the receiver of the event is not active, nothing happens.
3. After broadcasting the event, the broadcaster performs early return logic based on the type of action statement that caused the event.

For an understanding of early return logic, see “Early Return Logic for Event Broadcasts” on page 3-39.

Note Output edge trigger event execution in Simulink is equivalent to toggling the value of an output data value between 1 and 0. It is not treated as a Stateflow event. See “Defining Edge-Triggered Output Events” on page 10-26.

Executing a Chart

A Stateflow chart executes when it is triggered by an event from Simulink. Like all events, this event is processed top down in the updated chart. See "Executing an Event" on page 3-3.

A chart is inactive when it is first triggered by an event from the Simulink model and has no active states within it. After the chart executes and completely processes its initial trigger event from the Simulink model, it exits to the model and goes to sleep, but still remains active. A sleeping chart has active states within it, but no events to process. When Simulink triggers the chart the next time, it is an active but sleeping chart.

- "Executing an Inactive Chart" on page 3-6
- "Executing an Active Chart" on page 3-6
- "Executing a Chart at Initialization" on page 3-7

Executing an Inactive Chart

When a chart is inactive and first triggered by an event from Simulink, it first executes its set of default flow graphs (see "Executing a Set of Flow Graphs" on page 3-9). If this does not cause an entry into a state and the chart has parallel decomposition, then each parallel state is entered (see "Entering a State" on page 3-21).

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

Executing an Active Chart

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

Executing a Chart at Initialization

By default, the first time a chart wakes up it executes the default transition paths, at which time it 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 option to *execute at initialization*. When you turn on this option, Stateflow initializes a chart's state configuration at time 0 instead of at the first occurrence of an input event. The default transition paths of the chart are executed during the model initialization phase at time 0, corresponding to the mdlInitializeConditions() phase for S-functions.

You enable the option **Execute (enter) Chart At Initialization** in Stateflow chart properties, as described in "Setting Properties for Individual Charts" on page 10-6.

Note If an output of this chart connects to a SimEvents™ block, you should not enable this option. To learn more about using Stateflow and SimEvents blocks together in a model, see "Using Stateflow with SimEvents" in the SimEvents documentation.

Due to the transient nature of the initialization phase, you should not perform certain actions in the default transition paths of the chart (and associated state entry actions) which are set to execute at initialization. Follow these guidelines:

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

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

Executing a Transition

Transitions play a large role in defining the animation or execution of a system. If your chart has exclusive (OR) states, its execution begins with the default transitions that point to the first active states in your chart.

Transitions have sources and destinations; thus, any actions associated with the sources or destinations are related to the transition that joins them. The type of the source and destination is equally important to define the semantics.

See the following topics:

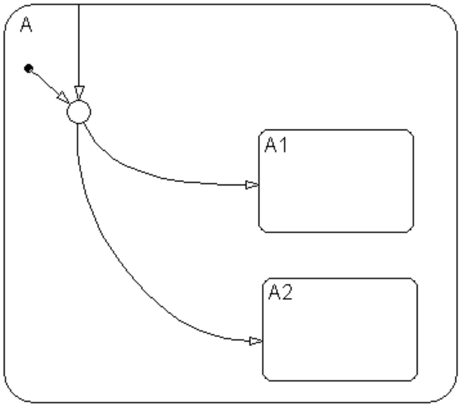
- “Transition Flow Graph Types” on page 3-8
- “Executing a Set of Flow Graphs” on page 3-9

Transition Flow Graph Types

Before transitions are executed for an active state or for a chart, they are grouped by the following types:

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

Each set of flow graphs 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 graphs includes the inner transition and the outgoing transitions from the junction to state A.A1 and A.A2. In addition, state A's set of default flow graphs includes the default transition to the junction along with 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 become members of more than one flow graph type.

Executing a Set of Flow Graphs

Each flow graph group is executed in the order of group priority until a valid transition is found. The default transitions group is executed first, followed by the outer transitions group and then the inner transitions group. Each flow graph group is executed with the following procedure.

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

   An active state can have several possible outgoing transitions. These are ordered before checking them for a valid transition. See "Transition Testing Order" on page 3-11.

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:
   1. No more transition segments are tested and a transition path is formed by including the transition segment from each preceding junction back to the starting transition.
   2. The states that are the immediate children of the parent of the transition path are exited (see “Exiting an Active State” on page 3-23).
   3. The transition action for the final transition segment of the full transition path is executed.
   4. The destination state is entered (see “Entering a State” on page 3-21).
6. If the destination is a junction with no outgoing transition segments, do the following:
   1. Testing stops without any states being exited or entered.
7. If the destination is a junction with outgoing transition segments, repeat step 1 for the set of outgoing segments from the junction.
8. After testing all outgoing transition segments at a junction, back up the incoming transition segment that brought you to the junction and continue at step 2, starting with the next transition segment after the backup segment. The set of flow graphs is done executing when all starting transitions have been tested.

Transition Testing Order

If there is more than one transition from a source (state or junction) in a Stateflow diagram, then the transitions are numbered 1, 2, 3, ..., according to their testing order.

By default, Stateflow determines the order of testing transitions from a single source based on a set of internal rules. This is called the implicit order. You also have an option to switch from implicit ordering of transitions to a user-defined, or explicit, ordering. In this mode, you control the order in which transitions are tested for execution.

- "Implicit Order Mode" on page 3-11
- "Explicit Order Mode" on page 3-15

Implicit Order Mode

Implicit order mode is the default mode both for old models and for newly created models. Transitions from a single source are ordered for testing according to the following three sorting guidelines, which appear in order of their precedence (first step is highest priority):

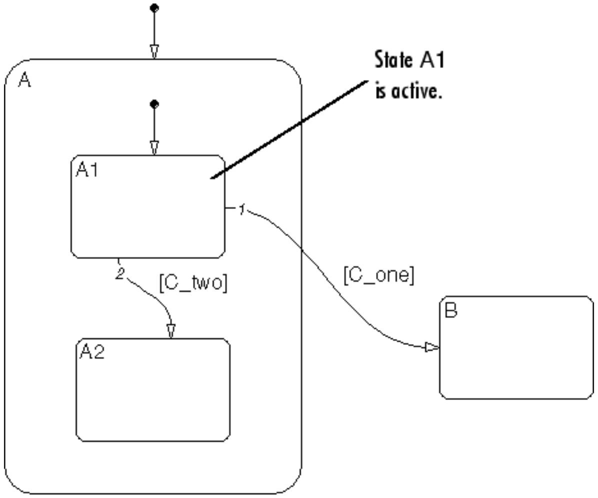
1. Endpoint Hierarchy – Transitions whose end points are attached to higher hierarchical levels are placed first in testing order. See the topic "Ordering by Hierarchy" on page 3-11.

2. Label – Transitions are ordered for testing according to the types of action language present in their labels. See "Ordering by Label" on page 3-12.

3. Angular Surface Position of Transition Source – Transitions are ordered for testing based on the angular position of the transition source on the surface of the originating object. See "Ordering by Geometric Position of Source" on page 3-12.

Ordering by Hierarchy

Transitions are evaluated in a top-down manner based on hierarchy. In the following example, an event occurs while state `A1` is active.



Because state `B` is a sibling of state `A` and at a higher hierarchical level than state `A2`, a sibling of `A1`, the transition from state `A1` to state `B` takes precedence over the transition from state `A1` to state `A2`.

Ordering by Label

Transitions of equal endpoint hierarchical level are evaluated based on their labels, in the following order of precedence:

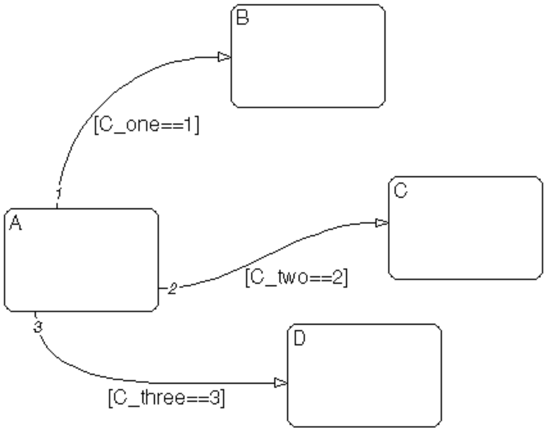
1. Labels with events and conditions
2. Labels with events
3. Labels with conditions
4. No label

The following example demonstrates ordering of single source transitions by the angular surface position of the source.

Ordering by Geometric Position of Source

Equivalent transitions (based on their labels and the hierarchy of their source and endpoints) are ordered based on the angular position on the surface of the source object for the outgoing transitions. 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 possible priority.

Multiple outgoing transitions from states that are of equivalent label and source and end point hierarchy priority are evaluated in a clockwise progression starting at the upper left corner of the source state.



In this example, the transitions are of equivalent label priority. The conditions [C_one == 1] and [C_two == 2] are both false and the condition [C_three == 3] is true. Also, the hierarchical level of the endpoint of each transition is the same because all the states in the example are siblings.

The outgoing transitions from state A in the preceding diagram are evaluated in the following order:

1 Starting at the upper left corner of the source state A in a clockwise progression, the first transition is the transition from state A to state B.

   Since the condition [C_one == 1] is false, this transition is not valid.

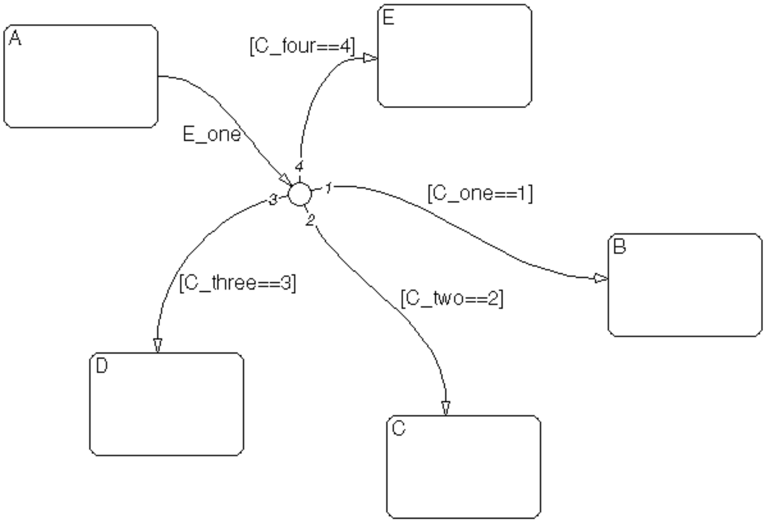
2 The next transition in a clockwise progression is the transition from state A to state C.

   Since the condition [C_two == 2] is false, this transition is not valid.

3 The next transition is the transition from state A to state D.

   Since the condition [C_three == 3] is true, this transition is valid and is taken.

Multiple outgoing transitions from junctions that are of equivalent label priority are evaluated according to the same angular position prioritization.



In this example,

- All outgoing transitions from the junction have conditions, which makes them equal in label priority.
- The conditions [C_three == 3] and [C_four == 4] are true.
- The junction source point for the transition to state E is exactly 12 o'clock.

The outgoing transitions from the junction are evaluated in the following order:

1. The transition to state B is evaluated. Since the condition [`C_one` == 1] is false, this transition is not valid.
2. The transition to state C is evaluated. Since the condition [`C_two` == 2] is false, this transition is not valid.
3. The transition to state D is evaluated. Since the condition [`C_three` == 3] is true, this transition is valid and taken.

   Since the transition to D is taken, the transition to state E is not evaluated.

Explicit Order Mode

Implicit ordering rules are complex and hard to master. Additionally, when you modify a diagram for cosmetic purposes, rearranging transitions may inadvertently change execution. This is why you have an option to switch from implicit ordering of transitions to a user-defined, or explicit, ordering. In this mode, you control the order in which transitions are tested for execution.

Note You can reorder transitions only within their type (inner, outer, or default). For more information, see “Transition Flow Graph Types” on page 3-8.

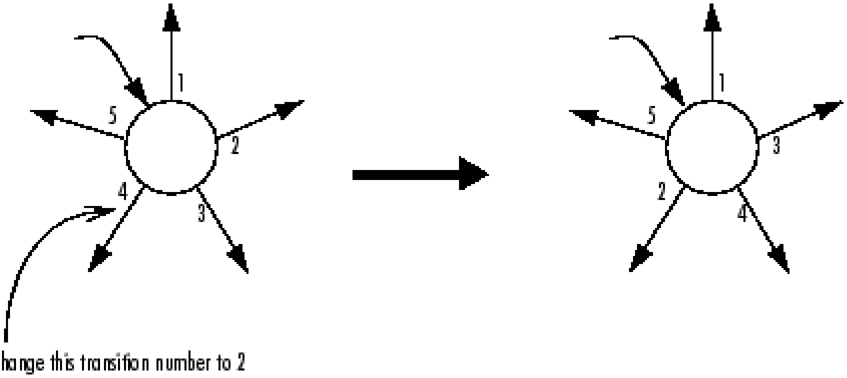
To control the order of transitions, you have to perform the following steps:

1. “Switching to Explicit Order Mode” on page 3-16
2. “Changing the Transition Order” on page 3-18

When you switch to explicit transition ordering, Stateflow stops evaluating the implicit rules. All the existing transitions in a diagram retain their current order numbers until you explicitly change them. All the newly created transitions for a source are automatically numbered in the order you create them, starting with the next available number for the source.

You can change the order of outgoing transitions for a source by explicitly renumbering them. When you change a transition number, Stateflow automatically renumbers the other outgoing transitions for the source by preserving their relative order. This is similar to taking a book out of a stack and then putting it back in a different place: the order of the other books is unchanged, and the books are renumbered accordingly. This behavior is consistent with the automatic renumbering rules for the Simulink ports.

For example, if you have a source with five outgoing transitions, as shown below, changing transition 4 to 2 results in the following automatic renumbering.



Automatic Renumbering of Transitions During Explicit Reordering

Switching to Explicit Order Mode

You switch to explicit ordering of transitions by setting your chart property preferences.

1 In the Stateflow diagram editor, from the **File** menu, select **Chart Properties**.

   The properties dialog for the chart appears, as shown:

Enables explicit ordering

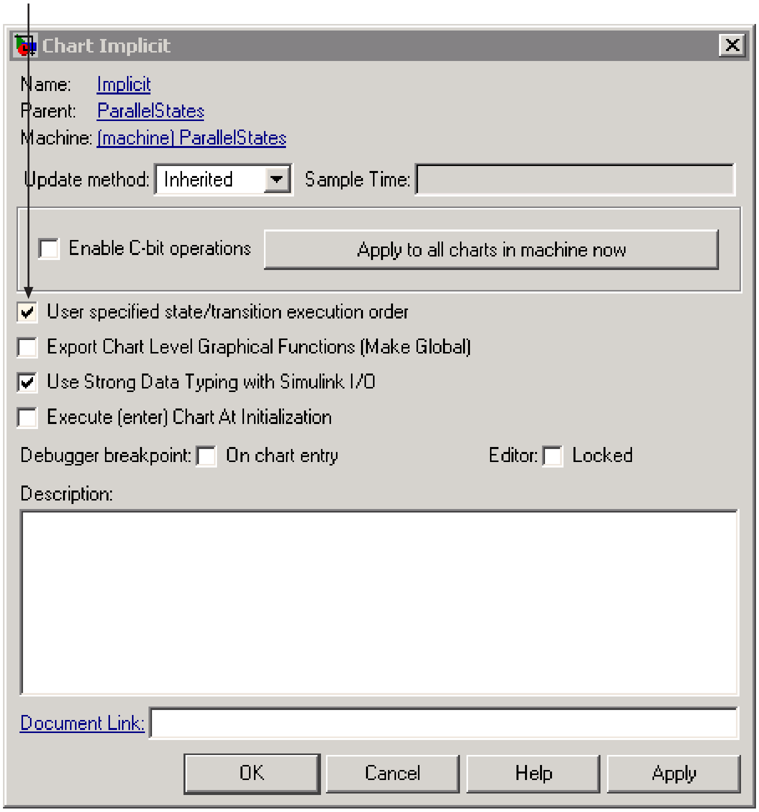


Chart Implicit

Name: Implicit
Parent: ParallelStates
Machine: [machine] ParallelStates

Update method: Inherited Sample Time:

□ Enable C-bit operations

☑ User specified state/transition execution order
□ Export Chart Level Graphical Functions (Make Global)
☑ Use Strong Data Typing with Simulink I/O
□ Execute (enter) Chart At Initialization

Debugger breakpoint: □ On chart entry Editor: □ Locked

Description:

Document Link:

2 Select the **User specified transition execution order** check box.

3 Click **OK** to apply the change and close the dialog.

Now you can change the transition execution order for any source in the chart.

Switching between modes. If you switch back to implicit order mode after having explicitly reordered the transitions, the transition order is reset to follow the implicit rules.

Similarly, if you eventually change back to explicit order mode, without making any changes to the diagram, Stateflow restores the previous explicit transition order. Whenever you switch from one transition ordering mode to another, Stateflow displays the warnings about the changes in transition numbers in the diagnostic viewer.

Note If you change back to explicit order mode after having made changes to the diagram, Stateflow may not be able to restore the previous explicit transition order. Review the warnings in the diagnostic viewer and change the transition order, as necessary.

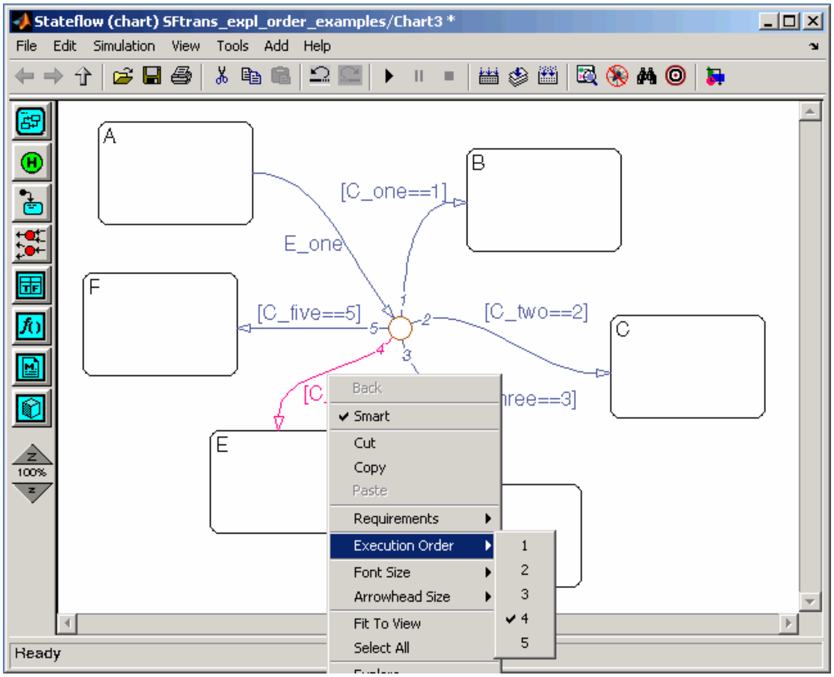
Changing the Transition Order

You change the order of transitions originating from a source by explicitly renumbering them.

1 Right-click a transition and select **Execution Order**.

Note If you select **Execution Order** while in implicit order mode, the only option available is **Enable 'User specified execution order' for this chart**. This opens the properties dialog for the chart, to let you switch to explicit order mode, as described in "Switching to Explicit Order Mode" on page 3-16.

A context menu of available transition numbers appears, with a checkmark next to the current number for this transition. For example, if there are five transitions originating from a source, and you are modifying the execution order for transition 4, the context menu will contain numbers from 1 to 5, with a checkmark next to number 4, as shown in the following illustration.



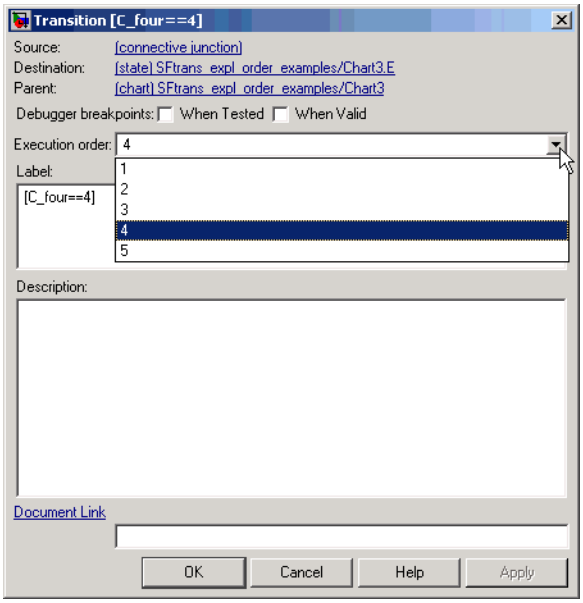
2 Select the new transition number. Stateflow automatically renumbers the other transitions for the source by preserving the relative transition order, as shown in the illustration.

3 Repeat this procedure to renumber the other transitions as necessary.

Another way to access the transition order number is through its properties:

1 Right-click a transition and select **Properties**. The properties dialog for the transition appears.

2 Click in the **Execution order** box. A drop-down list of valid transition numbers appears, as shown in the following illustration.



Transition [C_four==4]

Source: (connective junction)

Destination: (state) SFtrans_expl_order_examples/Chart3.E

Parent: (chart) SFtrans_expl_order_examples/Chart3

Debugger breakpoints: □ When Tested □ When Valid

Execution order: 4

Label: [C_four==4]

3 Select the new transition number and click **Apply**. If the explicit order mode is enabled, Stateflow assigns the new number to the current transition and automatically renumbers the other transitions. If Stateflow is in the implicit order mode, an error dialog is displayed and the old number is retained.

Entering, Executing, and Exiting a State

States are either active or inactive. The following topics describe the stages of state execution that take place between becoming active and becoming inactive:

- "Entering a State" on page 3-21
- "Executing an Active State" on page 3-23
- "Exiting an Active State" on page 3-23
- "State Execution Example" on page 3-24

Entering a State

A state is entered (becomes active) in one of the following ways:

- Its boundaries are crossed by an incoming executed transition.
- Its boundary terminates the arrow end of an incoming transition.
- It is the parallel state child of an activated state.

A state performs its `entry` action (if specified) when it becomes active. The state is marked active before its `entry` action is executed and completed.

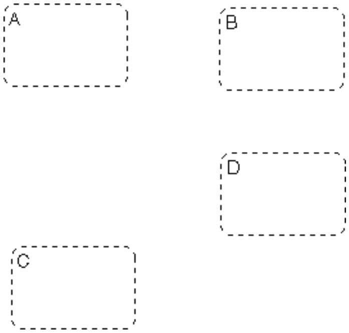
The execution steps for entering a state are as follows:

1. If the parent of the state is not active, perform steps 1 through 4 for the parent first.

2. If this is a parallel state, check if a sibling parallel state previous in entry order is active. If so, start at step 1 for this parallel state.

   Parallel (AND) states are ordered for entry based on their vertical top-to-bottom position in the diagram editor. Parallel states that occupy the same vertical level are ordered for entry from left to right.

   In the following example, parallel states `A` and `B` are aligned at the same vertical level while states `A` and `C` and states `B` and `D` are aligned at the same horizontal position.



Based on their top-down positions in the diagram editor, the order of entry for these states is A or B, then C, then D. Because A is left of B, A is evaluated first and the order of entry is A, B, D, C. Stateflow marks this order with an order number in the upper right-hand corner of the state (1, 2, 3, 4, respectively)

Step 2 says that if you are entering state D in step 1, check if state B is active. If it is not, start at step 1 for state B. Step 2 repeats for state B and, if A is not active, start at step 1 for A. Since there are no parallel states of lesser entry order, continue with step 3 for state A.

3 Mark the state active.

4 Perform any entry actions.

5 Enter children, if needed:

  a Execute the default flow paths for the state unless it contains a history junction.

  b If the state contains a history junction and there is an active child of this state at some point after the most recent chart initialization, perform the entry actions for that child.

  c If this state has children that are parallel states (parallel decomposition), perform entry steps 1 to 5 for each state according to its entry order.

6 If this 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.

8. The chart goes to sleep.

Executing an Active State

Active states that receive an event that does not result in an exit from that state execute a `during` action to completion if a `during` action is specified for that state. An `on` *`event_name`* action executes to completion when the event specified, *`event_name`*, occurs and that state is active. An active state executes its `during` and `on` *`event_name`* actions before processing any of its children's valid transitions. `During` and `on` *`event_name`* actions are processed based on their order of appearance in the state label.

The execution steps for executing a state that receives an event while it is active are as follows:

1. The set of outer flow graphs is executed (see "Executing a Set of Flow Graphs" on page 3-9).

   If this causes a state transition, execution of the state stops.

   Note This step is never required for parallel states.

2. `During` actions and valid `on` *`event name`* actions are performed.

3. The set of inner flow graphs is executed. If this does not cause a state transition, the active children are executed, starting at step 1. Parallel states are executed in the same order that they are entered.

Exiting an Active State

A state is exited (becomes inactive) in one of the following ways:

- Its boundary is the origin of an outgoing executed transition.
- Its boundary is crossed by an outgoing executed transition.
- It is a parallel state child of an activated state.

A state performs its `exit` action (if specified) before it becomes inactive. The state is marked inactive after the `exit` action has executed and completed.

The execution steps for exiting a state are as follows:

1 If this is a parallel state, and one of its sibling states was entered before this state, exit the siblings starting with the last-entered and progressing in reverse order to the first-entered. See step 2 of "Entering a State" on page 3-21.

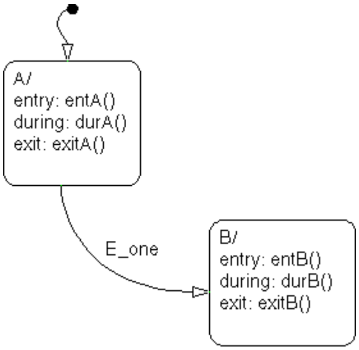
2 If there are any active children, perform the exit steps on these states in the reverse order they were entered.

3 Perform any exit actions.

4 Mark the state as inactive.

State Execution Example

The following example demonstrates the execution semantics (behavior) of event reactive behavior by active and inactive states.



Inactive Diagram Event Reaction

Initially the Stateflow diagram and its states are inactive. This is the semantic sequence that follows an event:

1 An event occurs and the Stateflow diagram is awakened.

2 The Stateflow diagram checks to see if there is a valid transition as a result of the event.

   A valid default transition to state `A` is detected.

3 State `A` is marked active.

4 State `A` entry actions (`entA()`) execute and complete.

5 The Stateflow diagram goes back to sleep.

Sleeping Diagram Event Reaction

The Stateflow diagram is now asleep and waiting to be awakened by another event.

1 Event `E_one` occurs and the Stateflow diagram is awakened.

   State `A` is active from the preceding steps 1 to 5.

2 The Stateflow diagram root checks to see if there is a valid transition as a result of `E_one`. A valid transition is detected from state `A` to state `B`.

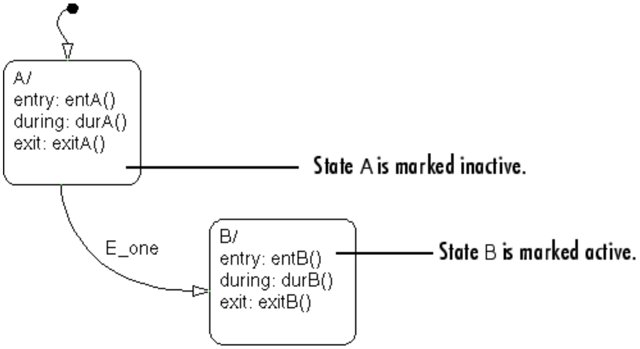
3 State `A` exit actions (`exitA()`) execute and complete.

4 State `A` is marked inactive.

5 State `B` is marked active.

6 State `B` entry actions (`entB()`) execute and complete.

7 The Stateflow diagram goes back to sleep, to be awakened by the next event.



State A is marked inactive.

State B is marked active.

Execution Order for Parallel States

Although multiple parallel (AND) states in the same chart execute concurrently, Stateflow 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, as described in "Entering, Executing, and Exiting a State" on page 3-21.

Unlike exclusive (OR) states, parallel states do not typically use transitions. Instead, order of execution is determined by one of the following mechanisms:

- Implicit ordering by geometry

  Stateflow uses a set of internal rules to order parallel states according to geometric position (see "Implicit Ordering of Parallel States" on page 3-28).

- Explicit ordering, specified by user

  You can override implicit rules by explicitly specifying the execution order of parallel states on an individual basis (see "Explicit Ordering of Parallel States" on page 3-29).

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

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

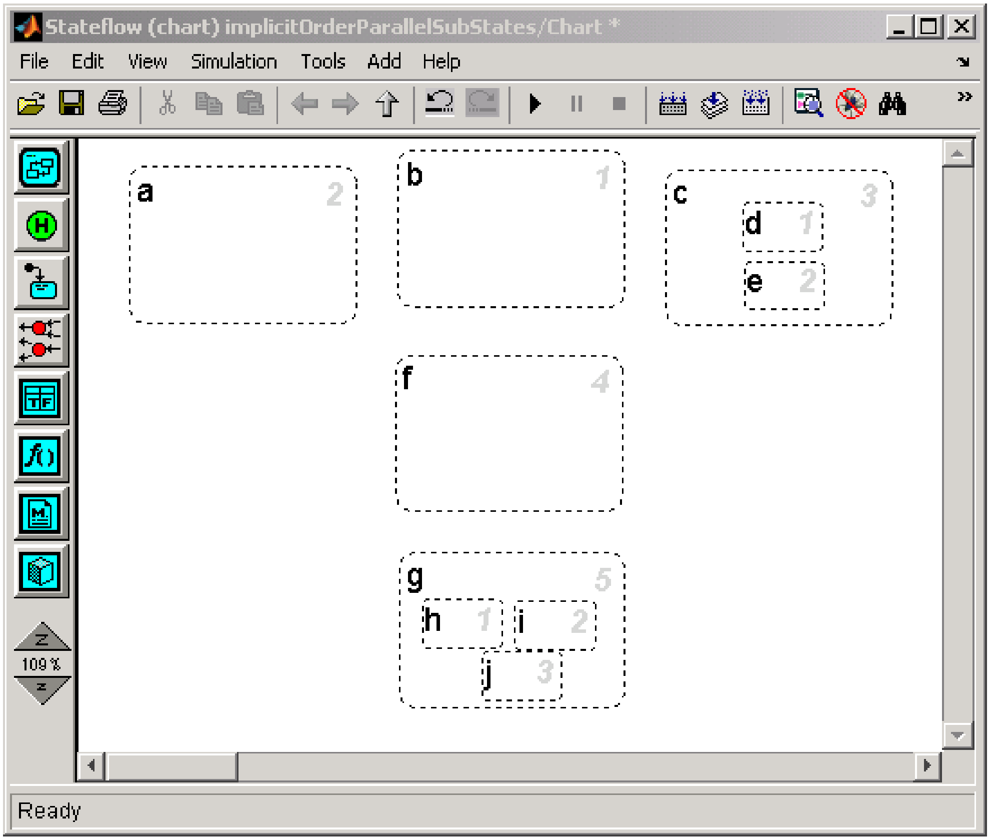
- "Implicit Ordering of Parallel States" on page 3-28
- "Explicit Ordering of Parallel States" on page 3-29
- "Maintaining Order of Parallel States" on page 3-31
- "How Stateflow Assigns Priorities to Restored States" on page 3-35
- "Switching Between Implicit and Explicit Ordering" on page 3-37
- "Ordering of Parallel States in Boxes and Subcharts" on page 3-37

Implicit Ordering of Parallel States

By default, Stateflow orders parallel states implicitly based on where they are located in the state diagram. Priority goes from top to bottom and then left to right, according to these rules:

- The higher a parallel state's vertical position in the diagram, the higher its priority for execution.
- Among parallel states with the same vertical position, the left-most state receives highest priority.

The following example illustrates how these rules apply to top-level parallel states and parallel substates:



Explicit Ordering of Parallel States

A disadvantage of implicit ordering is that it creates a dependency between design layout and execution priority. When you rearrange parallel states in your diagram, you may inadvertently change order of execution and affect simulation results. To gain more control over your designs, you can override implicit ordering by explicitly setting execution priorities.

Using Explicit Ordering for Parallel States

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

1. "Enabling Explicit Ordering at the Chart Level" on page 3-29

2. "Setting Execution Order for Parallel States Individually" on page 3-31

Enabling Explicit Ordering at the Chart Level. To enable explicit ordering for parallel states, follow these steps:

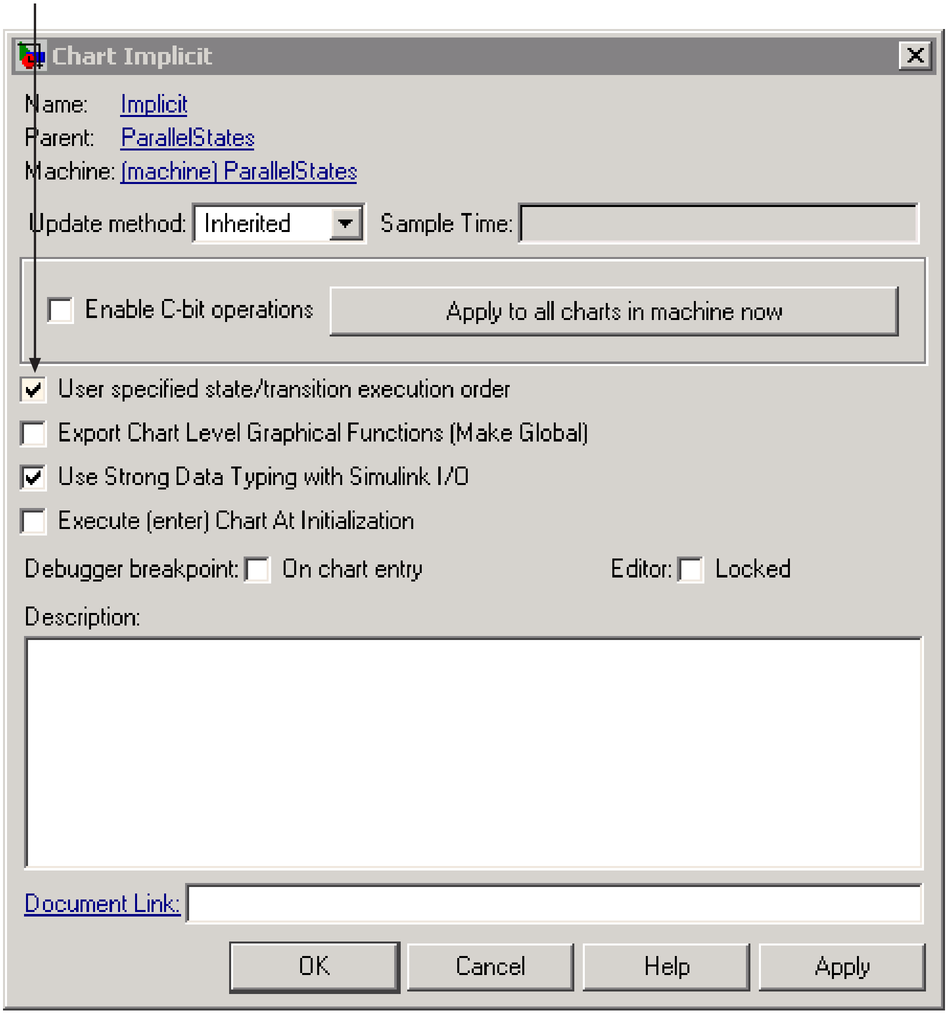
1. Open the properties dialog for your chart by selecting **Chart Properties** from the **File** menu in the Stateflow diagram editor.

   Tip You can also use one of these methods:

   - Right-click inside the top level of the Stateflow chart and select **Properties** from the drop-down menu.
   - Right-click inside one of the parallel states in the chart and select **Execution Order > Enable user-specified execution order for this chart** from the drop-down menu.

   The properties dialog appears.

2. In the properties dialog, select the check box labeled **User specified state/transition execution order**, as shown:



Enables explicit ordering

Chart Implicit

Name: Implicit
Parent: ParallelStates
Machine: (machine) ParallelStates

Update method: Inherited
Sample Time:

□ Enable C-bit operations

☑ User specified state/transition execution order
□ Export Chart Level Graphical Functions (Make Global)
☑ Use Strong Data Typing with Simulink I/O
□ Execute (enter) Chart At Initialization

Debugger breakpoint: □ On chart entry
Editor: □ Locked

Description:

Document Link:

3 Click **OK**.

If your Stateflow 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, Stateflow automatically assigns priorities based on order of creation (see “How

Explicit Ordering Works" on page 3-31). However you can now explicitly change execution order on a state by state basis, as described in "Setting Execution Order for Parallel States Individually" on page 3-31.

Setting Execution Order for Parallel States Individually. After you enable explicit ordering, 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.

How Explicit Ordering Works

When you enable explicit ordering on a new Stateflow chart — or one that does not yet contain any parallel states — Stateflow automatically assigns priority numbers to parallel states in the order you create them, starting with the next available number within the parent container.

When you first enable explicit ordering on a Stateflow chart that already contains parallel states, the original 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 explicitly override execution order assignments at any time on a state by state basis, as described in "Setting Execution Order for Parallel States Individually" on page 3-31. When you change execution order for a parallel state, Stateflow automatically renumbers the other parallel states to preserve their relative execution order, as described in "Maintaining Order of Parallel States" on page 3-31.

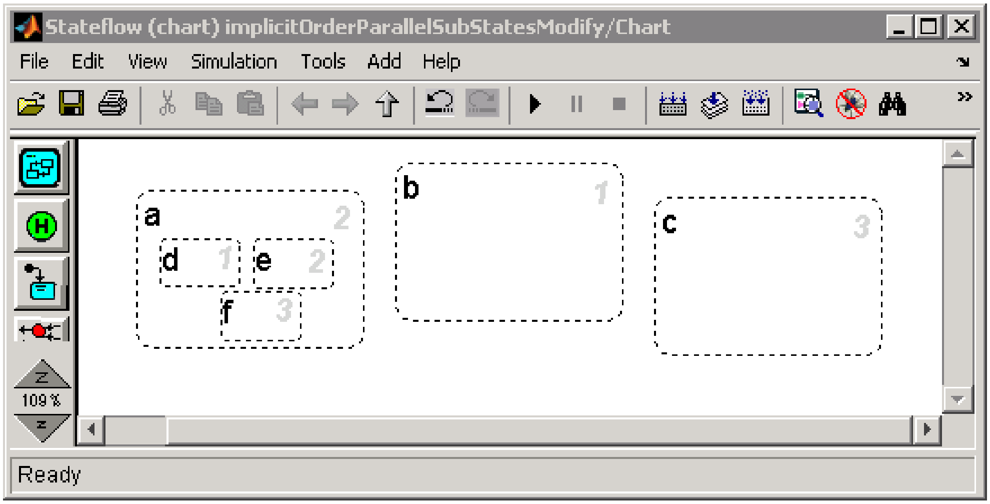
Maintaining Order of Parallel States

Whether you use implicit or explicit ordering, Stateflow attempts to reconcile execution priorities when you remove, renumber, or add parallel states in a chart. In these situations, Stateflow reprioritizes the parallel states to

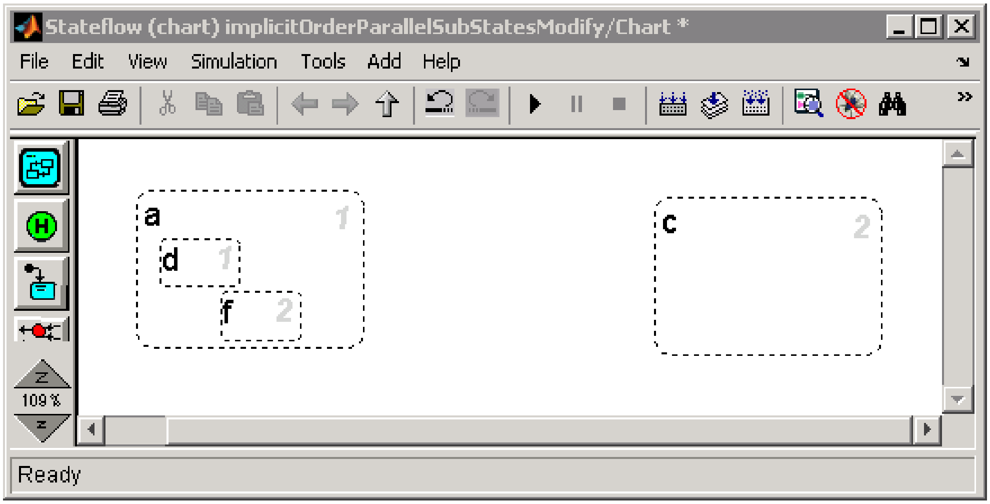
- Fill in gaps in the sequence so that ordering is always contiguous
- Ensure that no two states have the same priority
- Preserve the intended relative priority of execution

Preserving Relative Priorities in Implicit Ordering Mode

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

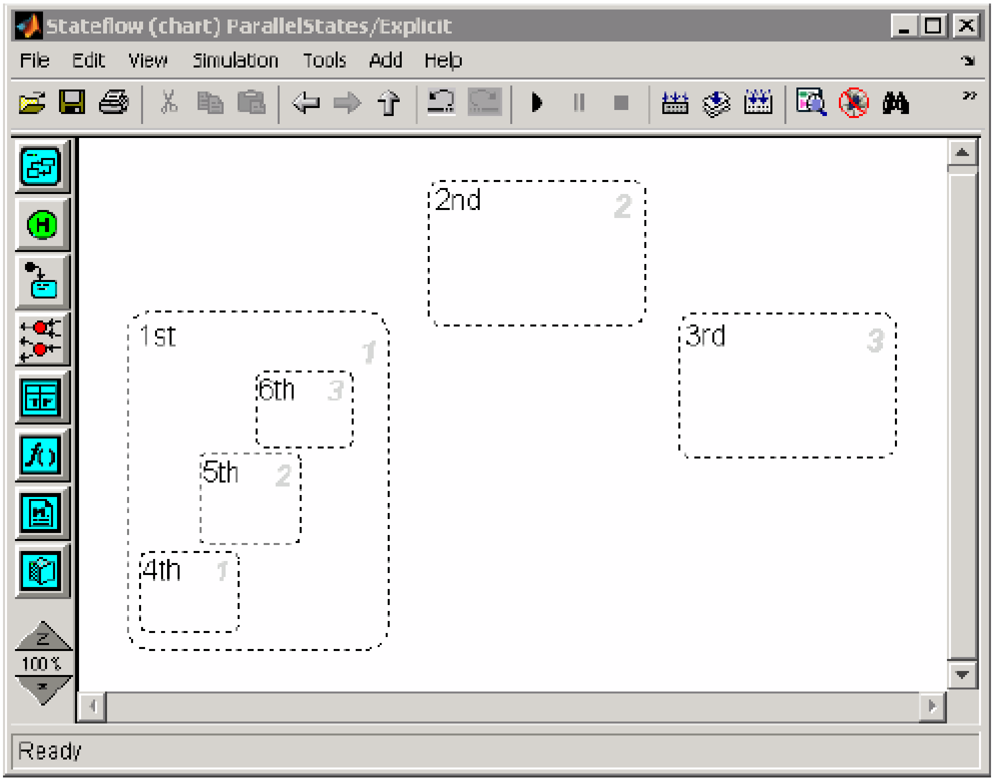

Stateflow (chart) implicitOrderParallelSubStatesModify/Chart
File
Edit
View
Simulation
Tools
Add
Help
a
2
d
1
e
2
f
3
b
1
c
3
109 %
Ready

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

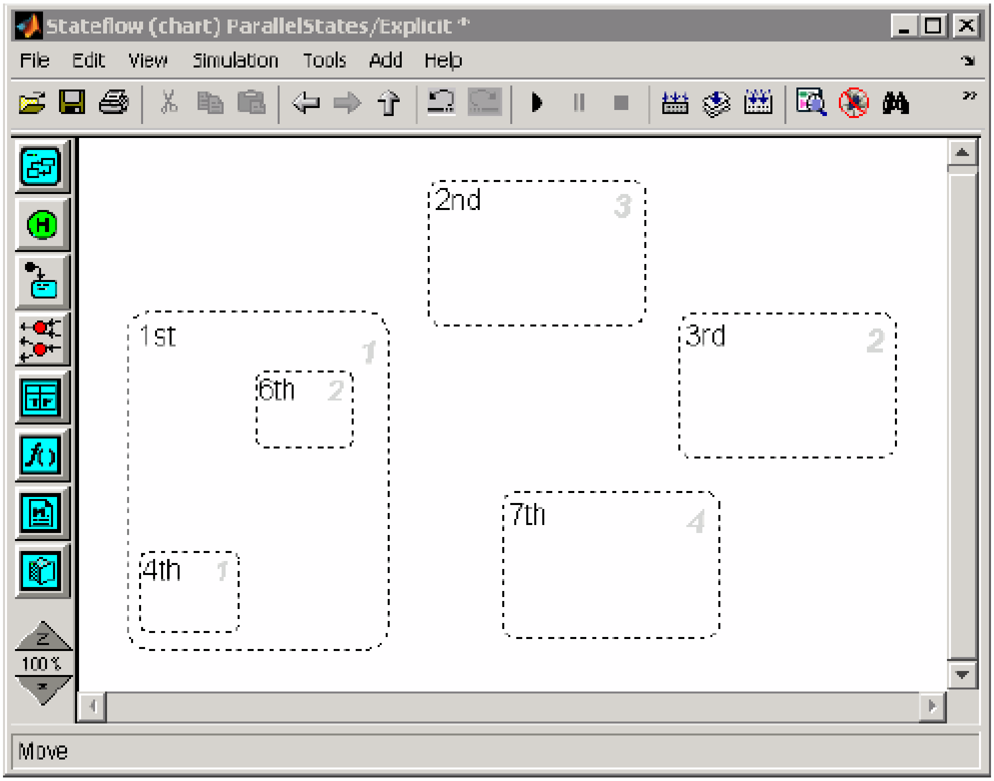

Stateflow (chart) implicitOrderParallelSubStatesModify/Chart *
File
Edit
View
Simulation
Tools
Add
Help
109 %
a
1
d
1
f
2
c
2
Ready

Preserving Relative Priorities in Explicit Ordering Mode

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


Stateflow (chart) ParallelStates/Explicit
File Edit View Simulation Tools Add Help
2nd 2
1st 1
6th 3
5th 2
4th 1
3rd 3
100%
Ready

Note that the ordinal names of the parallel states indicate the order in which they were created. If you change the priority of top-level state `2nd` to `3`, add a top-level state 7th, and remove substate `5th`, Stateflow automatically reprioritizes the parallel states and substates as follows:


Stateflow (chart) ParallelStates/Explicit *
File Edit View Simulation Tools Add Help
2nd 3
1st 1
6th 2
3rd 2
7th 4
4th 1
100%
Move

As you can see, Stateflow preserved the priority explicitly set for top-level state 2nd, but renumbered all other parallel states in the chart to preserve their prior relative order.

How Stateflow Assigns Priorities to Restored States

There are situations in which you need to restore a parallel state after you have removed it from a Stateflow diagram. In implicit order mode, Stateflow reassigns the execution priority based on where the state is restored in the diagram. If the state returns to its original location in the diagram, its original priority is restored.

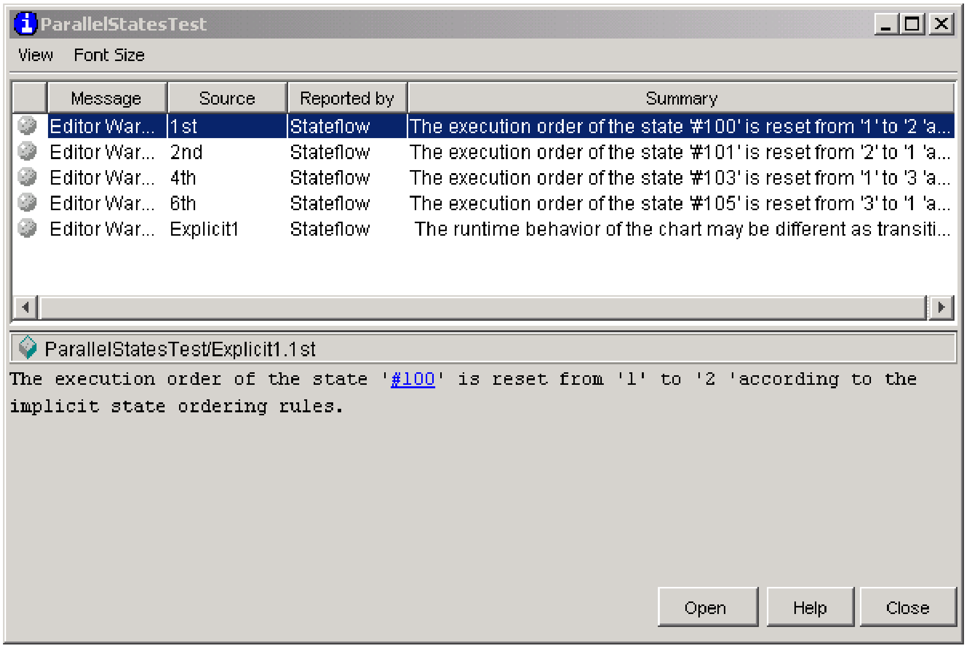
However, in explicit order mode, Stateflow cannot always reinstate the original execution priority to a restored state. It depends on *how* the state is restored, as follows:

If state is removed by:	And restored 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 *and* releasing the mouse button	Dragging it back into the parent state	The original priority is lost. Stateflow 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 *without* 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. Stateflow treats the restored state as the last created and assigns it the lowest execution priority.

Switching Between Implicit and Explicit Ordering

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

Whenever you switch from one ordering mode to another, Stateflow alerts you to changes in execution priorities in the diagnostic viewer. Here is an example of the types of warnings issued after switching from explicit to implicit ordering for parallel states:



Message	Source	Reported by	Summary
Editor War...	1st	Stateflow	The execution order of the state '#100' is reset from '1' to '2 'a...
Editor War...	2nd	Stateflow	The execution order of the state '#101' is reset from '2' to '1 'a...
Editor War...	4th	Stateflow	The execution order of the state '#103' is reset from '1' to '3 'a...
Editor War...	6th	Stateflow	The execution order of the state '#105' is reset from '3' to '1 'a...
Editor War...	Explicit1	Stateflow	The runtime behavior of the chart may be different as transiti...

ParallelStatesTest/Explicit1.1st

```
The execution order of the state '#100' is reset from '1' to '2 'according to the
implicit state ordering rules.
```

Ordering of Parallel States in Boxes and Subcharts

When you group a set of parallel states inside a box, they retain their relative execution order. In addition, Stateflow assigns the box its own priority according to whatever implicit or explicit ordering rules apply. This priority determines when Stateflow 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 according to the prevailing implicit or explicit rules.

Early Return Logic for Event Broadcasts

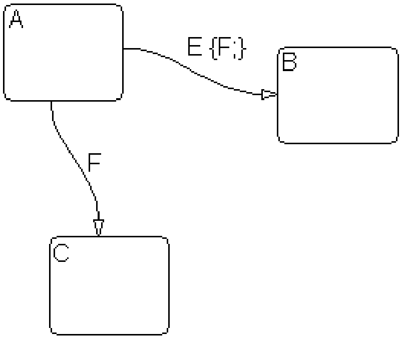
Stateflow employs early return logic in order to satisfy conflicts with proper diagram behavior that result from event broadcasts in state or transition actions.

The following statements are primary axioms of proper Stateflow behavior:

1. Whenever a state is active, its parent should also be active.
2. A state (or chart) with exclusive (OR) decomposition must never have more than one active child.
3. If a parallel state is active, siblings with higher priority (higher graphical position in the Stateflow diagram) must also be active.

Because Stateflow runs on a single thread, when it receives an event it must interrupt its current activity to process all activity resulting from the broadcast event before returning to its original activity. However, activity resulting from an event broadcast can conflict with the current activity, giving rise to the event broadcast. This conflict is resolved through early return logic.

The need for early return logic is best illustrated with an example like the following:



In this example, assume that state `A` is initially active. An event, `E`, occurs and the following behavior is expected:

1. The Stateflow diagram root checks to see if there is a valid transition out of the active state A as a result of event E.

2. A valid transition terminating in state B is found.

3. The condition action of the valid transition executes and broadcasts event F.

   Stateflow must now interrupt the anticipated transition from A to B and take care of any behavior resulting from the broadcast of the event F before continuing with the transition from A to B.

4. The Stateflow diagram root checks to see if there is a valid transition out of the active state A as a result of event F.

5. A valid transition terminating in state C is found.

6. State A executes its `exit` action.

7. State A is marked inactive.

8. State C is marked active.

9. State C executes and completes its `entry` action.

State C is now the only active child of its chart. Stateflow cannot return to the transition from state A to state B and continue after the condition action that broadcast event F (step 3). First, its source, state A, is no longer active. Second, if Stateflow were to allow the transition, state B would become the second active child of the chart. This violates the second Stateflow axiom that a state (or chart) with exclusive (OR) decomposition can never have more than one active child. Consequently, early return logic is employed, and the transition from state A to state B is halted.

In order to maintain primary axiomatic behavior in Stateflow diagrams, Stateflow employs early return logic for event broadcasts in each of its action types as follows:

Action Type	Early Return Logic
Entry	If the state is no longer active at the end of the event broadcast, any remaining steps for entering a state are not performed.
Exit	If the state is no longer active at the end of the event broadcast, any remaining exit actions or steps in transitioning from state to state are not performed.
During	If the state is no longer active at the end of the event broadcast, any remaining steps in the execution of active state are not performed.
Condition	If the origin state of the inner or outer flow graph or parent state of the default flow graph is no longer active at the end of the event broadcast, the remaining steps in the execution of the set of flow graphs are not performed.
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 are not performed.

Semantic Examples

The following is a list of the examples provided to demonstrate the semantics (behavior) of Stateflow charts.

- “Processing the First Event with an Inner Transition to a Connective Junction” on page 3-65
- “Processing a Second Event with an Inner Transition to a Connective Junction” on page 3-67
- “Inner Transition to a History Junction Example” on page 3-68

“Connective Junction Examples” on page 3-70

- “If-Then-Else Decision Construct Example” on page 3-71
- “Self-Loop Transition Example” on page 3-73
- “For Loop Construct Example” on page 3-74
- “Flow Diagram Notation Example” on page 3-75
- “Transitions from a Common Source to Multiple Destinations Example” on page 3-77
- “Transitions from Multiple Sources to a Common Destination Example” on page 3-78
- “Transitions from a Source to a Destination Based on a Common Event Example” on page 3-79

“Event Actions in a Superstate Example” on page 3-82

“Parallel (AND) State Examples” on page 3-84

- “Event Broadcast State Action Example” on page 3-84
- “Event Broadcast Transition Action with a Nested Event Broadcast Example” on page 3-87
- “Event Broadcast Condition Action Example” on page 3-91

Directed Event Broadcasting

- “Directed Event Broadcast Using Send Example” on page 3-96
- “Directed Event Broadcasting Using Qualified Event Names Example” on page 3-98

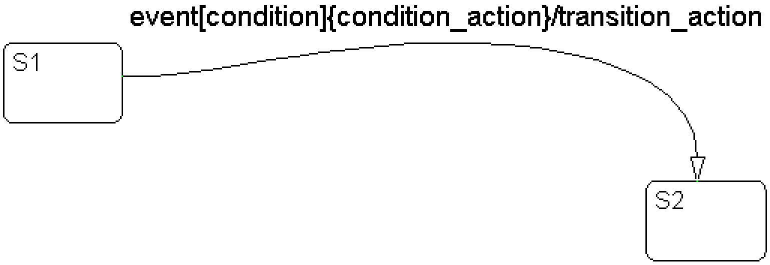
Transitions to and from Exclusive (OR) States Examples

The following examples demonstrate the use of state-to-state transitions to and from exclusive (OR) states in Stateflow:

- "Label Format for a State-to-State Transition Example" on page 3-44 — Shows the semantics for a transition with a general label format.
- "Transitioning from State to State with Events Example" on page 3-45 — Shows the behavior of a simple transition focusing on the implications of whether states are active or inactive for handling events.
- "Transitioning from a Substate to a Substate with Events Example" on page 3-48 — Shows the behavior of a transition from an OR substate to an OR substate.

Label Format for a State-to-State Transition Example

The following example shows the general label format for a transition entering a state:



Execution of the above transition occurs 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 `condition` evaluates to true, the condition action `condition_action` (`{condition_action}`) is executed.

4. If the destination state is determined to be a valid destination, the transition is taken.

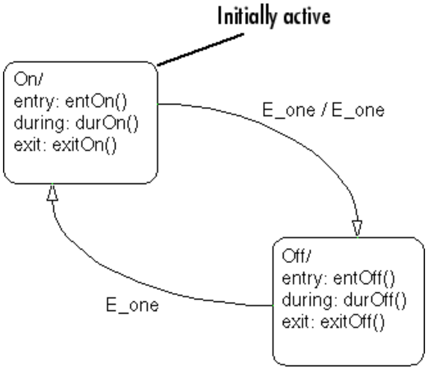
5. State S1 is exited.

6. The transition action `transition_action` is executed when the transition is taken.

7. State S2 is entered.

Transitioning from State to State with Events Example

The following example shows the behavior of a simple transition focusing on the implications of whether states are active or inactive.



Processing of a First Event

Initially the Stateflow diagram is asleep. State `On` and state `Off` are OR states. State `On` is active. Event `E_one` occurs and awakens the Stateflow diagram. Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1. The Stateflow diagram 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. Had a valid transition been possible as a result of the broadcast of E_one, the processing of the first broadcast of E_one would be preempted by the second broadcast of E_one. See "Early Return Logic for Event Broadcasts" on page 3-39.

5 State Off is marked active.

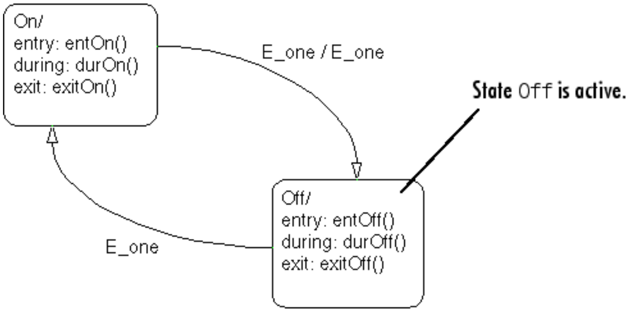
6 State Off entry actions (entOff()) execute and complete.

7 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of the Stateflow diagram associated with event E_one when state On is initially active.

Processing of a Second Event

Using the same example, what happens when the next event, E_one, occurs while state Off is active?



Again, initially the Stateflow diagram is asleep. State Off is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram with the following steps:

1 The Stateflow diagram 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.

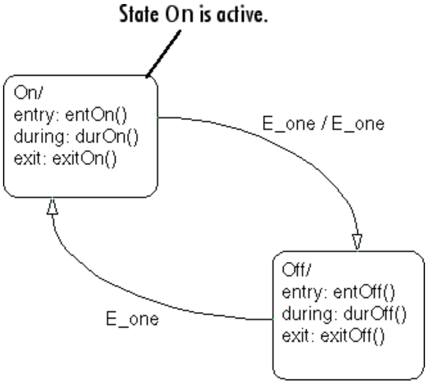
5 State On entry actions (entOn()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of the Stateflow diagram associated with the second event E_one when state Off is initially active.

Processing of 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 Stateflow diagram is asleep and state On is active.

1 Event E_two occurs and awakens the Stateflow diagram.

Event E_two is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram.

2 The Stateflow diagram root checks to see if there is a valid transition as a result of E_two. There is none.

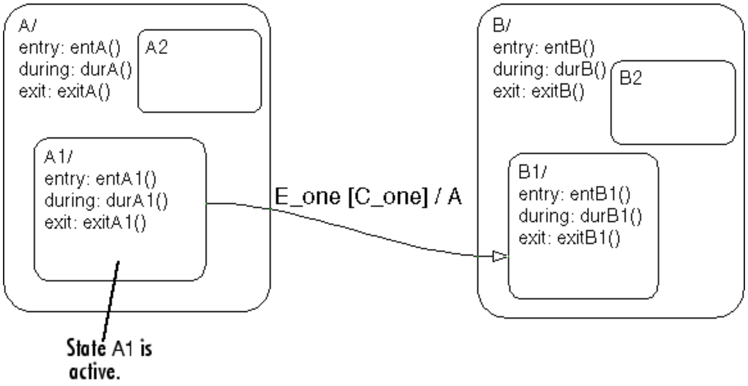
3 State On during actions (durOn()) execute and complete.

4 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of the Stateflow diagram associated with event E_two when state On is initially active.

Transitioning from a Substate to a Substate with Events Example

This example shows the behavior of a transition from an OR substate to an OR substate.



Initially the Stateflow diagram is asleep. State A.A1 is active. Event E_one occurs and awakens the Stateflow diagram. Condition C_one is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

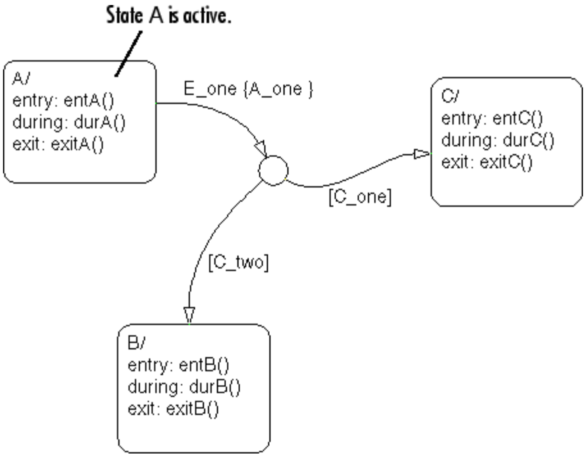
Condition Action Examples

The following examples demonstrate the use of condition actions in Stateflow:

- "Condition Action Example" on page 3-50 — Shows the behavior of a simple condition action in a multiple segment transition.
- "Condition and Transition Actions Example" on page 3-51 — Shows the behavior of a simple condition and transition action specified on a transition from one exclusive (OR) state to another.
- "Condition Actions in For Loop Construct Example" on page 3-53 — Shows the use of a condition action and connective junction to create a for loop construct.
- "Condition Actions to Broadcast Events to Parallel (AND) States Example" on page 3-54 — Shows the use of condition actions used to broadcast events immediately to parallel (AND) states.
- "Cyclic Behavior to Avoid with Condition Actions Example" on page 3-54 — Shows a notation to avoid when using event broadcasts as condition actions because the semantics result in cyclic behavior.

Condition Action Example

This example shows the behavior of a simple condition action in a multiple segment transition.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Conditions C_one and C_two are false. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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.

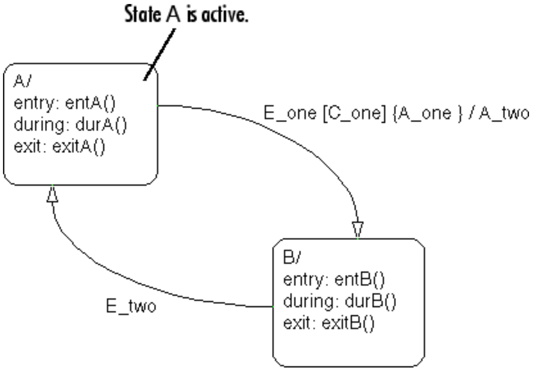
   State A remains active.

4 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one when state A is initially active.

Condition and Transition Actions Example

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 Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Condition C_one is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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.

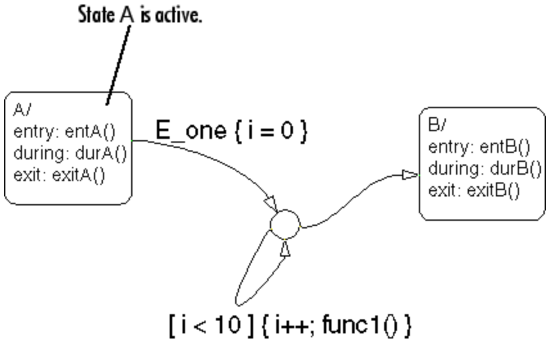
6 State B entry actions (entB()) execute and complete.

7 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one when state A is initially active.

Condition Actions in For Loop Construct Example

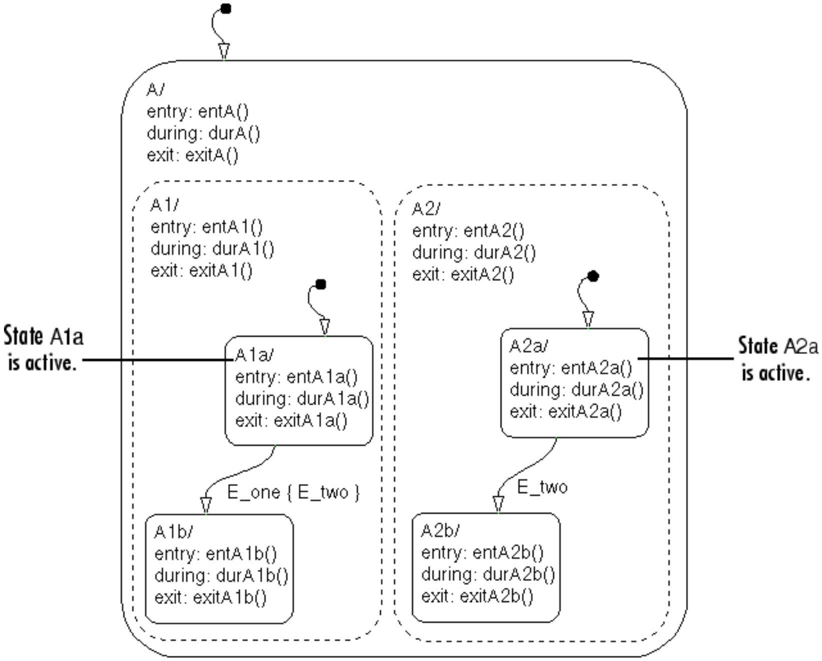
Condition actions and connective junctions are used to design a `for` loop construct. This example shows the use of a condition action and connective junction to create a `for` loop construct.



See “For Loop Construct Example” on page 3-74 to see the behavior of this example.

Condition Actions to Broadcast Events to Parallel (AND) States Example

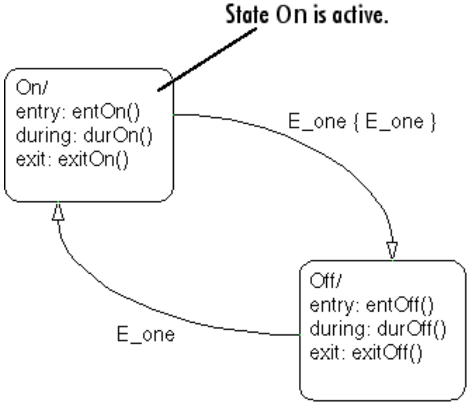
This example shows the use of condition actions used to broadcast events immediately to parallel (AND) states.



See “Event Broadcast Condition Action Example” on page 3-91 to see the behavior of this example.

Cyclic Behavior to Avoid with Condition Actions Example

This example shows a notation to avoid when using event broadcasts as condition actions because the semantics result in cyclic behavior.



Initially the Stateflow diagram is asleep. State On is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 Stateflow diagram a second time.

5 Go to step 1.

Steps 1 to 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.

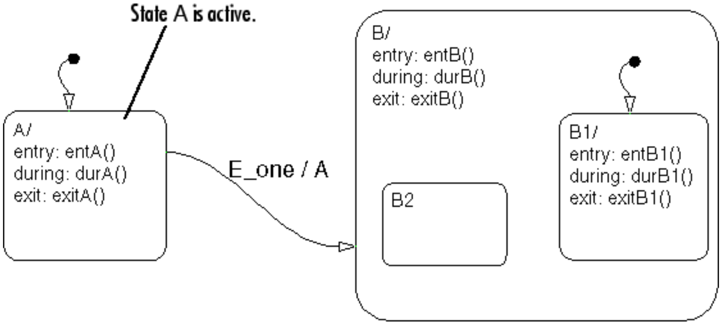
Default Transition Examples

The following examples demonstrate the use of default transitions in Stateflow:

- "Default Transition in Exclusive (OR) Decomposition Example" on page 3-56 — Shows the behavior of a transition from an OR state to a superstate with exclusive (OR) decomposition, where a default transition to a substate is defined.
- "Default Transition to a Junction Example" on page 3-57 — Shows the behavior of a default transition to a connective junction.
- "Default Transition and a History Junction Example" on page 3-58 — Shows the behavior of a superstate with a default transition and a history junction.
- "Labeled Default Transitions Example" on page 3-59 — Shows the use of a default transition with a label.

Default Transition in Exclusive (OR) Decomposition Example

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 Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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.

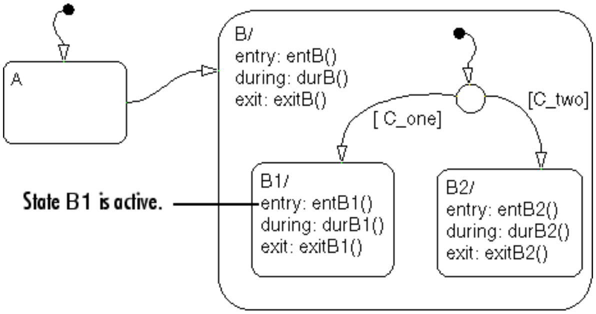
9 State B.B1 entry actions (entB1()) execute and complete.

10 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one when state A is initially active.

Default Transition to a Junction Example

The following example shows the behavior of a default transition to a connective junction.



Initially the Stateflow diagram is asleep. State B.B1 is active. An event occurs and awakens the Stateflow diagram. Condition [C_two] is true. The event is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

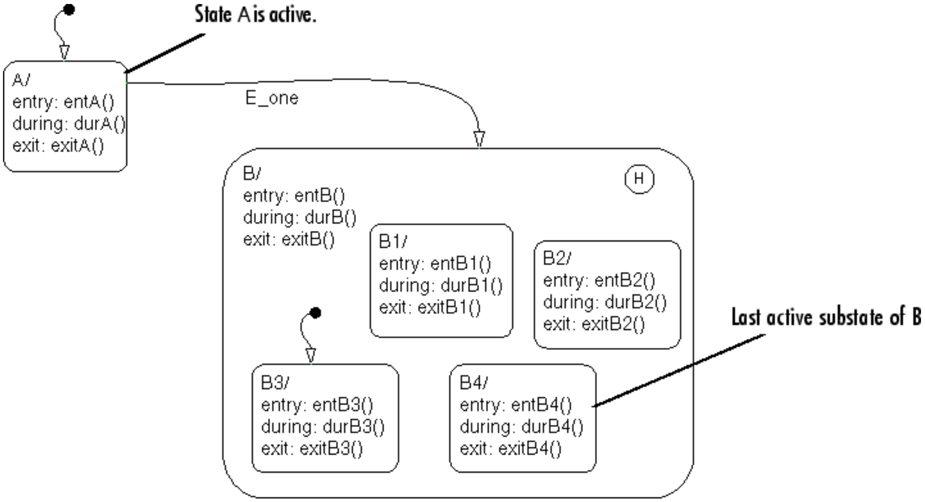
1 State B checks to see if there is a valid transition as a result of any event. There is none.

2 State B1 during actions (durB1()) execute and complete.

This sequence completes the execution of this Stateflow diagram associated with the occurrence of any event.

Default Transition and a History Junction Example

This example shows the behavior of a superstate with a default transition and a history junction.



Initially the Stateflow diagram is asleep. State A is active. There is a history junction and state B4 was the last active substate of superstate B. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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.

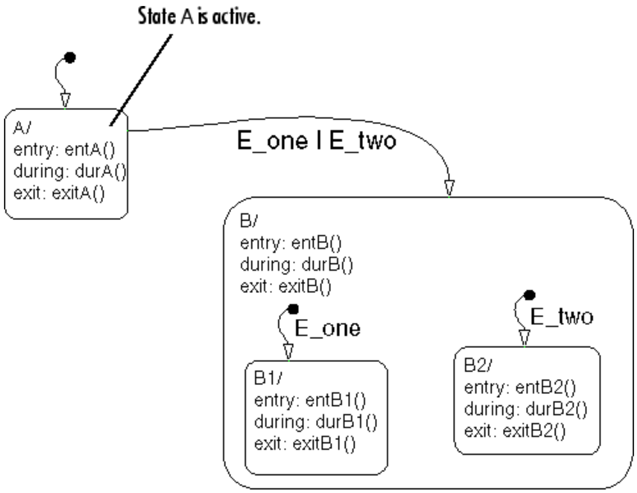
8 State B.B4 entry actions (entB4()) execute and complete.

9 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Labeled Default Transitions Example

This example shows the use of a default transition with a label.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs, awakening the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram with the following steps:

1 The Stateflow diagram 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 Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event `E_one` when state `A` is initially active.

Inner Transition Examples

The following examples demonstrate the use of inner transitions in Stateflow:

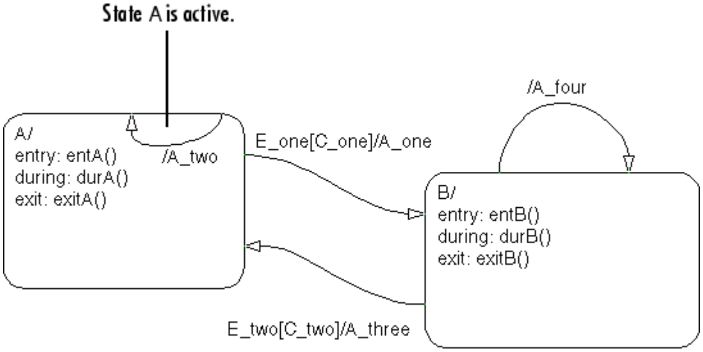
- "Processing Events with an Inner Transition in an Exclusive (OR) State Example" on page 3-62 — Shows what happens when processing repeated events using an inner transition in an exclusive (OR) state.
- "Processing Events with an Inner Transition to a Connective Junction Example" on page 3-65 — Shows the behavior of handling repeated events using an inner transition to a connective junction.
- "Inner Transition to a History Junction Example" on page 3-68 — Shows the behavior of an inner transition to a history junction.

Processing Events with an Inner Transition in an Exclusive (OR) State Example

This example shows what happens when processing three events using an inner transition in an exclusive (OR) state.

Processing One Event in an Exclusive (OR) State

This example shows the behavior of an inner transition.



Initially the Stateflow diagram is asleep. State `A` is active. Event `E_one` occurs and awakens the Stateflow diagram. Condition `[C_one]` is false. Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 Stateflow diagram goes back to sleep, waiting to be awakened by another event.

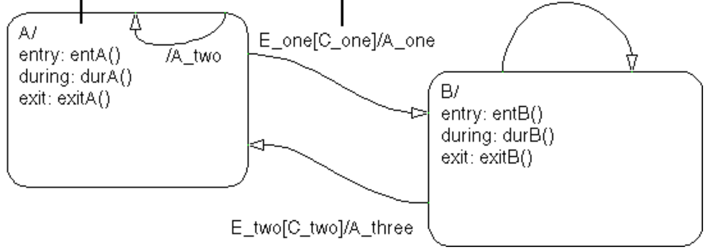
This sequence completes the execution of this Stateflow diagram associated with event E_one.

Processing a Second Event in an Exclusive (OR) State

Using the previous example, this example shows what happens when a second event E_one occurs.

State A still is active.

Condition C_one is true.



Initially the Stateflow diagram is asleep. State A is still active. Event E_one occurs and awakens the Stateflow diagram. Condition [C_one] is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram with the following steps:

1 The Stateflow diagram 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.

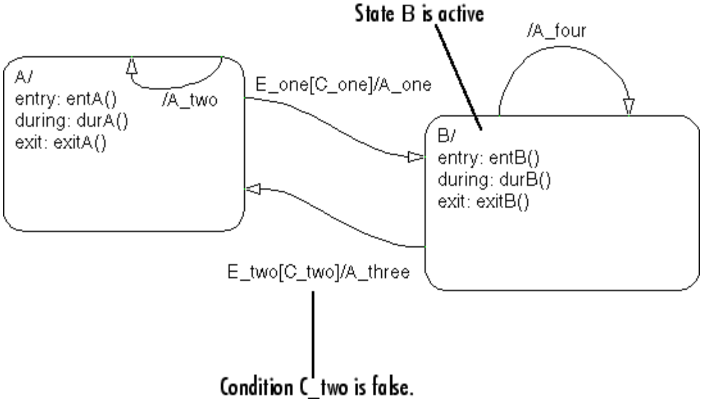
6 State B entry actions (entB()) execute and complete.

7 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Processing a Third Event in an Exclusive (OR) State

Using the previous example, this example shows what happens when a third event, E_two, occurs.



Initially the Stateflow diagram is asleep. State B is now active. Event E_two occurs and awakens the Stateflow diagram. Condition [C_two] is false. Event

E_two is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 Stateflow diagram goes back to sleep, waiting to be awakened by another event.

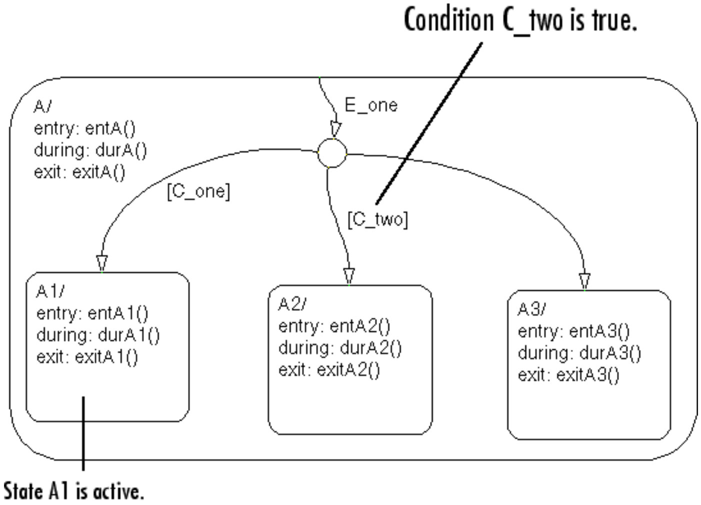
This sequence completes the execution of this Stateflow diagram associated with event E_two. This example shows the difference in behavior between inner and self-loop transitions.

Processing Events with an Inner Transition to a Connective Junction Example

This example shows the behavior of handling repeated events using an inner transition to a connective junction.

Processing 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 an initial event.



Initially the Stateflow diagram is asleep. State A1 is active. Event E_one occurs and awakens the Stateflow diagram. Condition [C_two] is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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. The segments labeled with a condition are evaluated before the unlabeled segment. The evaluation starts from a twelve 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.

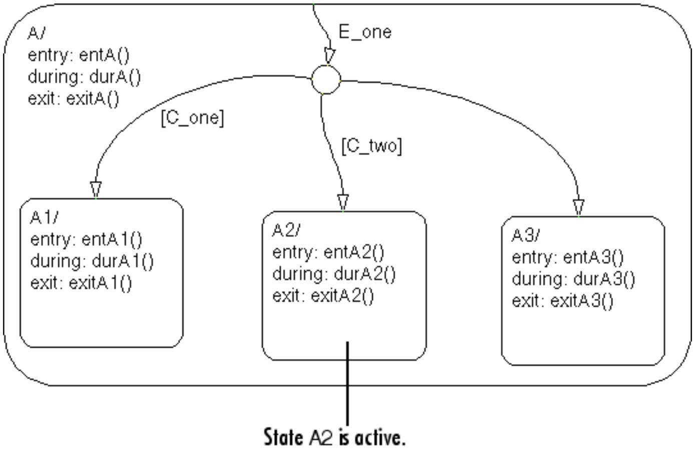
7 State A.A2 entry actions (entA2()) execute and complete.

8 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one when condition C_two is true.

Processing 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.



Initially the Stateflow diagram is asleep. State A2 is active. Event E_one occurs and awakens the Stateflow diagram. Neither [C_one] nor [C_two] is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 segments labeled with a condition are evaluated before the unlabeled segment. The evaluation starts from a twelve o'clock position on the junction and progresses in a clockwise manner. Because neither [C_one] nor [C_two] is true, the unlabeled transition segment is evaluated and is determined to be valid. The full transition from the inner transition to state A.A3 is valid.

4 State A.A2 exit actions (exitA2()) execute and complete.

5 State A.A2 is marked inactive.

6 State A.A3 is marked active.

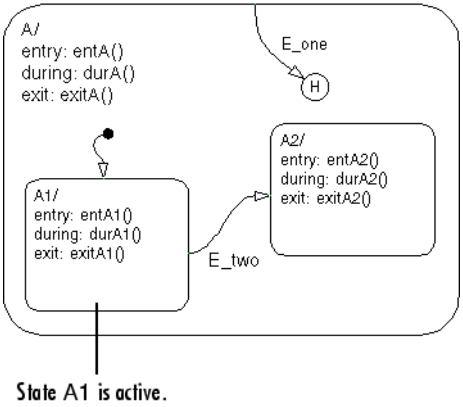
7 State A.A3 entry actions (entA3()) execute and complete.

8 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one when neither [C_one] nor [C_two] is true.

Inner Transition to a History Junction Example

This example shows the behavior of an inner transition to a history junction.



Initially the Stateflow diagram is asleep. State `A.A1` is active. There is history information because superstate `A` is active. Event `E_one` occurs and awakens the Stateflow diagram. Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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. According to the behavior of history junctions, 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 Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event `E_one` when there is an inner transition to a history junction and state `A.A1` is active.

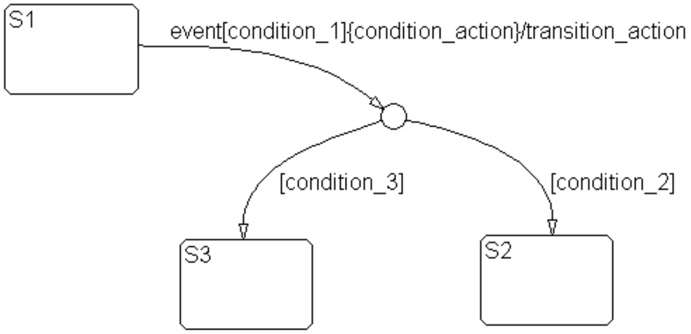
Connective Junction Examples

The following examples demonstrate the use of connective junctions in Stateflow:

- “Label Format for Transition Segments Example” on page 3-70 — Shows the general label format for a transition segment.
- “If-Then-Else Decision Construct Example” on page 3-71 — Shows the behavior of an if-then-else decision construct using a connective junction.
- “Self-Loop Transition Example” on page 3-73 — Shows the behavior of a self-loop transition using a connective junction.
- “For Loop Construct Example” on page 3-74 — Shows the behavior of a for loop using a connective junction.
- “Flow Diagram Notation Example” on page 3-75 — Shows the behavior of a flow notation in a Stateflow diagram.
- “Transitions from a Common Source to Multiple Destinations Example” on page 3-77 — Shows the behavior of transitions from a common source to multiple conditional destinations using a connective junction.
- “Transitions from Multiple Sources to a Common Destination Example” on page 3-78 — Shows the behavior of transitions from multiple sources to a single destination using a connective junction.
- “Transitions from a Source to a Destination Based on a Common Event Example” on page 3-79 — Shows the behavior of transitions from multiple sources to a single destination based on the same event using a connective junction.
- “Backtracking Behavior in Flow Graphs Example” on page 3-80 — Shows the behavior of transitions with junctions that force backtracking behavior in flow graphs.

Label Format for Transition Segments Example

The general label format for a transition segment entering a junction is the same as for transitions entering states, as shown in the following example:



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 (S1 to S2) is found.

5 State S1 is exited (this includes the execution of S1's `exit` action).

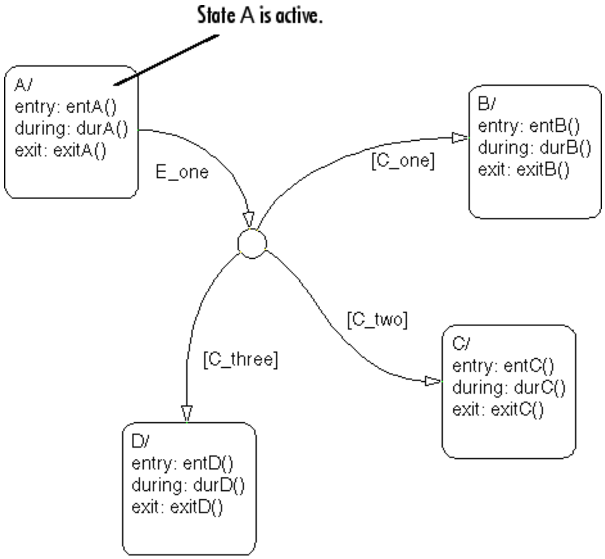
6 The transition action `transition_action` is executed.

7 The completed state-to-state transition (S1 to S2) is taken.

8 State S2 is entered (this includes the execution of S2's `entry` action).

If-Then-Else Decision Construct Example

This example shows the behavior of an `if-then-else` decision construct.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Condition [C_two] is true. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 segments beginning from a twelve 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.

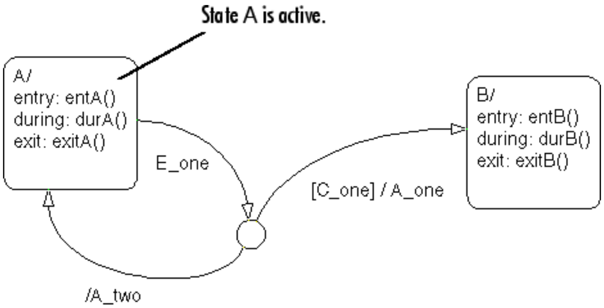
5 State C entry actions (entC()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Self-Loop Transition Example

This example shows the behavior of a self-loop transition using a connective junction.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Condition [C_one] is false. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 labeled with a condition and action 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.

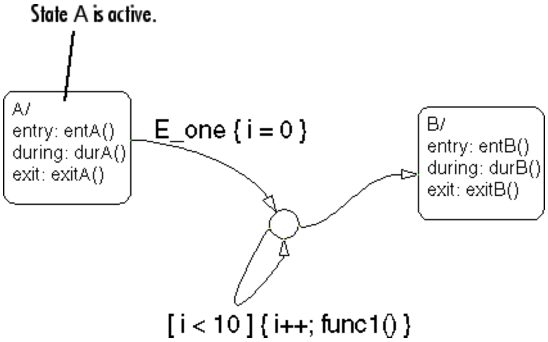
6 State A entry actions (entA()) execute and complete.

7 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

For Loop Construct Example

This example shows the behavior of a for loop using a connective junction.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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, is executed and completed. Of the two transition segments leaving the connective junction, the transition segment that is a self-loop back to the connective junction is evaluated next for validity. That segment takes priority in evaluation because it has a condition specified, whereas the other segment is unlabeled.

2 The condition [i < 10] is evaluated as true. The condition actions i++ and a call to func1 are executed and completed until the condition becomes false. A connective junction is not a final destination; thus the transition destination remains to be determined.

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.

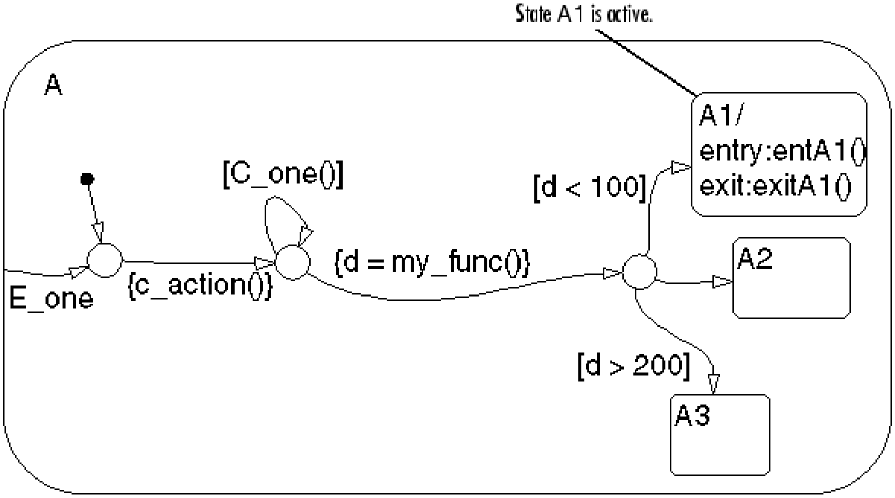
7 State B entry actions (entB()) execute and complete.

8 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Flow Diagram Notation Example

This example shows the behavior of a Stateflow diagram that uses flow notation.



Initially the Stateflow diagram is asleep. State A.A1 is active. The condition [C_one()] is initially true. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1. The Stateflow diagram 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. There is only one outgoing transition and it has a condition action defined. The condition action is executed and completed.

4. The next possible segments are evaluated. There are two outgoing transitions; one is a conditional self-loop transition and the other is an unconditional transition segment. The conditional transition segment takes precedence. The condition [C_one()] is tested and 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()}, is executed and completed. The returned value of d is 84.

6. The next possible transition segment is evaluated. There are three possible outgoing transition segments to consider. Two are conditional; one is unconditional. The segment labeled with the condition [d<100] is evaluated first based on the geometry of the two outgoing conditional transition segments. Because the return 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.

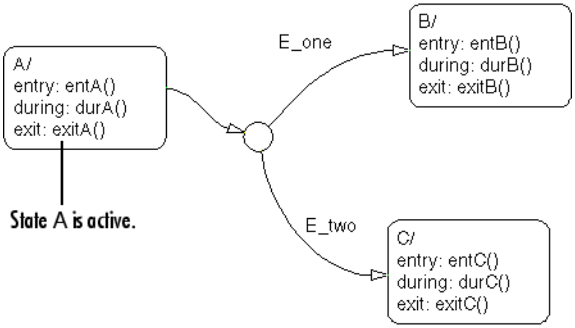
10. State A.A1 entry actions (entA1()) execute and complete.

11 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Transitions from a Common Source to Multiple Destinations Example

This example shows the behavior of transitions from a common source to multiple conditional destinations using a connective junction.



Initially the Stateflow diagram is asleep. State A is active. Event E_two occurs and awakens the Stateflow diagram. Event E_two is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram root checks to see if there is a valid transition as a result of E_two. There is a valid transition segment from state A to the connective junction. Given that the transition segments are equivalently labeled, evaluation begins from a twelve 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.

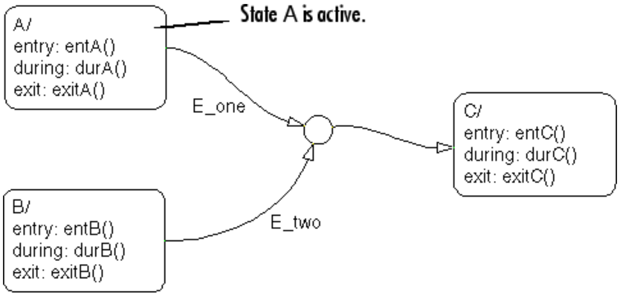
5 State C entry actions (entC()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_two.

Transitions from Multiple Sources to a Common Destination Example

This example shows the behavior of transitions from multiple sources to a single destination using a connective junction.



Initially the Stateflow diagram is asleep. State A is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 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.

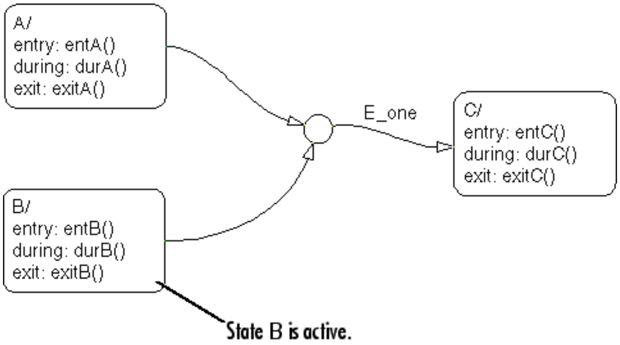
5 State C entry actions (entC()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Transitions from a Source to a Destination Based on a Common Event Example

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 Stateflow diagram is asleep. State B is active. Event E_one occurs and awakens the Stateflow diagram. Event E_one is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram root checks to see if there is a valid transition as a result of E_one. There is a valid transition segment 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.

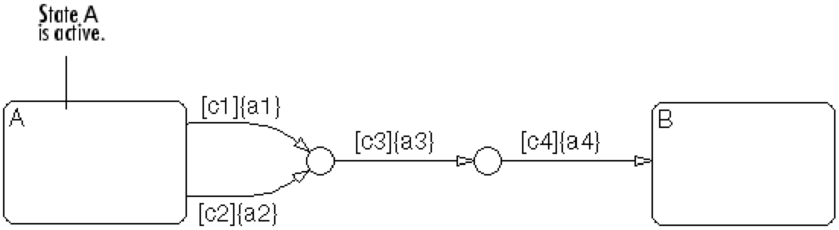
5 State C entry actions (entC()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one.

Backtracking Behavior in Flow Graphs Example

This example shows the behavior of transitions with junctions that force backtracking behavior in flow graphs.



Initially, state A is active and conditions c1, c2, and c3 are true:

1 The Stateflow diagram 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, therefore action a1 is executed.

3 Condition c3 is true, therefore action a3 is executed.

4 Condition c4 is not true, therefore control flow is backtracked to state A.

5 The Stateflow diagram 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.

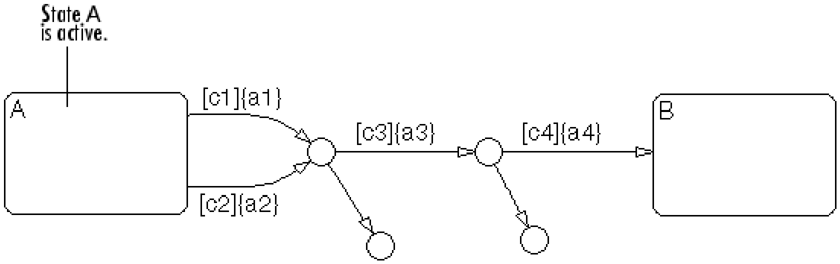
6 Condition c2 is true, therefore action a2 is executed.

7. Condition c3 is true, therefore action a3 is executed.

8. Condition c4 is not true, therefore control flow is backtracked to state A.

9. The Stateflow chart goes to sleep.

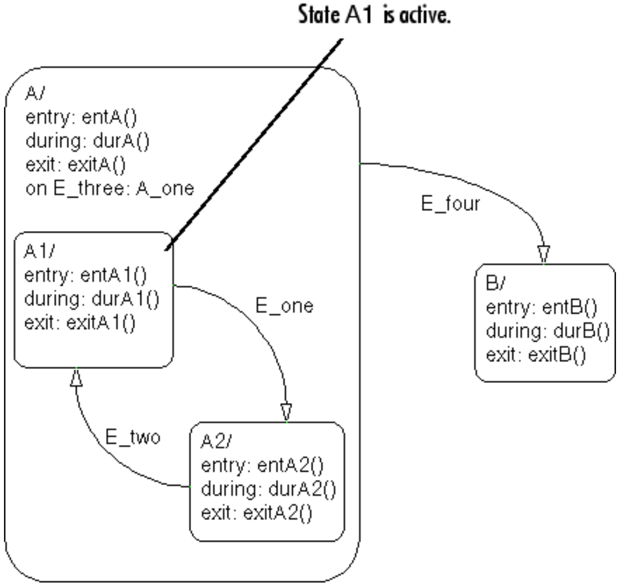
The preceding example shows the unanticipated behavior of executing both actions a1 and a2 and executing action a3 twice. To resolve this problem, consider the following.



In this example, the previous example is amended with two terminating junctions that allow flow to terminate if either c3 or c4 is not true. This leaves state A active without taking any unnecessary actions.

Event Actions in a Superstate Example

The following example demonstrates the use of event actions in a superstate:



Initially the Stateflow diagram is asleep. State A.A1 is active. Event E_three occurs and awakens the Stateflow diagram. Event E_three is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram root checks to see if there is a valid transition as a result of E_three. There is no valid transition.

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. There are no valid transitions.

5 State A1 during actions (durA1()) execute and complete.

6 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event `E_three`.

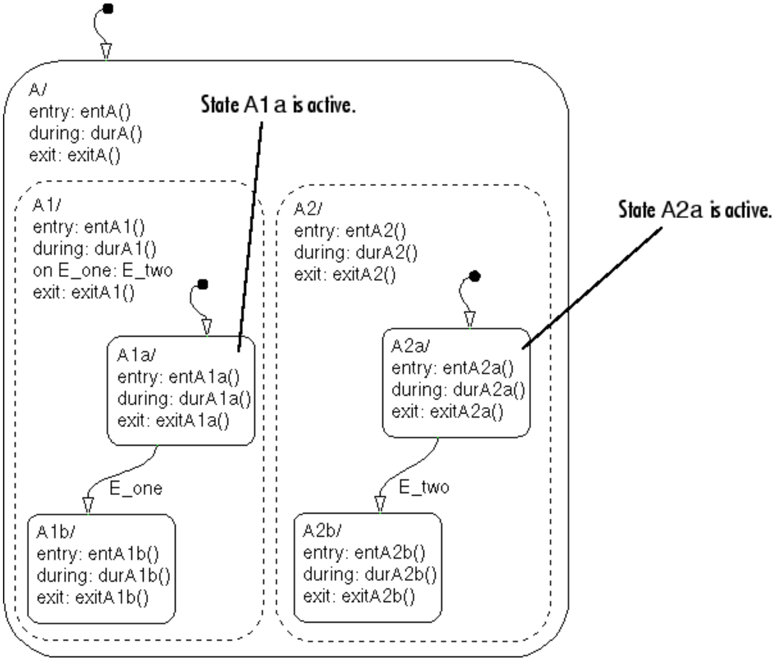
Parallel (AND) State Examples

The following examples demonstrate the use of parallel (AND) states:

- "Event Broadcast State Action Example" on page 3-84 — Shows the behavior of event broadcast actions in parallel states.
- "Event Broadcast Transition Action with a Nested Event Broadcast Example" on page 3-87 — Shows the behavior of an event broadcast transition action that includes a nested event broadcast in a parallel state.
- "Event Broadcast Condition Action Example" on page 3-91 — Shows the behavior of a condition action event broadcast in a parallel (AND) state.

Event Broadcast State Action Example

This example shows the behavior of event broadcast actions in parallel states.



Initially the Stateflow diagram is asleep. Parallel substates `A.A1.A1a` and `A.A2.A2a` are active. Event `E_one` occurs and awakens the Stateflow diagram.

Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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's children are parallel (AND) states. They 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`. `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 Stateflow diagram a second time. The Stateflow diagram 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 checks its children for valid transitions. There are no valid transitions.

   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 `during` actions (`durA1a()`) execute.

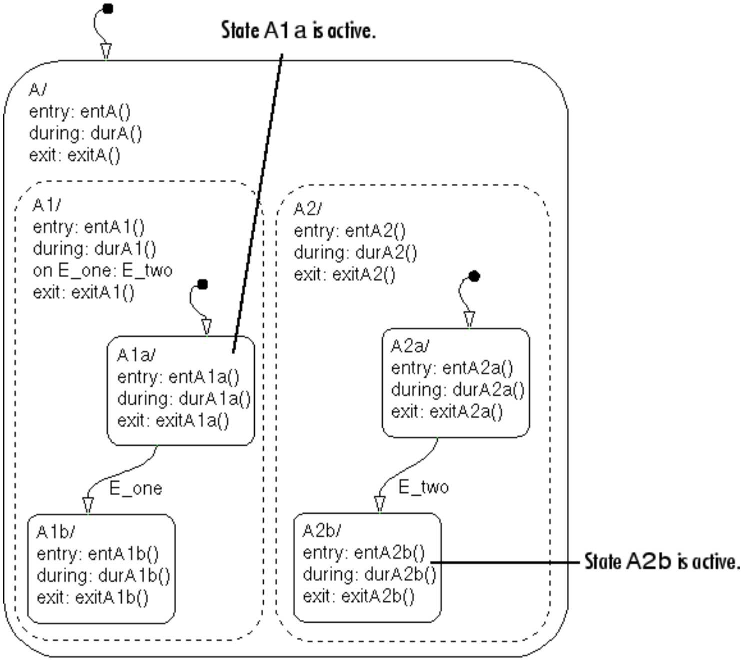
   f State `A.A2` is evaluated. State `A.A2` `during` actions (`durA2()`) execute and complete. State `A.A2` checks for valid transitions. State `A.A2` has a valid transition as a result of `E_two` from state `A.A2.A2a` to state `A.A2.A2b`.

   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. The Stateflow diagram activity now looks like this:



4 State A.A1.A1a executes and completes exit actions (exitA1a).

5 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. There is a valid transition from state A.A1.A1a to state A.A1.A1b.

6 State A.A1.A1a is marked inactive.

7 State A.A1.A1b entry actions (entA1b()) execute and complete.

8 State A.A1.A1b is marked active.

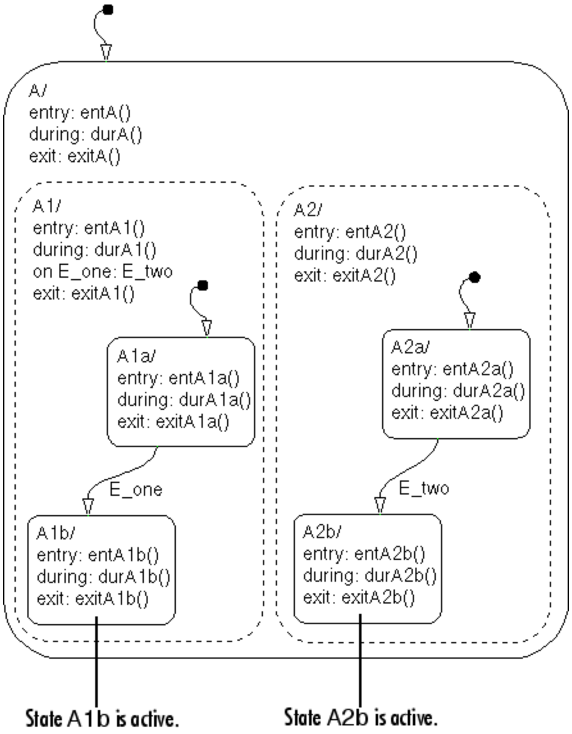
9 Parallel state A.A2 is evaluated next. State A.A2 during actions (durA2()) execute and complete. There are no valid transitions as a result of E_one.

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.

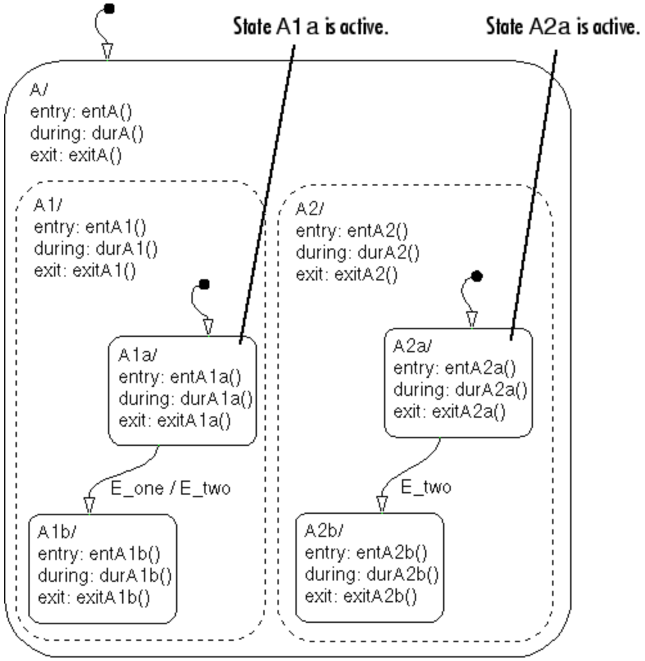
11 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event `E_one` and the `on` event broadcast to a parallel state of event `E_two`. The final Stateflow diagram activity looks like this.



Event Broadcast Transition Action with a Nested Event Broadcast Example

This example shows the behavior of an event broadcast transition action that includes a nested event broadcast in a parallel state.



Start of Event E_one Processing

Initially the Stateflow diagram is asleep. Parallel substates `A.A1.A1a` and `A.A2.A2a` are active. Event `E_one` occurs and awakens the Stateflow diagram. Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1. The Stateflow diagram 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. They are evaluated and executed from left to right and top to bottom. State `A.A1` is evaluated first. State `A.A1during` 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.

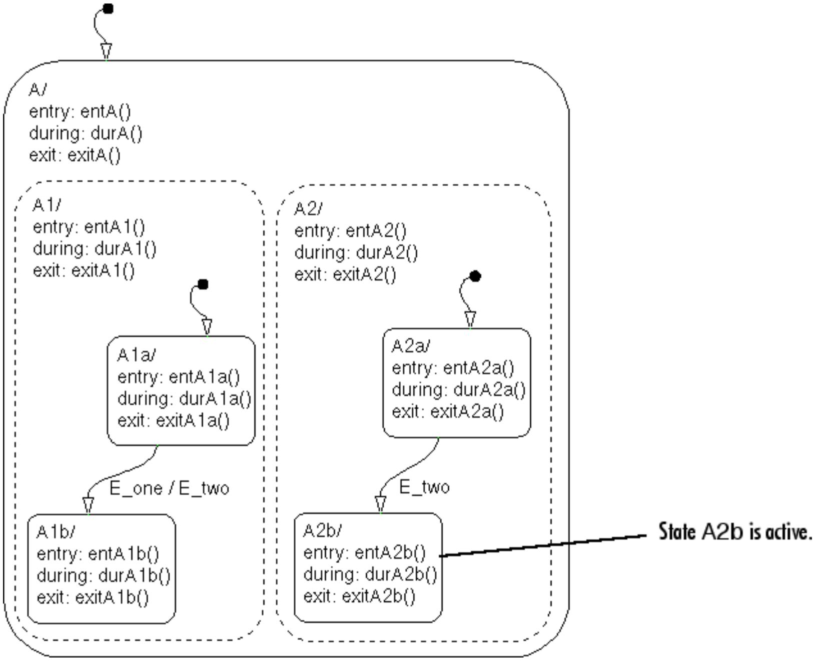
Event E_two Preempts E_one

7 Transition action generating event E_two is executed and completed:

- a The transition from state A1a to state A1b (as a result of event E_one) is now preempted by the broadcast of event E_two.
- b The broadcast of event E_two awakens the Stateflow diagram a second time. The Stateflow diagram root checks to see if there is a valid transition as a result of E_two. There is no valid transition.
- c State A during actions (durA()) execute and complete.
- d State A' s children are evaluated starting with state A.A1. State A.A1during 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_two Processing Ends

The Stateflow diagram activity now looks like this.



Event E_one Processing Resumes

8 State `A.A1.A1b` is marked active.

9 State `A.A1.A1b` entry actions (`entA1b()`) execute and complete.

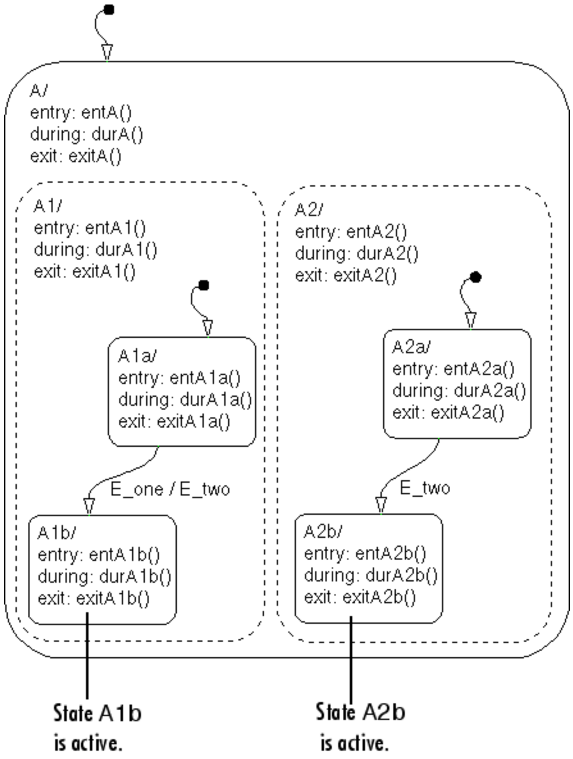
10 Parallel state `A.A2` is evaluated next. State `A.A2` during actions (`durA2()`) execute and complete. There are no valid transitions as a result of `E_one`.

11 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 transition action event broadcast of `E_two`.

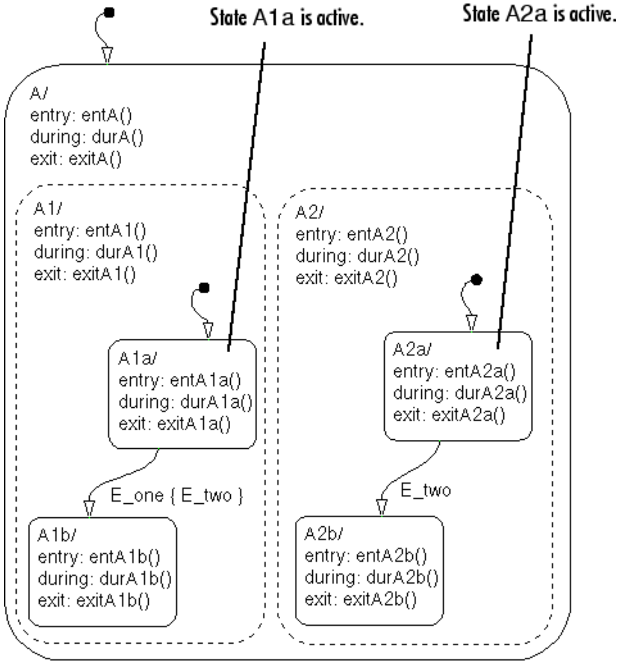
12 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

This sequence completes the execution of this Stateflow diagram associated with event E_one and the transition action event broadcast to a parallel state of event E_two. The final Stateflow diagram activity now looks like this.



Event Broadcast Condition Action Example

This example shows the behavior of a condition action event broadcast in a parallel (AND) state.



Initially the Stateflow diagram is asleep. Parallel substates `A.A1.A1a` and `A.A2.A2a` are active. Event `E_one` occurs and awakens the Stateflow diagram. Event `E_one` is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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. Parallel states are evaluated and executed from top to bottom. In the case of a tie, they are evaluated 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`. There is a valid transition from state `A.A1.A1a` to state `A.A1.A1b`. There is also a valid condition action. The condition action event broadcast of `E_two` is executed and completed. State `A.A1.A1a` is still active:

a The broadcast of event `E_two` awakens the Stateflow diagram a second time. The Stateflow diagram 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.

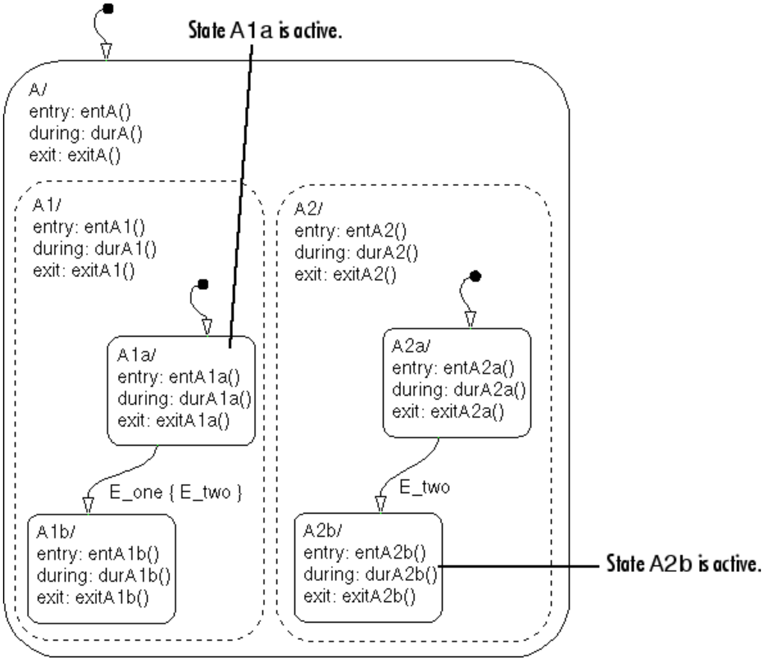
e State `A.A2` is evaluated. State `A.A2` `during` actions (`durA2()`) execute and complete. State `A.A2` checks for valid transitions. State `A.A2` has a valid transition as a result of `E_two` from state `A.A2.A2a` to state `A.A2.A2b`.

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` `entry` actions (`entA1b()`) execute and complete.

8 State `A.A1.A1b` is marked active.

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`.

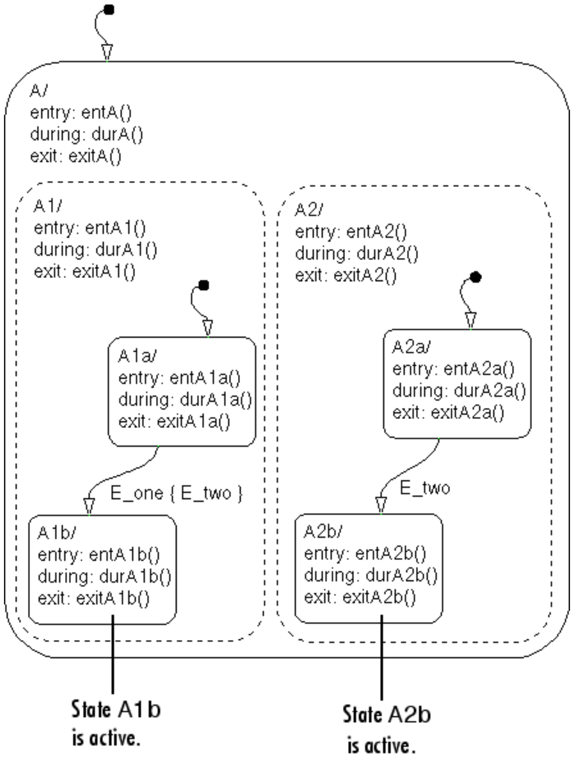
10 State `A.A2.A2b` `during` actions (`durA2b()`) execute and complete.

State `A.A2.A2b` is now active as a result of the processing of the condition action event broadcast of `E_two`.

11 The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

The Stateflow diagram activity now looks like this.

This sequence completes the execution of this Stateflow diagram associated with event `E_one` and the condition action event broadcast to a parallel state of event `E_two`. The final Stateflow diagram activity now looks like this.



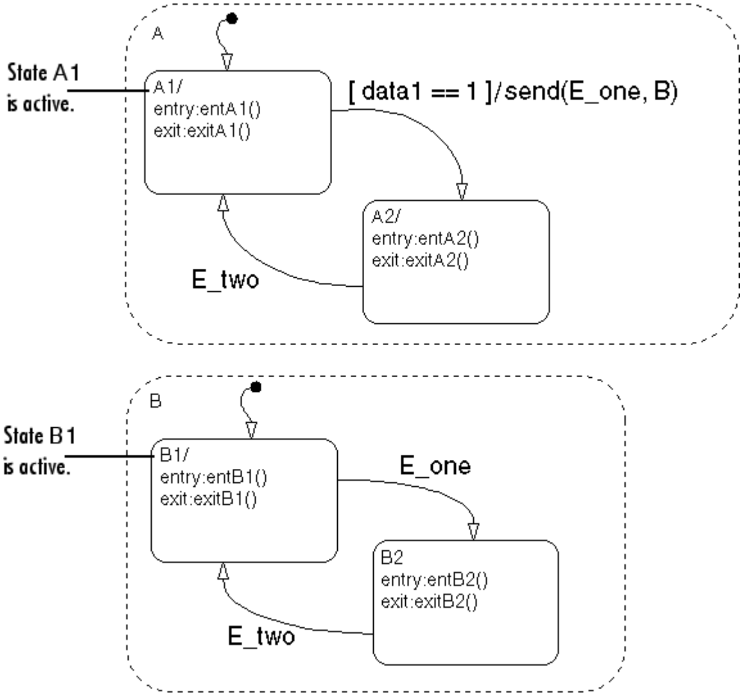
Directed Event Broadcasting Examples

The following examples demonstrate the use of directed event broadcasting:

- "Directed Event Broadcast Using Send Example" on page 3-96 — Shows the behavior of directed event broadcast using the send function in a transition action
- "Directed Event Broadcasting Using Qualified Event Names Example" on page 3-98 — Shows the behavior of directed event broadcast using a qualified event name in a transition action

Directed Event Broadcast Using Send Example

This example shows the behavior of directed event broadcast using the `send(event_name,state_name)` function in a transition action.



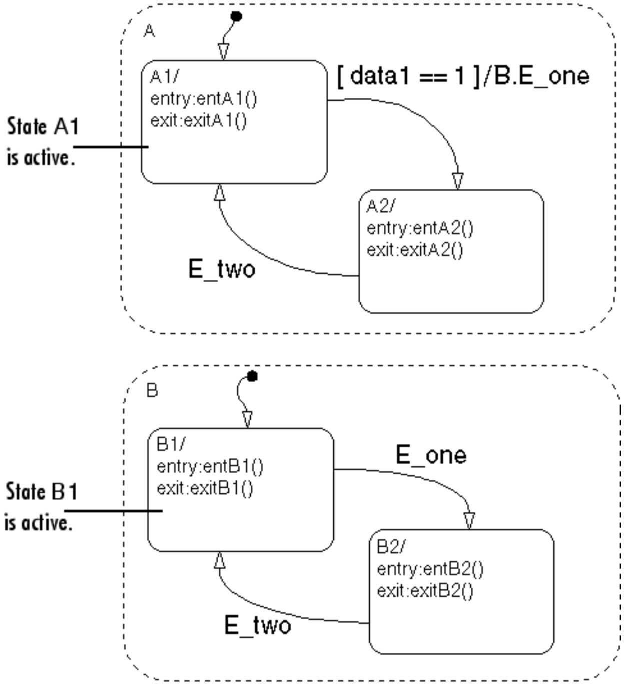
Initially the Stateflow diagram is asleep. Parallel substates A.A1 and B.B1 are active. By definition, this implies that parallel (AND) superstates A and B are active. An event occurs and awakens the Stateflow diagram. The condition [data1==1] is true. The event is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1. The Stateflow diagram 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. State A.A1 exit actions (exitA1()) execute and complete.
4. State A.A1 is marked inactive.
5. The transition action send(E_one,B) is executed and completed:
   a. The broadcast of event E_one awakens state B. (This is a nested event broadcast.) Because state B is active, the directed broadcast is received and state B 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 is marked inactive.
   d. State B.B2 is marked active.
   e. State B.B2 entry actions (entB2()) execute and complete.
6. State A.A2 is marked active.
7. State A.A2 entry actions (entA2()) execute and complete.

This sequence completes the execution of this Stateflow diagram associated with an event broadcast and the directed event broadcast to a parallel state of event E_one.

Directed Event Broadcasting Using Qualified Event Names Example

This example shows the behavior of directed event broadcast using a qualified event name in a transition action.



Initially the Stateflow diagram is asleep. Parallel substates A.A1 and B.B1 are active. By definition, this implies that parallel (AND) superstates A and B are active. An event occurs and awakens the Stateflow diagram. The condition [data1==1] is true. The event is processed from the root of the Stateflow diagram down through the hierarchy of the Stateflow diagram:

1 The Stateflow diagram 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 State A.A1 exit actions (exitA1()) execute and complete.

4 State A.A1 is marked inactive.

5 The transition action, a qualified event broadcast of event E_one to state B (represented by the notation B.E_one), is executed and completed:

   a The broadcast of event E_one awakens state B. (This is a nested event broadcast.) Because state B is active, the directed broadcast is received and state B 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 is marked inactive.

   d State B.B2 is marked active.

   e State B.B2 entry actions (entB2()) execute and complete.

6 State A.A2 is marked active.

7 State A.A2 entry actions (entA2()) execute and complete.

This sequence completes the execution of this Stateflow diagram associated with an event broadcast using a qualified event name to a parallel state.

4

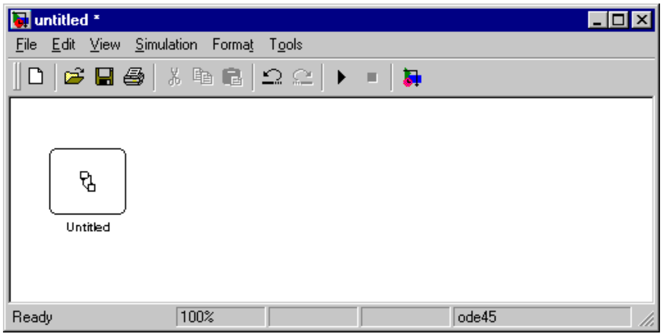
Creating Stateflow Chart Diagrams

This chapter takes you through the steps of creating graphical Stateflow objects in the Stateflow diagram editor. It includes the following sections:

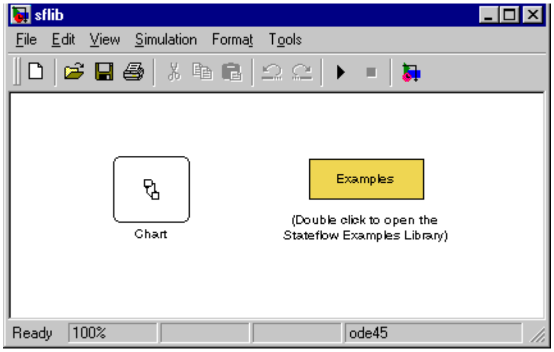
Creating a Stateflow Chart

Charts contain a Stateflow diagram that you build with Stateflow objects. You create charts by adding them to a Simulink system. Create a Stateflow chart in a Simulink system with the following steps:

1 Enter `sfnew` or `stateflow` at the MATLAB command prompt to create a new empty model with a Stateflow chart.



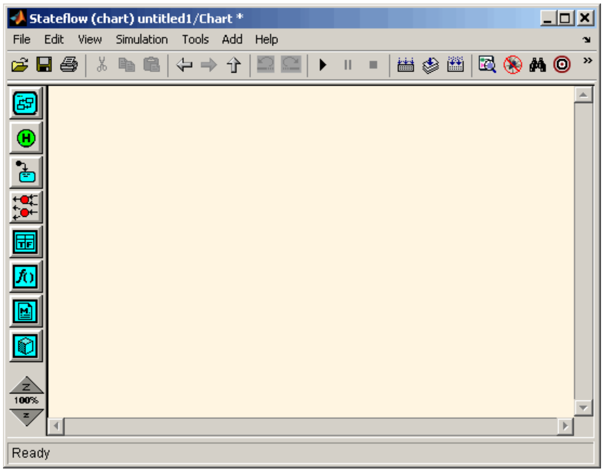
The `stateflow` command also displays the Stateflow block library.


sflib
File Edit View Simulation Format Tools
Chart
Examples
(Double click to open the
Stateflow Examples Library)
Ready
100%
ode45

You can drag and drop additional charts in your Simulink system from this library in case you want to create multiple charts in your model. You can also drag and drop new charts into existing systems from the Stateflow library in the Simulink Library browser. For information on creating your own chart libraries, see “Creating Chart Libraries” on page 10-29.

2 Open the chart by double-clicking the Chart block.

Stateflow opens the empty chart in a Stateflow editor window.


Stateflow (chart) untitled1/Chart *
File Edit View Simulation Tools Add Help
100%
Ready

3 Open the Chart properties dialog box.

See “Setting Properties for Individual Charts” on page 10-6.

4 In the Chart properties dialog box, select a chart type from the drop-down menu in the **State Machine Type** field:

Type	Description
Classic	The default machine type. Provides the full set of Stateflow semantics (see Chapter 3, “Stateflow Semantics”).
Mealy	Machine type in which output is a function of inputs *and* state.
Moore	Machine type in which output is a function *only* of state.

Mealy and Moore charts use a subset of Stateflow semantics. For more information, see Chapter 5, “Building Mealy and Moore Charts in Stateflow”.

5 In the Chart properties dialog box, specify an update method for the chart in the **Update Method** field.

This value determines when and how often the chart is called during the execution of the Simulink model.

6 Use the Stateflow editor to draw a Stateflow chart.

See “Using the Stateflow Editor” on page 4-27 and the remaining sections in this chapter for more information on how to draw Stateflow diagrams.

7 Interface the chart to other blocks in your Stateflow model, using events and data.

See Chapter 7, “Defining Events and Data” and Chapter 10, “Defining Interfaces to Simulink and MATLAB” for more information.

8 Rename and save the model chart by selecting **Save Model As** from the Stateflow editor menu or **Save As** from the Simulink menu.

Note Trying to save a model with more than 25 characters produces an error. Loading a model with more than 25 characters produces a warning.

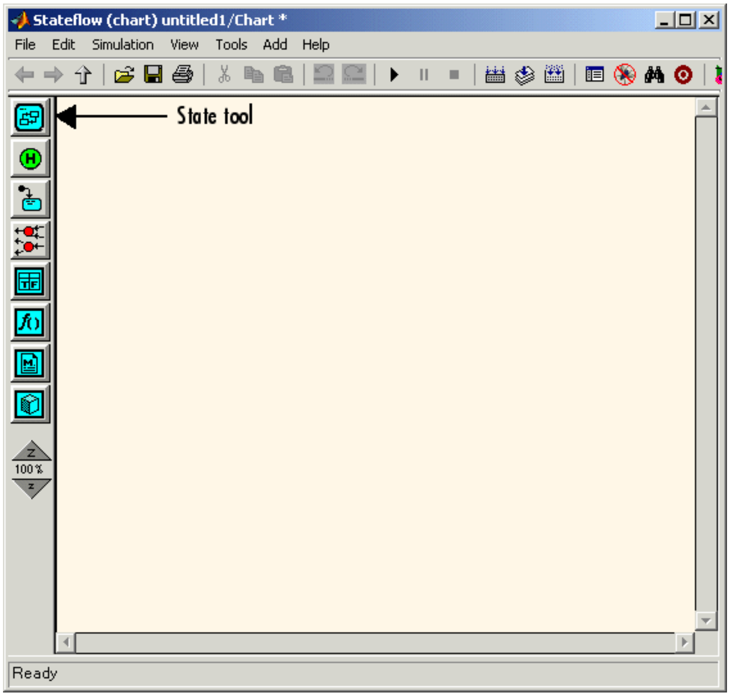
Creating States in Stateflow Charts

Stateflow charts react to events by changing states, which are modes of a chart. The following topics describe how to create and specify a state in a Stateflow chart:

- "Creating a State" on page 4-5
- "Moving and Resizing States" on page 4-7
- "Creating Substates and Superstates" on page 4-7
- "Grouping States" on page 4-8
- "Specifying Substate Decomposition" on page 4-8
- "Specifying Activation Order for Parallel States" on page 4-9
- "Changing State Properties" on page 4-9
- "Labeling States" on page 4-11
- "Outputting State Activity to Simulink" on page 4-14

Creating a State

You create states by drawing them in the Stateflow diagram editor for a particular Stateflow chart (block). The following is a depiction of the Stateflow diagram editor:


Stateflow (chart) untitled1/Chart *
File Edit Simulation View Tools Add Help
State tool
100%
Ready

1 Select the State tool.

2 Move the mouse cursor into the drawing area.

In the drawing area, the mouse cursor 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 “Labeling States” on page 4-11 for more detail.

To delete a state, click it to select it and choose **Cut** (**Ctrl+X**) from the **Edit** or any shortcut menu or press the **Delete** key.

Moving and Resizing 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 the cursor over a corner of the state.

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

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

Creating 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. Stateflow creates the substate in the specified parent state. You can nest states in this way to any depth. To change a substate’s parentage, drag it from its current parent in the state diagram 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 “Using Subcharts to Extend Charts” on page 6-6 for details.

Grouping States

Grouping a state causes Stateflow to treat the state and its contents as a graphical unit. This simplifies editing a state diagram. For example, moving a grouped state moves all its substates as well.

To group a state, double-click the state or its border.

Stateflow thickens the grouped state's border and grays its contents to indicate that it is grouped.

You can also group a state by right-clicking it and then selecting **Make Contents** and then **Grouped** from the resulting shortcut menu.

You must ungroup a superstate to select objects within the superstate. To ungroup a state, double-click it or its border or select **Ungrouped** from the **Make Contents** shortcut menu.

Specifying 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 is said to have parallel (AND) decomposition. A state in which only one substate is active when it is active is said to have 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 shortcut menu, and choose either **Parallel (AND)** or **Exclusive (OR)** from the menu.

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

The appearance of a superstate's substates indicates the superstate's decomposition. 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.

Specifying Activation Order for Parallel States

You specify the activation order of parallel states by arranging them from top to bottom and left to right in the state diagram. Stateflow activates the states in the order in which you arrange them. In particular, a top-level parallel state activates before all the states whose top edges reside at a lower level in the state diagram. A top-level parallel state also activates before any other state that resides to the right of it at the same vertical level in the diagram. The same top to bottom, left to right activation order applies to parallel substates of a state.

Note Stateflow displays the activation order of a parallel state in its upper right corner.

Changing State Properties

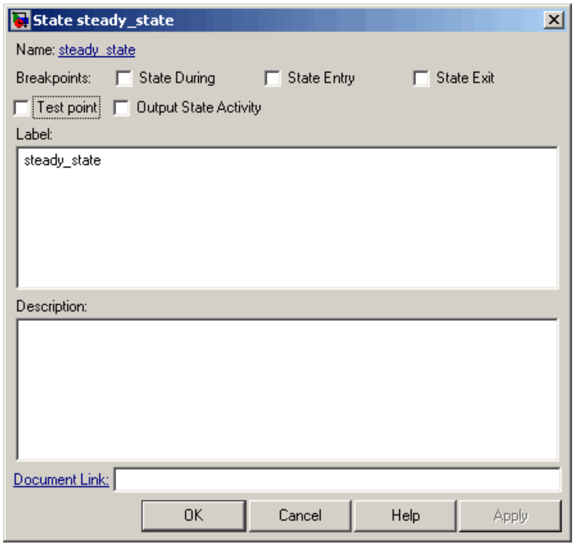
Use the **State** dialog box to view and change the properties for a state. To access the **State** dialog for a particular state, do the following:

1. Right-click the state.

   A shortcut pop-up menu appears.

2. Choose **Properties** from the shortcut menu.

   Stateflow displays the **State** dialog for the state as shown.



State steady_state

Name: steady_state

Breakpoints: □ State During □ State Entry □ State Exit

□ Test point □ Output State Activity

Label:

steady_state

Description:

Document Link:

The **State** dialog contains the following properties for a state:

Field	Description
Name	Stateflow diagram name; read-only; click this hypertext link to bring the state to the foreground.
Debugger breakpoints	Click the check boxes to set debugging breakpoints on the execution of state `entry`, `during`, or `exit` actions during simulation. See Chapter 15, "Debugging and Testing" for more information.
Test point	Select this check box to set the state as a Stateflow 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 "Monitoring Stateflow Test Points" on page 15-32 in the online Stateflow documentation.
Output State Activity	Select this check box to cause Stateflow to output the activity status of this state to Simulink via a data output port on the Chart block containing the state. See "Outputting State Activity to Simulink" on page 4-14 for more information.

Field	Description
Label	The label for the state. This includes the name of the state and its associated actions. See the section titled "Labeling States" on page 4-11 for detailed information.
Description	Textual description/comment.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit /spec/data/speed.txt`.

3 After making changes, select one of the following:

- **Apply** to save the changes and keep the **State** dialog open.
- **Revert** to return to the previous settings
- **Close** to save the changes and close the dialog box
- **Help** to display the Stateflow documentation in an HTML browser window.

Labeling 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_name:on event_name actions
```

The italicized entries in this format have the following meanings:

Keyword	Entry	Description
NA	*name*	A unique reference to the state with optional slash
`entry` or `en`	*entry actions*	Actions executed when a particular state is entered as the result of a transition taken to that state
`during` or `du`	*during actions*	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`	*exit actions*	Actions executed when a state is exited as the result of a transition taken away from the state
bind	*events* or *data*	Binds the specified events or data to this state. Bound data can only be changed 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`	*event_name* and *on event_name actions*	A specified event and Actions executed when a state is active and the specified event *event_name* occurs See "Adding Events" on page 7-4 for information on defining and using events.

Entering the Name

Initially, a state's label is empty. Stateflow indicates this by displaying a ? in the state's label position (upper left corner). Begin the 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.

If you are finished labeling the state, click outside of the state. Otherwise, continue entering actions. To reedit the label, simply click the label text near the character position you want to edit.

Entering Actions

After entering the name of the state in the state's 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, us 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, us a comma or a semicolon.
- **During 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, us 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, us a comma or a semicolon.
- **On <event_name> Actions** — begin with the keyword `on`, followed by a space and the name of an event, 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 event_name` blocks in the state's label, each specifying the action for a particular event or set of events, for example:

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

Note The execution of the actions you enter for a state is dependent only on their action type, and not on the order in which you enter them in the label.

You can also edit the state's label through the properties dialog for the state. See "Changing State Properties" on page 4-9.

Outputting State Activity to Simulink

Stateflow allows a chart to output the activity of its states to Simulink via a data port on the state's Chart block. To enable output of a particular state's activity, first name the state (see "Entering the Name" on page 4-12), if unnamed, then select the **Output State Activity** check box on the state's property dialog (see "Changing State Properties" on page 4-9). Stateflow creates a data output port on the Chart block containing the state. The port has the same name as the state. Stateflow also adds a corresponding data object of type State to the Stateflow data dictionary. During simulation of a model, the port outputs 1 at each time step in which the state is active; 0, otherwise. Attaching a scope to the port allows you to monitor a state's activity visually during the simulation. See "Sharing Input and Output Data with Simulink" on page 7-46 for more information.

Note If a chart has multiple states with the same name, only one of those states can output activity data. If you check the `Output State Activity` property for more than one state with the same name, Stateflow outputs data only from the first state whose `Output State Activity` property you specified.

Creating Transitions in Stateflow Charts

Charts change active states using pathways called transitions. The following topics describe how to create, move, change, and specify properties for Stateflow transitions:

Creating a Transition

Use the following procedure for creating transitions between states and junctions:

1. Place the cursor on or close to the border of a source state or junction.

   The cursor 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.

   Notice that the source of the transition sticks to the initial source point for the transition.

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.
- Newly created transitions have smart behavior. See "Setting Smart Behavior in Transitions" on page 6-19.

To delete a transition, select it and choose **Ctrl+X** or **Cut** from the **Edit** menu, or press the **Delete** key.

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

- "Creating Self-Loop Transitions" on page 4-20
- "Creating Default Transitions" on page 4-21

Creating Straight Transitions

While creating a transition, notice that the source of the transition sticks to the initial source point. This often results in a curved transition. To create a perfectly straight transition, while clicking and dragging from one state to another, do one of the following:

- Press the **S** key (works on all platforms).
- Right-click the mouse (works on *most* platforms).

Either of these actions straightens the transition perpendicular to the transition's source state or junction surface, if possible, and allows the transition source point to slide to maintain straightness. For states, if the cursor is out of range of perpendicularity with the source state, the transition is unaffected.

Labeling Transitions

Transition labels contain Stateflow action language that accompanies the execution of a transition. Creating and editing transition labels is described in the following topics:

- “Editing Transition Labels” on page 4-17
- “Transition Label Format” on page 4-17

For more information on transition concepts, see “Transition Label Notation” on page 2-15.

For more information on transition label contents, see Chapter 8, “Using Actions in Stateflow”.

Editing Transition Labels

Label unlabeled transitions as follows:

1. Select (left-click) the transition.

   The transition turns 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.

   An editing cursor appears. You are now free to 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 [condition]{condition_action}/transition_action
```

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

Label Field	Description
`event`	Event that causes the transition to be evaluated.
`condition`	Defines what, if anything, has to be true for the condition action and transition to take place.
`condition_action`	If the condition is true, the action specified executes and completes.
`transition_action`	This action executes after the source state for the transition is exited but before the destination state is entered.

Transitions do not have to have labels. You can specify some, all, or none of the parts of the label. Valid transition labels are defined by the following:

- 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

Moving Transitions

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

- "Bowing the Transition Line" on page 4-19
- "Moving Transition Attach Points" on page 4-19
- "Moving Transition Labels" on page 4-19

In addition, transitions move along with the movements of states and junctions. See "Setting Smart Behavior in Transitions" on page 6-19 for a description of *smart* and *nonsmart* transition behavior.

Bowing the Transition Line

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

1. Place the cursor on the transition at any point along the transition except the arrow or attach points.
2. Click and drag the mouse 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.

Moving Transition Attach Points

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

1. Place the cursor over an attach point until it changes to a small circle.
2. Click and drag the mouse 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.

Moving Transition Labels

You can move transition labels to make the Stateflow diagram 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 the mouse on an empty location in the diagram editor to deselect the label.

Changing 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 from the **Transition** shortcut menu:

1. Select the transitions whose arrowhead size you want to change.
2. Place the cursor over a selected transition and right-click to display the shortcut menu.

   A menu of arrowhead sizes appears.
3. Select an arrowhead size from the menu.

To adjust arrowhead size from the **Junction** shortcut menu:

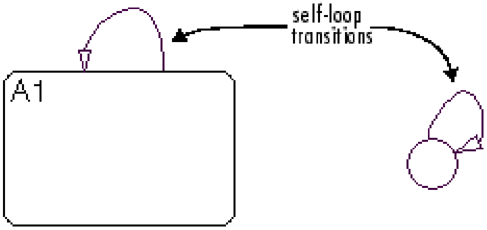
1. Select the junctions whose incoming arrowhead size you want to change.
2. Place the cursor over a selected junction and right-click.
3. In the resulting submenu, place the cursor over **Arrowhead Size**.

   A menu of arrowhead sizes appears.
4. Select a size from the menu.

Creating Self-Loop Transitions

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

The following is an example of a self-loop transition:



To create a self-loop transition, do the following:

1 Create the transition as usual by clicking and dragging it out from the source state or junction.

2 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 2-21.

Creating Default Transitions

A default transition is a transition with a destination (a state or a junction), but no apparent source object. See “Default Transitions” on page 1-14 for an explanation of 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.

The size of the endpoint of the default transition is proportional to the arrowhead size. See “Changing Transition Arrowhead Size” on page 4-20.

Default transitions can be labeled just like other transitions. See “Labeling Default Transitions” on page 2-27 for an example.

Changing Transition Properties

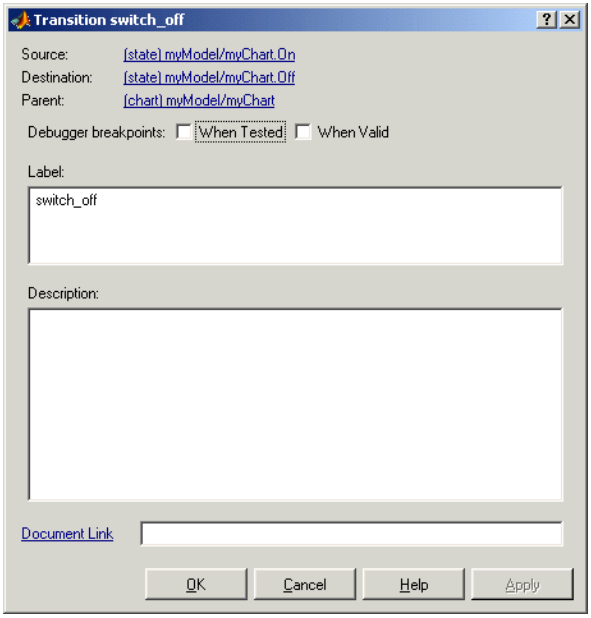
Use the **Transition** dialog box to view and change the properties for a transition. To access the **Transitions** dialog for a particular transition, do the following:

1 Right-click on the transition.

A shortcut pop-up menu appears.

2 Choose **Properties** from the shortcut menu.

Stateflow displays the **Transition** dialog for the transitions as shown.



Transition switch_off

Source: (state) myModel/myChart.On

Destination: (state) myModel/myChart.Off

Parent: (chart) myModel/myChart

Debugger breakpoints: □ When Tested □ When Valid

Label:

switch_off

Description:

Document Link

The following table lists and describes the properties displayed for a transition in its **Transition** dialog:

Field	Description
Source	Source of the transition; read-only; click the hypertext link to bring the transition source to the foreground.
Destination	Destination of the transition; read-only; click the hypertext link to bring the transition destination to the foreground.
Parent	Parent of this state; read-only; click the hypertext link to bring the parent to the foreground.
Debugger breakpoints	Select the check boxes to set debugging breakpoints either when the transition is tested for validity or when it is valid.
Label	The transition's label. See "Transition Label Notation" on page 2-15 for more information on valid label formats.
Description	Textual description/comment.
Document Link	Enter a Web URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

3 After making changes, select one of the following:

- **Apply** to save the changes and keep the **Transition** dialog open.
- **Revert** to return to the previous settings for the dialog
- **Close** to save the changes and close the dialog box
- **Help** to display Stateflow online help in an HTML browser window.

Creating Flowcharts with Connective Junctions

Connective junctions provide decision points between alternate transition paths. The following topics describe how to create, move, and specify properties for connective junctions:

- "Creating a Connective Junction" on page 4-24
- "Changing Connective Junction Size" on page 4-25
- "Changing Junction Properties" on page 4-25

Creating a Connective Junction

To create a junction, do the following:

1. In the diagram toolbar, click the **Connective Junction** tool .
2. Move the cursor into the diagram editor.

   The cursor takes on the shape of a connective junction.
3. Click to place a connective junction in the desired location in the drawing area.

To create multiple connective junctions, do the following:

1. In the diagram toolbar, double-click the **Connective Junction** tool.
2. The button is now in multiple object mode.
3. Click anywhere in the drawing area to place a connective junction in the drawing area.
4. Move to and click another location to create an additional connective junction.
5. Click the **Connective Junction** tool or press the **Esc** key to cancel the operation.

To move a connective junction to a new location, click and drag it to the new position.

Changing Connective Junction Size

To change the size of connective junctions, do the following:

1. Select the connective junctions whose size you want to change.
2. Place the cursor over one of the connective junctions and right-click.
3. In the resulting submenu, place the cursor over **Junction Size**.

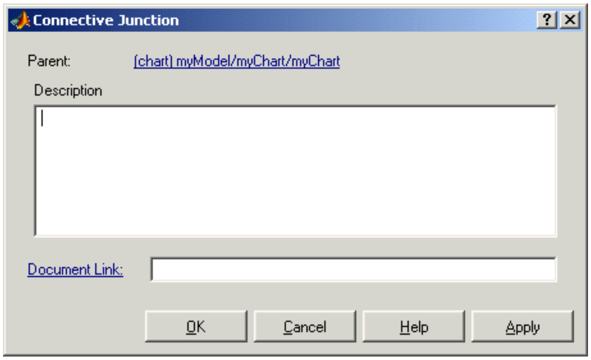
   A menu of junction sizes appears.
4. Select a size from the menu of junction sizes.

Changing Junction Properties

To edit the properties for a connective junction, do the following:

1. Right-click a connective junction.
2. In the resulting submenu select **Properties**.

   The **Connective Junction** dialog box appears as shown.



Connective Junction

Parent: (chart) myModel/myChart/myChart

Description

Document Link:

3. Edit the fields in the properties dialog, which are described in the following table:

Field	Description
Parent	Parent of this state; read-only; click the hypertext link to bring the parent to the foreground.
Description	Textual description/comment.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

4 When finished editing, select one of the following:

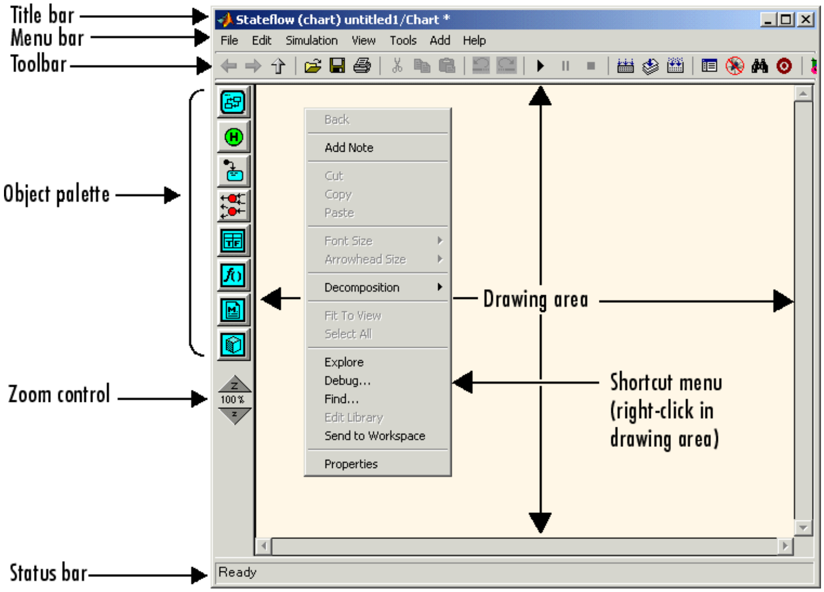
- Select the **Apply** button to save the changes.
- Select the **Cancel** button to cancel any changes you've made.
- Select **OK** to save the changes and close the dialog box.
- Select the **Help** button to display the Stateflow online help in an HTML browser window.

Using the Stateflow Editor

You edit your Stateflow chart diagrams in the Stateflow Editor. This section describes each part of the Stateflow diagram editor window displaying the chart you created. It contains the following topics:

Stateflow Diagram Editor Window

You use the Stateflow diagram editor to draw, zoom, modify, print, and save a state diagram displayed in the window. It has the following appearance:



The Stateflow diagram editor window includes the following elements:

- Title bar

  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.

- Menu bar

  Most editor commands are available from the menu bar.

- Toolbar

  Contains buttons for cut, copy, paste, and other commonly used editor commands. You can identify each tool of the toolbar by placing the mouse cursor over it until an identifying tool tip appears.

  The toolbar also contains buttons for navigating a chart's subchart hierarchy (see "Navigating Subcharts" on page 6-10).

- Object palette

Displays a set of tools for drawing states, transitions, and other state chart objects.

- Drawing area

  Displays an editable copy of a state diagram.

- Zoom control

  See “Viewing Stateflow Objects in the Model Explorer” on page 4-38 for information on using the zoom control.

- 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 diagram editor, the shortcut menu applies to the chart object. See “Displaying the Context Menu for Objects” on page 4-29 for more information.

- Status bar

  Displays tool tips and status information.

Displaying the Context Menu for Objects

Every object that you create in a state diagram has a shortcut menu associated with it. To display the shortcut (context) menu, do the following:

1. Move the cursor over the object.

2. Right-click the object.

   Stateflow pops up a menu of operations that apply to the object.

To display the context menu for the chart object, do the following:

1. Move the cursor to an unoccupied location in the diagram.

2 Right-click the location.

Stateflow pops up a menu of operations that apply to the chart.

Specifying Colors and Fonts

You can specify the color and font for items in the diagram editor, as described in the following topics:

- "Changing Fonts for an Individual Text Item" on page 4-30 — Tells you how to set color and font for an individual item in the Stateflow diagram editor.
- "Using the Colors & Fonts Dialog" on page 4-30 — Shows you how to set default colors and fonts for all Stateflow diagram editor items in the Colors and Fonts dialog

Changing Fonts for an Individual Text Item

You can change the font for an individual text item as follows:

1 Right-click the individual item.

2 From the resulting submenu, select **Font Size** -> *size of font*.

You can also specify the label font size of a particular object:

1 Left-click an individual text item in the editor.

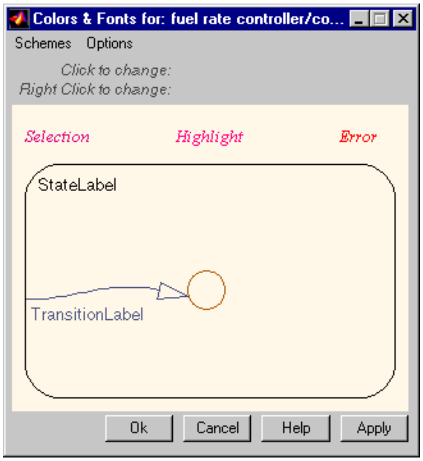
2 From the editor's **Edit** menu, select **Set Font Size.**

3 From the resulting submenu, select the font size.

Using the Colors & Fonts Dialog

The Stateflow **Colors & Fonts** dialog allows you to specify a color scheme for a chart as a whole, or colors and label fonts for different types of objects in a chart.

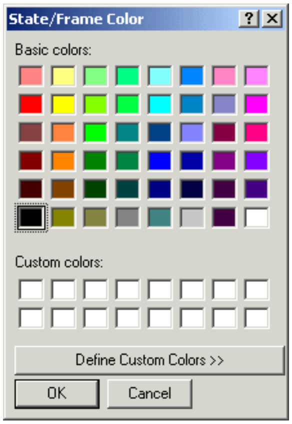
To display the **Colors & Fonts** dialog, select **Style** from the Stateflow editor's **Edit** menu.



The drawing area of the dialog displays examples of the types of objects whose colors and font labels you can specify. The examples use the colors and label fonts specified by the current color scheme for the chart. To choose another color scheme, select the scheme from the dialog's **Schemes** menu. The dialog displays the selected color scheme. Click **Apply** to apply the selected scheme to the chart or **OK** to apply the scheme and dismiss the dialog.

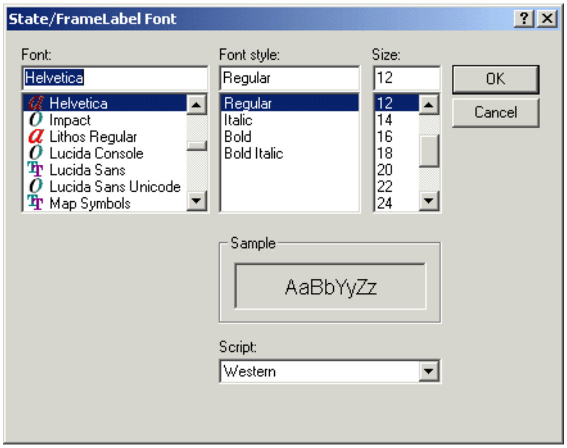
To make the selected scheme the default scheme for all Stateflow charts, select **Make this the "Default" scheme** from the dialog's **Options** menu.

To modify the current scheme, position the cursor over the example of the type of object whose color or label font you want to change. Then left-click to change the object's color or right-click to change the object's font. If you left-click, Stateflow displays a color chooser dialog.



Use the dialog to select a new color for the selected object type.

If the selected object is a label and you right-click, Stateflow displays a font selection dialog.



Font: Helvetica

Font style: Regular

Size: 12

Script: Western

Use the font selector to choose a new font for the selected label.

To save changes to the default color scheme, select **Save defaults to disk** from the **Colors & Fonts** dialog's **Options** menu.

Note Choosing **Save defaults to disk** has no effect if the modified scheme is not the default scheme.

Differentiating Syntax Elements in the Stateflow Action Language

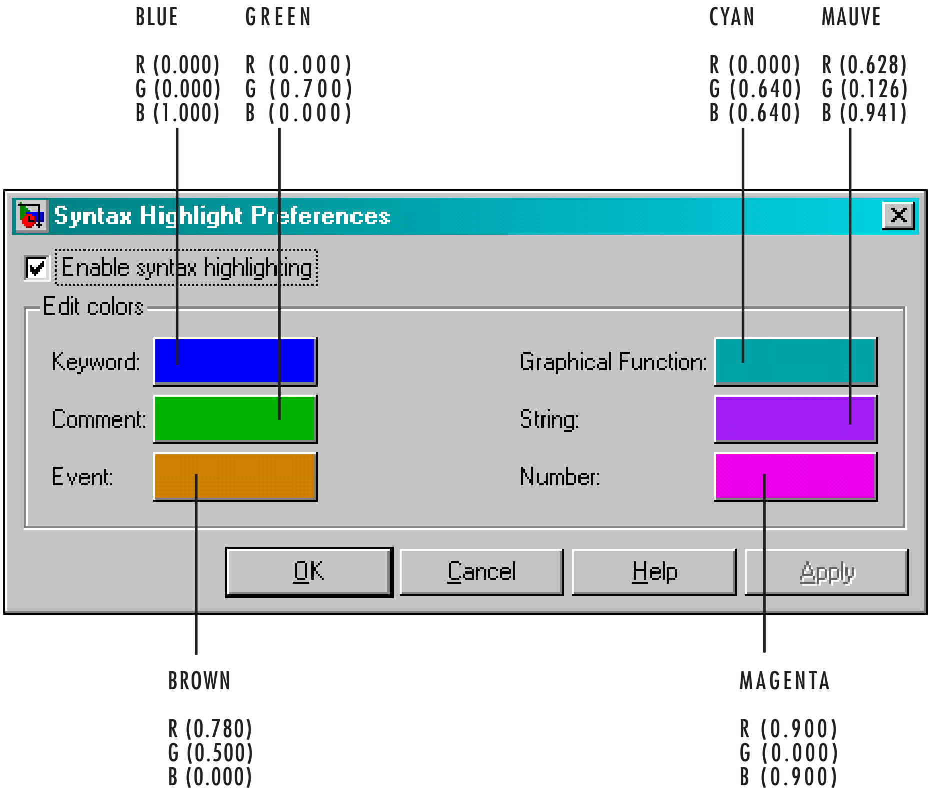
This release gives you the option of using color highlighting to differentiate the following syntax elements in the Stateflow action language:

- Keyword
- Comment
- Event
- Graphical function
- String
- Number

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

Default Syntax Highlighting

Syntax highlighting is enabled by default, assigning the following colors to syntax elements:



Syntax Highlight Preferences

☑ Enable syntax highlighting

Edit colors

Keyword: 🟦

Comment: 🟩

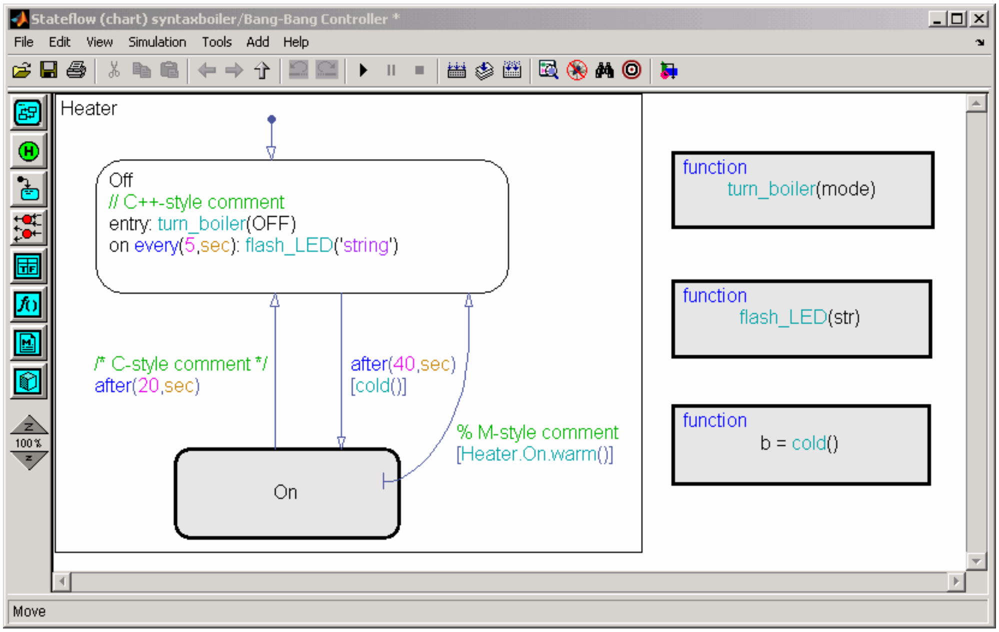
Event: 🟧

Graphical Function: 🟦

String: 🟪

Number: 🟪

Here is a Stateflow chart that illustrates the default highlighting for each language element:


Stateflow (chart) syntaxboiler/Bang-Bang Controller *
File Edit View Simulation Tools Add Help
Heater
Off
On
100%
Move

```
Off
// C++-style comment
entry: turn_boiler(OFF)
on every(5,sec): flash_LED('string')

/* C-style comment */
after(20,sec)

after(40,sec)
[cold()]

% M-style comment
[Heater.On.warm()]

function
    turn_boiler(mode)

function
    flash_LED(str)

function
    b = cold()
```

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

To modify color assignments, see “Editing Syntax Highlighting” on page 4-35. To disable syntax highlighting, see “Enabling and Disabling Syntax Highlighting” on page 4-36.

Editing Syntax Highlighting

To edit syntax highlighting, follow these steps:

1. In the Stateflow Editor, select **Highlight Preferences** from the **Edit** menu.

   The Syntax Highlight Preferences dialog appears.

2. Click the color you want to change, choose an alternative from the color palette, and click **OK**.

3. Click **OK** to close the Syntax Highlight Preferences dialog.

Enabling and Disabling Syntax Highlighting

You can toggle syntax highlighting from the Tools and Edit menus in the Stateflow Editor. From the **Tools** menu, select **Syntax Highlighting**. From the **Edit** menu, follow these steps:

1. Select **Highlighting Preferences** to open the Syntax Highlight Preferences dialog.

2. Check or uncheck **Enable Syntax Highlighting** and click **OK**.

Selecting and Deselecting Objects

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

Select objects in the Stateflow diagram editor as follows:

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

  All objects or portions of objects within the rubberband are selected.
- To select multiple separate objects, simultaneously press the **Shift** key and click an object or rubberband a group of objects.

  This 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 when you rubberband select a state and all of its objects and then Shift-click inside the containing state to deselect it.
- To select all objects in the Stateflow diagram, from the **Edit** menu select **Select All**.

  You can also select all objects by selecting **Select All** from the right-click shortcut menu.
- To deselect all selected objects, press the **Esc** key.

  Pressing the **Esc** key again displays the parent of the current chart.

When an object is selected, it is highlighted in the color set as the selection color (blue by default; see “Specifying Colors and Fonts” on page 4-30 for more information).

Cutting and Pasting 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 Stateflow diagram to another. Stateflow retains a selection list of the most recently cut objects. The objects are pasted in the drawing area location closest to the current mouse location.

To cut an object, select the object and choose **Cut** from one of the following:

- The **Edit** menu on the main window
- The right-click shortcut menu

Pressing the **Ctrl** and **X** keys simultaneously is the keyboard equivalent to the **Cut** menu item.

To paste the most recently cut selection of objects, choose **Paste** from either of the following:

- The **Edit** menu on the main window
- The right-click shortcut menu

Pressing the **Ctrl** and **V** keys simultaneously is the keyboard equivalent to the **Paste** menu item.

Copying 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 Stateflow clipboard.

Alternatively, to copy from one Stateflow diagram to another, choose the **Copy** and then **Paste** menu items from either of the following:

- The **Edit** menu on the Stateflow graphics editor window

- The right-click shortcut menu

Pressing the **Ctrl** and **C** keys simultaneously is the keyboard equivalent to the **Copy** menu item. States that contain other states (superstates) can be grouped together.

Editing Object Labels

Some Stateflow objects (for example, states and transitions) have labels. To change these labels, place the cursor anywhere in the label and click. The cursor changes to an I-beam. You can then edit the text.

The shortcut (context) menus allows you to change a label's font size:

1. Select the states whose label font size you want to change.

2. Right-click to display the shortcut menu.

3. Place the cursor over the **Font Size** menu item.

   A menu of font sizes appears.

4. Select the desired font size from the menu.

   Stateflow changes the font size of all labels on all selected states to the selected size.

Viewing Stateflow Objects in the Model Explorer

To view or modify Stateflow diagram editor objects in the **Model Explorer**, do the following:

1. Position the mouse cursor over the state.

2. Right-click to display the state's context menu.

3. Select **Explore** from the context menu.

   The **Model Explorer** opens (if not already open) and highlights the state in the left hierarchy pane to show any events or data defined by the state.

To view events and data defined by the parent state of a transition or junction, select **Explore** from the transition or junction's context menu.

The **Model Explorer** is the only place where you can view and modify events and data. See Chapter 7, "Defining Events and Data" for more details on using the **Model Explorer** to view, add, delete, and modify data and events for Stateflow objects. See also "Using the Model Explorer with Stateflow Objects" on page 16-2 for more details on using the **Model Explorer** to view Stateflow objects.

Zooming a Diagram

You can magnify or shrink a diagram, using the following zoom controls:

- **Zoom Factor Selector**. Selects a zoom factor (see "Using the Zoom Factor Selector" on page 4-39).
- **Zoom In** button. Zooms in by the current zoom factor.

  You can also press the **R** key to increase the zoom factor.
- **Zoom Out** button. Zooms out by the current zoom factor.

  You can also press the **V** key to decrease the zoom factor.

Using the Zoom Factor Selector

The **Zoom Factor Selector** allows you to specify the zoom factor by

- Choosing a value from a menu.

  Click the selector to display the menu.
- Double-clicking the **Zoom Factor Selector** selects the zoom factor that will fit the view to all selected objects or all objects if none are selected.

  You can achieve the same effect by choosing **Fit to View** from the right-click context menu or by pressing the **F** key to apply the maximum zoom that includes all selected objects. Press the space bar to fit all objects to the view.
- Clicking the **Zoom Factor Selector** and dragging up or down.

  Dragging the mouse upward increases the zoom factor. Dragging the mouse downward decreases the zoom factor. Alternatively, right-clicking and dragging on the percentage value resizes while you are dragging.

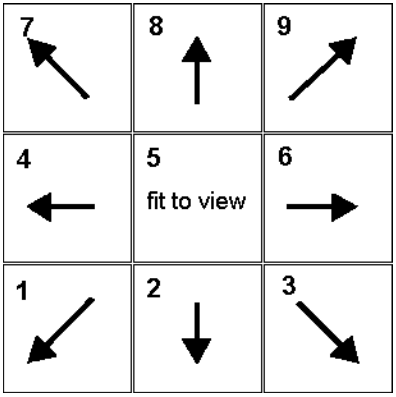
Zooming with Shortcut Keys

The following is a summary of the shortcut keys you can use to perform some of the zooming operations described above:

Key	Zoom Operation
F	Highlight (select) an object and press the **F** key to fit it to view.
space bar	Set to full view of diagram.
R or **+**	Increase zoom factor.
V or **-**	Decrease zoom factor.

Moving in Zoomed Diagrams with Shortcut Keys

You can also use number keys to move in zoomed diagrams according to their layout in the number keypad:



You can enter numbers for moving from the number keys above the alphabetic keys at any time or from the number keypad if NumLock is engaged for the keyboard. The **5** key fits the currently selected object to full view. If no object is selected, the entire diagram is fit to view.

Undoing and Redoing Editor Operations

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

To undo an operation in the Stateflow diagram editor, do one of the following:

- Select the **Undo** icon in the toolbar of the Stateflow diagram editor ↶.

  When you place your mouse cursor over the **Undo** button, the tool tip that appears indicates the nature of the operation to undo.

- From the **Edit** menu, select **Undo.**

To redo an operation in the Stateflow diagram editor, do one of the following:

- Select the **Redo** icon in the toolbar of the Stateflow diagram editor ↷.

  When you place your mouse cursor over the **Redo** button, the tool tip that appears indicates the nature of the operation to redo.

- From the **Edit** menu, select **Redo.**

Exceptions for Undo

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

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

  To understand subcharting, see “Using Subcharts to Extend Charts” on page 6-6.

- 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 “Drawing a Supertransition Into a

Subchart” on page 6-13 and “Drawing a Supertransition Out of a Subchart” on page 6-16.

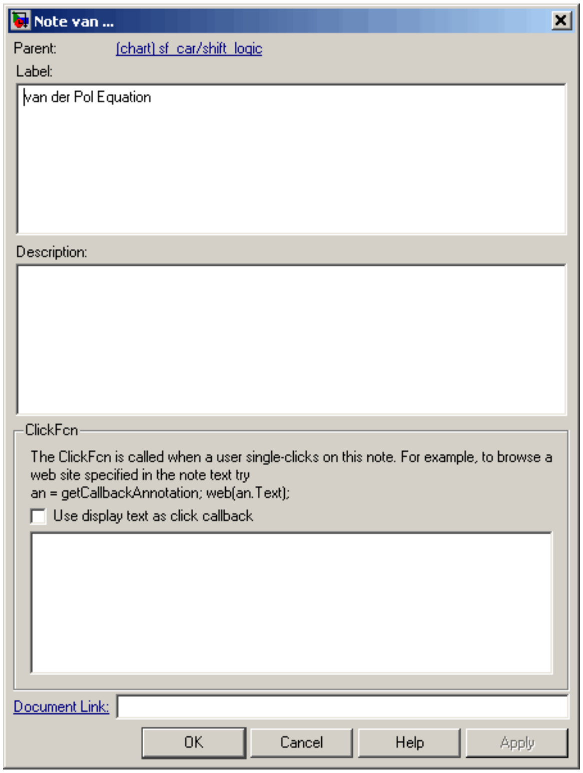
- You cannot undo any changes made to the diagram editor through the Stateflow API.

  For a description of the Stateflow API (Application Programming Interface), see “Using the API” in the Stateflow API Guide.

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

Stateflow Chart Notes Dialog Box

You can use the chart notes dialog box to edit note properties.



Note van ...

Parent: (chart) sf_car/shift_logic

Label:

van der Pol Equation

Description:

ClickFcn

The ClickFcn is called when a user single-clicks on this note. For example, to browse a web site specified in the note text try
an = getCallbackAnnotation; web(an.Text);

□ Use display text as click callback

Document Link:

The **Note** dialog contains the following properties for a chart note:

Field	Description
Label	The label for the note. This includes the name of the note and its associated actions.
Description	Textual description/comment.
Use display text as click callback	Checking this option causes Simulink to treat the text in the Text field as the note's click function. The specified text must be a valid MATLAB expression comprising symbols that are defined in the MATLAB workspace when the user clicks this annotation. Note that selecting this option disables the **ClickFcn** edit field.

Field	Description
ClickFcn	Specifies MATLAB code to be executed when a user single-clicks this annotation. Simulink stores the code entered in this field with the model.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit /spec/data/speed.txt`.

See “Annotation Callback Functions” in the Simulink User’s Guide documentation for a description of the **ClickFcn** edit field.

Keyboard Shortcuts for Stateflow Diagrams

The following table is a comprehensive list of keyboard shortcuts for the Stateflow diagram editor.

Task	Microsoft Windows	UNIX
Display the parent of the currently displayed chart or subchart. There is no limit on the time between the entry of each period.	.. (two periods)	.. (two periods)
Zoom in by an incremental amount.	**+** or **r**	**+** or **r**
Zoom out by an incremental amount.	**-** or **v**	**-** or **v**
Fit chart to screen.	**0** or **Space Bar**	**0** or **Space Bar**
Zoom to normal view.	**1**	**1**
Move the current diagram editor view down within the full diagram.	**2**	**2**
Move the current diagram editor view down and right within the full diagram.	**3**	**3**
Move the current diagram editor view left within the full diagram.	**4**	**4**

Task	Microsoft Windows	UNIX
Fit the currently selected object to full view. If no object is selected, the chart is fit to full view.	**5**	**5**
Move the current diagram editor view right within the full diagram.	**6**	**6**
Move the current diagram editor view up and left within the full diagram.	**7**	**7**
Move the current diagram editor view up within the full diagram.	**8**	**8**
Move the current diagram editor view right within the full diagram.	**9**	**9**
Delete the selected objects.	**Delete**	**Delete**
Access the contents of the currently highlighted subchart or truth table.	**Enter**	**Enter**
Perform any of the following actions: • If you are editing the label of an object, the **Esc** key disables label editing but leaves the object selected. • If objects are selected, the **Esc** key deselects all objects in the current view. • If the current diagram view is the contents of a subchart and no object is selected, the **Esc** key changes the view to the parent of the subchart. • If the current diagram view is at the chart level and no object is selected, the **Esc** key displays the Simulink window for that chart's block.	**Esc**	**Esc**
Fit the currently selected object to screen. If no object is selected, the chart is fit to screen.	**f**	**f**

Task	Microsoft Windows	UNIX
Pan left	**d** or **Ctrl+Left Arrow**	**d** or **Ctrl+Left Arrow**
Pan right	**g** or **Ctrl+Right Arrow**	**g** or **Ctrl+Right Arrow**
Pan up	**e** or **Ctrl+Up Arrow**	**e** or **Ctrl+Up Arrow**
Pan down	**c** or **Ctrl+Down Arrow**	**c** or **Ctrl+Down Arrow**
Go back in pan/zoom history	**b**	**b**
Go forward in pan/zoom history	**t**	**t**
Select the first state, function, truth table, or box parented (contained) by the currently selected object in the same diagram. Selection order of contained objects is top-down, left-right. See also **u** key.	**j** (jump)	**j** (jump)
Select the next state, function, truth table, or box at the same containment level. Selection order of objects is top-down, left-right.	**n** (next)	**n** (next)
Select the previous state, function, truth table, or box at the same containment level. Selection order of objects is top-down, left-right.	**p** (previous)	**p** (previous)
Select the parent object of the currently highlighted object in the same diagram. See also **J** key.	**u** (up)	**u** (up)

Customizing the Stateflow Editor

You can write M-code to customize the Stateflow Editor by

- Adding items and submenus to the end of Stateflow Editor menus (see "Adding Items to Stateflow Editor Menus" on page 4-47)
- Disabling and hiding items on menus in the Stateflow Editor (see "Disabling and Hiding Stateflow Editor Menu Items" on page 4-50)

Adding Items to Stateflow Editor Menus

You use the Simulink customization manager to add items, including submenus, to the end of menus in the Stateflow Editor. For example, you can add menu items that invoke your own M-code functions.

To add an item to the end of a Stateflow Editor menu, you must create the following functions in an `sl_customization.m` file on the MATLAB path:

- For each item, create a schema function, which defines a custom item on a menu owned by the Stateflow Editor.
- Create a custom menu function, which registers schema functions that define custom items that you want to add to a menu.
- Define the `sl_customization` function to register the custom menu function with the Simulink customization manager.
- Create callback functions for the items that you add to the Stateflow Editor menus.

For detailed descriptions of these procedures, see "Adding Items to Model Editor Menus" in the online Simulink documentation.

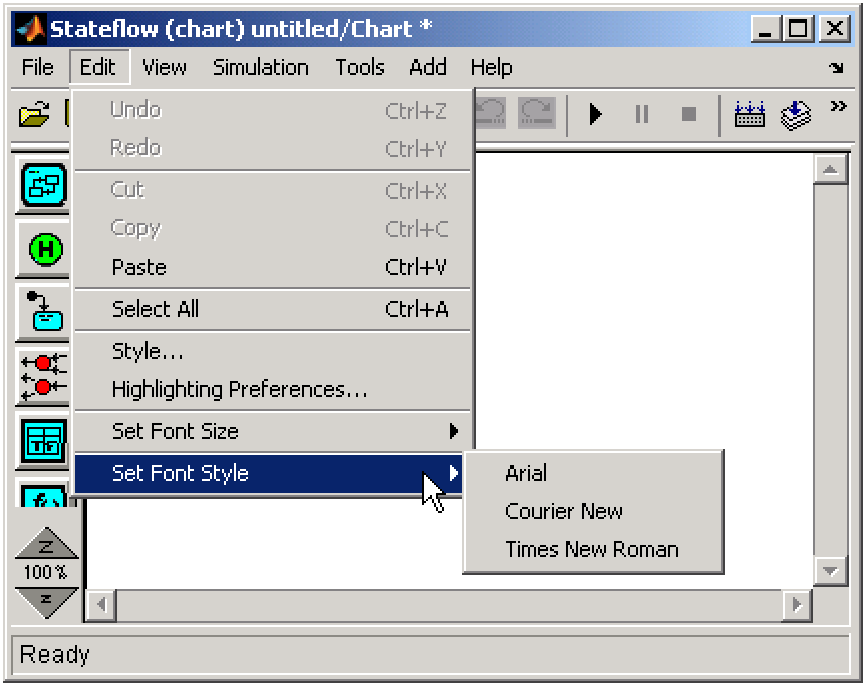
Code Example: Adding a Custom Submenu to the Stateflow Editor. The following `sl_customization.m` file adds a submenu called **Set Font Style** to the Stateflow Editor's Edit menu. The submenu contains three menu options for font style: **Arial**, **Courier New**, and **Times New Roman**. Your `sl_customization` function should accept one argument, a handle to an object called the `Simulink.CustomizationManager`. For example, you can set `cm = sl_customization_manager` at the MATLAB command line.

```
function sl_customization(cm)

  %% Register custom menu function.
  cm.addCustomMenuFcn('Stateflow:EditMenu', @getMyMenuItems);
end

%% Define the custom submenu function.

function schemaFcns = getMyMenuItems(callbackInfo)
  schemaFcns = {@getItem4};
end

%% Define the schema function for first submenu item
function schema = getItem1(callbackInfo)
  schema = sl_action_schema;
  schema.label = 'Arial';
  schema.userdata = 'font style Arial';
  schema.callback = @myCallback1;
end

%% Define the schema function for second submenu item.
function schema = getItem2(callbackInfo)
  schema = sl_action_schema;
  schema.label = 'Courier New';
  schema.userdata = 'font style Courier New';
  schema.callback = @myCallback1;

%% Define the schema function for third submenu item.
function schema = getItem3(callbackInfo)
  schema = sl_action_schema;
  schema.label = "Times New Roman';
  schema.userdata = 'font style Times New Roman';
  schema.callback = @myCallback1;
end

function myCallback1(callbackInfo)
  disp(['Callback for 'callbackInfo.userdata' was called']);
end

function schema = getItem4(callbackInfo)
```

```
  % Make a submenu label 'Set Font Style'
  % with the font styles defined in menu items above.
  schema = sl_container_schema;
  schema.label = 'Set Font Style';
  schema.childrenFcns = {@getItem1, @getItem2, @getItem3};
end
```

Note The `addCustomMenuFcn` function requires that you pass a string argument that identifies the menu or menu item you wish to customize. To determine the appropriate tag, see “Displaying Menu Tags” on page 4-51.

Custom Menu Example: Set Font Style. When you run `sl_customization(cm)` described in Code Example: Adding a Custom Submenu to the Stateflow Editor, the following new submenu appears in the Stateflow Editor:



Disabling and Hiding Stateflow Editor Menu Items

You can disable or hide items that appear on Stateflow Editor menus by

- Creating a filter function that disables or hides the menu item (see "Creating a Filter Function" in the Simulink User's Guide)
- Registering the filter function with the Simulink customization manager (see "Registering a Filter Function" in the Simulink User's Guide)

For detailed descriptions of these procedures, see "Disabling and Hiding Model Editor Menu Items" in the online Simulink documentation.

Code Example: Disabling the Print Command in the Stateflow Editor. The following `sl_customization.m` file disables the Print command in the File menu of the Stateflow Editor. The example assumes you set `cm = sl_customization_manager`.

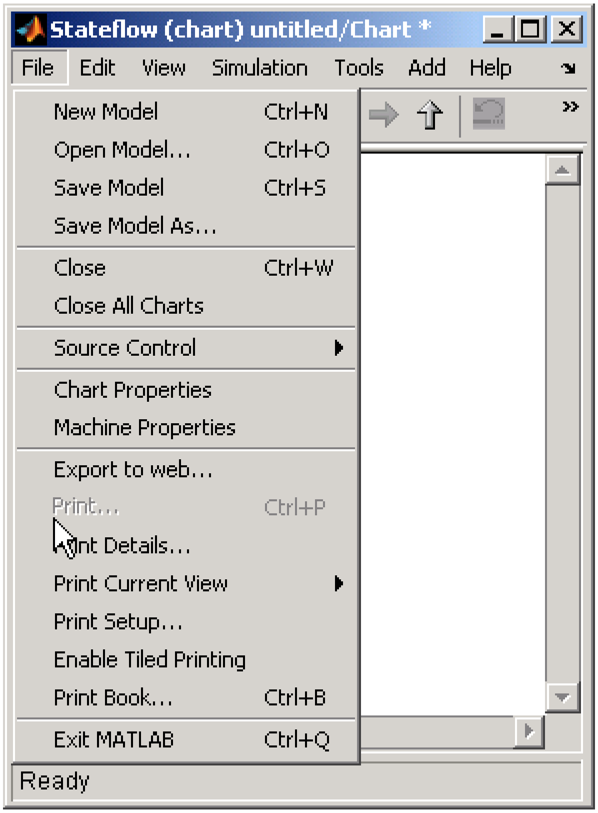
```
function sl_customization(cm)

  %%Register custom filter function.
  cm.addCustomFilterFcn('Stateflow:PrintMenuItem', @myFilter);

end

function state = myFilter(callbackInfo)
  state = 'Disabled';
end
```

Note The `addCustomFilterFcn` function requires that you pass a string argument that identifies the menu or menu item you wish to disable or hide. To determine the appropriate tag, see "Displaying Menu Tags" on page 4-51.

The `myFilter` function sets the state of the menu item. Valid states are:

- 'Hidden'
- 'Disabled'
- 'Enabled'

Custom Menu Example: Disable Print Menu Item. After you run `sl_customization(cm)` described in Code Example: Disabling the Print Command in the Stateflow Editor, the Stateflow Editor's File menu looks like this:

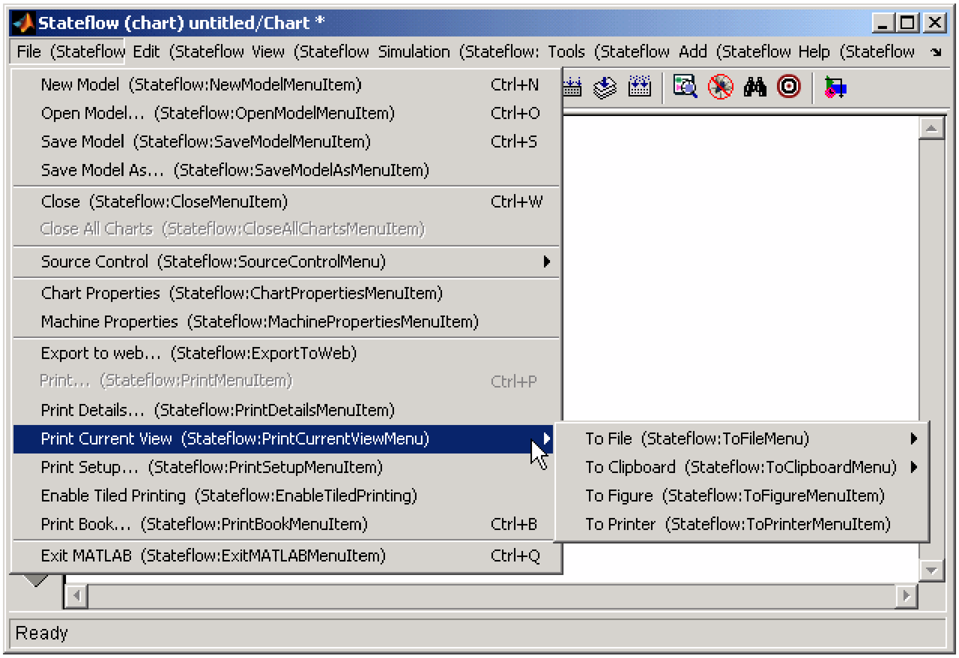


Displaying Menu Tags

To determine the tags that identify the menus or menu items you wish to customize on the Stateflow Editor, set the Simulink customization manager's `showWidgetIdAsToolTip` property to true by entering the following commands at the MATLAB command line:

```
cm = sl_customization_manager;
cm.showWidgetIdAsToolTip = true;
```

After enabling this property, Stateflow displays the tag of each menu or menu item next to its label in the Stateflow Editor:


Stateflow (chart) untitled/Chart *
File (Stateflow Edit (Stateflow View (Stateflow Simulation (Stateflow: Tools (Stateflow Add (Stateflow Help (Stateflow
New Model (Stateflow:NewModelMenuItem) Ctrl+N
Open Model... (Stateflow:OpenModelMenuItem) Ctrl+O
Save Model (Stateflow:SaveModelMenuItem) Ctrl+S
Save Model As... (Stateflow:SaveModelAsMenuItem)
Close (Stateflow:CloseMenuItem) Ctrl+W
Close All Charts (Stateflow:CloseAllChartsMenuItem)
Source Control (Stateflow:SourceControlMenu)
Chart Properties (Stateflow:ChartPropertiesMenuItem)
Machine Properties (Stateflow:MachinePropertiesMenuItem)
Export to web... (Stateflow:ExportToWeb)
Print... (Stateflow:PrintMenuItem) Ctrl+P
Print Details... (Stateflow:PrintDetailsMenuItem)
Print Current View (Stateflow:PrintCurrentViewMenu)
Print Setup... (Stateflow:PrintSetupMenuItem)
Enable Tiled Printing (Stateflow:EnableTiledPrinting)
Print Book... (Stateflow:PrintBookMenuItem) Ctrl+B
Exit MATLAB (Stateflow:ExitMATLABMenuItem) Ctrl+Q
To File (Stateflow:ToFileMenu)
To Clipboard (Stateflow:ToClipboardMenu)
To Figure (Stateflow:ToFigureMenuItem)
To Printer (Stateflow:ToPrinterMenuItem)
Ready

To turn off tag display, enter the following command at the MATLAB command line:

```
cm.showWidgetIdAsToolTip = false;
```

Note Some Stateflow Editor menu items may not work while menu tags are displayed. Thus, you should turn off menu tag display before attempting to use the menus.

Building Mealy and Moore Charts in Stateflow

Stateflow allows you to build charts that model the Mealy and Moore paradigms for finite state machines. This chapter presents an overview of these paradigms and describes how to implement Mealy and Moore semantics in Stateflow.

Overview of Mealy and Moore Machines

Mealy and Moore are often considered the basic, industry-standard paradigms for modeling finite-state machines. Generally in state machine models, the next state is a function of the current state and its inputs, as follows:

$$X(n+1) = f(X(n), u)$$

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

In this context, Mealy and Moore machines each have well-defined semantics.

Type of Machine	Semantics	Applications
Mealy	Output is a function of inputs *and* state: $y = g(X, u)$	Clocked synchronous machines where state transitions occur on clock edges
Moore	Output is a function *only* of state: $y = g(X)$	Clocked synchronous machines where outputs are modified at clock edges

You can create Stateflow charts that implement pure Mealy or Moore semantics as a subset of Stateflow semantics (see “Creating Mealy and Moore Charts” on page 5-5). Mealy and Moore charts can be used in simulation and code generation of C and hardware description language (HDL).

Note To generate HDL code from Stateflow charts, you must use Simulink HDL Coder, available as a separate product.

The Default State Machine Type. When you create a chart in Stateflow, the default type is a hybrid state machine model that combines the semantics of Mealy and Moore charts with the extended semantics provided by Stateflow (see Chapter 3, "Stateflow Semantics"). This default chart type is called *Classic*.

What is State?. *State* is a combination of local data and chart activity. Therefore, computing state means updating local data and making transitions from a currently active state to a new state. State persists from one time step to another. In Classic Stateflow, output behaves like state because output values persist between time steps. However unlike state, output is available outside the chart through output ports. By contrast, output in Mealy and Moore charts does not persist and instead must be computed in each time step.

Availability of Output. Stateflow guarantees that the output of Mealy and Moore machines is well defined at every time step by enforcing the option **Initialize Outputs Every Time Chart Wakes Up** for these chart types. This option initializes outputs to a default value whenever the chart is triggered (see "Setting Properties for Individual Charts" on page 10-6). Normally, charts compute output data in every execution. In this case, computed outputs override the default values. However, when output is not computed, the default value applies.

Mealy machines compute output on transitions, while Moore machines compute outputs in states. Therefore, Mealy charts can compute output earlier than Moore charts — that is, at the time Stateflow executes the chart's default path. If you enable the chart property **Execute (enter) Chart At Initialization**, this computation occurs at t = 0 (first time step); otherwise, it occurs at t = 1 (next time step). By contrast, Moore machines can compute outputs only *after* Stateflow executes the default path. Until then, outputs take the default values.

The following table summarizes the earliest time at which output can be computed in Mealy and Moore charts:

Execute (enter) Chart at Initialization	Mealy Computes Outputs at:	Moore computes Outputs at:
Enabled	t = 0	t = 1
Disabled	t = 1	t = 2

Advantages of Mealy and Moore Charts Over Classic Stateflow. Mealy and Moore charts offer the following advantages over Classic Stateflow:

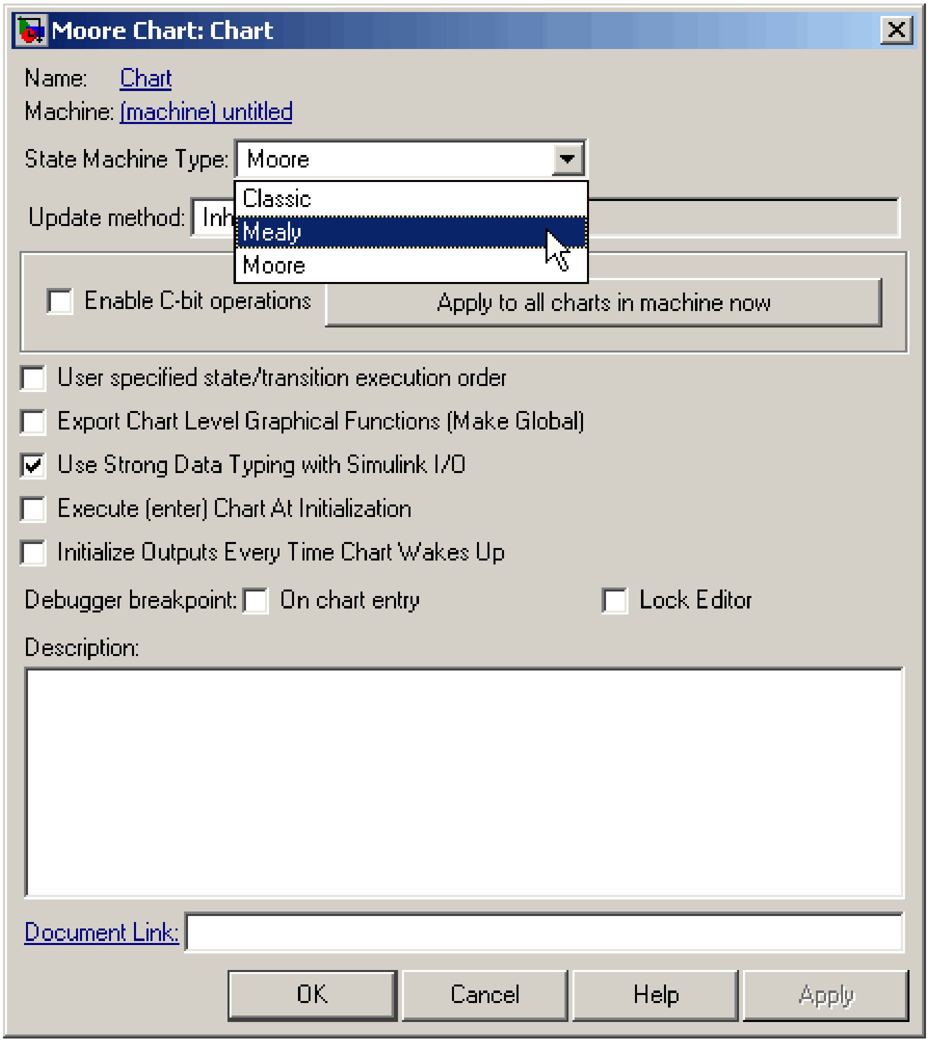
- Stateflow verifies the Mealy and Moore charts you create to ensure that they conform to their formal definitions and semantic rules. Stateflow reports violations at compile time (not at design time).
- Moore charts provide a more efficient implementation of Stateflow than Classic charts, both for C and HDL targets.

Creating Mealy and Moore Charts

To create a new Mealy or Moore chart, follow these steps:

1. Add a new Stateflow block to a Simulink model, then double-click the block to open the Stateflow Editor.
2. Right-click in the Stateflow Editor and select **Properties**.

   The Chart Properties dialog box opens on your desktop.
3. From the State Machine Type drop-down menu, select **Mealy** or **Moore**.



Moore Chart: Chart

Name: Chart

Machine: (machine) untitled

State Machine Type: Moore

Update method: Inh

☐ Enable C-bit operations

☐ User specified state/transition execution order

☐ Export Chart Level Graphical Functions (Make Global)

☑ Use Strong Data Typing with Simulink I/O

☐ Execute (enter) Chart At Initialization

☐ Initialize Outputs Every Time Chart Wakes Up

Debugger breakpoint: ☐ On chart entry ☐ Lock Editor

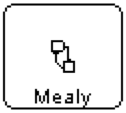
Description:

Document Link:

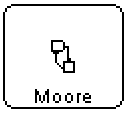
4 Click **OK**.

The Stateflow chart icon updates to display the selected chart type:

Mealy



Moore



The title bar of the Stateflow Editor also displays the selected chart type.

5 Design your chart according to the guidelines for the chart type (see "Design Considerations for Mealy Charts" on page 5-8 and "Design Considerations for Moore Charts" on page 5-14.

Design Considerations for Mealy Charts

To implement Mealy semantics in a Stateflow chart, you must use a restricted subset of Stateflow semantics. This section explains how to design charts in Stateflow that accurately model Mealy semantics.

- "Mealy Semantics" on page 5-8
- "Design Rules for Mealy Charts" on page 5-8
- "Example: Mealy Vending Machine" on page 5-11

Mealy Semantics

To ensure that output is a function of input *and* state, Mealy state machines enforce the following semantics:

- Outputs never depend on previous outputs
- Outputs never depend on the next state
- Chart wakes up periodically based on a system clock

Note Stateflow provides one time base for input and clock (see "Calculate Output and State Using One Time Base" on page 5-11).

- Chart must compute outputs whenever there is a change on the input port
- Chart must compute outputs only in transitions, not in states

Design Rules for Mealy Charts

To conform to the Mealy definition of a state machine, Stateflow must ensure that a Mealy chart computes outputs every time there is a change on the input port. As a result, Stateflow imposes a set of design rules for Mealy charts.

- "Compute Outputs in Condition Actions Only" on page 5-9
- "Do Not Use State Actions or Transition Actions" on page 5-9
- "Restrict Use of Data" on page 5-9
- "Restrict Use of Events" on page 5-10

- “Initialize Outputs Every Time Chart Wakes Up” on page 5-10
- “Calculate Output and State Using One Time Base” on page 5-11

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 you from computing output without considering changes on the input port
- Ensuring that output depends on current state and not next state

Restrict Use of Data

You can define inputs, outputs, local data, parameters, and constants in Mealy charts, but other data restrictions apply:

- “Restrict Machine-Parented Data to Constants and Parameters” on page 5-9
- “Do Not Define Data Store Memory” on page 5-10

Restrict Machine-Parented Data to Constants and Parameters. Machine-parented data is data that you define for a Stateflow machine, which is the collection of all Stateflow blocks in a Simulink model. The Stateflow machine is the highest level of the Stateflow hierarchy. When you define data at this level, every Stateflow 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, Stateflow only allows you to define constants and parameters at the machine level.

Note Stateflow parameters have constant value during simulation and code generation.

Do Not Define Data Store Memory. You cannot define data store memory (DSM) in Mealy charts because DSM objects can be modified by objects external to the chart. Stateflow uses data store memory to share data with Simulink. Data store memory acts as global data that can be modified by other blocks and models in the Simulink hierarchy that contains the chart. Mealy charts should not access data that can change unpredictably.

Restrict Use of Events

You must limit the use of events in Mealy charts as follows:

Do:	Do Not:
Use input events to trigger the chart	Broadcast any type of event
Use temporal logic to guard transitions You can use temporal logic in Mealy charts because it behaves synchronously. Think of the change in value of a temporal logic condition as an event that the chart schedules internally. Therefore, at each time step, the chart retains its notion of state because it knows how many ticks remain before the temporal event executes. **Note** In Mealy charts, the base event for temporal logic operators must be a predefined event such as `tick` or `wakeup` (see "Referencing Implicit Events" on page 7-24).	Use local or machine-parented events to guard transitions You cannot use local or machine-parented events in Mealy charts because they are not deterministic. These events can occur while the chart computes outputs and, therefore, violate Mealy semantics which require charts to compute outputs whenever input changes.

Initialize Outputs Every Time Chart Wakes Up

Stateflow automatically applies the initial value of outputs every time a Mealy chart wakes up to prevent latching of outputs. This is a requirement for Mealy charts to ensure that outputs do not depend on previous values of outputs.

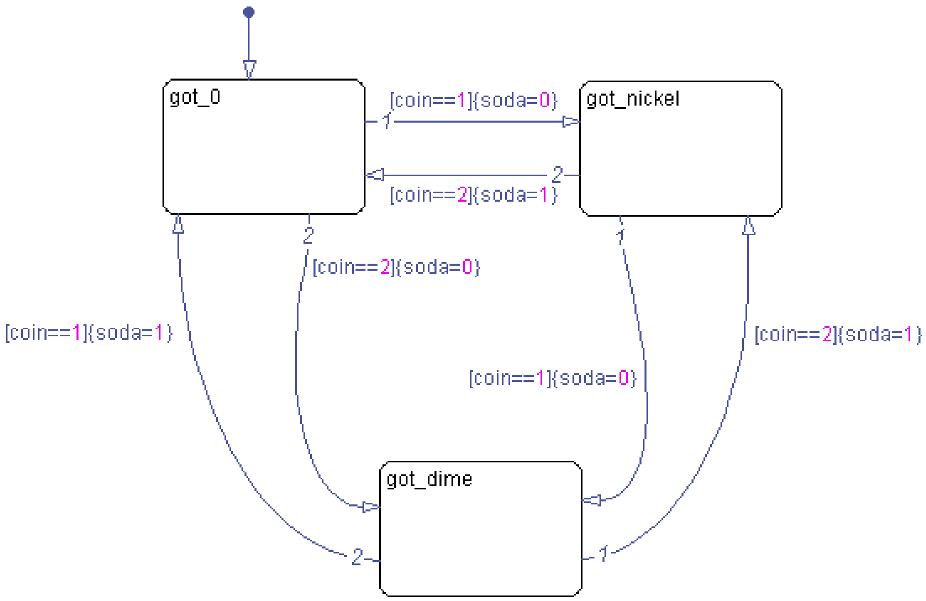
When you create a Mealy chart, Stateflow enforces the chart property **Initialize Outputs Every Time Chart Wakes Up** . For more information about this property, see “Setting Properties for Individual Charts” on page 10-6.

Calculate Output and State Using One Time Base

Stateflow provides one time base for clock and input, as determined by the Simulink solver (see “Solvers”). The Simulink solver sets the clock rate to be fast enough to capture input changes. As a result, in Mealy charts, Stateflow commonly computes outputs and changes states in the same time step.

Example: Mealy Vending Machine

The following chart uses 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, as follows:

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 is 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 the following 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.

Design Considerations for Moore Charts

To implement Moore semantics in a Stateflow chart, you must use a restricted subset of Stateflow semantics. This section explains how to design charts in Stateflow that accurately model Moore semantics.

- "Moore Semantics" on page 5-14
- "Design Rules for Moore Charts" on page 5-14
- "Example: Moore Traffic Light" on page 5-20

Moore Semantics

In Moore charts, output is a function of current state only. At every time step, a Moore chart wakes up, computes its outputs, and then evaluates its inputs to reconfigure itself for the next time step. For example, after evaluating its inputs, the Moore chart may take transitions to a new configuration of active states, also called *next state*. However, the Moore chart must always compute its outputs before changing state.

To ensure that output is a function *only* of state, Moore state machines enforce the following semantics:

- Outputs depend only on the current state, not the next state
- Outputs never depend on previous outputs
- Chart must compute outputs only in states, not in transitions
- Chart must compute outputs before updating state

Design Rules for Moore Charts

To conform to the Moore definition of a state machine, Stateflow must ensure that every time a Moore chart wakes up, it computes outputs from the current set of active states without regard to input. As a result, Stateflow imposes a set of design rules for Moore charts.

- "Compute Outputs in State Actions, Not on Transitions" on page 5-15
- "Restrict Data to Inputs, Outputs, and Constants" on page 5-17
- "Reference Input Only in Conditions" on page 5-18

- "Do Not Use Actions on Transitions" on page 5-19
- "Do Not Use Graphical Functions" on page 5-19
- "Restrict Use of Events" on page 5-19
- "Initialize Outputs Every Time Chart Wakes Up" on page 5-20

Compute Outputs in State Actions, Not on Transitions

To ensure that outputs depend solely on current state, you must compute outputs in state actions, subject to the following restrictions:

- "Combine During and Exit Actions" on page 5-15
- "Allow Actions in Leaf States Only" on page 5-16
- "Do Not Label State Actions" on page 5-17

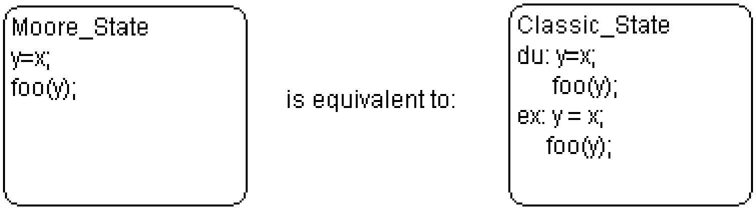
You cannot define actions on transitions because transitions almost always depend on inputs. For example, if you compute outputs in a condition action on a transition, Stateflow updates outputs whenever there is a change on the input — a violation of Moore semantics.

Combine During and Exit Actions. For Classic charts, Stateflow allows you to define different types of actions in states (see "State Action Types" on page 8-3). Each action can consist of multiple command statements. However, in Moore charts, Stateflow allows *only one action per state*, but executes the action as both a `during` *and* `exit` action. This duality ensures that Stateflow never exits a state before computing its outputs because:

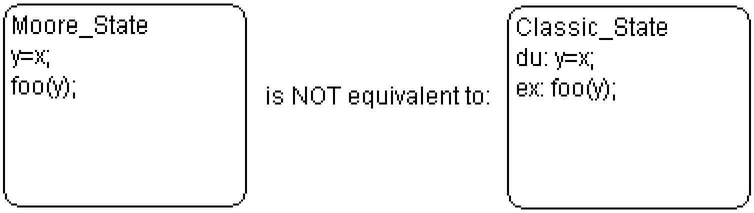
- Stateflow executes the action while the state is active and there are no valid transitions to take (like a `during` action)
- Stateflow also executes the action just before exiting the state to take a valid transition (like an `exit` action)

In other words, all active states in Moore charts compute their outputs in a consistent way whether an outer transition is valid or not.

To implement the duality of execution, the `during` and `exit` actions must be identical, as in this example:



Moore states do *not* differentiate between `during` and `exit` actions, as illustrated here:



Note There are no labels on state actions in Moore charts (see "Do Not Label State Actions" on page 5-17).

Allow Actions in Leaf States Only. In Moore charts, you can add actions only to leaf states. A leaf state is a state that resides at the lowest level of the Stateflow hierarchy and, therefore, does not parent any other states. This restriction ensures that when you compute outputs in state actions

- Outputs are not defined at multiple levels in the hierarchy with different values
- Stateflow can use the same top-down semantics for executing Moore charts as for Classic charts. In this way Stateflow computes outputs *as if* it evaluates actions before inner and outer flow graphs and, therefore, guarantees that the outputs will be identical for both chart types.

You can compute outputs in leaf states that have exclusive (OR) or parallel (AND) decomposition. However, you should not compute the same outputs in sibling parallel (AND) states because the values computed by the last state executed will prevail, overwriting the previously computed values.

For descriptions of Stateflow chart execution semantics, see “Executing a Chart” on page 3-6 and Semantic Rules Summary.

Do Not Label State Actions. Do not label state actions in Moore charts with any keywords — such as `du`, `during`, `ex`, or `exit`. Stateflow executes the state actions in Moore charts as `during` and `exit` actions automatically, as explained in “Combine During and Exit Actions” on page 5-15. Moore charts never execute `entry` actions because these actions always execute as the result of a transition and, therefore, depend on inputs.

Restrict Data to Inputs, Outputs, and Constants

You can define inputs, outputs, parameters, and constants in Moore charts, but other data restrictions apply:

- “Do Not Define Local Data” on page 5-17
- “Restrict Machine-Parented Data to Constants and Parameters” on page 5-17
- “Do Not Define Data Store Memory” on page 5-18

Do Not Define Local Data. You cannot define local data in Moore charts. In Classic Stateflow charts, you can use local data to transfer inputs to outputs, as in this example:

```
local_D = input_U;
output_Y = local_D;
```

However, in Moore charts, you compute outputs from current state only, but never from local data. When a chart contains local data, Stateflow cannot easily verify that outputs do not depend on inputs.

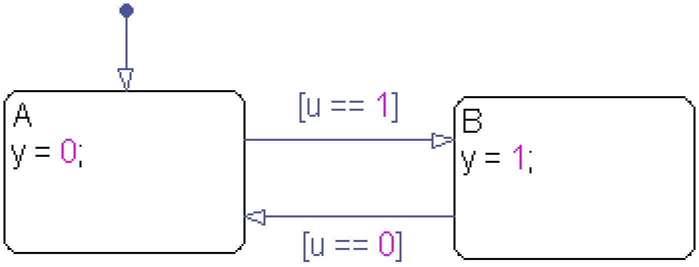
Restrict Machine-Parented Data to Constants and Parameters. Machine-parented data is data that you define for a Stateflow machine, which is the collection of Stateflow blocks in a Simulink model. The Stateflow machine is the highest level of the Stateflow hierarchy. When you define data at this level, every Stateflow 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, Stateflow only allows you to define constants and parameters at the machine level.

Note Stateflow parameters have constant value during simulation and code generation.

Do Not Define Data Store Memory. You cannot define data store memory (DSM) in Moore charts because DSM objects can be modified by objects external to the chart. Stateflow uses data store memory to share data with Simulink. Data store memory acts as global data that can be modified by other blocks and models in the Simulink hierarchy that contains the chart. Moore charts should not access data that can change unpredictably.

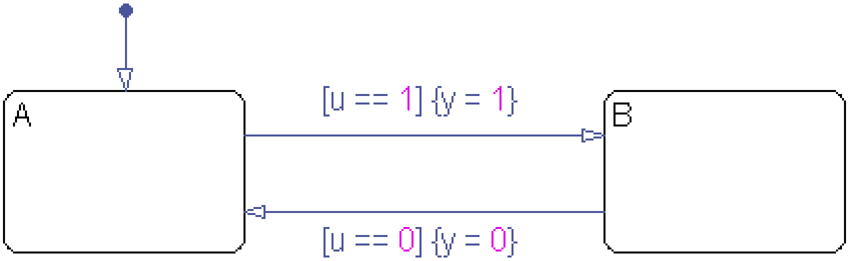
Reference Input Only in Conditions

In Classic Stateflow, you can you can test inputs in conditions on transitions, and then modify outputs in associated condition actions and transition actions. However in Moore charts, outputs can never depend on inputs. Therefore, you can set up conditions on transitions that reference inputs, but you cannot add actions to transitions that modify outputs based on those conditions. For example, the following transitions are allowed in a Moore chart:



In this example, each transition tests input `u` in a condition, but modifies output `y` in a state action.

By contrast, the following transitions are *illegal* in a Moore chart:



Here, each transition tests input u in a condition, but modifies output y in a condition action, based on the value of the input. This construct violates Moore semantics and generates a compiler error. Similarly, you cannot use transition actions in Moore charts.

Do Not Use Actions on Transitions

You cannot define condition actions or transition actions in Moore charts (see "Reference Input Only in Conditions" on page 5-18).

Do Not Use Graphical Functions

You cannot use graphical functions in Moore charts. This restriction prevents scenarios that violate Moore semantics, such as

- Adding conditions that call functions which compute outputs as a side effect
- Adding state actions that call functions which reference inputs

Restrict Use of Events

You must limit the use of events in Moore charts as follows:

Do:	Do Not:
Use input events to trigger the chart	Broadcast any type of event
Use temporal logic to guard transitions You can use temporal logic in Moore charts because it behaves synchronously. Think of the change in value of a temporal logic condition as an event that the chart schedules internally. Therefore, at each time step, the chart retains its notion of state because it knows how many ticks remain before the temporal event executes. **Note** In Moore charts, the base event for temporal logic operators must be a predefined event such as `tick` or `wakeup` (see "Referencing Implicit Events" on page 7-24).	Use local or machine-parented events to guard transitions You cannot use local or machine-parented events in Moore charts because they are not deterministic. These events can occur while the chart computes outputs and, therefore, violate Moore semantics which require charts to compute outputs whenever input changes.

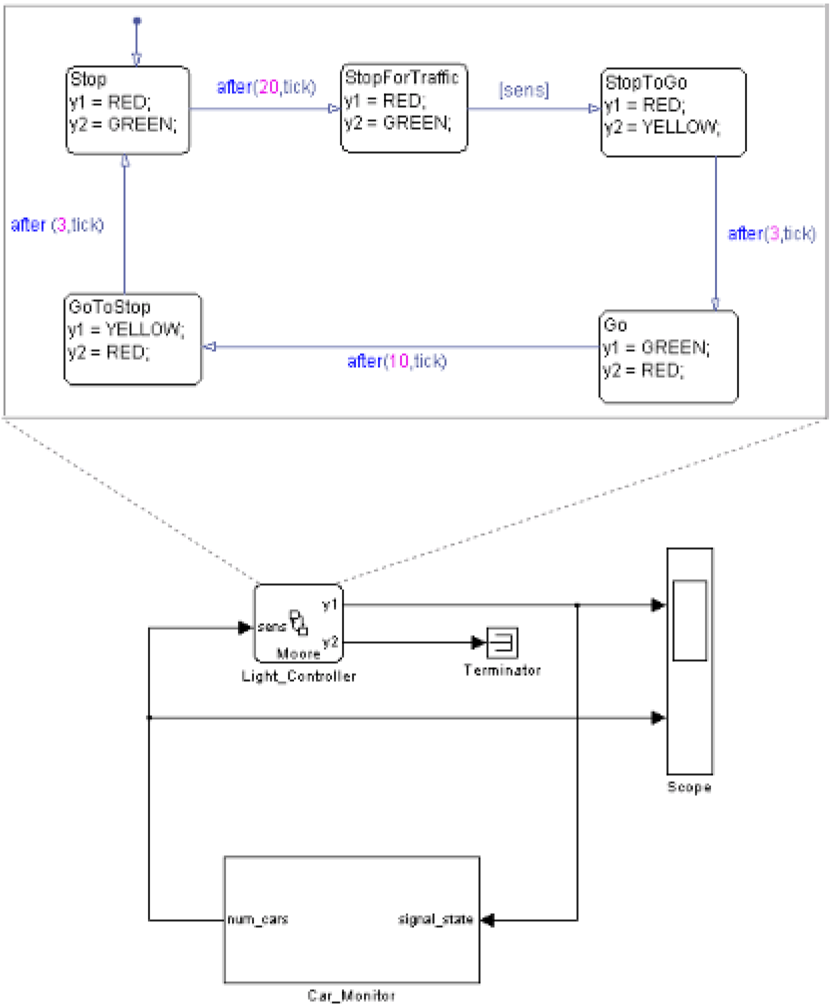
Initialize Outputs Every Time Chart Wakes Up

Stateflow automatically applies the initial value of outputs every time a Moore chart wakes up to prevent latching of outputs. This is a requirement for Moore charts to ensure that outputs do not depend on previous values of outputs.

When you create a Moore chart, Stateflow automatically enables the chart property **Initialize Outputs Every Time Chart Wakes Up** and does not allow you to disable it. For more information about this property, see "Setting Properties for Individual Charts" on page 10-6.

Example: Moore Traffic Light

The following chart uses Moore semantics to model a traffic light:



Logic of the Moore Traffic Light

In this example, the traffic light model contains a Stateflow 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 Stateflow 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, as follows:

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 the following Moore design rules:

- The chart computes outputs in state actions.
- Actions appear in leaf states only.
- Leaf states contain no more than one action.
- 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`)

Changing Chart Type

The best practice is not to change from one Stateflow chart type to another in the middle of development. Stateflow does not *automatically* convert the semantics of the original chart to conform to the design rules of the new chart type. Changing type usually requires you to redesign your chart to achieve *equivalent behavior* — that is, where both charts produce the same sequence of outputs given the identical sequence of inputs. To assist you, Stateflow provides informative diagnostic messages at compile time (see "Debugging Mealy and Moore Charts" on page 5-25). In some cases, however, there may be no way to translate specific behaviors without violating chart definitions.

Here is a summary of how Stateflow responds when you change chart types mid-design:

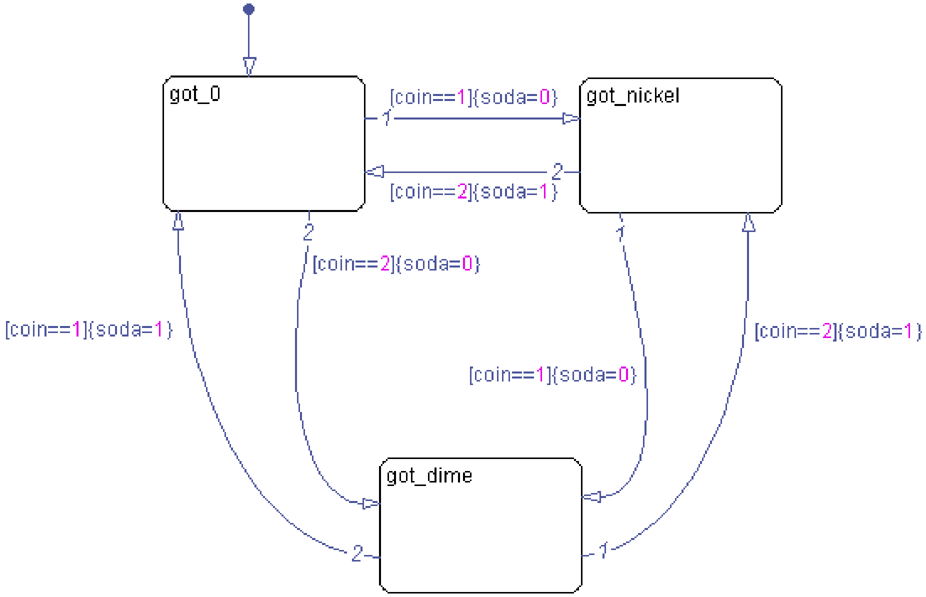
From	To	Result
Mealy	Classic	Mealy charts retain their semantics when changed to Classic type.
Classic	Mealy	If the Classic chart confirms to Mealy semantic rules, the Mealy chart exhibits equivalent behavior, provided that output is defined at every time step.
Moore	Classic	Stateflow interprets the state actions in the Moore chart as `entry` actions because they are not labeled. Therefore, the Classic chart will not exhibit behavior that is equivalent to the original Moore chart. Requires redesign.
Classic	Moore	Stateflow interprets actions that are unlabeled in the Classic chart (`entry` actions by default) as `during` and `exit` actions. Therefore, the Moore chart will not exhibit behavior that is equivalent to the original Classic chart. Requires redesign.
Mealy	Moore	Converting between these two types does not produce equivalent behavior because Mealy and Moore rules about placement of actions are mutually exclusive. Requires redesign.
Moore	Mealy	

Debugging Mealy and Moore Charts

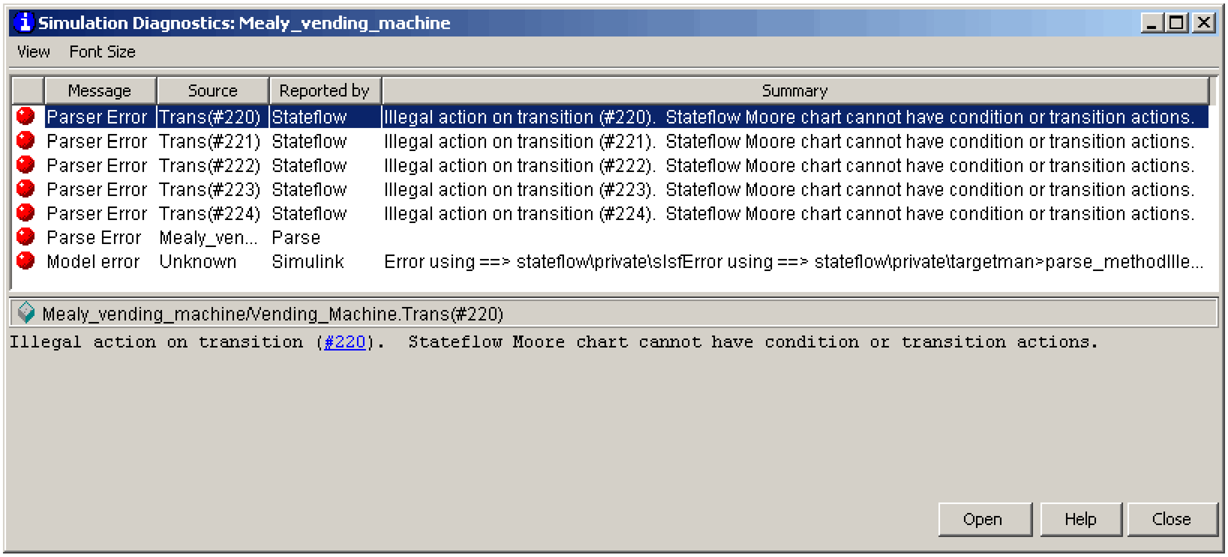
Stateflow verifies the semantics of Mealy and Moore charts at compile time and provides informative diagnostic messages to help you

- Design Mealy and Moore charts from scratch
- Redesign legacy Classic charts to conform to Mealy and Moore semantics
- Redesign charts to convert between Mealy and Moore types

For example, recall the Mealy vending machine chart described in "Example: Mealy Vending Machine" on page 5-11:



If you change the chart type to **Moore** and rebuild, Stateflow provides the following diagnostics:



	Message	Source	Reported by	Summary
●	Parser Error	Trans(#220)	Stateflow	Illegal action on transition (#220). Stateflow Moore chart cannot have condition or transition actions.
●	Parser Error	Trans(#221)	Stateflow	Illegal action on transition (#221). Stateflow Moore chart cannot have condition or transition actions.
●	Parser Error	Trans(#222)	Stateflow	Illegal action on transition (#222). Stateflow Moore chart cannot have condition or transition actions.
●	Parser Error	Trans(#223)	Stateflow	Illegal action on transition (#223). Stateflow Moore chart cannot have condition or transition actions.
●	Parser Error	Trans(#224)	Stateflow	Illegal action on transition (#224). Stateflow Moore chart cannot have condition or transition actions.
●	Parse Error	Mealy_ven...	Parse	
●	Model error	Unknown	Simulink	Error using ==> stateflow\private\slsfError using ==> stateflow\private\targetman>parse_methodIlle...

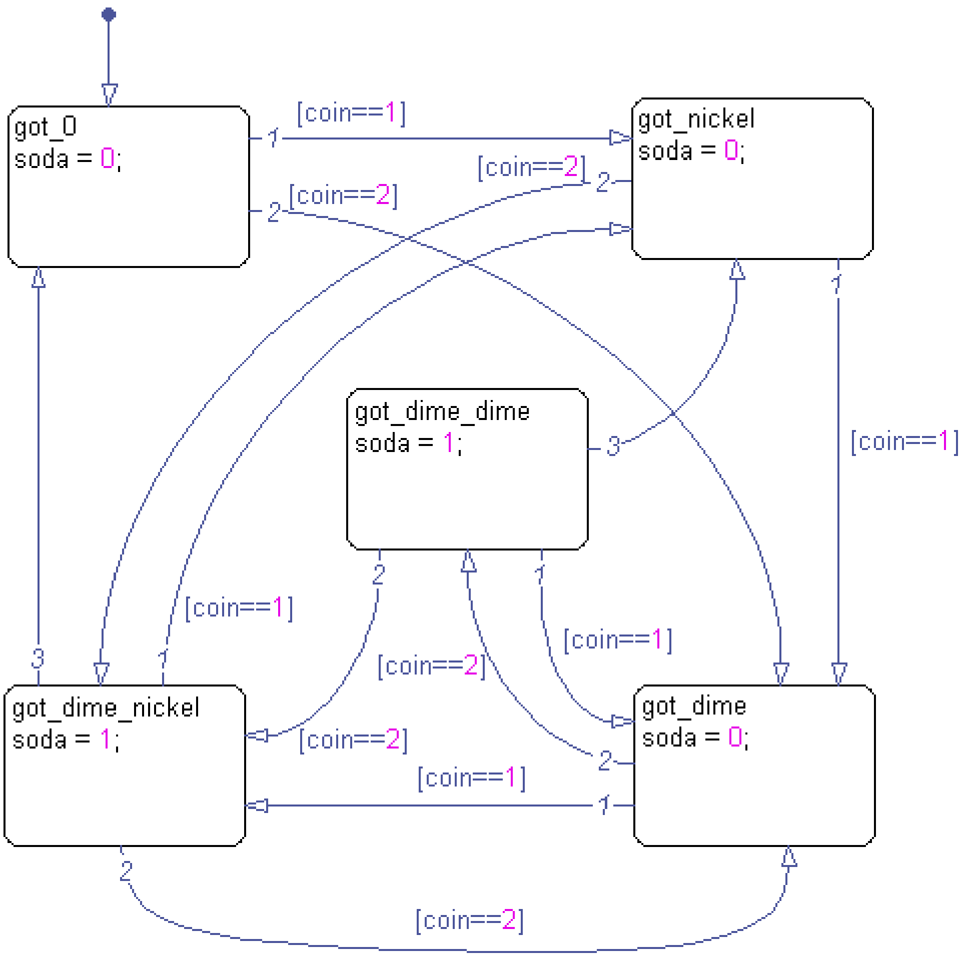
Mealy_vending_machine/Vending_Machine.Trans(#220)

```
Illegal action on transition (#220).  Stateflow Moore chart cannot have condition or transition actions.
```

These diagnostics alert you to the fact that you cannot define actions on transitions. Without actions, you cannot compute outputs on transitions in Moore charts (see “Do Not Use Actions on Transitions” on page 5-19). According to Moore semantics, you must instead compute outputs in state actions (see “Design Rules for Moore Charts” on page 5-14).

In the Mealy chart, each condition action computes output (*whether or not soda is released*) based on input (*the coin received*). Each state represents one of the three possible coin inputs: nickel, dime, or no coin. Stateflow computes the output as the Mealy chart transitions to the next state. When you move this logic out of transitions and into state actions in the Moore chart, you need more states. The reason is that in the Moore chart, each state must represent not only coins received, but also the soda release condition. In the Moore chart, Stateflow must compute output according to the active state *before* considering input. As a result, there will be a delay in releasing soda, even if the machine receives enough money to cover the cost.

Here is the equivalent vending machine, designed as a Moore chart:



The following table compares the semantics of the two charts:

Mealy Vending Machine	Moore Vending Machine
Uses 3 states	Uses 5 states

Mealy Vending Machine	Moore Vending Machine
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

Note For this vending machine, Mealy is a better modeling paradigm because there is no delay in releasing soda once sufficient coins are received. By contrast, the Moore vending machine requires an extra time step to pass before producing soda. Since the Moore vending machine accepts a nickel, a dime, or no coin in a given time step, it is possible that the soda will be produced in a time step in which a coin is accepted toward the next purchase. In this situation, the delivery of a soda may appear to be in response to this coin, but actually occurs because the vending machine received the purchase price in previous time steps.

6

Extending Stateflow Chart Diagrams

This chapter takes you through the steps of extending Stateflow states, transitions, and junctions with subcharts, boxes, functions, and notes. It includes the following sections:

Using History Junctions to Extend Charts and States

History junctions extend the ability of charts and states by recording the activity of substates inside superstates. Use a history junction in a chart or superstate to indicate that its last active substate becomes active when the chart or superstate becomes active.

The following topics describe how to create, and specify properties for history junctions in Stateflow:

- "Creating a History Junction" on page 6-3
- "Changing History Junction Size" on page 6-4
- "Changing History Junction Properties" on page 6-4

Creating a History Junction

To create a junction, do the following:

1. In the diagram toolbar, click the **History Junction** tool Ⓗ.
2. Move the cursor into the diagram editor.

   The cursor takes on the shape of a junction.
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 diagram toolbar, double-click the **History Junction** tool.
2. The button is now in multiple object mode.
3. Click anywhere in the drawing area to place a history junction.
4. Move to and click another location to create an additional history junction.
5. Click the **History Junction** tool 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.

Changing History Junction Size

To change the size of junctions, do the following:

1 Select the history junctions whose size you want to change.

2 Place the cursor over one of the junctions and right-click.

3 In the resulting submenu, place the cursor over **Junction Size**.

A menu of junction sizes appears.

4 Select a size from the menu of junction sizes.

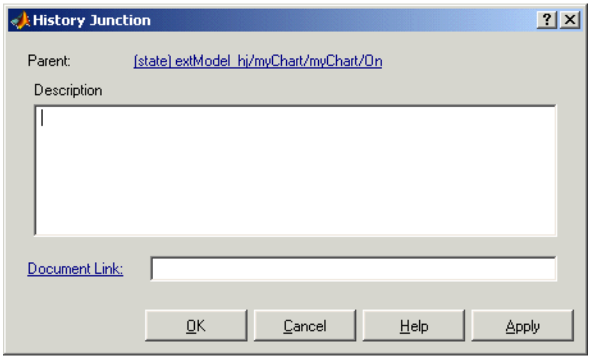
Changing History Junction Properties

To edit the properties for a junction, do the following:

1 Right-click a junction.

2 In the resulting submenu select **Properties**.

The **History Junction** dialog appears as shown.



History Junction

Parent: [state] extModel_hj/myChart/myChart/On

Description

Document Link:

3 Edit the fields in the properties dialog, which are described in the following table:

Field	Description
Parent	Parent of this history junction; read-only; click the hypertext link to bring the parent to the foreground.
Description	Textual description/comment.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

4 When finished editing, select one of the following:

- Select the **Apply** button to save the changes.
- Select the **Cancel** button to cancel any changes you've made.
- Select **OK** to save the changes and close the dialog box.
- Select the **Help** button to display the Stateflow online help in an HTML browser window.

Using Subcharts to Extend Charts

Subcharts are charts within charts. They help make your charts more readable and compact. This topic describes how to create and work with subcharts:

- "What Is a Subchart?" on page 6-6
- "Creating a Subchart" on page 6-7
- "Manipulating Subcharts as Objects" on page 6-8
- "Opening a Subchart" on page 6-9
- "Editing a Subchart" on page 6-10
- "Navigating Subcharts" on page 6-10

What Is a Subchart?

Stateflow allows you to create charts within charts. A chart that is embedded in another chart is called a *subchart*. The subchart can contain anything a top-level chart can, including other subcharts. In fact, you can nest subcharts to any level.

A subcharted state is a superstate of the states and charts that it contains. It 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. Further, 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 "Using Supertransitions to Extend Transitions" on page 6-12 for more information.

Subcharts enable you to reduce a complex chart to a set of simpler, hierarchically organized diagrams. This makes the chart easier to understand and maintain. Nor do you have to worry about changing the semantics of the chart in any way. Stateflow ignores subchart boundaries when simulating and generating code from Stateflow models.

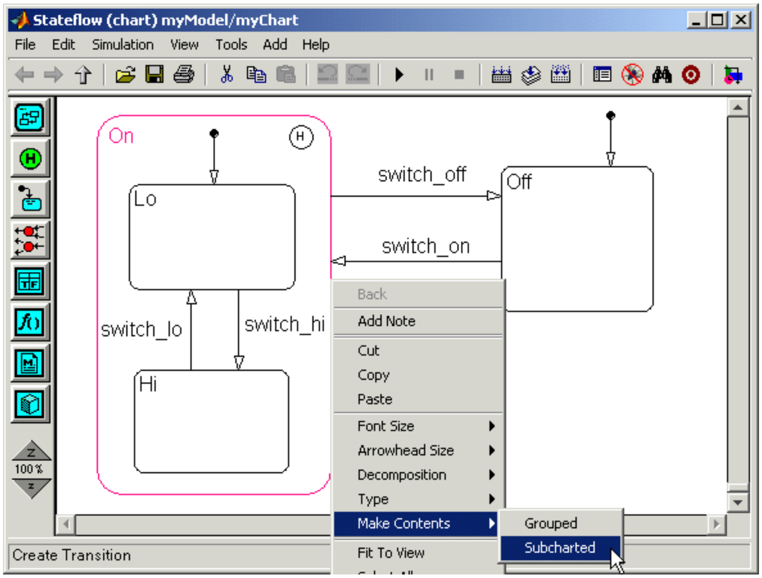
Subcharts define a containment hierarchy within a top-level chart. A subchart or top-level chart is said to be the *parent* of the charts it contains at the first level and an *ancestor* of all the subcharts contained by its children and their descendants at lower levels.

Creating a Subchart

You create a subchart by converting an existing state, box, or graphical function into the subchart. The object to be converted can be one that you have created expressly for the purpose of making a subchart or it can be 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:

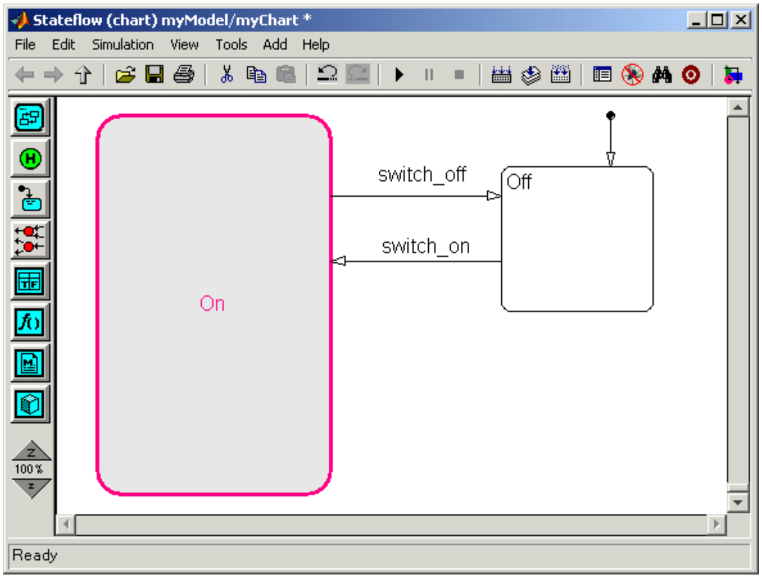
1. Select the object and right-click a state (SC1 in the example below) to display the Stateflow shortcut menu for that state.



2. Select **Make Contents** from the resulting menu.

3. Select **Subcharted** from the resulting submenu.

   Stateflow converts the state (or a graphical function or box) to a subchart.


Stateflow (chart) myModel/myChart *
File Edit Simulation View Tools Add Help
switch_off
Off
switch_on
On
100%
Ready

Note When you convert a box to a subchart, the subchart retains the attributes of a box. In particular, the resulting subchart's position in the chart determines its activation order (see "Using Boxes to Extend Chart Diagrams" on page 6-45 for more information).

To convert the subchart back to its original form, right-click the subchart. In the pop-up menu that results, select **Make Contents**. In the resulting submenu select the **Subcharted** item.

Caution 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.

Manipulating Subcharts as Objects

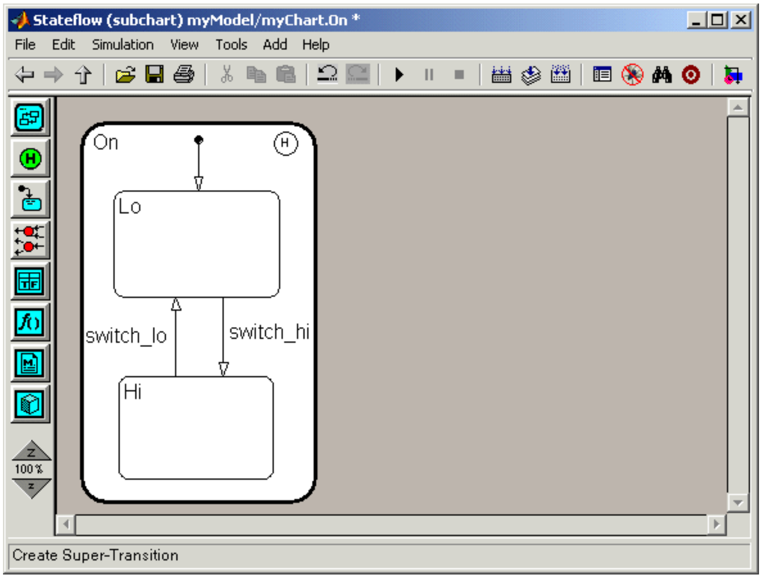
Subcharts also act as individual objects in Stateflow. You can move, copy, cut, paste, relabel, and resize subcharts as you would states and boxes. You can also draw transitions to and from a subchart and any other state or subchart at the same or different levels in the chart hierarchy (see "Using Supertransitions to Extend Transitions" on page 6-12).

Opening 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.

Stateflow replaces the current diagram editor display with the contents of the subchart, as shown.


Stateflow (subchart) myModel/myChart.On *
File Edit Simulation View Tools Add Help
100 %
On
H
Lo
switch_lo
switch_hi
Hi
Create Super-Transition

A shaded border surrounds the contents of the subchart. Stateflow uses the border to display supertransitions.

To return to the previous view, select **Back** from the Stateflow shortcut menu, press the **Esc** key on your keyboard, or select the up or back arrow on the Stateflow toolbar.

Editing a Subchart

After you open a subchart (see “Opening a Subchart” on page 6-9), 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 “Using Supertransitions to Extend Transitions” on page 6-12 for information on creating supertransitions.

Navigating Subcharts

The Stateflow toolbar contains a set of buttons for navigating a chart’s subchart hierarchy.

Tool	Description
⇧	If the Stateflow editor is displaying a subchart, replaces the subchart with the subchart’s parent in the editor. If the editor is displaying a top-level chart, this button raises the Simulink model window containing that chart.
⇦	Returns to the chart that you visited before the current chart. Lets you navigate up the hierarchy.
⇦	Returns to the chart that you visited after visiting the current chart. Lets you navigate down the hierarchy.

Note You can also use the key sequence **..** (that is, press the period key twice) to navigate up to the parent object for a subcharted state, box, or function.

Using Supertransitions to Extend Transitions

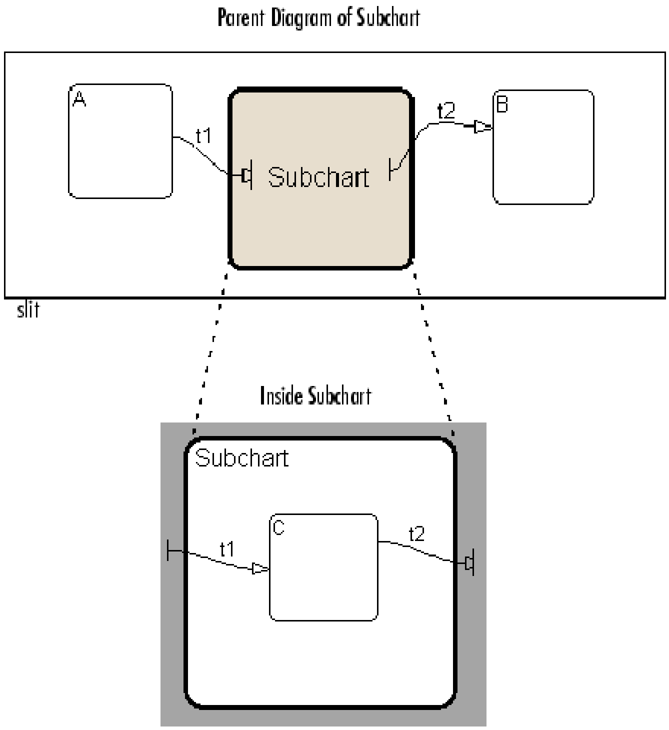
Supertransitions connect transitions from outside a subchart to an object inside a subchart. The following topics explain how to work with supertransitions:

- "What Is a Supertransition?" on page 6-12
- "Drawing a Supertransition Into a Subchart" on page 6-13
- "Drawing a Supertransition Out of a Subchart" on page 6-16
- "Labeling Supertransitions" on page 6-17

What Is a Supertransition?

A *supertransition* is a transition between different levels in a chart, for example, 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 diagram. Stateflow allows you to 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, the following diagram shows two supertransitions as seen from the perspective of a subchart and its parent chart, respectively.



In this example, supertransition t1 goes from state A in the parent chart to state C in the subchart and supertransition t2 goes from state C in the subchart to state B in the parent chart. Note that both segments of t1 and t2 have the same label.

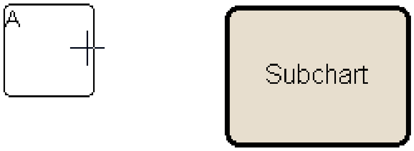
Drawing a Supertransition Into a Subchart

Use the following steps to draw a supertransition from an object outside a subchart to an object inside the subchart.

Caution 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.

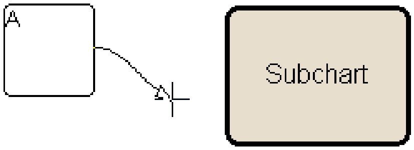
1 Position the mouse cursor over the border of the state.

The cursor assumes the crosshairs shape.



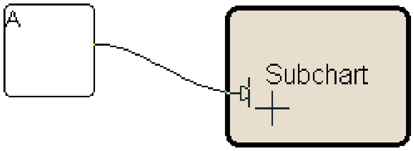
2 Drag the mouse.

Dragging the mouse causes a supertransition segment to appear. The segment looks like a regular transition. It is curved and is tipped by an arrowhead.



3 Drag the segment's tip anywhere just inside the border of the subchart.

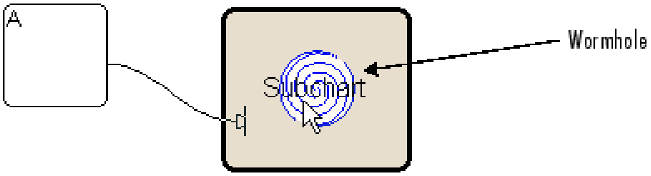
The arrowhead now penetrates the slit.



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.

4 Continue dragging the cursor toward the center of the subchart.

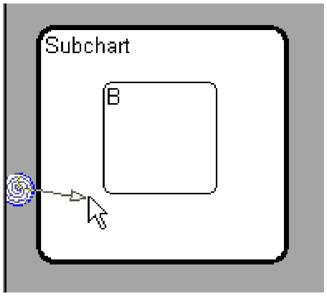
A wormhole appears in the center of the subchart.



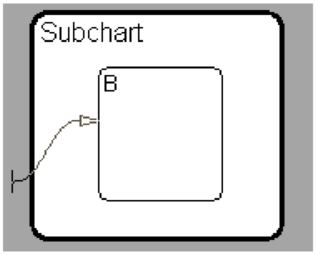
A *wormhole* allows you to open a subchart while drawing a supertransition.

5 Drag the mouse pointer over the center of the wormhole.

The subchart opens. Now the wormhole and supertransition are visible inside the subchart.



6 Drag and drop the tip of the supertransition anywhere on the border of the object that you want to terminate the transition.



Note If the terminating object resides within a subchart in the current subchart, continue to drag the tip of the supertransition through the wormhole of the inner subchart and complete the connection inside the inner chart. In this way, you can draw a supertransition to an object at any subchart depth in the chart.

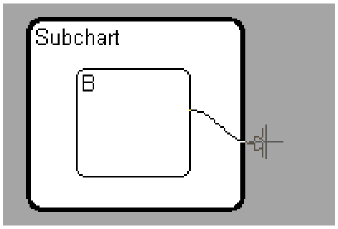
Drawing a Supertransition Out of a Subchart

Use the following steps to draw a supertransition out of a subchart.

Caution 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.

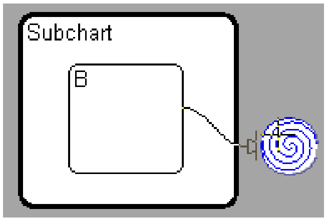
1 Draw an inner transition segment from the source object anywhere just outside the border of the subchart

A slit appears as shown.



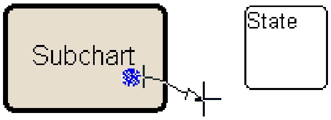
2 Keep dragging the transition away from the border of the subchart.

A wormhole appears.

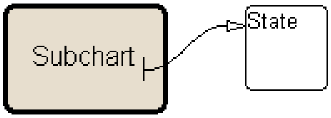


3 Drag the transition down the wormhole.

The parent of the subchart appears.



4 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, you can continue drawing by dragging the supertransition into the border of the parent subchart. This allows you to continue drawing the supertransition at the higher level. In this way, you can connect objects separated by any number of layers in the subchart hierarchy.

Labeling 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 “Labeling Transitions” on page 4-17). 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.

Extending Transitions with Smart Behavior

Transitions with smart behavior — known as *smart transitions* — attach their ends to the surfaces of Stateflow objects and, therefore, maintain their shapes and uniqueness when you rearrange chart objects.

The following topics explain how to work with smart transitions:

- "Setting Smart Behavior in Transitions" on page 6-19
- "What Smart Transitions Do" on page 6-20
- "What Nonsmart Transitions Do" on page 6-26

Setting Smart Behavior in Transitions

Transitions are automatically created with smart behavior, on the assumption that this behavior is desirable in most circumstances. You can disable or enable smart behavior in existing transitions with the following procedure:

1. Right-click a transition.

   On the resulting menu, observe the selection titled **Smart**. If a check mark appears in front of **Smart**, the transition has smart behavior.

2. If **Smart** is not checked, select it to enable smart behavior.

   To disable smart transition behavior, select **Smart** if it is already checked.

See the following sections for a comparison of behavior between smart and nonsmart transitions:

- "What Smart Transitions Do" on page 6-20
- "What Nonsmart Transitions Do" on page 6-26

Note Transitions with smart behavior differ graphically only. Apart from graphical behavior, there is no difference in meaning between a transition with and without smart behavior.

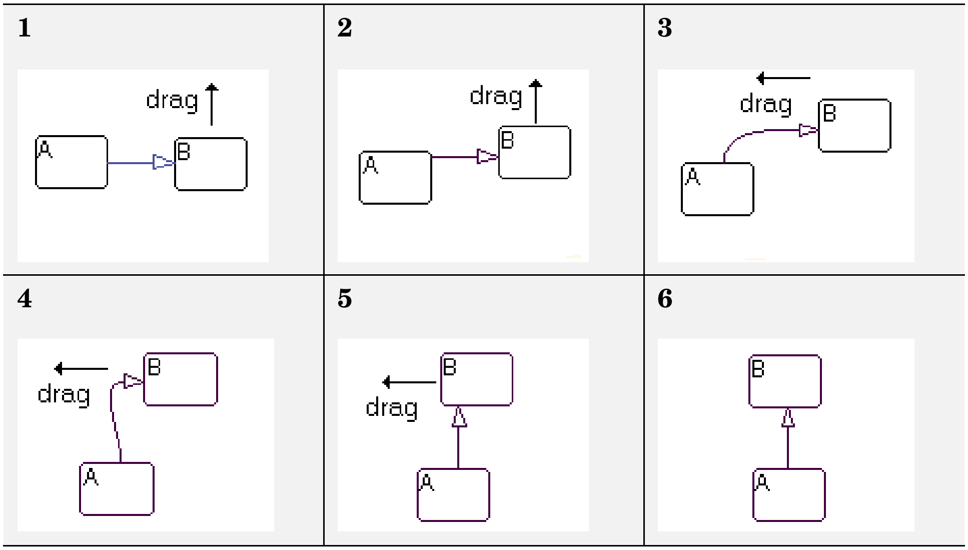
What Smart Transitions Do

The following topics discuss some of the behaviors of smart transitions:

- "Smart Transitions Slide Around Surfaces" on page 6-20
- "Smart Transitions Slide and Maintain Shape" on page 6-21
- "Smart Transitions Connect States to Junctions at 90 Degree Angles" on page 6-22
- "Smart Transitions Snap to an Invisible Grid" on page 6-24
- "Smart Transitions Bow Symmetrically" on page 6-25

Smart Transitions Slide Around Surfaces

In the following example, state B is attached to state A by a smart transition. The example shows state B being dragged counterclockwise around the upper right corner of state A. When this occurs, state B turns to its selection color and the transition turns to a very light shade of gray, a sure sign of smart behavior. Dragging direction is shown by the arrows.



Note the following step-by-step behavior for the preceding example:

1 The first capture shows states A and B at the beginning of movement.

2 As B moves upward, the transition's back end slides upward on A, maintaining the transition straight.

3 As B moves around A's corner, the back end of the transition suddenly hops around A's upper right-hand corner. The transition is now curved from A's top surface to B's left side, maintaining perpendicularity with each attached state side.

Note A hop around a state's corner is a necessity because transitions are restricted from attaching at corners of states.

4 As B moves on top of A, the transition stays curved but its front end slides down to B's lower left-hand corner.

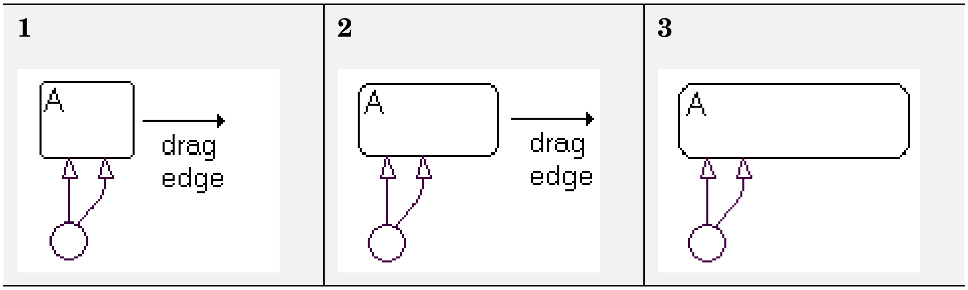
5 As B continues to move to the left over A, the transition's front end hops around B's lower left-hand corner.

6 Finally, as B moves directly over A, the transition's front end slides onto B's bottom edge.

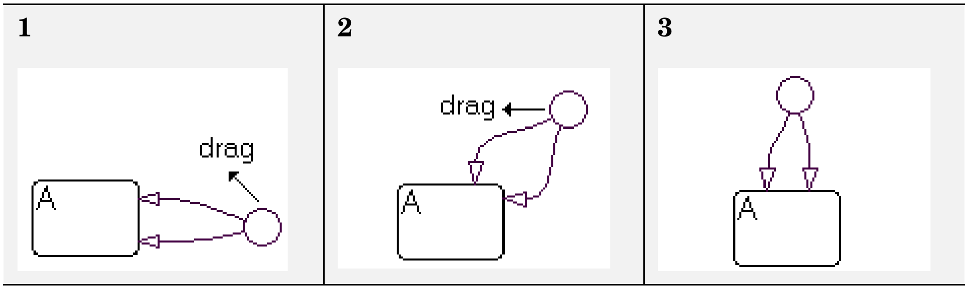
As B continues to circle A, steps 1 through 6 repeat for each of A's remaining sides.

Smart Transitions Slide and Maintain Shape

While transitions with smart behavior allow their ends to slide around the surfaces of their connected objects, they also attempt to maintain their original shape during moving. In the following example, a pair of transitions with smart behavior slide during a resizing to maintain their original shape.

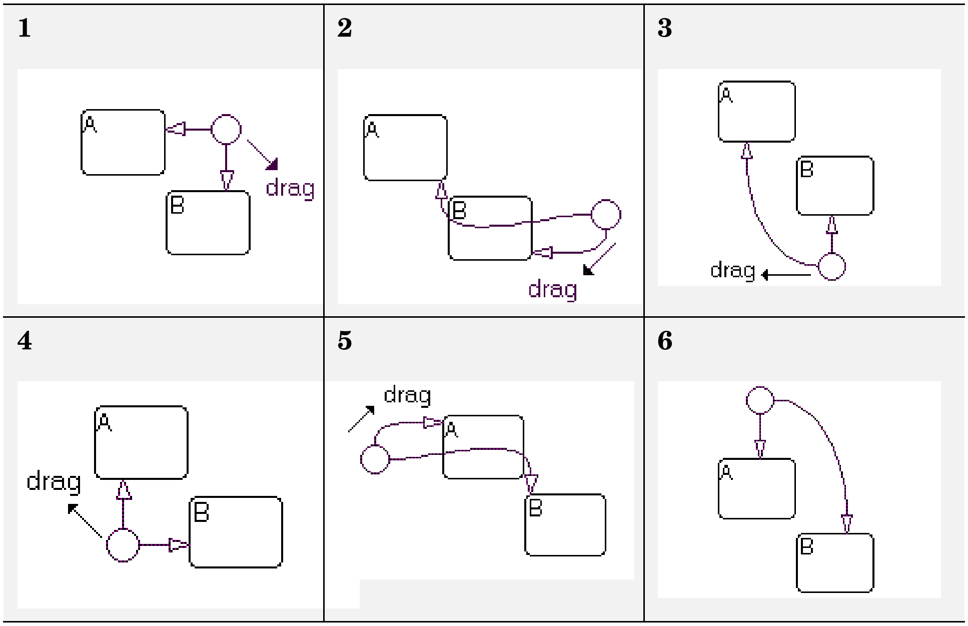


In the following example, the ends of a pair of transitions with smart behavior emanate from a junction and terminate in a state. As the junction is dragged around the state, the ends slide around the state and maintain the same relative spacing between each other. Direction is indicated by the arrows.



Smart Transitions Connect States to Junctions at 90 Degree Angles

Straight-line connections to states must be in one of four directions: left, right, up, or down. To maintain their straightness, smart transitions from junctions always seek to connect to a state through equivalent locations on the junction (left, right, top, bottom). In the following example, a junction is connected to two states, A and B. Watch the behavior of two straight smart transitions as the junction is moved to different locations.



1. The junction starts with two straight smart transition connections to states A and B.

2. Stateflow chooses to connect the junction to state A through the junction's left side. Since the junction is below A, only a curved connection is possible.

   State B could be connected by a straight line through the junction's left side, but this is already occupied by the connection to A. Therefore, B is connected through the junction's bottom, and must be curved.

3. Stateflow connects the junction to B by a straight transition through the junction's top connection. No straight-line connection to A is possible, therefore the junction is connected to state A with a curved transition through its left side.

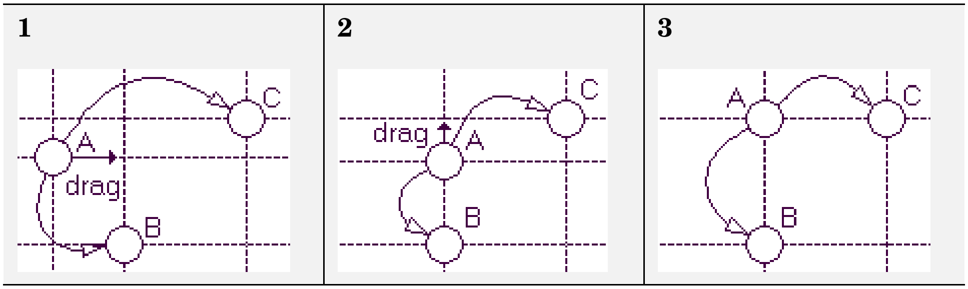
4. At this location (under A, to the left of B), straight-line transitions to A and B are possible from the junction's top and right connection points, respectively.

5 At the location left of state A, Stateflow chooses to connect to state B through its right connection point. Since the junction is above B, only a curved connection is possible.

6 Above A, a straight-line transition to state A is possible through the junction's bottom connector. A straight-line connection to state B is not possible, so the junction is connected to state B through a curved transition from its right connection.

Smart Transitions Snap to an Invisible Grid

Junctions that are connected to other junctions with smart transitions will snap to an invisible grid consisting of horizontal and vertical lines that pass through the center of each junction. The following example depicts this behavior.



Here, the invisible grid is depicted for each of the three junctions by dashed vertical and horizontal lines. Each junction is connected to each other through nonlinear smart transitions:

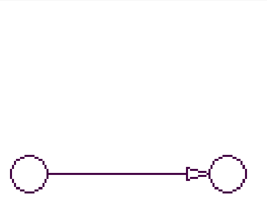
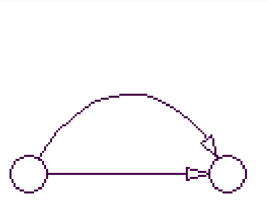
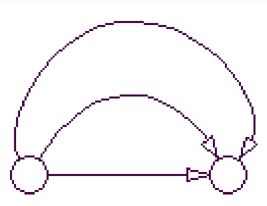
1 In the first scene, the snap grid for each junction does not overlap. The arrow indicates that junction A is being moved toward the vertical snap line for junction B.

2 When A is within a very small distance of B's snap line, A snaps into position directly above B and centered in its vertical snap line. The arrow indicates that A is now being moved toward the horizontal snap line for junction C.

3 When A is within a very small distance of C's horizontal snap line, A snaps into position directly to the side of C and centered in its horizontal snap line.

Smart Transitions Bow Symmetrically

Transitions with smart behavior bow symmetrically between junctions. In the following examples, transitions with smart behavior are drawn between two junctions:

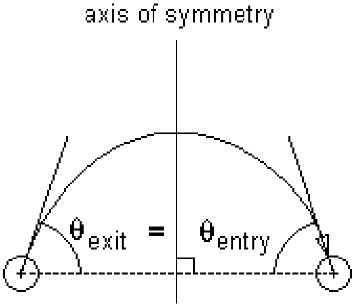
1	2	3
		

1 In the first case, a transition originates at the junction on the left and terminates on the left side of the right junction. This results in a straight line.

2 In the second case, a transition originates at the junction on the left and terminates on the top of the right junction. This results in a transition line bowed up.

3 In the third case, a transition originates at the junction on the left and terminates on the right side of the right junction. This results in a transition line bowed up even more.

Bowed smart transitions maintain symmetry by maintaining equality between transition entry and exit angles as shown below.



You can bow a smart transition between two junctions to any degree by placing the mouse cursor on any point in the transition (except the attachment points) and clicking and dragging in a direction perpendicular to a straight line connecting the two junctions. You can move the mouse in any direction to bow the transition but Stateflow only uses the component perpendicular to the line connecting the two junctions.

Disabling smart behavior for a transition allows you to distort the transition asymmetrically (see section “Nonsmart Transitions Distort Asymmetrically” on page 6-27). However, if you enable smart behavior again, the transition automatically returns to its prior symmetric bowed shape.

What Nonsmart Transitions Do

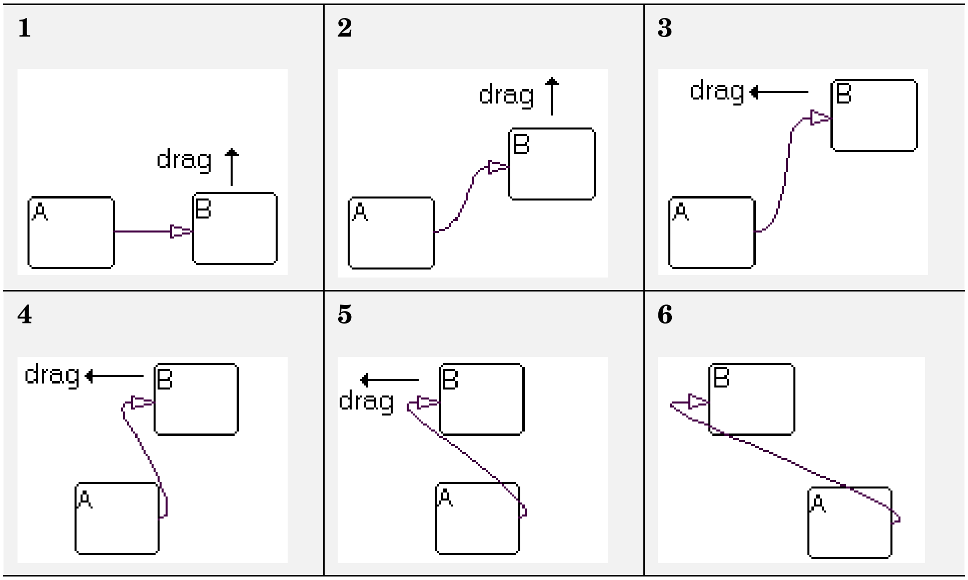
The following topics describe some of the behavior exhibited by transitions without smart behavior.

- “Nonsmart Transitions Anchor Connection Points” on page 6-26
- “Nonsmart Transitions Distort Asymmetrically” on page 6-27

You can disable and enable smart behavior in transitions. See the section “Setting Smart Behavior in Transitions” on page 6-19.

Nonsmart Transitions Anchor Connection Points

Contrast the example in the section “Smart Transitions Slide Around Surfaces” on page 6-20 with the example shown below.

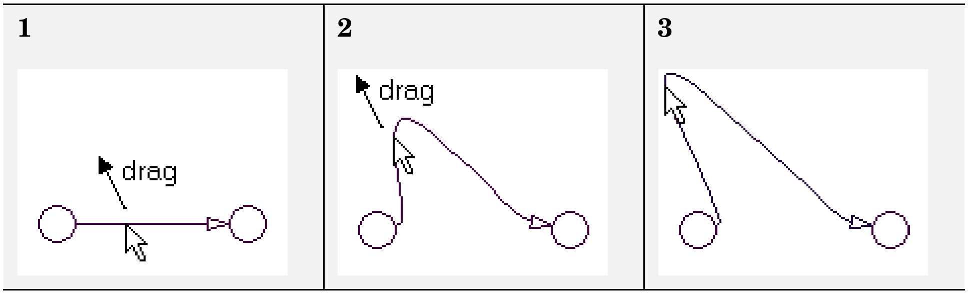


A nonsmart transition connects state A to state B. The mouse cursor is then placed over state B and clicked and dragged to new locations counterclockwise around A. When this occurs, state B turns to its highlight color but the transition remains unchanged, a sure sign of a nonsmart transition.

As B is moved around A, the transition changes into a distorted curve that seeks to maintain the original attachment points. These remain unchanged in position, although the angle of attachment is always perpendicular to the side of the state.

Nonsmart Transitions Distort Asymmetrically

Simply by clicking and dragging on different locations along a transition without smart behavior, you can reshape it into an asymmetric curve suited to your individual preferences. This is illustrated in the following example:



For this example, use the following procedure:

1 Drag a horizontal transition between two junctions.

2 Right-click the transition and select **Smart** from the resulting shortcut menu to disable smart behavior.

3 Place the mouse cursor on any point on the transition.

4 Click and drag the mouse cursor up and to the left.

Using Functions to Extend Actions

A function in Stateflow is an extension of Stateflow actions. You define a program once in a function, but call it as many times as you need to using Stateflow action language.

Stateflow defines three types of functions: graphical, truth table, and Embedded MATLAB. This section describes graphical functions:

- "Creating a Graphical Function" on page 6-29
- "Programming Different Types of Functions" on page 6-33
- "Defining Graphical Function Data" on page 6-39
- "Calling Graphical Functions in Stateflow" on page 6-41
- "Exporting Graphical Functions" on page 6-41
- "Specifying Graphical Function Properties" on page 6-42

For information about other types of Stateflow functions, see Chapter 12, "Truth Table Functions" and Chapter 13, "Using Embedded MATLAB Functions".

Creating a Graphical Function

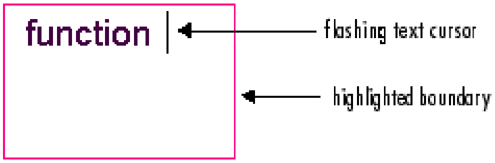
You create a Stateflow graphical, truth table, or embedded MATLAB function in Stateflow diagrams with the following steps:

1 Select a drawing tool for the function from the Stateflow drawing toolbar as follows:

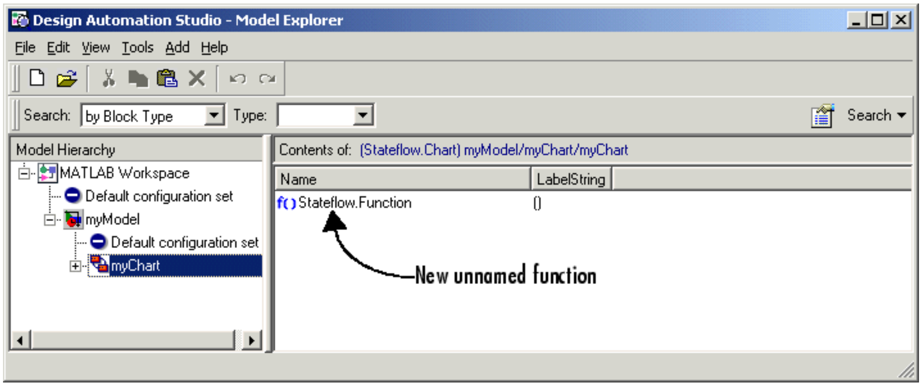
Tool	Function
f()	Graphical
TF	Truth Table
M	Embedded MATLAB

2 Move the cursor to the location for the new function and click to place it.

The new function appears as an unnamed object in the Stateflow diagram editor with a flashing text cursor as seen in the following graphical function example.



The new function also appears in the **Model Explorer** as a child of the chart or state in which it is drawn. In the following example, a graphical function is added to its parent Stateflow chart, `myChart`.


Design Automation Studio - Model Explorer
File Edit View Tools Add Help
Search: by Block Type
Type:
Search
Model Hierarchy
MATLAB Workspace
Default configuration set
myModel
Default configuration set
myChart
New unnamed function

Contents of: (Stateflow.Chart) myModel/myChart/myChart

Name	LabelString
f() Stateflow.Function	()

A function can reside anywhere in a chart, state, or subchart. The location of a function determines its scope, that is, the set of states and transitions that can call the function. In particular, functions are visible to the chart, to the parent state and its parents, and to sibling transitions and states with the following exceptions.

- If the chart containing the function exports its graphical functions, the scope of the function is the entire Stateflow machine, which encompasses all the charts in the model. See "Exporting Graphical Functions" on page 6-41 for more information.

- A function defined in a state or subchart overrides any functions of the same name defined in the parents and ancestors of that state or subchart.

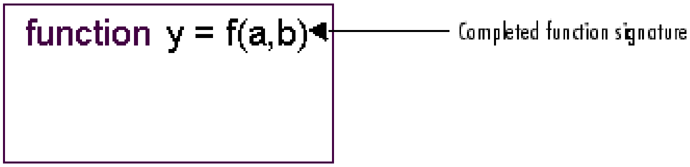
3 Enter the function signature and click outside of the function box.

The function signature specifies a name for the function and formal names for its arguments and return value. A signature has the following syntax:

$$\texttt{r = func(}\texttt{a}_1\texttt{,a}_2\texttt{,...a}_n\texttt{)}$$

where `func` is the function's name, $\texttt{a}_1$, $\texttt{a}_2$, $\texttt{a}_n$ are formal names for its arguments, and `r` is the formal name for its return value (only one return is allowed). Arguments and return values can be scalars, vectors, or 2-dimensional matrices of any type. Matrices with a row or column dimension of 1 are treated as row or column vectors, respectively.

The following example shows a signature for a graphical function named `f1` that takes two arguments, `a` and `b`, and returns a value `y`.

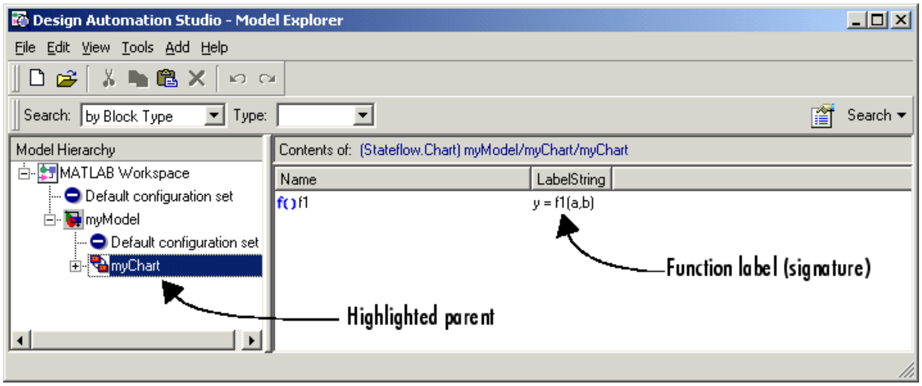


```
function y = f(a,b)
```

Completed function signature

Notice that the function box in the preceding example has been enlarged to accommodate the width of its label signature. You enlarge function boxes in their corners, just as for state and box objects.

The signature for a function appears as a property of its owning object in the **Model Explorer**.


Design Automation Studio - Model Explorer
File Edit View Tools Add Help
Search
Model Hierarchy
MATLAB Workspace
Default configuration set
myModel
Default configuration set
myChart

Search: by Block Type Type:

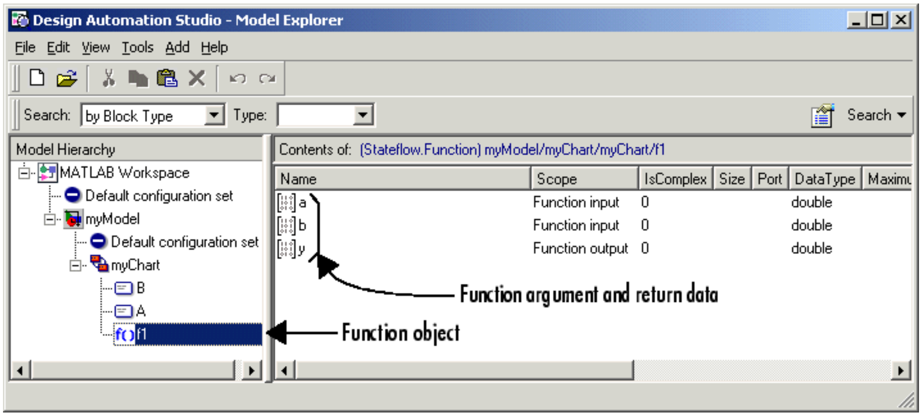
Contents of: (Stateflow.Chart) myModel/myChart/myChart

Name	LabelString
f() f1	y = f1(a,b)

Function label (signature)

Highlighted parent

If you expand the parent object in the **Model Explorer**, you can see the return values and arguments that you declare in the signature for a function as data items parented by the function.


Design Automation Studio - Model Explorer
File Edit View Tools Add Help
Search
Model Hierarchy
MATLAB Workspace
Default configuration set
myModel
Default configuration set
myChart
B
A
f() f1

Search: by Block Type Type:

Contents of: (Stateflow.Function) myModel/myChart/myChart/f1

Name	Scope	IsComplex	Size	Port	DataType	Maximu
a	Function input	0			double	
b	Function input	0			double	
y	Function output	0			double	

Function argument and return data

Function object

The **Scope** field in the Explorer indicates the role of each argument or return value. Arguments have the scope `Function input`, and return values have scope `Function output`.

Note You can use the Stateflow diagram editor to change the signature of a graphical function at any time. When you are done editing the signature, Stateflow updates the data dictionary and the **Model Explorer** to reflect the changes.

Programming Different Types of Functions

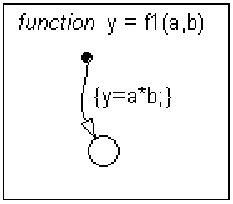
In “Creating a Graphical Function” on page 6-29, you learn how to create a function with a return value and arguments in a Stateflow diagram. In the context of programming a function, arguments and return values have local scope. They are visible only in the environment that programs the function. This topic introduces you to the environment for each function in which you program its behavior with the function subtopics that follow.

Graphical Functions

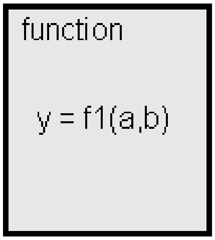
A Stateflow graphical function is a program written with Stateflow flow graphs using connective junctions and transitions. You create a graphical function, fill it with a flow diagram, and call it repeatedly in the actions of states and transitions.

Because a function must execute completely when it is called, states are not allowed in graphical functions. When a state is entered, execution stops until an event occurs.

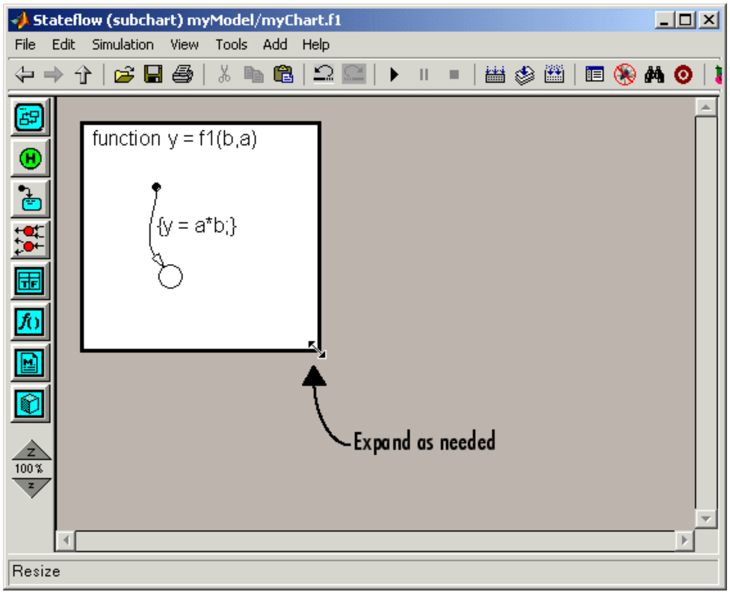
At a minimum, the flow diagram must include a default transition with a terminating junction. The following example shows a minimal flow diagram for a graphical function that returns the product of its arguments.



You can make a graphical function as complicated and as long as you want. However, because complicated graphical functions can become very large, it may be difficult to fit it into the Stateflow diagram. To make the function smaller, hide the function's contents by selecting **Subcharted** from the **Make Contents** menu of the function's shortcut menu. This makes the graphical function opaque as shown.



To access the programming of a subcharted graphical function, double-click it. This dedicates the entire Stateflow diagram window to programming the function, as shown.

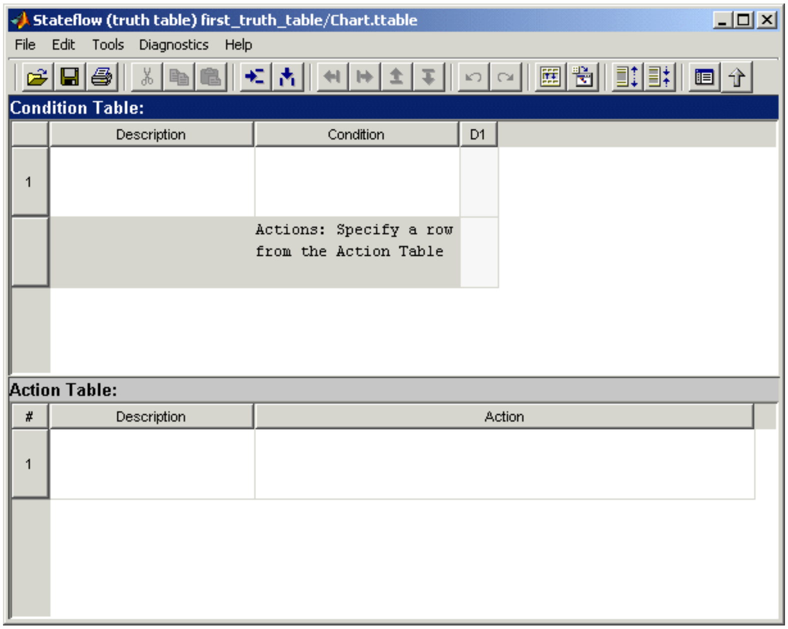


Expand as needed

To access the original Stateflow diagram, select the Back button ⇦.

Truth Table Functions

You program a truth table in the truth table editor. Access this editor for a truth table by double-clicking it in the Stateflow diagram, and the truth table editor appears.



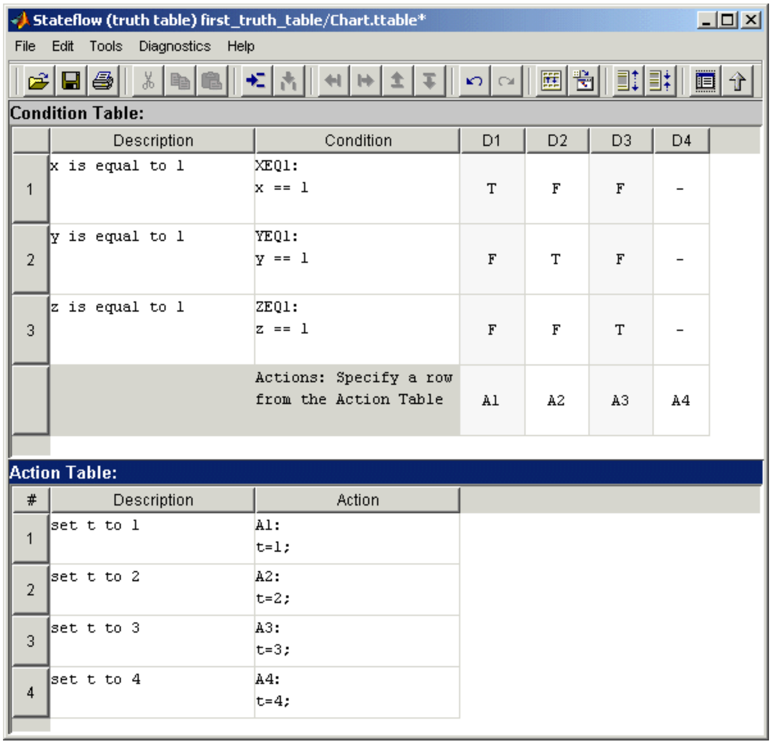
Condition Table:

	Description	Condition	D1
1			
		Actions: Specify a row from the Action Table	

Action Table:

#	Description	Action
1		

Truth table functions in Stateflow are very suitable for implementing functions with logical behavior. You program truth tables with logical behavior in the form of action language conditions, decisions, and actions. For example, the following truth table


Stateflow (truth table) first_truth_table/Chart.ttable*
File Edit Tools Diagnostics Help

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	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

implements the following logic expressed in pseudocode:

Description	Pseudocode

Decision 1
Decision 1 Action
	`if ((x == 1) & !(y == 1) & !(z == 1))`
	` t = 1;`

Decision 2
Decision 2 Action
	`elseif (!(x == 1) & (y == 1) !(z == 1))`
	` t = 2;`

Description	Pseudocode

Decision 3
Decision 3 Action
	`elseif (!(x == 1) & !(y == 1) (z == 1))`
	` t = 3;`

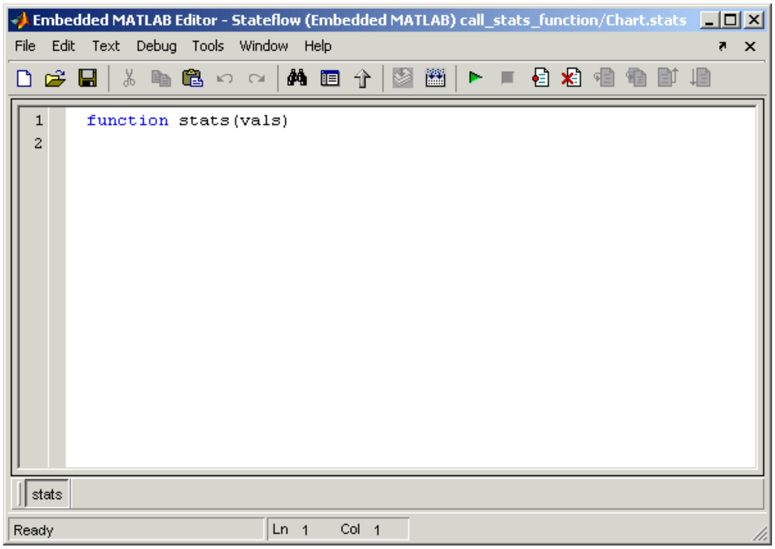
Default Decision
Default Decision Action
	`else`
	` t = 4;`
	`endif`

When you try to simulate your truth tables, Stateflow detects whether they are underspecified or overspecified. Underspecified truth tables contain fewer than all possible decisions for the conditions you specify. Overspecified truth tables contain redundant decisions that prevent other decisions from being evaluated. Stateflow detects both underspecified and overspecified truth tables and tells you the decisions you need to specify or remove in the truth table.

See Chapter 12, “Truth Table Functions”, for a thorough understanding of truth table functions in Stateflow.

Embedded MATLAB Functions

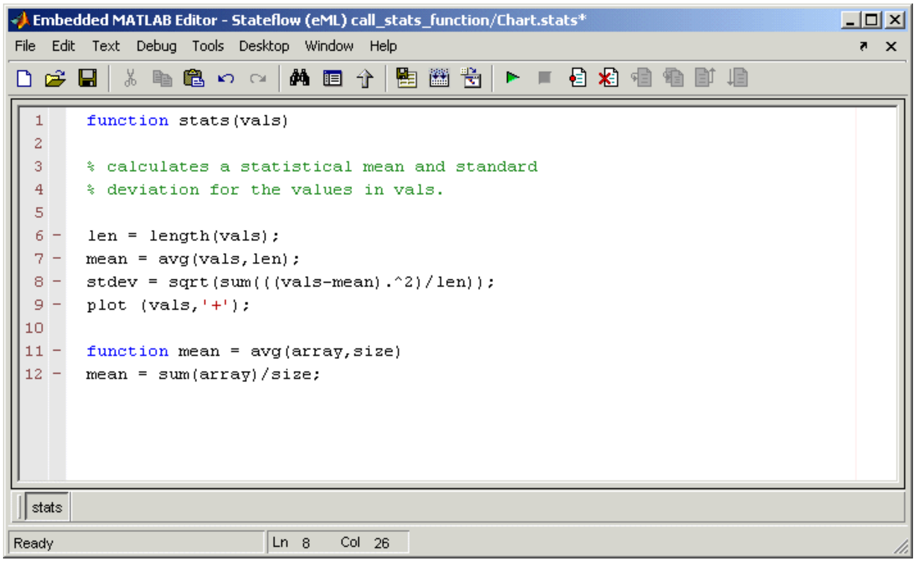
You program an embedded MATLAB function in the Embedded MATLAB Editor. Access this editor for an embedded MATLAB function by double-clicking it in the Stateflow diagram. The following is an example of a newly created function in Stateflow that you open to program:


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call_stats_function/Chart.stats
File Edit Text Debug Tools Window Help
stats
Ready
Ln 1 Col 1

```
function stats(vals)
```

You program embedded MATLAB functions just like you would a MATLAB function. Embedded MATLAB functions in Stateflow use a rich subset of MATLAB language and functions to generate code for applications that can reside in target applications with operating systems and platforms that have strict memory and data type requirements.

The following embedded MATLAB function calculates a mean and a standard deviation for a set of value input to the function as a vector argument:


Embedded MATLAB Editor - Stateflow (eML) call_stats_function/Chart.stats*
File Edit Text Debug Tools Desktop Window Help
stats
Ready
Ln 8 Col 26

```
function stats(vals)

% calculates a statistical mean and standard
% deviation for the values in vals.

len = length(vals);
mean = avg(vals,len);
stdev = sqrt(sum(((vals-mean).^2)/len));
plot (vals,'+');

function mean = avg(array,size)
mean = sum(array)/size;
```

For a detailed example and information on programming embedded MATLAB functions in Stateflow, see Chapter 13, “Using Embedded MATLAB Functions”.

Defining Graphical Function Data

Before you can finish a function, you need to define all or some of its data. Use the following steps to define data for a Stateflow function:

1 Specify the data properties (data type, initial value, and so on) for the function arguments and return value.

   - Change data properties directly in the **Contents** pane of the **Model Explorer** by clicking values in the displayed columns for a data row.
   - Change data properties in the **Data** dialog for a data.

     If you right-click a data row in the **Model Explorer** and select **Properties** from the resulting pop-up menu, its **Data** dialog appears. See “Setting Data Properties in the Data Dialog” on page 7-31 for information on setting data properties.

The following restrictions apply to setting properties for the arguments and return value of a function:

- Each argument and the return value can be a scalar or matrix of values.
- A function can have only one return.
- Arguments cannot have initial values.

2 Create any additional data items that the function might need to process its programming when it is called.

A function can access its own data or data belonging to parent states or the chart. The items that you create for the function itself can have any of the following scopes:

- `Local`

  A local data item persists from invocation to invocation. For example, if the item is equal to 1 when the function returns from one invocation, the item will equal 1 the next time the function is invoked.

- `Temporary`

  Stateflow creates and initializes a copy of a temporary item for each invocation of the function.

- `Constant`

  Constant data retains its initial value through all invocations of the function.

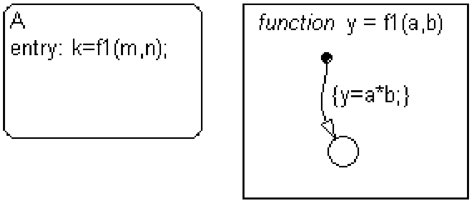
All data items (other than arguments and return values) parented by a function can be initialized from the workspace. However, only local items can be saved to the workspace.

It is not necessary to assign local data to an Embedded MATLAB function. You create local data in an Embedded MATLAB function simply by using it. In this case, Stateflow uses first use assignments to determine the type, size, and value of the local data. See “Creating Local Variables Implicitly” in Simulink documentation.

Calling Graphical Functions in Stateflow

Once you create a graphical function, you use it by calling it in Stateflow action language. Any state or transition action in the scope of a function can call that function. The calling syntax is the same as that of the function signature, with actual arguments replacing the formal parameters specified in the signature. If the data types of the actual and formal argument differ, Stateflow casts the actual argument to the type of the formal parameter.

The following example shows a state entry action that invokes a graphical function that returns the product of its arguments.

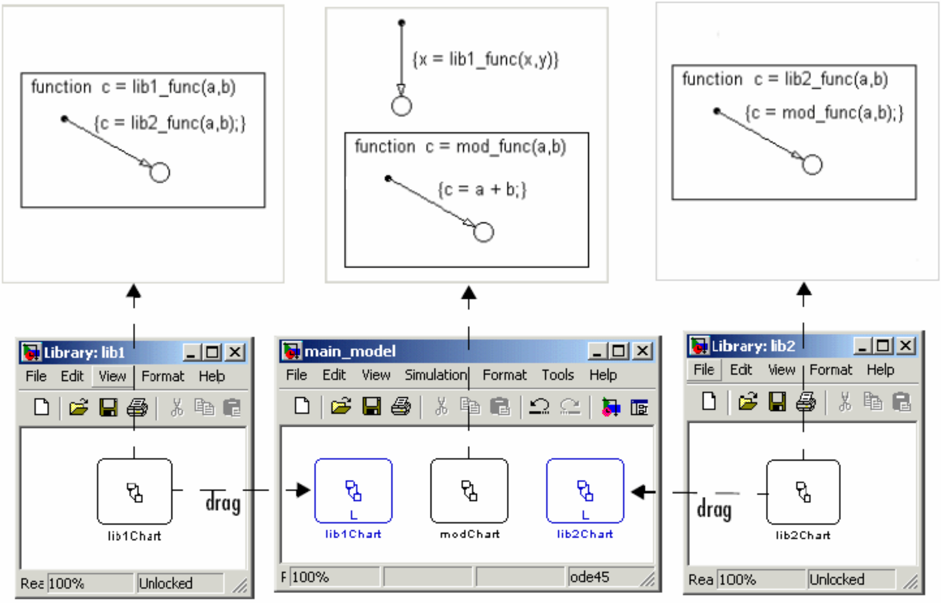


Exporting Graphical Functions

You can export the root-level functions of a chart to the remaining charts in the chart's model. Exporting a chart's functions extends their scope to include all other charts in the same model.

You can also export functions in library charts to a model as long as the library charts are present in the model. To export a chart's root-level functions, select **Export Chart Level Functions** on the chart's **Chart Properties** dialog box (see "Specifying Chart Properties" on page 10-6).

In the following example, the model `main_model` has two library Stateflow charts, `lib1Chart` and `lib2Chart`:



Both `lib1Chart` and `lib2Chart` are dragged into the model `main_model` from the library models `lib1` and `lib2` in which they were created. In the properties dialog for all three charts, the **Export Chart Level Functions** option is selected. Each chart now defines a graphical function that can be called by any other chart placed in `main_model`.

The sequence of action in simulation of `main_model` is as follows:

- The chart `modChart` calls the graphical function `lib1_func`, with the two arguments, `x` and `y`.
- `lib1_func` calls the graphical function `lib2_func`, passing the same two arguments.
- `lib2_func` calls the graphical function `mod_func`, which adds `x` and `y`.
- The result of the addition is assigned to `x`.

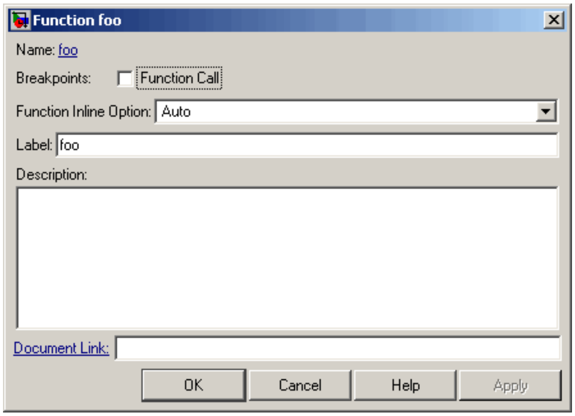
Specifying Graphical Function Properties

You can set general properties for a graphical function through its function dialog as follows:

1 Right-click the graphical function box.

2 Select **Properties** from the resulting submenu.

   The **Function Properties** dialog for the graphical function appears, as shown:



Function foo

Name: foo

Breakpoints: □ Function Call

Function Inline Option: Auto

Label: foo

Description:

Document Link:

The fields in the **Function Properties** dialog are as follows:

Field	Description
Name	Function name; read-only; click this hypertext link to bring the function to the foreground in its native diagram.
Breakpoints	Select **Function Call** to set a breakpoint to pause execution during simulation when the graphical function is called.

Field	Description
Function Inline Option	This option controls the inlining of this function in generated code through the following selections: • **Auto** Stateflow decides whether or not to inline the function based on an internal calculation. • **Inline** Stateflow inlines the function as long as it is not exported to other charts and is not part of a recursion. A recursion exists if the function calls itself either directly or indirectly through another called function. • **Function** The function is not inlined.
Label	You can specify the signature label for the function through this field. See "Creating a Graphical Function" on page 6-29 for more information.
Description	Textual description/comment.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

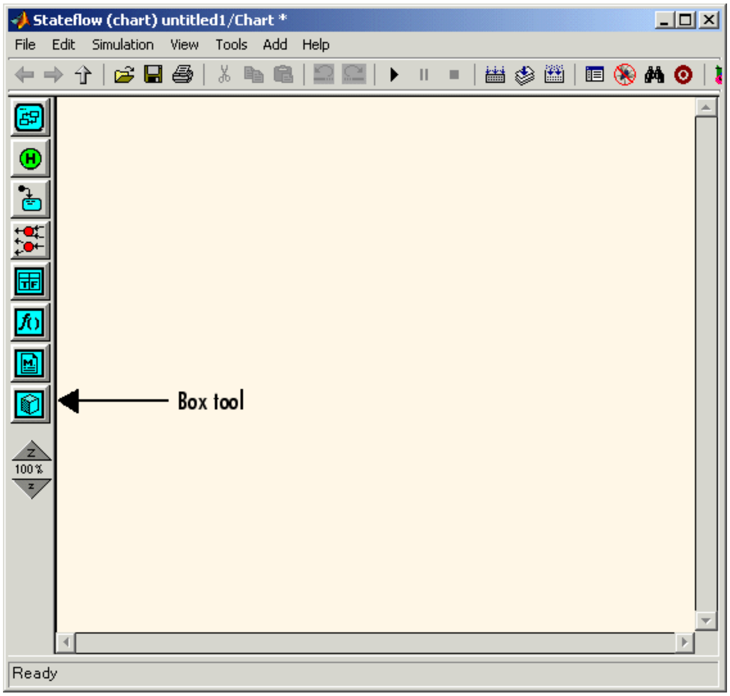
Using Boxes to Extend Chart Diagrams

Boxes are a convenience for organizing related items in your charts. The following topics explain how to use boxes in Stateflow diagrams:

- "Creating a State" on page 6-45
- "Changing a State to a Box" on page 6-46
- "Using Boxes in Stateflow" on page 6-47

Creating a State

Like states, you create boxes by drawing them in the Stateflow diagram editor with the box tool shown below:



1 Select the Box tool.

2 Move your cursor into the drawing area.

In the drawing area, the mouse cursor becomes box-shaped.

3 Click in a particular location to create a box.

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

4 Click the question mark label.

A text cursor appears in place of the question mark.

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

To delete a box, click it to select it and choose **Cut** (**Ctrl+X**) from the **Edit** or any shortcut menu or press the **Delete** key.

You can change a state to a box or a box to a state. See "Changing a State to a Box" on page 6-46 for details.

Changing a State to a Box

You can change an existing state to a box and back to a state with the following procedure:

1 Right-click the state.

A shortcut pop-up menu appears.

2 From the pop-up menu, select **Type**.

A submenu appears adjacent to the pop-up menu.

3 From the submenu, select **Box**.

Stateflow converts the state to a box, redrawing its border with sharp corners to indicate its changed status.

4 Repeat the preceding steps on the box and select **State** from the submenu instead of **Box** to change the box to a state

Using Boxes in Stateflow

Once you create a box you can use it in one of the following ways:

- You can move or draw objects inside of a box to organize your diagram.

  You can draw the box first as a state around the objects you want inside it and then convert it to a box.
- 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 "Grouping States" on page 4-8.
- You subchart a box to hide its elements.

  See "Using Subcharts to Extend Charts" on page 6-6 for more information.

For the most part, boxes do not contribute to the semantics of a Stateflow diagram. They do, however, affect the activation order of a diagram's parallel states. A box wakes up before any parallel states or boxes that are lower or to the right of it in a Stateflow diagram. Within a box, parallel states still wake up in top-down, left to right order.

Using Notes to Extend Chart Diagrams

The following topics describe how to create, edit, and delete descriptive notes in Stateflow charts:

- “Creating Notes” on page 6-48
- “Editing Existing Notes” on page 6-48
- “Changing Note Font and Color” on page 6-49
- “Moving Notes” on page 6-50
- “Deleting Notes” on page 6-50

Creating Notes

You can enter comments/notes in any location on the chart with the following procedure:

1. Place the cursor at the desired location in the Stateflow chart.
2. Right-click the mouse.
3. From the resulting menu, select **Add Note**.

   A blinking cursor appears at the location you selected. Default text is italic, 9 point.
4. Begin typing your comments.

   As you type, the text moves left to right.
5. Press the **Return** key to start a new line.
6. When finished typing, click outside the typed note text.

Editing Existing Notes

To edit existing note text,

1. Left-click the mouse on the comment location you want to edit.

2 Once the blinking cursor appears, begin typing or use the arrow keys to move to a new text location.

Changing Note Font and Color

To change font and color for your Stateflow chart notes, follow the procedures described in the section "Specifying Colors and Fonts" on page 4-30.

You can also change your note text to bold or italic text by doing the following:

1 Right-click the note text.

2 From the resulting shortcut menu, select **Text Format**.

3 From the resulting submenu, select **Bold** or **Italic** (default).

TeX Instructions

In the preceding procedure, note a third selection of the **Text Format** submenu called **TeX Instructions**. This selection sets the text `Interpreter` property to `Tex`, which allows you to use a subset of TeX commands embedded in the string to produce special characters such as Greek letters and mathematical symbols.

The **TeX Instructions** selection is used in the following example:

1 Right-click the text of an example note.

2 In the resulting shortcut menu, select **Text Format**.

3 In the submenu that results, make sure that **TeX Instructions** has a check mark positioned in front of it. Otherwise, select it.

4 Click the note text to place the cursor in it.

5 Replace the existing note text with the following expression.

```
\it{\omega_N = e^{(-2\pii)/N}}
```

6 Click outside the note.

The note now has the following appearance:

$$\omega_N = e^{(-2\pi i)/N}$$

Moving Notes

To move your notes,

1 Place the cursor over the text of the note.

2 Click and drag the note to a new location.

3 Release the left mouse button.

Deleting Notes

To delete your notes, do the following:

1 Place the mouse cursor over the text of the note.

2 Click and hold the left mouse button on the note.

A dim rectangle appears surrounding the note.

3 Select the **Delete** key.

Alternatively, you can also do the following:

1 Place the mouse cursor over the text of the note.

2 Right-click the note.

3 From the resulting shortcut menu, select **Cut**.

Reporting Chart Diagrams

Stateflow generates reports on all or part of your Stateflow chart:

- “Printing and Reporting on Stateflow Charts” on page 6-51
- “Generating a Model Report in Stateflow” on page 6-53
- “Printing the Current Stateflow Diagram” on page 6-56
- “Printing a Stateflow Book” on page 6-56

You can also use the Report Generator for MATLAB and Simulink to generate a report that documents an entire Stateflow model, including both Simulink and Stateflow components. See the MATLAB Report Generator documentation.

Printing and Reporting on Stateflow Charts

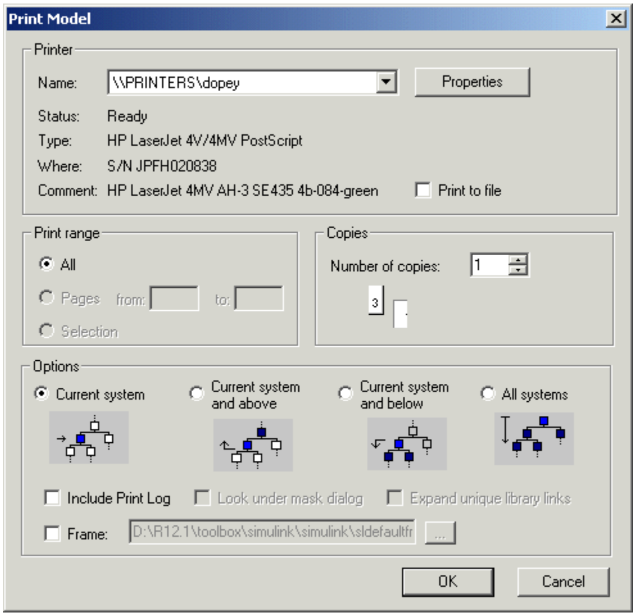
The **Print** option prints a copy of the current Stateflow diagram loaded in the Stateflow diagram editor. You can also select to print subcharts of the current diagram or the chart, subcharts, and Simulink subsystems that contain the current diagram.

Print a copy of a Stateflow diagram by doing the following:

1. Open the Stateflow chart or subchart you want to print.

2. Select **Print** from the **File** menu.

   The **Print Model** dialog box appears as follows:



Print Model

Printer

Name: \\PRINTERS\dopey

Status: Ready

Type: HP LaserJet 4V/4MV PostScript

Where: S/N JPFH020838

Comment: HP LaserJet 4MV AH-3 SE435 4b-084-green

□ Print to file

Print range

● All

○ Pages from: to:

○ Selection

Copies

Number of copies: 1

Options

● Current system ○ Current system and above ○ Current system and below ○ All systems

□ Include Print Log □ Look under mask dialog □ Expand unique library links

□ Frame: D:\R12.1\toolbox\simulink\simulink\sldefaultfr

In the resulting **Print Model** window, select the printer for this report and one of the following options for the type of report you receive:

- **Current system** – Prints the current chart or subchart in view in the Stateflow editor.
- **Current system and above** – Prints the current chart or subchart in view in the Stateflow editor and all the subcharts and Simulink subsystems that contain it.
- **Current system and below** – Prints the current chart or subchart in view in the Stateflow editor and all the subcharts that it contains.
- **All systems** – Prints the current chart or subchart in view in the Stateflow editor, all the subcharts that it contains, and all the subcharts and Simulink subsystems that contain it.

Further enhance the above reports with the following options:

- **Include Print Log** — Includes a list of all printed diagrams as a preface to the print report.

- **Look under mask dialog** — Applies only to the masked subsystems that might appear in Simulink subsystems that are printed with the report options **Current system and below** and **All systems**.
- **Expand unique library links** — Applies only to the library blocks that might appear in Simulink subsystems that are printed with the report options **Current system and below** and **All systems**.
- **Frame** — Prints a title block frame that you specify in the adjacent field on each diagram in the report.

Note This option is also available in the Simulink window. See the topic "Printing a Block Diagram" in the Using Simulink documentation for more information on the preceding options and on the behavior of this command as used in Simulink. The information in this topic describes the behavior of this option only when it is used in a Stateflow diagram editor window.

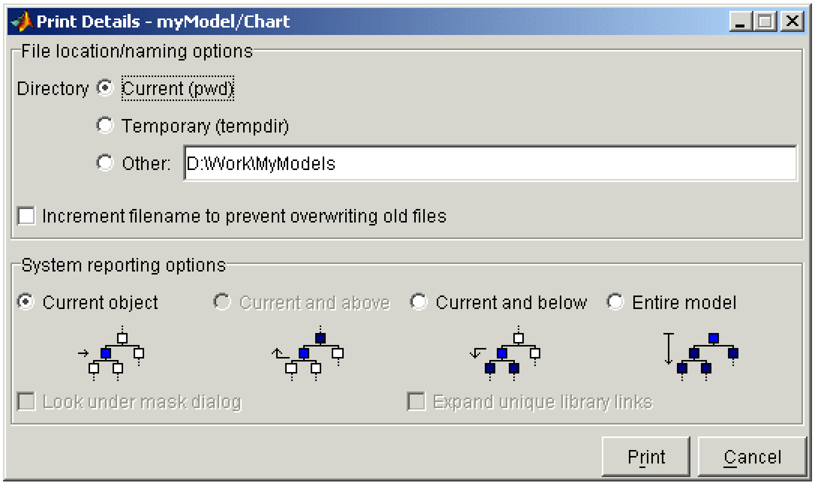
Generating a Model Report in Stateflow

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

To generate a model report on Stateflow diagram objects, do the following:

1. Open the Stateflow chart or subchart whose objects you want to report on.
2. In the diagram editor window, select **Print Details** from the **File** menu.

   The **Print Details** dialog box appears as follows:



Print Details - myModel/Chart

File location/naming options

Directory ● Current (pwd)

○ Temporary (tempdir)

○ Other: D:\Work\MyModels

□ Increment filename to prevent overwriting old files

System reporting options

● Current object ○ Current and above ○ Current and below ○ Entire model

□ Look under mask dialog □ Expand unique library links

3 Make selections for the destination directory of the report file and reporting options that determine what objects get reported.

For details on setting the fields in the **File locations/naming options** section of this dialog, see “Generating a Model Report” in the Using Simulink documentation. For details on the report you receive from the report option you choose in the **System reporting options** section, see “System Report Options” on page 6-54 and “Report Format” on page 6-55.

4 Select **Print**.

The **Print Details** dialog box appears and tracks the activity of the report generator during report generation. See “Generating a Model Report” in the Using Simulink documentation for more details on this window.

If no serious errors are encountered, the resulting HTML report is displayed in your default browser.

System Report Options

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

- **Current** — Reports on the chart or subchart in the current Stateflow diagram editor and its immediate parent Simulink system.
- **Current and above** — This option is grayed out and unavailable for printing chart details in Stateflow.
- **Current and below** — Reports on the chart or subchart in the current Stateflow diagram editor and all contents at lower levels of containment (children) along with the immediate Simulink system.
- **Entire model** — Reports on the entire model including all Stateflow charts in the model for the chart in the current Stateflow diagram editor and all Simulink systems.

  If this option is selected, the following options are enabled to modify this report:

  - **Look under mask dialog** – Include the contents of masked subsystems in the report.
  - **Expand unique library links** – Include 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 in Stateflow is as follows:

- The report is titled with the system in Simulink containing the chart or subchart in current view in Stateflow.
- A representation of Simulink hierarchy for the containing system and its subsystems follows. Each subsystem in the hierarchy is linked to the report of its Stateflow diagrams.
- The report section for the Stateflow diagrams of each system or subsystem begins with a small report on the system or subsystem and is followed by a report of each contained diagram.
- Each Stateflow diagram report includes a reproduction of its diagram with links for subcharted states that have reports of their own.

- Covered Stateflow and Simulink objects are tabulated and counted in a concluding appendix to the report.

Printing the Current Stateflow Diagram

The **Print Current View** option prints an individual Stateflow chart or subchart diagram as follows:

1. Open the chart or subchart that you want to print.

2. Select **Print Current View** from the Stateflow editor's **File** menu.

3. In the resulting submenu, choose one of the following destination options:

- **To File** — Converts the current view to a graphics file.

  Select the format of the graphics file from a resulting submenu of graphical file types.

- **To Clipboard** — Copies the current view to the system clipboard.

  Select the graphical format for the copy to the clipboard from a resulting submenu of graphical formats.

- **To Figure** — Converts the current view to a MATLAB figure window.
- **To Printer** — Prints the current view on the current printer.

You can also print the current view from the MATLAB command line using the `sfprint` function.

Printing a Stateflow Book

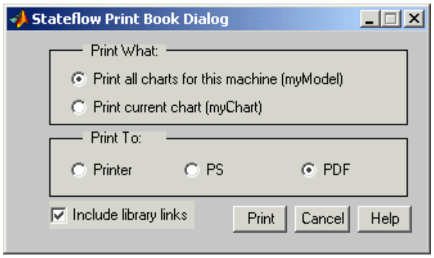
The **Print Book** report documents all the elements of a Stateflow chart, including states, transitions, junctions, events, and data. You can generate a book documenting a specific chart or all charts in a model.

To generate a book report of the objects of a Stateflow diagram, do the following:

1. Select and open a chart or subchart that you want to document.

2. Select **Print Book** from the Stateflow editor's **File** menu.

The **Print Book** dialog box appears as follows:



Stateflow Print Book Dialog

Print What:

● Print all charts for this machine (myModel)

○ Print current chart (myChart)

Print To:

○ Printer ○ PS ● PDF

☑ Include library links

3 Select the desired print options on the dialog.

4 Click the **Print** button to generate the report.

Defining Events and Data

Stateflow uses events and data to manage the behavior of finite state machine charts. Events control state transitions. Data objects store information that is evaluated by conditions and actions. Together, events and data influence the flow of control logic in the Stateflow design hierarchy.

The highest-level object in the hierarchy is the *Stateflow machine*. It contains all other Stateflow objects in a Simulink model including Stateflow charts, along with their states and substates. You can define events and data for all Stateflow objects in the design hierarchy. Each event and data object comes with its own set of configurable properties, based on where in the hierarchy the object is defined.

The *Stateflow data dictionary* is the internal representation of the hierarchy of all graphical and nongraphical Stateflow objects that reside in a Simulink model. When you create graphical objects — such as states, transitions, junctions, and graphical functions — in a Stateflow chart, they are added automatically to the data dictionary. However, you must define nongraphical objects explicitly. Events and data are nongraphical objects in the Stateflow hierarchy. This chapter explains how to define events and data in the Stateflow data dictionary.

Adding Events

An *event* is a Stateflow object that triggers actions in a Stateflow machine or its environment.

Stateflow uses a set of implicit events that typically fire whenever a Stateflow machine wakes up (see “Defining Implicit Events” on page 7-24). You can also define your own events in any of the following scopes:

- **Local** — Event is broadcast in the Stateflow chart.
- **Input from Simulink** — Event is broadcast by another Simulink block to the Stateflow chart.
- **Output to Simulink** — Event is broadcast from the Stateflow chart to another Simulink block.

This topic describes how to add events to a Stateflow chart.

- “Visibility of Events” on page 7-4
- “How to Add Events” on page 7-4

Visibility of Events

The visibility of events extends down through the Stateflow design hierarchy as follows:

Event Defined In	Visible To
Stateflow machine	All Stateflow charts in the model, along with their states and substates
Stateflow chart	The chart, along with all of its states and substates
State	To the state and all of its substates

How to Add Events

There are two ways to add events in Stateflow:

- Add events to a specific chart using the Stateflow Editor

- Add events at any level of Stateflow hierarchy using the Model Explorer.

Adding Events Using the Stateflow Editor

With the Stateflow Editor, you can add events to the open Stateflow chart. Follow these steps:

1. From the **Add** menu of the Stateflow Editor, select **Event**.

2. In the resulting submenu, select the scope for the event:

   - **Local** – Event is broadcast in the Stateflow chart.
   - **Input from Simulink** – Event is broadcast by another Simulink block to the Stateflow chart.
   - **Output to Simulink** – Event is broadcast from the Stateflow chart to another Simulink block.

   Stateflow adds a default definition of the new event to the Stateflow data dictionary and displays the **Event** properties dialog box.

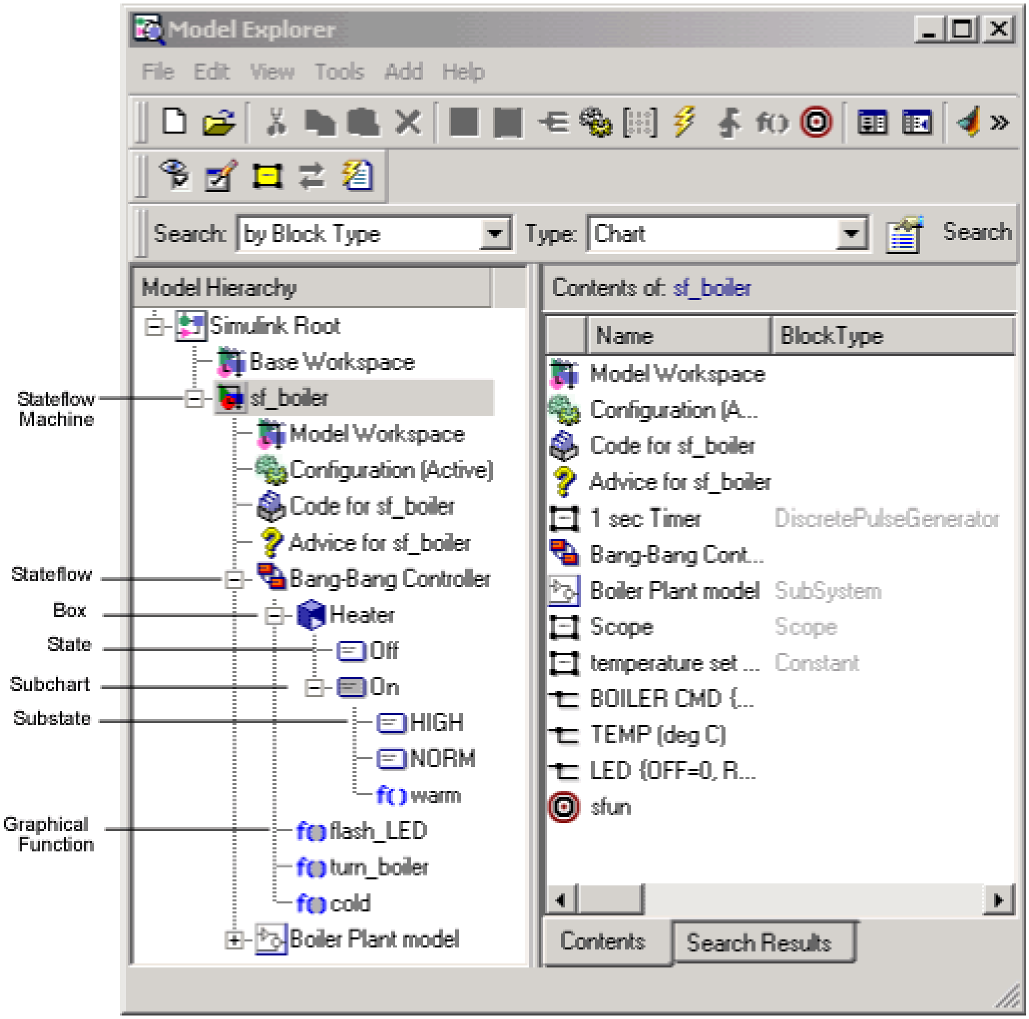
3. Specify properties for the event in the **Event** properties dialog box, as described in “Setting Event Properties in the Event Dialog” on page 7-8.

Adding Events Using the Model Explorer

With the **Model Explorer**, you can add events at the following levels in the Stateflow hierarchy:

- Stateflow machine
- Stateflow chart
- Subchart
- State
- Substate
- Box

You select an object in the Stateflow hierarchy to be the parent of your event. The following example shows the Stateflow objects that can parent events in the `sf_boiler` model hierarchy in the **Model Explorer**:



To add events using the **Model Explorer**, follow these steps:

1 Select **Explore** from the Stateflow Editor's **Tools** menu.

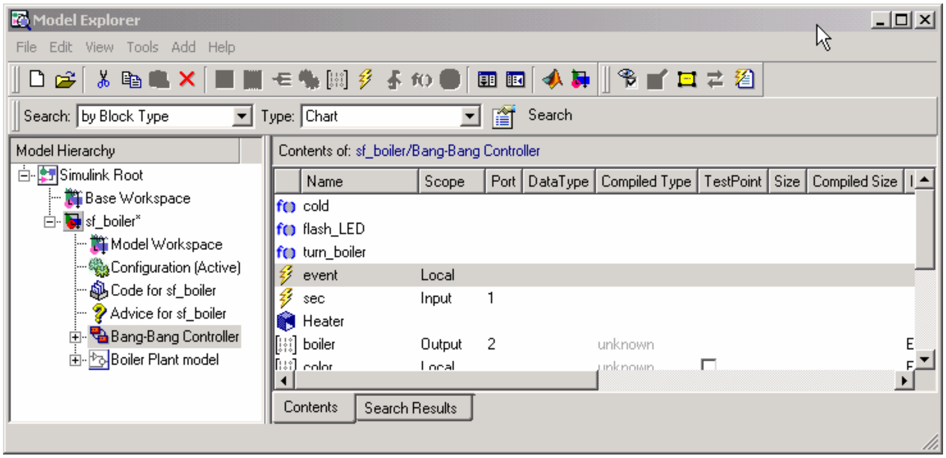
Stateflow opens the **Model Explorer**. If no object is selected, the current chart or subchart is highlighted in the **Model Hierarchy** pane of the **Model Explorer**. Otherwise, the selected object is highlighted.

2 Select the object in the Stateflow hierarchy where you want the new event to be visible.

The object you select becomes the *parent* of the event.

3 Select **Event** from the **Add** menu, or click the **Add Event** button:

Stateflow adds a default definition for the new event in the data dictionary and displays an entry row for the new event in the Explorer's Contents pane, as in this example:



Contents of: sf_boiler/Bang-Bang Controller

Name	Scope	Port	DataType	Compiled Type	TestPoint	Size	Compiled Size	I
cold								
flash_LED								
turn_boiler								
event	Local							
sec	Input	1						
Heater								
boiler	Output	2		unknown				E
color	Local			unknown	☐			F

4 Change the properties of the event you add in one of the following ways:

- Right-click the event row and select **Properties** to open the **Event** properties dialog.

  See "Setting Event Properties in the Event Dialog" on page 7-8 for a description of each property for an event.

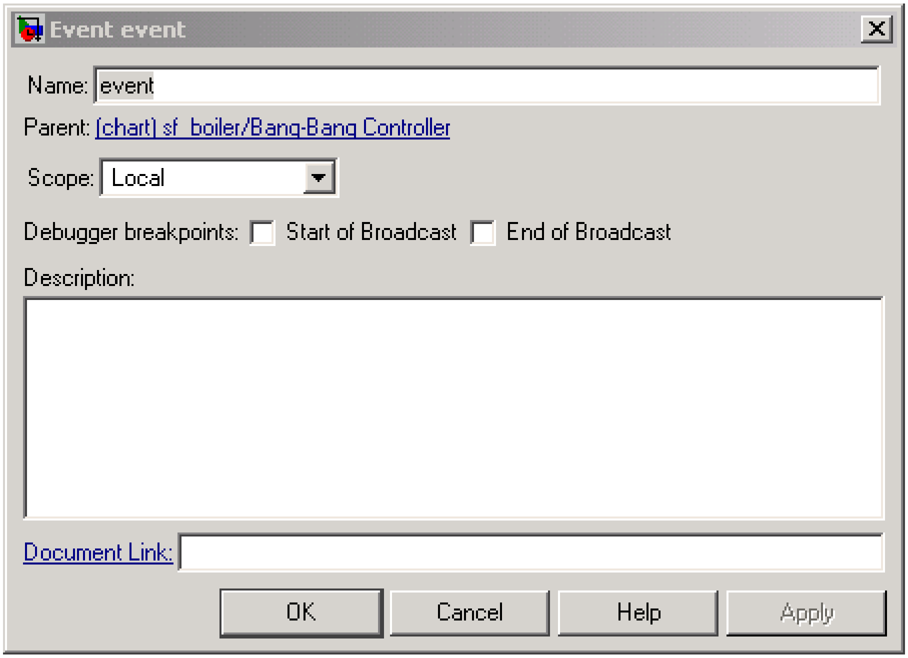
- Click individual cells in the entry row to set specific properties such as **Name**, **Scope**, and **Port**.

Setting Event Properties in the Event Dialog

You can set properties for an event through its **Event** properties dialog. This section shows you how to access the dialog and describes the property fields.

Event Properties Dialog

The **Event** properties dialog allows you to set and modify the properties of events in Stateflow. Properties vary according to the scope of the event. Therefore, the **Event** properties dialog is dynamic, displaying only the property fields that are relevant for the event you are configuring. For example, the dialog displays the following properties and default values for an event whose scope is **Local**:



Event event

Name: event

Parent: (chart) sf_boiler/Bang-Bang Controller

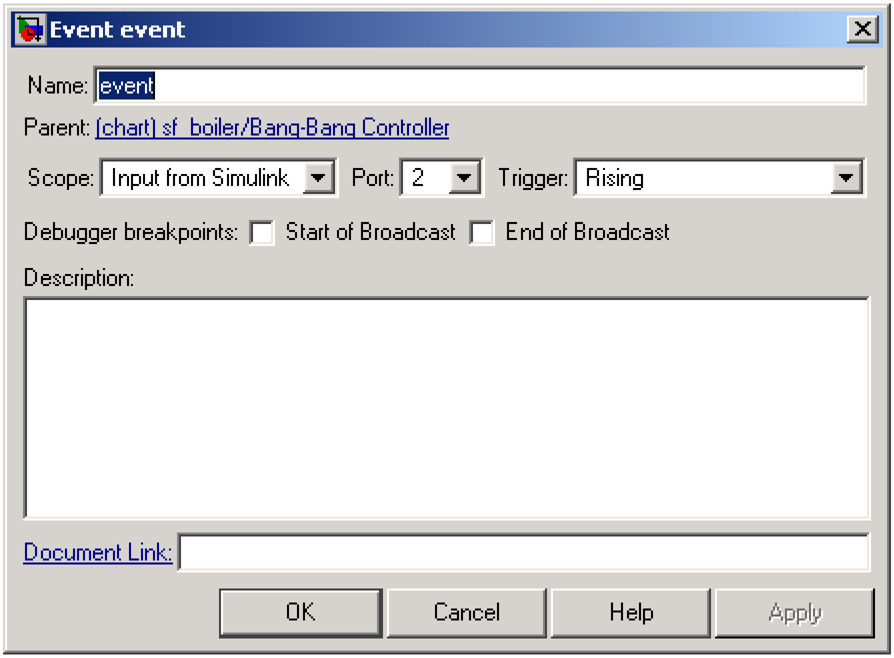
Scope: Local

Debugger breakpoints: □ Start of Broadcast □ End of Broadcast

Description:

Document Link:

For input and output events, the dialog displays these properties and defaults:



Event event

Name: event

Parent: (chart) sf_boiler/Bang-Bang Controller

Scope: Input from Simulink Port: 2 Trigger: Rising

Debugger breakpoints: □ Start of Broadcast □ End of Broadcast

Description:

Document Link:

Accessing the Event Properties Dialog

To access the **Event** properties dialog, use one of these methods:

- Add a new event from the Stateflow Editor.

  The **Event** properties dialog opens on your desktop, as described in "Adding Events Using the Stateflow Editor" on page 7-5.

- Open the **Event** properties dialog in the **Model Explorer** using one of these techniques:
  - Double-click the event in the **Contents** pane.
  - Right-click the event in the **Contents** pane and select **Properties**.
  - Select the event in the **Contents** pane and then select **Dialog View** from the **View** menu.

The **Event** properties dialog opens inside the **Model Explorer**.

See “Adding Events Using the Model Explorer” on page 7-5.

Property Fields

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.

Parent

Parent of the event. The parent can be a Stateflow machine, chart, box, or state. When an event is triggered, Stateflow broadcasts the event to its parent and all the parent’s descendants. You specify the parent when you add the event to the data dictionary (see “Adding Events” on page 7-4). This field is read-only, but you can click the associated link to display the parent object in the Stateflow Editor.

Note You can also change the parent by dragging the event from the **Contents** pane of the **Model Explorer** to a different object in the **Model Hierarchy** pane.

Scope

Scope of the event. The scope specifies where the event occurs relative to its parent. You can choose from the following scopes:

Scope	Description
Local	Event that can occur anywhere in a Stateflow machine, but is visible only in its parent object (and its parent’s descendants).
Input from Simulink	Event that occurs in a Simulink block, but is broadcast in a Stateflow chart. See “Defining Input Events” on page 7-13.

Scope	Description
Output to Simulink	Event that occurs in a Stateflow chart, but is broadcast in a Simulink block. See "Defining Output Events" on page 7-14.
Exported	Event that can be broadcast by external code built into a standalone or Real-Time Workshop target. You can define exported events only for a Stateflow machine. See "Exporting Events to Stateflow External Code" on page 7-21.
Imported	Externally-defined event that can be broadcast anywhere within the hierarchy of a Stateflow machine. You can define imported events only for a Stateflow machine. See "Importing Events from Stateflow External Code" on page 7-22.

Port

This property applies to *input* and *output* events. For input events, port is the index of the input signal that triggers the event. For output events, port is the index of the port that outputs this event. By default, the port number is assigned based on order of creation. For example, the first input event is assigned to port 1 and the third output event is assigned to port 3. You can change the default port numbers in the **Model Explorer** or **Event** properties dialog. When you change the number of one port, the numbers of other ports are adjusted automatically to preserve their relative order. See "Associating Input Events with Control Signals" on page 7-14 and "Associating an Output Event with an Output Port" on page 7-15.

Trigger

Type of signal that triggers an input or output event. See "Defining Input Events" on page 7-13 or "Defining Output Events" on page 7-14.

Debugger Breakpoints

Option for setting debugger breakpoints at the start and/or end of an event broadcast.

Description

Description of this event. Stateflow allows you to enter brief descriptions of events in the data dictionary.

Document Link

Link to online documentation for events defined by a Stateflow chart. To document a particular event, set its **Document Link** property to a Web URL address or MATLAB expression that displays documentation in a suitable online format (for example, an HTML file or text in the MATLAB command window). Stateflow evaluates the expression when you click the blue **Document Link** text.

Sharing Events with Simulink

Before a Stateflow block can send events or receive them from other Simulink blocks, you need to define them for the Stateflow chart. Use the following topics to define input and output events:

- "Defining Input Events" on page 7-13 — Describes input events that allow other Simulink blocks, including other Stateflow charts, to notify a particular chart of events that occur outside it.
- "Associating Input Events with Control Signals" on page 7-14 — Tells you how to associate multiple control signals with a single trigger port for the Stateflow block.
- "Defining Output Events" on page 7-14 — Describes output events that allow a chart to notify other blocks in a model of occurrences in that chart.
- "Associating an Output Event with an Output Port" on page 7-15 — Tells you how to position the output ports for multiple output events.
- "Accessing Simulink Subsystems from Stateflow Events" on page 7-16 — Explains how to access the Simulink subsystem associated with an event directly from the Stateflow Editor.
- Setting Event Triggers — Explains how to trigger a Stateflow block via a change in control signal or a Simulink block that outputs function-call events.

Defining Input Events

An input event occurs outside a chart and is visible only in that chart. This type of event allows other Simulink blocks, including other Stateflow charts, to notify a particular chart of events that occur outside it. To define an event as an input event, set its **Scope** property to **Input from Simulink**.

The following steps describe how to add an input event to a chart in the **Model Explorer**:

1. Add an event to the Stateflow chart.

   You must add an input event to the chart and not to one of its objects. See "Adding Events" on page 7-4 for a description of how to add events to Stateflow charts.

2 Set the **Scope** property for the event to **Input from Simulink**.

   A single trigger port is added to the top of the Stateflow block.

3 If you want a Simulink block to trigger the Stateflow chart through this input event, specify a trigger, as described in Setting Event Triggers.

Associating Input Events with Control Signals

When you define one or more input events for a chart, Stateflow adds a single trigger port to the chart block. External Simulink blocks can trigger the input events via a signal or vector of signals connected to the trigger port. The **Port** property of an input event associates the event with a specific element of a control signal vector that is connected to the trigger port (see "Port" on page 7-11).

The number of the port assigned to the input event acts as an index into the control signal vector. For example, the first element of the signal vector triggers the input event assigned to port 1, the fourth element triggers the input event assigned to port 4, and so on. By default, port numbers are assigned to events in order of creation. However, you can change these assignments by setting the event's **Port** property to the index of the signal that you want to trigger the event.

At any given time step, input events are checked in ascending order based on their port numbers. The chart is awakened (triggered) once per valid event. When events are edge-triggered, multiple edges can occur in the same time-step, thereby waking the chart more than once in the same time-step. In this situation, events occur (and wake the chart) in an ascending sequence based on their port numbers.

In case of function-call input events, there is one trigger event only. The caller of the function-call event explicitly calls and executes the chart. Only one function-call can be valid in a single time step.

Defining Output Events

An output event is an event that occurs in Stateflow chart, but is visible in Simulink blocks outside the chart. This type of event allows a chart to notify other blocks in a model of events that occur in the chart. To define an event as an output event, set its **Scope** property to **Output to Simulink**. You can define multiple output events for a given chart. Stateflow creates a chart output port for each output event that you define (see “Port” on page 7-11). Your model can use the output ports to trigger the output events in other Simulink blocks in the same model.

To define an output event, follow these steps:

1 Add an event to the Stateflow chart, as described in “Adding Events” on page 7-4.

2 Set the **Scope** field to **Output to Simulink**.

   For each output event you define, a Simulink output port is added to the Stateflow block. Output events must be scalar.

3 If you want this chart to call a subsystem, do one of the following:

   - To call an edge-triggered subsystem, set the **Trigger** property of the output event to **Either Edge**.

     See “Defining Edge-Triggered Output Events” on page 10-26 for an example of a Stateflow block calling an edge-triggered subsystem in Simulink.

   - To call a function-call subsystem, set the **Trigger** property of the output event to **Function Call**.

     For an example of a Stateflow block calling a function-call subsystem, see “Defining Function Call Output Events” on page 10-22.

Associating an Output Event with an Output Port

The **Port** property for an output event associates it with an output port on the chart block that parents the event. It specifies the position of the output port relative to other output event ports on the Chart block. Output event ports appear below output data ports on the right side of a chart block.

Stateflow numbers all output ports sequentially from top to bottom; therefore, output data ports are numbered before output events ports. As you add output events, their default **Port** properties are assigned sequentially to the end of the existing port list.

You can change the default port assignment of an event by resetting its **Port** property. When you change the **Port** property for an output event, the ports for the remaining output events are automatically renumbered, preserving original order. For example, assume that there are three output events, `OE1`, `OE2`, and `OE3`, that are associated with the output ports 4, 5, and 6, respectively. If you change the **Port** property for `OE2` to 6, the ports for `OE1` and `OE3` are renumbered to 4 and 5, respectively.

Accessing Simulink Subsystems from Stateflow Events

You can access the Simulink subsystem associated with a Stateflow event directly from the Stateflow Editor. Follow these steps:

1. Right-click the state that contains the event of interest.

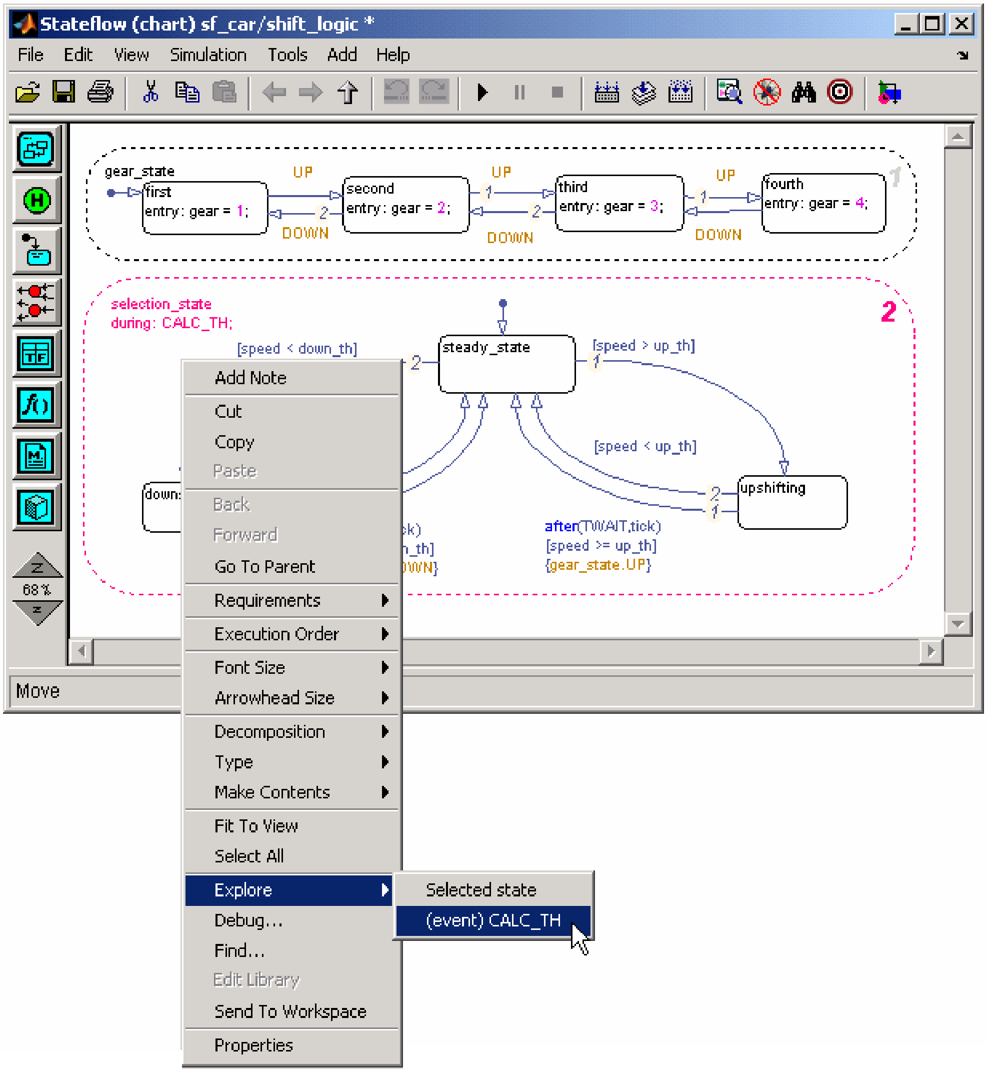
2. Select **Explore**.

   The Explore menu lets you access all events defined in the selected state.

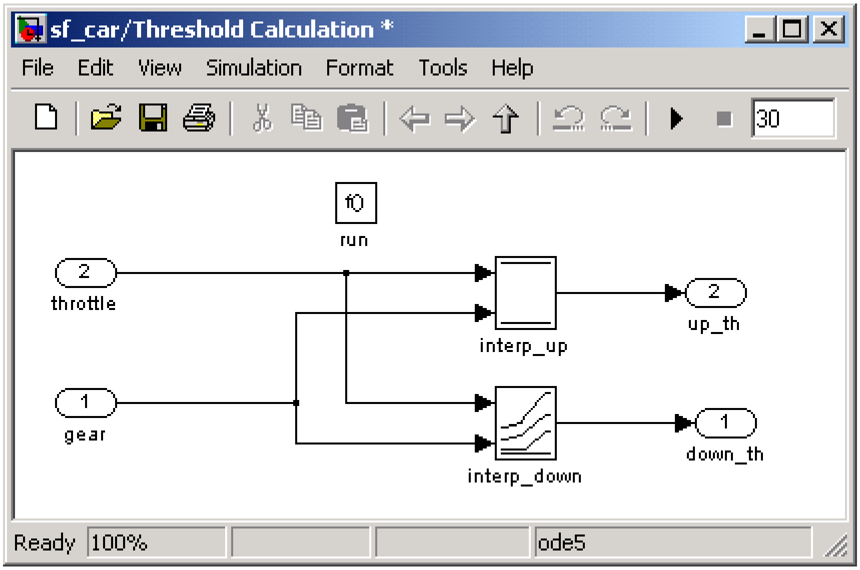
3. Select the desired event.

   The Simulink subsystem associated with the event is displayed.

For example, you can use this procedure to access the Simulink subsystem associated with the Stateflow `shift_logic_chart` in the `sf_car` model, as shown:



In this example, when you select the CALC_TH event, the Simulink subsystem Threshold Calculation is displayed:


sf_car/Threshold Calculation *
File Edit View Simulation Format Tools Help
30
f()
run
2
throttle
1
gear
interp_up
interp_down
2
up_th
1
down_th
Ready 100%
ode5

Setting Event Triggers

You can trigger a Stateflow block via a change in control signal (edge-triggered event) or a Simulink block that outputs function-call events (function-call-triggered event). You specify the trigger by selecting an option in the **Trigger** field of the **Event** properties dialog.

Note You cannot mix function-call-triggered and edge-triggered input events in a single Stateflow chart. If Stateflow detects this condition during parsing or code generation, it generates an error.

This section describes the trigger options.

Using Control Signal Triggers

You can use edge triggers to trigger a Stateflow block when a control signal changes. Use edge triggers when you can tolerate a delay from the time the trigger occurs to the time of execution. An edge trigger causes a subsystem to execute at the beginning of the next simulation time step, regardless of when triggering actually occurred during the previous time step.

To trigger a Stateflow block via a change in control signal, set the **Trigger** property in the **Event** properties dialog to one of the following edge triggers:

Edge Trigger Type	Description
Rising	Rising edge trigger, where the control signal changes from either 0 or a negative value to a positive value.
Falling	Falling edge trigger, where the control signal changes from either 0 or a positive value to a negative value.
Either	Either rising or falling edge trigger.
Function call	A function-call subsystem in Simulink that triggers an event in a Stateflow chart. **Note** To use this type of trigger, you must have already defined a programmed function-call subsystem and a Stateflow block in the Simulink model.

In all cases, the signal must cross 0 to constitute a valid edge trigger. For example, a signal that changes from -1 to 1 is a valid rising edge, but signal that changes from 1 to 2 is not a valid rising edge.

Using Function Call Triggers

You can use a function-call subsystem in Simulink to trigger an event in a Stateflow chart. Before using this type of trigger, you must first create a triggered subsystem in Simulink whose execution is determined by logic internal to an S-function instead of by the value of a signal (see “Function-Call Subsystems” in the Simulink documentation).

Function-call triggers call function-call subsystems immediately, even if the call is made in the middle of a time step.

To trigger the Stateflow block via a Simulink block that outputs function-call events, set the **Trigger** property in the **Event** properties dialog to **Function call**. Stateflow changes all other input events for the Stateflow chart to **Function call**.

Sharing Events with Stateflow External Code

Stateflow allows external code defined for the Stateflow machine to send exported events to trigger Stateflow charts in the model. It also allows external code to receive imported events from other charts to trigger parts of external code. The following topics explain how to export and import events for external code in Stateflow.

- "Exporting Events to Stateflow External Code" on page 7-21 — Describes how to export events that enable external code to trigger events in the Stateflow machine.
- "Importing Events from Stateflow External Code" on page 7-22 — Describes how to import events that allow a Stateflow machine built into a standalone or Real-Time Workshop target to trigger an event in external code.

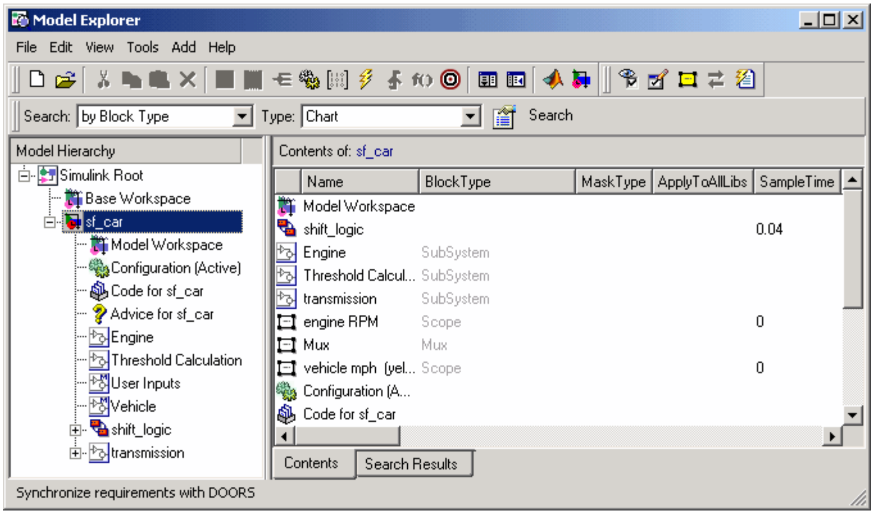
Exporting Events to Stateflow External Code

Stateflow machines can export events that trigger Stateflow charts in the model. Exported events are children of the Stateflow machine; they cannot be defined at any other level in the Stateflow design hierarchy.

To export an event, follow these steps:

1. Use the Model Explorer to add an event to the Stateflow machine, as described in "Adding Events Using the Model Explorer" on page 7-5.

   In the Model Hierarchy pane of the Model Explorer, the Stateflow machine has the same name as the Simulink model. For example, consider the model `sf_car`:



Search: by Block Type Type: Chart

Contents of: sf_car

Name	BlockType	MaskType	ApplyToAllLibs	SampleTime
Model Workspace				
shift_logic				0.04
Engine	SubSystem			
Threshold Calcul...	SubSystem			
transmission	SubSystem			
engine RPM	Scope			0
Mux	Mux			
vehicle mph (yel...	Scope			0
Configuration (A...				
Code for sf_car				

In this model, the Stateflow machine is `sf_car` (highlighted) and **not** `shift_logic`, which is the Stateflow chart.

2 Set the **Scope** property of the event to **Exported**, as described in "Setting Event Properties in the Event Dialog" on page 7-8.

The Stateflow code generator generates a function for each exported event. The C prototype for the exported event function takes the form

```
void external_broadcast_EVENT()
```

In this function, `EVENT` is the name of the exported event. External code built into a target can trigger the event by invoking the event function. For example, suppose you define an exported event named `switch_on`. External code can trigger this event by invoking the generated function `external_broadcast_trigger_on`. See "Exported Events" on page 10-31 for examples of how to trigger an exported event and of a Stateflow event exported to Stateflow external code.

Importing Events from Stateflow External Code

A Stateflow machine serves as a surrogate parent for imported events defined by external code. Importing an event allows Stateflow to build a custom or Real-Time Workshop (RTW) target, that triggers the imported event in external code.

To import an event, add an event to the Stateflow machine that needs to trigger the event and set its **Scope** property to **Imported**.

Note You must use the **Model Explorer** to add imported events to the Stateflow machine (see "Adding Events Using the Model Explorer" on page 7-5).

Stateflow assumes that external code defines each imported event as a function of the form

```
void external_broadcast_EVENT
```

where `EVENT` is the Stateflow name of the imported event. For example, suppose that the Stateflow machine imports an external event named `switch_on`. In this case, Stateflow assumes that external code defines a function named `external_broadcast_switch_on` that broadcasts the event to external code. Later, when you build a target for the Stateflow machine, the Stateflow code generator encodes actions that signal imported events as calls to the corresponding external broadcast event functions defined by the external code.

See "Imported Events" on page 10-33 for an example of a Stateflow external code event imported into Stateflow.

Defining Implicit Events

Stateflow recognizes the following built-in events that typically occur whenever a chart executes:

- Chart waking up
- Entry into a state
- Exit from a state
- Value assigned to an internal data object

These events are called *implicit events* because you do not have to define or trigger them explicitly. Implicit events are children of the chart in which they occur and therefore are visible only in the parent chart.

This chapter covers the following topics:

- "Referencing Implicit Events" on page 7-24
- "Example of an Implicit Event" on page 7-25

Referencing Implicit Events

Action expressions use the following syntax to reference implicit events:

```
event(object)
```

where `event` is the name of the implicit event and `object` is the state or data in which the event occurred.

Each of the following keywords generates implicit events in the action language notation for states and transitions.

Implicit Event	Meaning
`change(`*`data_name`*`)` or `chg(`*`data_name`*`)`	Specifies and implicitly generates a local event when the value of `data_name` changes.

`enter (`*`state_name`*`)`
`en(`*`state_name`*`)`
	Specifies and implicitly generates a local event when the specified `state_name` is entered.

Implicit Event	Meaning
`exit` (*state_name*) `ex`(*state_name*)	Specifies and implicitly generates a local event when the specified `state_name` is exited.
`tick`	Same as `wakeup` keyword.
`wakeup`	Specifies and implicitly generates a local event when the chart of the action being evaluated awakens.

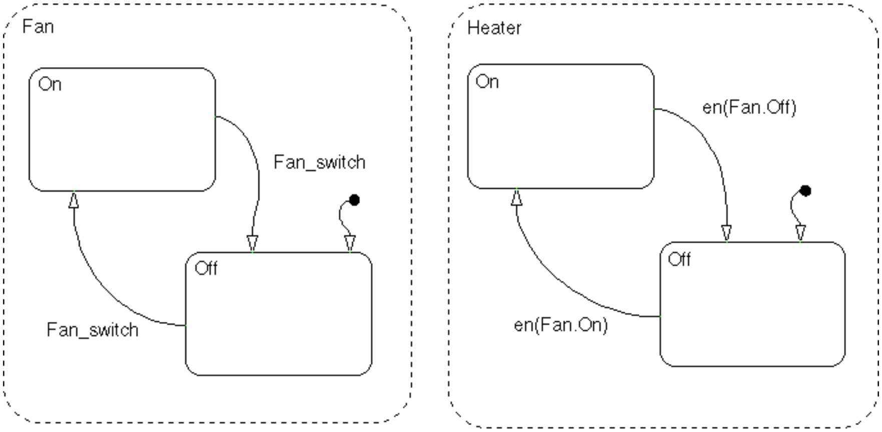
If more than one object has the same name, the event reference must qualify the object's name with that of its ancestor. Here are some examples of valid references to implicit events.

```
enter(switch_on)
en(switch_on)
change(engine.rpm)
```

Note The `wakeup` (or `tick`) event always refers to the chart containing the action being evaluated. It cannot reference a different chart by argument.

Example of an Implicit Event

This example illustrates use of an implicit `enter` event.



Fan and Heater are parallel (AND) superstates. By default, the first time the Stateflow chart is awakened by an event, the states Fan.Off and Heater.Off become active. The first time event Fan_switch occurs, the transition from Fan.Off to Fan.On occurs. When the entry action of Fan.On executes, an implicit local event is broadcast (i.e., en(Fan.On) == 1). This event broadcast triggers the transition from Heater.Off to Heater.On (triggered by the condition en(Fan.On). Similarly, when the system transitions from Fan.On to Fan.Off and the implicit local event Fan.Off is broadcast, the transition from Heater.On to Heater.Off is triggered.

Adding Data

Stateflow can store and retrieve data that resides internally in its own workspace, and externally in the Simulink model or application that embeds the Stateflow chart. Stateflow actions can reference internal and external data.

This section describes how to add data to the Stateflow data dictionary. There are two methods:

- Add data to a specific chart using the Stateflow Editor.
- Add data at any level of Stateflow hierarchy using the Model Explorer.

Adding Data Using the Stateflow Editor

With the Stateflow Editor, you can add data to the open Stateflow chart. The data is visible to all objects in the chart. Follow these steps:

1. From the **Add** menu of the Stateflow Editor, select **Data**.

2. In the pop-up menu, select a scope for the new data object.

   See “Scope” on page 7-10 for a description of each type of scope.

   Stateflow adds a default definition of the new data object to the Stateflow data dictionary and displays the **Data** properties dialog.

3. Specify properties for the new data object in the **Data** properties dialog, as described in “Setting Data Properties in the Data Dialog” on page 7-31 .

Adding Data Using the Model Explorer

With the **Model Explorer**, you can add data at all levels in the Stateflow hierarchy, including the Stateflow machine, Stateflow chart, and individual states in the chart. The data is visible to the parent object and its children.

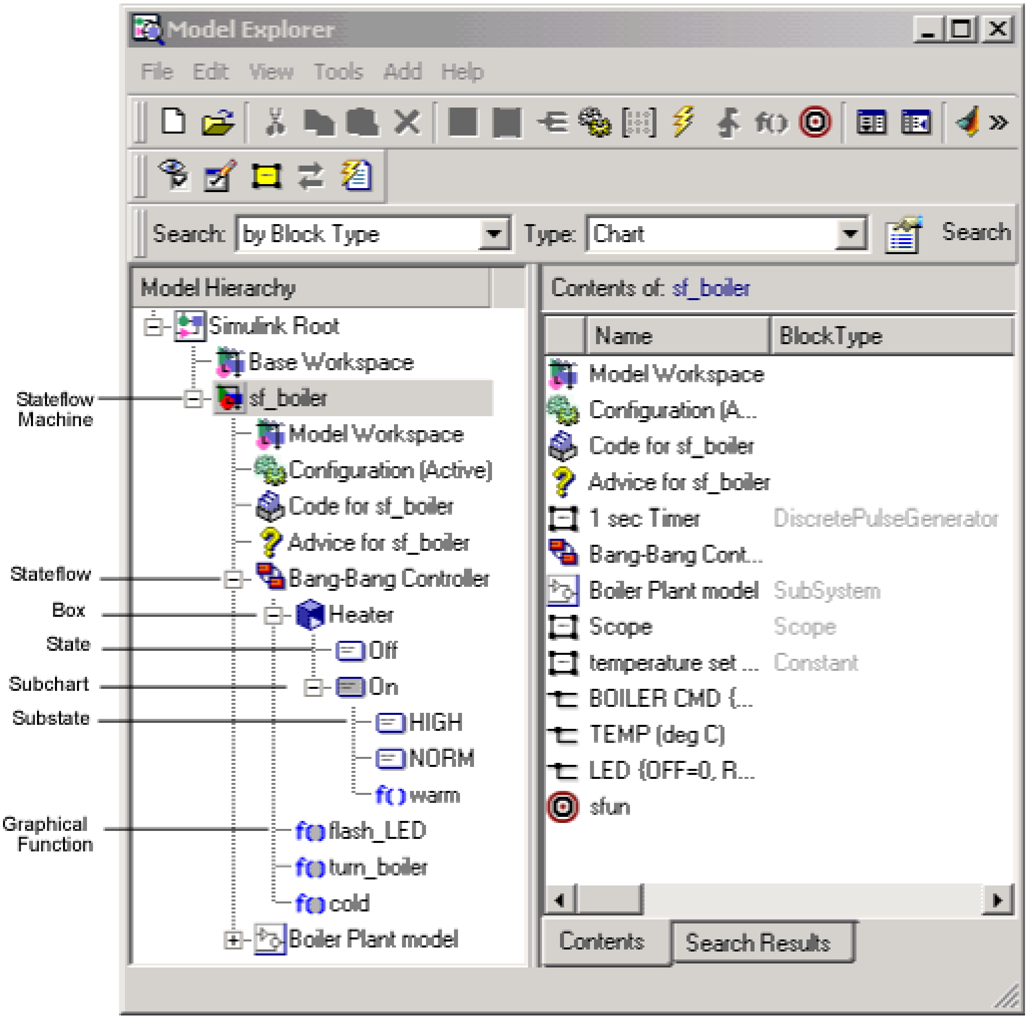
With the **Model Explorer**, you can add data at the following levels in the Stateflow hierarchy:

- Stateflow machine

- Stateflow chart
- Subchart
- State
- Substate
- Box
- Function

  Stateflow charts can contain graphical, truth table, and Embedded MATLAB functions.

You select an object in the Stateflow hierarchy to be the parent of your data object. The data will be visible to the parent object and its children. The following example shows the Stateflow objects that can parent data objects in the `sf_boiler` model hierarchy in the **Model Hierarchy** pane of the **Model Explorer**:



Name	BlockType
Model Workspace	
Configuration (A...	
Code for sf_boiler	
Advice for sf_boiler	
1 sec Timer	DiscretePulseGenerator
Bang-Bang Cont...	
Boiler Plant model	SubSystem
Scope	Scope
temperature set ...	Constant
BOILER CMD {...	
TEMP (deg C)	
LED {OFF=0, R...	
sfun	

To add data using the **Model Explorer**, follow these steps:

1 Select **Explore** from the **Tools** menu in the Stateflow Editor.

The **Model Explorer** opens.

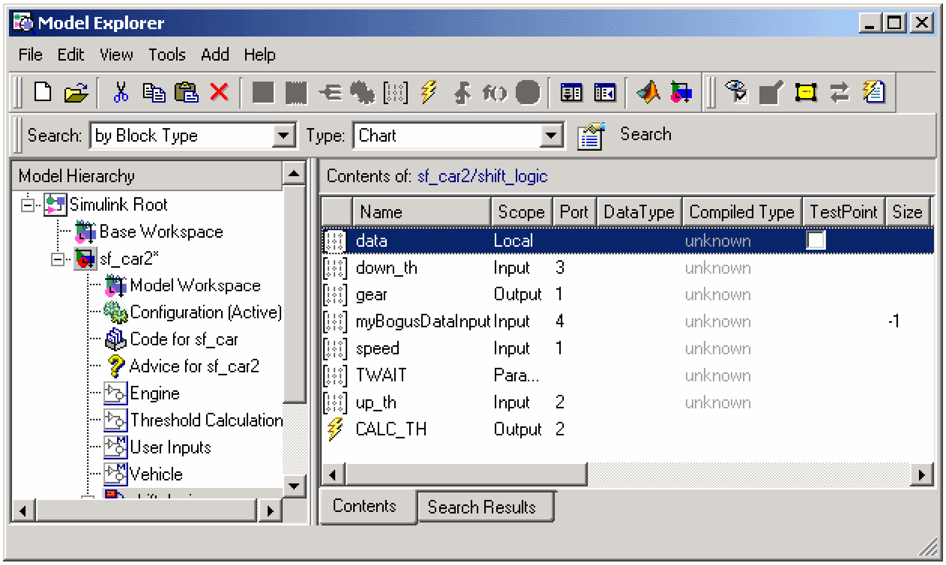
If no object is selected, the current chart or subchart is highlighted in the **Model Hierarchy** pane of the **Model Explorer**. Otherwise, the selected object is highlighted.

2 In the **Model Hierarchy** pane, select the object in the Stateflow hierarchy where you want the new data to be visible.

The object you select becomes the *parent* of the data object.

3 Select **Data** from the **Add** menu, or click the **Add Data** button:

Stateflow adds a default definition for the data in the data dictionary and displays the data definition in a new row in the Model Explorer Contents pane, as in this example:



Search: by Block Type   Type: Chart

Contents of: sf_car2/shift_logic

Name	Scope	Port	DataType	Compiled Type	TestPoint	Size
data	Local			unknown	☐	
down_th	Input	3		unknown		
gear	Output	1		unknown		
myBogusDataInput	Input	4		unknown		-1
speed	Input	1		unknown		
TWAIT	Para...			unknown		
up_th	Input	2		unknown		
CALC_TH	Output	2				

4 Change the properties of the data, as described in “Setting Data Properties in the Data Dialog” on page 7-31.

Setting Data Properties in the Data Dialog

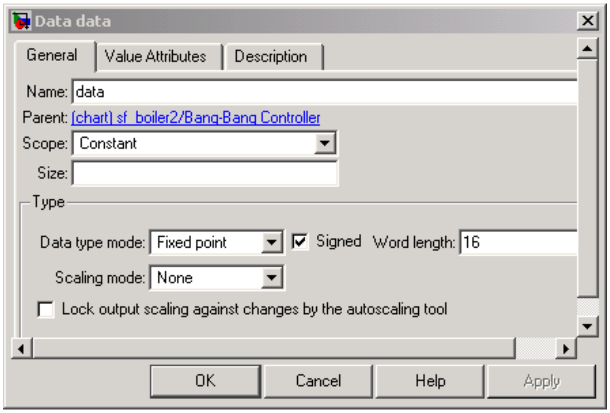
You set properties for a data object through its **Data** properties dialog. For many properties, you can enter expressions or parameters values. Using parameters to set properties for large numbers of data objects simplifies maintenance of your model because it allows you to update multiple properties by changing a single parameter.

This section covers the following topics:

- "The Data Properties Dialog" on page 7-31
- "Setting General Properties" on page 7-33
- "Setting Value Attributes Properties" on page 7-39
- "Setting Description Properties" on page 7-42
- "Entering Expressions and Parameters for Data Properties" on page 7-42

The Data Properties Dialog

The **Data** properties dialog allows you to set and modify the properties of data objects in Stateflow. Properties vary according to the scope and type of the data object. Therefore, the **Data** properties dialog is dynamic, displaying only the property fields that are relevant for the data object you are defining. For example, the dialog displays the following properties and default values for a data object whose scope is **Constant** and type is **Fixed point**:



Name: data

Parent: (chart) sf_boiler2/Bang-Bang Controller

Scope: Constant

Size:

Type

Data type mode: Fixed point ☑ Signed Word length: 16

Scaling mode: None

☐ Lock output scaling against changes by the autoscaling tool

Opening the Data Properties Dialog

To open the **Data** properties dialog, use one of these methods:

- Add a new data item from the Stateflow Editor, as described in “Adding Data Using the Stateflow Editor” on page 7-27.

  After you add the data item, the **Data** properties dialog opens on your desktop.

- Open the **Data** properties dialog from the **Model Explorer** for a data object that you have already added to Stateflow. Use one of these techniques:

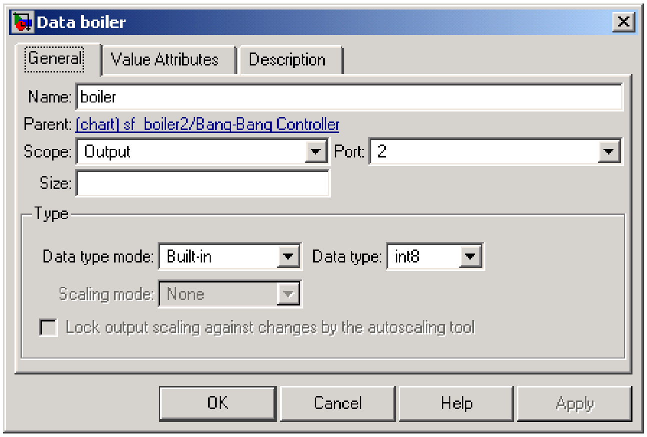
  - Double-click the data object in the **Contents** pane.
  - Right-click the data object in the **Contents** pane and select **Properties**.
  - Select the data object in the **Contents** pane and then select **Dialog View** from the **View** menu.

    The **Data** properties dialog opens inside the **Model Explorer**.

  For more information about adding data objects from the Model Explorer, see “Adding Data Using the Model Explorer” on page 7-27.

Data Properties Dialog Panes

The **Data** properties dialog provides a set of dynamic tabbed panes, as in this example:



Data boiler

Name: boiler

Parent: (chart) sf_boiler2/Bang-Bang Controller

Scope: Output

Port: 2

Size:

Type

Data type mode: Built-in

Data type: int8

Scaling mode: None

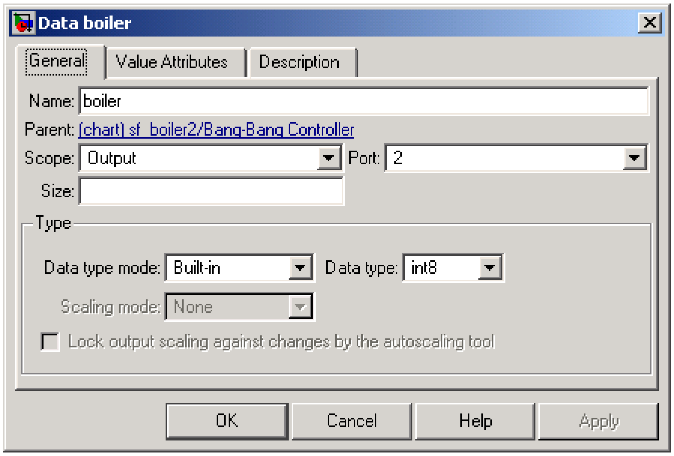
□ Lock output scaling against changes by the autoscaling tool

Each pane lets you define different features of your data object:

- The **General** pane lets you define the scope, size, and type of the data object. See “Setting General Properties” on page 7-33
- The **Value Attributes** pane lets you set an initial value, limit range, and index into the data object array. See “Setting Value Attributes Properties” on page 7-39.
- The **Description** pane lets you enter a data description and link to documentation about the data object. See “Setting Description Properties” on page 7-42

Setting General Properties

The **General** tab of the **Data** properties dialog looks like this:



Name: boiler
Parent: (chart) sf_boiler2/Bang-Bang Controller
Scope: Output
Port: 2
Size:
Type
Data type mode: Built-in
Data type: int8
Scaling mode: None
□ Lock output scaling against changes by the autoscaling tool

This section describes the fields in the **General** tab.

Name

Name of the data object. The name can be of any length and consist of any combination of alphanumeric and special characters. The only restrictions are that the name cannot begin with a numeric character or contain embedded spaces.

Parent

Parent of the data object. Only the parent and its children can access the data object. This field is read-only, but you can click the link to display the parent object in the Stateflow Editor.

Scope

Where data resides in memory, relative to its parent. You can set scope to one of the following values:

Scope Value	Description
Local	Data defined in the current Stateflow 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 workspace, or derived from a Simulink parameter that is defined and initialized in the parent masked subsystem. The Stateflow data object must have the same name as the parameter. See "Mask Editor" in Simulink documentation for information on how to assign a parameter to a masked subsystem. See "Bringing Simulink Parameters into Stateflow" on page 7-49 to learn how to use Simulink parameters with Stateflow blocks.
Input	If the parent is a graphical, truth table, or Embedded MATLAB function, the data is an input argument to the function. Otherwise, the data is provided by the Simulink model to the Stateflow chart via an input port to the Stateflow block. See "Sharing Input and Output Data with Simulink" on page 7-46.

Scope Value	Description
Output	If the parent is a graphical, truth table, or Embedded MATLAB function, the data is a value returned by the function. Otherwise, the data is provided by the Stateflow chart to the Simulink model via an output port on the Stateflow block. See “Sharing Input and Output Data with Simulink” on page 7-46.
Data Store Memory	Data object that binds to a Simulink data store, which is a signal that functions like a global variable because it can be accessed by all blocks in a model. The binding allows the Stateflow chart to read and write the Simulink data store, thereby sharing global data with the model. The Stateflow object must have the same name as the Simulink data store. See “Sharing Global Data with Simulink” on page 7-53.
Temporary	Data that persists only during the execution of a function. Temporary data can be defined only for a graphical, truth table, or Embedded MATLAB functions, as described in Defining Temporary Data.
Exported	Data from the Simulink model that is made available to external code defined in Stateflow, as described in “Sharing Stateflow Data with External Modules” on page 7-60 . Exported data can be defined only for a Stateflow machine.
Imported	Data parented by the Simulink model that is defined by external code embedded in the Stateflow machine, as described in “Sharing Stateflow Data with External Modules” on page 7-60 . Imported data can be defined 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 “Sharing Input and Output Data with Simulink” on page 7-46

Size

Size of the data object. The size can be a scalar value or a MATLAB vector of values. Scalars are specified by setting the **Size** property to 1 or leaving it blank. MATLAB vectors are specified as multidimensional arrays, where the number of dimensions equals the length of the vector, and the size of each dimension corresponds to the value of each element of the vector.

The scope of the data object determines what sizes you can specify. Stateflow data store memory inherits all of its properties — including size — from the Simulink data store to which it is bound. For other scopes, follow these guidelines:

Scope	Scalar	Vector	Matrix 2-dimensions	Matrix n-dimensions
Constant	Yes			
Input from Simulink/Output to Simulink	Yes	Yes	Yes	
Local/Temporary	Yes	Yes	Yes	Yes
Imported/Exported	Yes	Yes	Yes	Yes
Graphical Function Input/Output	Yes	Yes	Yes	
Truth Table Function Input/Output	Yes	Yes	Yes	
Embedded MATLAB Function Input/Output			Yes	
Parameter	Yes	Yes	Yes	

For more information, see “Sizing Stateflow Data” on page 7-72.

Data Type Mode and Data Type

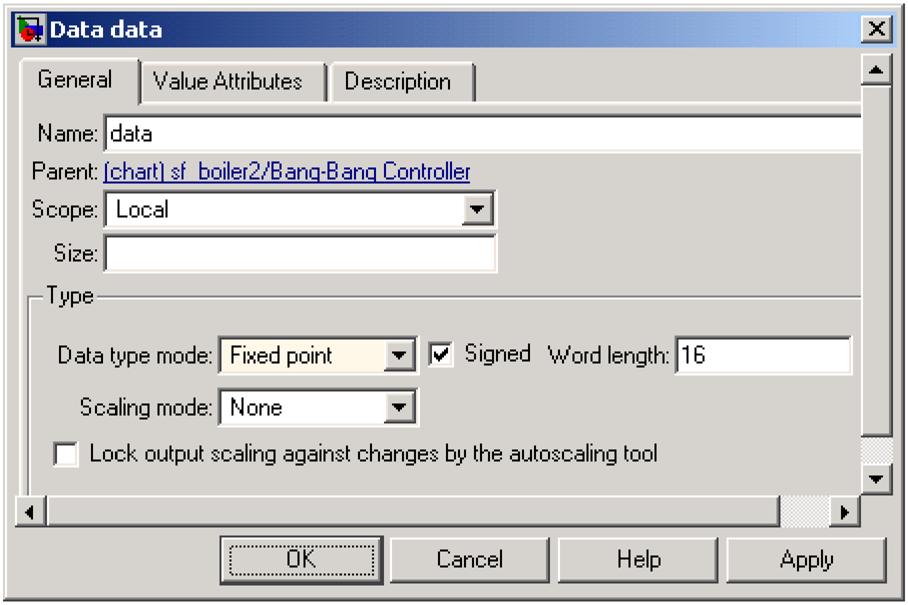
Type of the data object. Based on the mode you select, you can specify the data type by

- Selecting from built-in types, including fixed point
- Entering an expression that evaluates to a data type
- Inheriting the type from previously-defined data in Simulink or the MATLAB workspace

See “Typing Stateflow Data” on page 7-63.

Fixed-Point Data Properties

When you select the data type mode **Fixed point**, the **Data** properties dialog displays new fields for specifying additional information about your fixed-point data, as shown in the **Type** panel:



Name: data

Parent: (chart) sf_boiler2/Bang-Bang Controller

Scope: Local

Size:

Data type mode: Fixed point ☑ Signed Word length: 16

Scaling mode: None

□ Lock output scaling against changes by the autoscaling tool

For a detailed discussion about fixed-point data, see “Fixed-Point Concepts” in the online Fixed-Point Toolbox documentation.

You can set the following fixed-point properties:

Signed. Use this check box to indicate whether you want the fixed-point data to be signed or unsigned. Signed data can represent positive and negative quantities. Unsigned data represents positive values only.

Word length. Specify the size in bits of the word that will hold the quantized integer. Large word sizes represent large quantities with greater precision than small word sizes. Word length can be any integer between 0 and 32. If you do not specify a value, the default is 16.

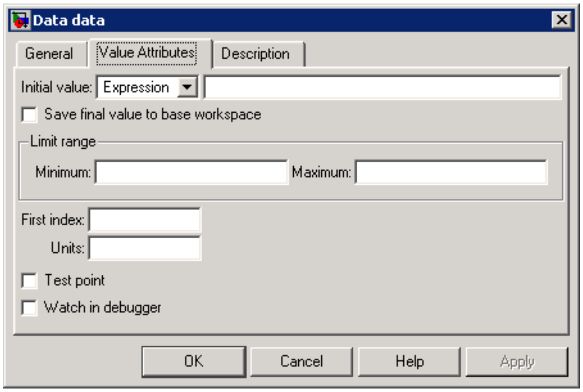
Scaling mode. Specify the method for scaling your fixed point data to avoid overflow conditions and minimize quantization errors. Scaling is disabled by default. However, you can select two scaling modes:

Scaling Mode	Description
Binary point	If you select this mode, the **Data** properties dialog displays a field for entering fraction length that specifies the binary point location. Binary points can be positive or negative integers. If you do not specify a value, the default is 0. A positive integer entry moves the binary point left of the rightmost bit by that amount. For example, an entry of 2 sets the binary point in front of the second bit from the right. A negative integer entry moves the binary point further right of the rightmost bit by that amount.
Slope and bias	If you select this mode, the **Data** properties dialog displays fields for entering separate values for the slope and bias. Slope can be any *positive* real number. If you do not specify a value, the default is 1.0. Bias can be any real number. If you do not specify a value, the default value is 0.0. You can enter slope and bias as expressions that contain parameters defined in the MATLAB workspace.

Lock output scaling against changes by the autoscaling tool. Use this check box to indicate whether you want to prevent Simulink from replacing the current fixed-point type with a type chosen by the autoscaling tool. See "Automatic Scaling" in Simulink Fixed Point documentation for instructions on autoscaling fixed-point data in Simulink.

Setting Value Attributes Properties

The **Value Attributes** tab of the **Data** properties dialog looks like this:



This section describes the fields in the **Value Attributes** tab.

Initial value

Initial value of the data object. If you do not specify a value, the default is 0.0. The options for initializing values depend on the scope of the data object, as follows:

Scope	What to Specify for Initial Value
Local	Expression or parameter defined in Stateflow data dictionary, MATLAB workspace, or Simulink masked subsystem
Constant	Constant value or expression. The expression will be evaluated when you update the diagram and the resulting value will be used as a constant for running the Stateflow chart.

Scope	What to Specify for Initial Value
Parameter	You cannot enter a value. The initial value is inherited from the parameter.
Input	You cannot enter a value. The initial value is inherited from the Simulink input signal on the designated port.
Output	Expression or parameter defined in Stateflow data dictionary, MATLAB workspace, or Simulink masked subsystem
Data Store Memory	You cannot enter a value. The initial value is inherited from the Simulink data store to which it is bound.

For more information, see "Initializing Data from the MATLAB Base Workspace" on page 7-50 and "Bringing Simulink Parameters into Stateflow" on page 7-49.

Save final value to base workspace

If you select this option, Stateflow assigns the value of the data item to a variable of the same name in the model's base workspace at the end of simulation (see "Working with Model Workspaces")

Limit range properties

The range of acceptable values for this data object. Stateflow uses this range to validate the data object during simulation. To establish the range, specify these properties:

- **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.
- **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.

If you do not specify a value, the default for Maximum is `inf` and the default for Minimum is `-inf`.

For more information, see "Entering Expressions and Parameters for Data Properties" on page 7-42.

First index

Specifies the index of the first element of the data array. If you do not specify a value, the default is `0`.

Units

A description field. You can enter the units of measurement that you want to associate with the data object. The value of this field is stored with the data object in the Stateflow data dictionary.

Test point

When enabled, this option designates the data object as a test point, which guarantees that it will be observable during simulation (see "Working with Test Points" in Simulink documentation). Data objects can be test points if

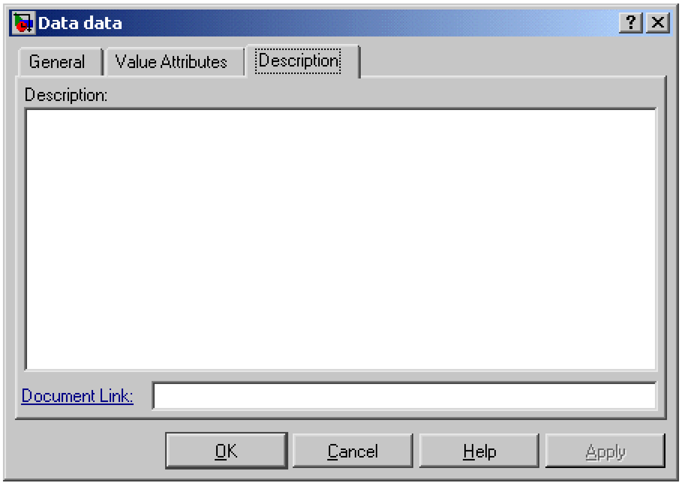
- Scope is **Local**
- Parent is *not* a Stateflow machine
- Data type is *not* **ml**

Watch in debugger

When enabled, the Stateflow debugger watches for changes in the data object. When it detects that the data has been modified, the debugger pauses and displays the data in its output display pane (see "Watching Data in the Stateflow Debugger" on page 15-26).

Setting Description Properties

The **Description** tab of the **Data** properties dialog looks like this:



This section describes the fields in the **Description** tab.

Description

Description of the data object.

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 blue text that reads **Document link** displayed at the bottom of the **Data** properties dialog, Stateflow evaluates the link and displays the documentation.

Entering Expressions and Parameters for Data Properties

You can enter expressions as values for the following properties in the Stateflow **Data** properties dialog:

- "Size" on page 7-36
- Data Type Mode and Data Type
- "Initial value" on page 7-39
- Minimum and Maximum (see "Limit range properties" on page 7-40)
- "Fixed-Point Data Properties" on page 7-37

Expressions can contain a mix of parameters, constants, arithmetic operators, and calls to MATLAB functions.

Default Data Property Values

When you leave an expression or parameter field blank, Stateflow assumes a default value, as follows:

Field	Default
Initial value	0.0
Maximum	`inf`
Minimum	`–inf`
Word Length	16
Slope	1.0
Bias	0.0
Binary point	0
First index	0
Size	• `-1` (inherited), for inputs, parameters, and Embedded MATLAB Function outputs • `scalar`, for all other data objects

Using Parameters in Expressions

The **Data** properties dialog allows you to include parameters in expressions. A parameter is a constant whose value can be

- Defined in the MATLAB workspace (see “Initializing Data from the MATLAB Base Workspace” on page 7-50)
- Derived from a Simulink parameter that is defined and initialized in the parent masked subsystem (see “Bringing Simulink Parameters into Stateflow” on page 7-49)

You can mix both types of parameters in an expression.

Using Constants in Expressions

You can use two types of constants in expressions in the **Data** properties dialog:

- Numeric constants of the appropriate type and size.
- Stateflow constants

  Stateflow constants are read-only Stateflow data objects that you add to your chart with the scope **Constant** (see “Adding Data” on page 7-27). Stateflow constants retain their initial values, which you set in the **Data** properties dialog (see “Initial value” on page 7-39).

Using Arithmetic Operators in Expressions

You can use the following arithmetic operators in expressions in the **Data** properties dialog:

- +
- –
- *
- /

Calling Functions in Expressions

In fields that accept expressions, you can call functions that return property values of other variables defined in the Stateflow Data Dictionary, MATLAB workspace, or Simulink masked subsystem. For example, the following functions may return appropriate values for specified fields in the Stateflow **Data** property dialog:

Function	Returns	For Field
MATLAB `size` function	Size of input array	Size
Stateflow `type` function	Type of input data	Data type
MATLAB `min` function	Smallest element or elements of input array	Minimum
MATLAB `max` function	Largest element or elements of input array	Maximum
Simulink `fixdt` function	`Simulink.NumericType` object that describes a fixed-point or floating-point data type	Data type

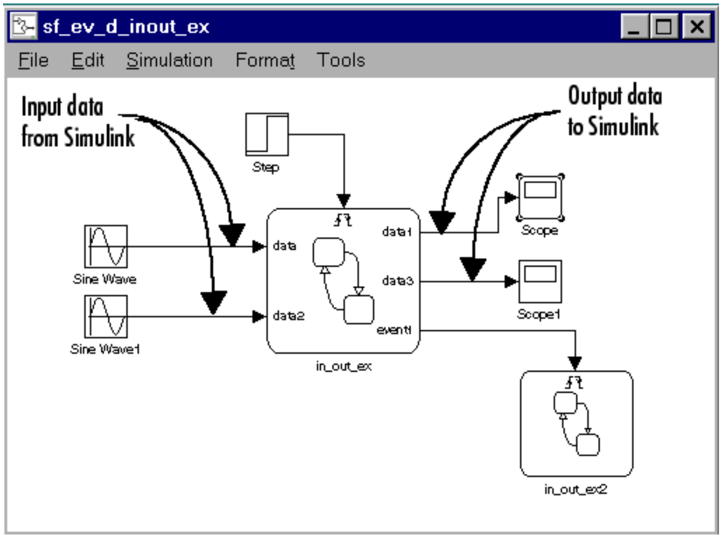
Sharing Stateflow Data with Simulink and MATLAB

Stateflow charts can receive input data from a Simulink input signal or a Simulink parameter defined for a masked subsystem. Stateflow charts can also send output data through a Simulink output signal. The following topics explain how Stateflow shares data with Simulink:

- "Sharing Input and Output Data with Simulink" on page 7-46
- "Resolving Signal Objects for Output Data" on page 7-48
- "Bringing Simulink Parameters into Stateflow" on page 7-49
- "Initializing Data from the MATLAB Base Workspace" on page 7-50
- "Saving Data to the MATLAB Workspace" on page 7-51

Sharing Input and Output Data with Simulink

Data flows between Simulink and Stateflow via input ports and output ports on the Stateflow chart block. The following example shows a Stateflow chart block with input and output data ports connected to the Simulink model.



To add input or output data to a Stateflow chart, follow these steps:

1. Add a data object to the Stateflow chart, as described in "Adding Data Using the Stateflow Editor" on page 7-27.

   Note The data must be added to the Stateflow chart, not to any other object in the chart.

2. Open the Data properties dialog, as described in "Opening the Data Properties Dialog" on page 7-32.

3. Set the **Scope** property to one of the following values:

   - **Input**

     This setting is the same as **Input from Simulink** from the **Add > Data** menu in the Stateflow Editor. A Simulink *input* port is added to the Stateflow chart block in the model.

   - **Output**

     This setting is the same as **Output to Simulink** from the **Add > Data** menu in the Stateflow Editor. A Simulink *output* port is added to the Stateflow chart block in the model.

   By default, Stateflow assigns inputs and outputs to ports in the order in which you add the data. For example, Stateflow assigns the first input to input port 1, the third output to output port 3. You can alter port assignments by editing the value displayed in the **Port** field of the **Data** properties dialog.

4. Set the type of the input or output data, as described in "Typing Stateflow Data" on page 7-63.

5. Consider whether you want to use strong data typing with Simulink, as described in "Strong Data Typing with Simulink I/O" on page 7-70.

6. Set the size of the input or output data, as described in "Sizing Stateflow Data" on page 7-72.

Note You cannot type or size Stateflow input data to accept frame-based data from Simulink.

Resolving Signal Objects for Output Data

Stateflow blocks participate in signal resolution with Simulink signal objects. By default, Stateflow output data objects become associated with Simulink signal objects of the same name during a process called *implicit signal resolution*. See Simulink documentation for a more detailed explanation of implicit signal resolution.

By default, implicit signal resolution generates a warning when the Simulink chart is updated. However, you can manage implicit signal resolution at various levels of the model hierarchy, as described in the following topics:

- "Eliminating Warnings for Implicit Signal Resolution for the Model" on page 7-48
- "Disabling Implicit Signal Resolution for a Stateflow Chart" on page 7-49
- "Enabling Explicit Signal Resolution for an Individual Output Data Signal" on page 7-49

Eliminating Warnings for Implicit Signal Resolution for the Model

If you want to enable implicit signal resolution for all model signals, including Stateflow output data, but eliminate the attendant warnings, do the following:

1. In Simulink, select **Configuration Parameters** from the **Simulation** menu.

   The **Configuration Parameters** dialog appears.

2. In the left pane of the dialog, under the **Diagnostics** node, select the **Data Validity** node.

   The **Data Validity** configuration parameters appear in the right pane of the **Configuration Parameters** dialog. By default, the **Signal resolution** field is set to **Explicit only**.

3 Set the **Signal resolution** field to **Explicit and implicit**.

Disabling Implicit Signal Resolution for a Stateflow Chart

If you enable implicit signal resolution for the model but want to eliminate it for an individual Stateflow chart, follow these steps:

1 Right-click the Stateflow block with output data that you do not want resolved.

2 From the resulting context menu select **Subsystem Parameters**.

3 In the resulting **Block Parameters** dialog, for the **Permit hierarchical resolution** field, select **ExplicitOnly** or **None**.

Enabling Explicit Signal Resolution for an Individual Output Data Signal

If you want to force signal resolution for an individual output signal for a Stateflow chart, follow these steps:

1 In Simulink, right-click the signal line connected to output data that you want to resolve.

2 From the resulting pop-up menu select **Signal Properties**.

The **Signal Properties** dialog appears.

3 In the **Signal Properties** dialog, enter a name for the signal corresponding to its signal object.

4 Select the **Signal name must resolve to Simulink signal object** check box.

5 Click **OK** to save and apply your settings, and close the **Signal Properties** dialog

Bringing Simulink Parameters into Stateflow

You might want to use Simulink parameters for a parent masked subsystem in Stateflow. To bring these parameters into Stateflow, follow these steps:

1. In the Simulink mask editor for the parent subsystem, define and initialize a Simulink parameter (see “Mask Editor” in the Simulink documentation).
2. In Stateflow, define a data object with the same name as the parameter (see “Adding Data” on page 7-27).
3. Set the scope of the data object to **Parameter**.

   Data of scope **Parameter** is defined as a constant in the Stateflow chart workspace. It cannot be changed during application execution. This scope is primarily designed for Stateflow developers who want to use Simulink parameters with Stateflow blocks and maintain consistency with the Simulink model.

When simulation starts, Simulink attempts 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.

Initializing Data from the MATLAB Base Workspace

Stateflow lets you initialize data from the MATLAB base workspace. Initializing data from the MATLAB base workspace requires that you define data in both the MATLAB base workspace and Stateflow as follows:

1. Define and initialize a variable in the MATLAB workspace.
2. In Stateflow, define a data object with the same name as the MATLAB variable (see “Adding Data” on page 7-27).
3. Set the scope of the Stateflow data object to **Parameter**.

When simulation starts, the data is resolved. During this process, the Stateflow data object gets its initial value from the associated MATLAB variable. For example, if the variable is an array, each element of the Stateflow array is initialized to the same value as the corresponding element of the MATLAB array.

Note that one-dimensional arrays in Stateflow 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]`.

Time of Initialization

The following table summarizes the time of initialization for Stateflow data objects, based on their parent and scope.

Data Parent	Scope	When Initialized
Machine	Local, Exported	Start of simulation
	Imported	Not applicable
Chart	Input	Not applicable
	Output, Local	Start of simulation or when chart is reinitialized as part of an enabled Simulink subsystem
State with History Junction	Local	Start of simulation or when chart is reinitialized as part of an enabled Simulink subsystem
State without History Junction	Local	State activation (state entered)
Function (graphical, truth table, and embedded MATLAB)	Input, Output	When function is invoked
	Local	Start of simulation or when chart is reinitialized as part of an enabled Simulink subsystem

Saving Data to the MATLAB Workspace

For all scopes except **Constant** and **Parameter**, you can instruct Stateflow to save the final value of a data object at the end of simulation in the MATLAB base workspace (not as a masked subsystem parameter). Use one of these techniques:

- In the **Value Attributes** panel of the **Data** properties dialog, select the check box **Save final value to base workspace**.
- In the **Contents** pane of the **Model Explorer**, follow these steps:
  - Select the row of the data object.
  - Select the check box in the **SaveToWorkspace** field.

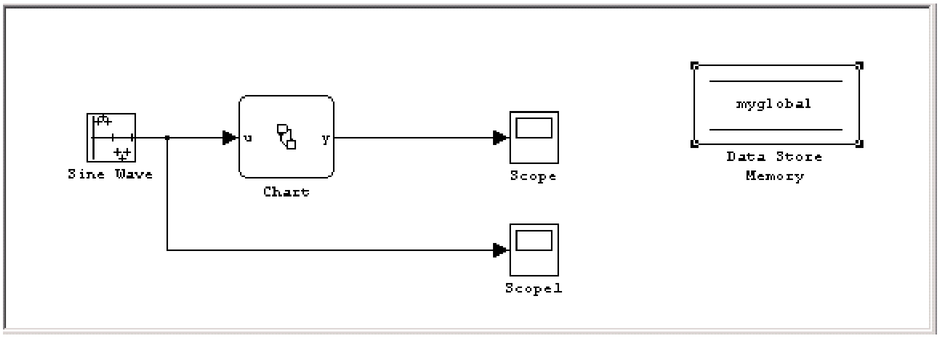
Sharing Global Data with Simulink

Stateflow provides an interface that allows Stateflow charts to access global variables in Simulink models. Simulink implements global variables as *data stores*, created either as data store memory blocks or as instances of `Simulink.Signal` objects. Using these constructs, multiple Simulink blocks can share data without the need for explicit I/O connections to pass data from one block to another. Stateflow charts share global data with Simulink by reading and writing data store memory symbolically using the Stateflow action language.

- "Stateflow Works with Local and Global Data Stores" on page 7-53
- "Accessing Data Store Memory from a Stateflow Chart" on page 7-54
- "Diagnostics for Sharing Data Between Stateflow and Simulink" on page 7-57
- "Best Practices for Using Data Stores in Stateflow" on page 7-58

Stateflow Works with Local and Global Data Stores

Stateflow charts can interface with local and global data stores. Local data stores, often implemented as data store memory blocks, are visible to all blocks in one model. To interact with local data stores, a Stateflow chart must reside in the model where the local data store is defined, as in this example:



Global data stores have a broader scope, which crosses model reference boundaries. To interact with global data stores, a Stateflow chart must reside either in the top model — where the global data store is defined — or in any model referenced by the top model. Global data stores are implemented as signal objects.

Accessing Data Store Memory from a Stateflow Chart

To access global data in Simulink from a Stateflow chart, you must bind a Stateflow data object to a Simulink data store — either a data store memory block or a signal object (see "Binding a Stateflow Data Object to Data Store Memory" on page 7-54). After you create the binding, the Stateflow data object becomes a symbolic representation of Simulink data store memory. You can then use this symbolic object to store and retrieve global data using the Stateflow action language (see "Reading and Writing Global Data Programmatically" on page 7-56).

Binding a Stateflow Data Object to Data Store Memory

To bind a Stateflow data object to Simulink data store memory, you must create a data object in Stateflow with the same name as the data store and with scope set to `Data Store Memory`. The Stateflow data object then inherits all properties from the data store to which it is bound. Follow guidelines for specifying data store properties in "Best Practices for Using Data Stores in Stateflow" on page 7-58.

You can bind a Stateflow data object to a data store from the Stateflow Editor or Model Explorer. From the Stateflow Editor, follow these steps:

1. From the **Add** menu, select **Data > Data Store Memory**.

   The properties dialog for the new data object appears with scope property set to **Data Store Memory** automatically.

2. In the **Name** field, enter the name of the Simulink data store that you want to bind to.

3. Click **OK**.

To use the Model Explorer, follow these steps:

1. Select **Explore** from the **Tools** menu in the Stateflow Editor.

2. In Model Explorer, select **Data** from the **Add** menu.

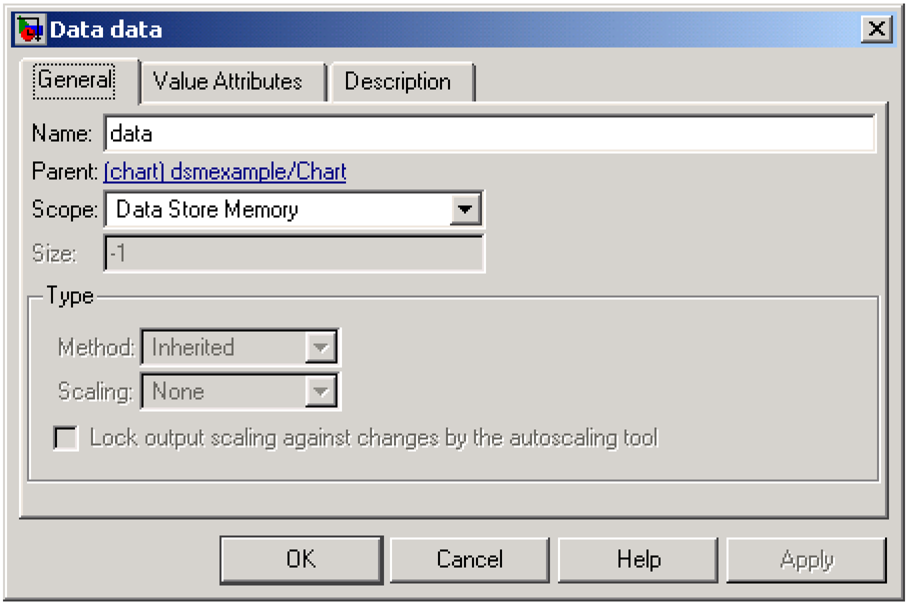
The Model Explorer adds a data object to the Stateflow chart.

3 Double-click the new data object to open its properties dialog, and enter the following information in the **General** panel:

Field	What to Specify
Name	Enter the name of the Simulink data store memory block you want to bind to.
Scope	Select `Data Store Memory` from the drop-down menu.

4 Click **OK**.

Here is an example of a properties dialog for a Stateflow data object that is bound to a data store:



Data data

Name: data
Parent: (chart) dsmexample/Chart
Scope: Data Store Memory
Size: -1
Type
Method: Inherited
Scaling: None
□ Lock output scaling against changes by the autoscaling tool

Note that you cannot edit properties that are inherited from the data store.

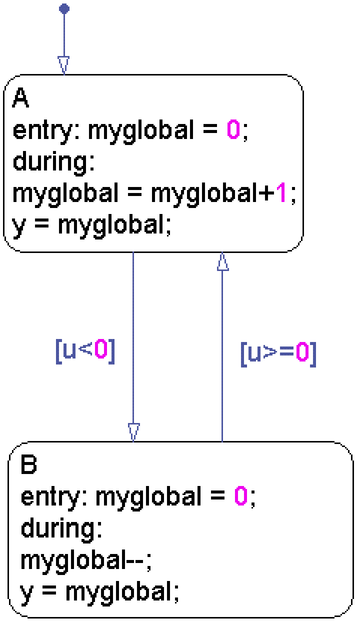
Resolving Data Store Bindings

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.

Reading and Writing Global Data Programmatically

The Stateflow data object that you bind to Simulink data store memory can be used to store and retrieve global data in states and transitions using the Stateflow action language. Think of this object as a global variable that you reference by its symbolic name — the same name as the data store to which it is bound. When you store numeric values in this variable, you are writing to Simulink data store memory. Similarly, when you retrieve numeric values from this variable, you are reading from the data store memory.

Here is an example of Stateflow action language code that reads from and writes to a data store memory block called `myglobal`:



Diagnostics for Sharing Data Between Stateflow and Simulink

The ability to share data between unconnected blocks in Simulink and Stateflow opens the possibility for multiple reads and writes to occur unintentionally in the same time step. To detect these situations, you can configure data store memory blocks to generate errors or warnings for the following conditions:

- Read before write
- Write after write
- Write after read

Note These diagnostics are available only for data store memory blocks, not for data stores created from signal objects.

When to Enable Diagnostics

Enable diagnostics on data store memory blocks to ensure the validity of global data that is shared by multiple unconnected blocks running at different rates. In this scenario, you can detect conditions when writes do not occur before reads in the same time step. To circumvent these violations, see “Best Practices for Using Data Stores in Stateflow” on page 7-58.

By contrast, if you use a data store memory block as a persistent global storage area for accumulating values across time steps, disable diagnostics to avoid generating unnecessary warnings.

How to Set Diagnostics for Shared Data

To set diagnostics on data store memory blocks, follow these steps:

1. Double-click the data store memory block in your Simulink model to open its block parameters dialog.

2. Click the **Diagnostics** tab.

3. Enable diagnostics by selecting `warning` or `error` from the drop-down menu for each condition you want to detect.

4. Click **OK**.

Best Practices for Using Data Stores in Stateflow

This section describes best practices for binding to data stores in Stateflow and for enforcing writes before reads when unconnected blocks share global data.

When Binding to Data Stores in Stateflow

When you bind a Stateflow data object to a data store, the Stateflow object inherits all properties from the data store. To ensure that properties are propagated unambiguously when you access data stores in Stateflow, create data stores with the following properties:

- Specify the signal type as `real`.
- Specify a data type other than `auto`.
- Minimize the use of automatic-mode properties in general.

When Enforcing Writes Before Reads in Unconnected Blocks

To enforce writes before reads when unconnected blocks share global data in Stateflow charts, follow these guidelines:

- Segregate reads into separate blocks from writes.
- Assign priorities to blocks so that write blocks are invoked before read blocks.

  To learn how to set a block's execution priority to influence its execution order, see the section on controlling and displaying sorted order in the Using Simulink documentation.

Sharing Data Between Charts and with External Modules

The Stateflow machine is the parent of all Stateflow charts in a model, along with external code that you include with a target for the model. You can share Stateflow data between charts in the Stateflow machine and with external modules.

- "Sharing Data Between Charts in a Stateflow Machine" on page 7-59
- "Sharing Stateflow Data with External Modules" on page 7-60

Sharing Data Between Charts in a Stateflow Machine

You can share data and events between Stateflow charts in a single Stateflow machine by

- Defining local data and events that are parented by the Stateflow *machine*
- Defining data store memory objects that are parented by each Stateflow *chart* that wants to share the data.

Sharing Local Data and Events Between All Charts in a Stateflow Machine

To share local data between all charts in a single Stateflow machine, follow these steps:

1. Use the Model Explorer to add a data object or event to the Stateflow machine in which the charts reside, as described in "Adding Data Using the Model Explorer" on page 7-27.

2. Set the scope of the data object or event to **Local**, as described in Setting Data Properties in the Data Dialog.

The new data object or event should be visible to all charts in the parent Stateflow machine.

Sharing Data Store Memory Between Charts in a Stateflow Machine

You can use data store memory objects as a mechanism for sharing data between selected charts in a single Stateflow machine. Follow these steps:

1. Use the Model Explorer to add a data object to each Stateflow chart that wants to share the data, as described in “Adding Data Using the Model Explorer” on page 7-27.

2. Give each data object the same name.

3. Set the scope of each data object to **Data Store Memory**.

Each data store memory object you add represents a common area of memory storage and, therefore, functions as a global variable. You can extend the use of data store memory objects for sharing data with Simulink, as described in “Sharing Global Data with Simulink” on page 7-53.

Sharing Stateflow Data with External Modules

A Stateflow machine can share data with external modules, such as Stateflow charts in other machines or external Stateflow code assigned to the machine. The methodology requires that a Stateflow machine *export* the data definition to the external module and, in turn, that the external module *import* the data definition from the Stateflow machine. Similarly, a Stateflow machine can import data that has been exported by an external module.

Exporting Data to External Modules

To export data from the Stateflow machine to external modules, follow these steps:

- In the **Model Explorer**, add a data object to the Stateflow *machine*, as described in Adding Data Using the Model Explorer.
- Set the scope of the data to **Exported**.

When Data is Exported to External Code Assigned to the Stateflow Machine. For each exported data object, the Stateflow code generator creates a C declaration of the form

```
type data;
```

where `type` is the C type of the exported data object — such as `int16` or `double` — and `data` is the object’s Stateflow name. For example, suppose that your Stateflow machine defines an exported `int16` item named `counter`. The Stateflow code generator exports the item as the C declaration

```
int16_T counter;
```

where `int16_T` is a defined type for `int16` integers in Stateflow.

The code generator includes declarations for exported data in the generated target's global header file, thereby making the declarations visible to external code compiled into or linked to the target.

See “Exported Data” on page 10-35 for an example of Stateflow data exported to Stateflow external code.

When Data is Exported to an External Stateflow Machine. For each Stateflow machine that wants to share the data exported from the external machine, you must define a data object of the same name as the exported data and set its scope to **Imported**.

Importing Data from External Modules

To import externally-defined data into a Stateflow machine, follow these steps:

1. In the **Model Explorer**, add a data object to the Stateflow *machine*, as described in Adding Data Using the Model Explorer.
2. Give the data object the same name as the external data.
3. Set the scope of the data to **Imported**.

When Data is Imported from External Code Assigned to the Stateflow Machine. For each imported data object, the Stateflow code generator assumes that external code provides a prototype of the form

```
type data;
```

where `type` is the C data type corresponding to the Stateflow data type of the imported item — such as `int32` or `double` — and `data` is the object's Stateflow name. For example, suppose that your Stateflow machine defines an imported `int32` integer named `counter`. The Stateflow code generator expects the item to be defined in the external C code as

```
int32_T counter;
```

See “Imported Data” on page 10-36 for an example of Stateflow external code data imported into Stateflow.

When Data is Imported from an External Stateflow Machine. Make sure that the external Stateflow machine contains a data definition of scope **Exported** with the same name as the imported data objects.

Typing Stateflow Data

The term *data type* refers to the way computers represent numbers in memory. The type determines the amount of storage allocated to data, the method used to encode its value as a pattern of binary digits, and the operations available for manipulating the data.

This section describes the methods for representing data types in Stateflow in the following topics:

- "Specifying Modes and Types" on page 7-63 — Explains how to specify data types based on modes and scopes
- "Built-In Data Types" on page 7-66 — Describes the data types that Stateflow supports
- "Inheriting Data Types from Simulink" on page 7-67 — Explains how to add input and output data that interacts with Simulink signals
- "Deriving Data Types from Previously Defined Data" on page 7-68 — Describes how to specify data types that are based on previously-defined data
- "Typing Data by Using an Alias" on page 7-69 — Shows how to use a data type alias
- "Strong Data Typing with Simulink I/O" on page 7-70 — Explains the impact of using strong data typing with Simulink I/O

Specifying Modes and Types

To specify the *type* of a Stateflow data object, follow these steps:

1. Choose a mode in the **Data type mode** field of the **Data** properties dialog.

   The following modes are defined for each scope:

Scope	Data Type Modes				
	Built-in	Expression	Fixed point	Inherited	Bus Object
Local	yes	yes	yes		yes
Constant	yes	yes	yes		
Parameter	yes	yes	yes	yes	
Input	yes	yes	yes	yes	yes
Output	yes	yes	yes	yes	yes
Data Store Memory				yes	

2. Based on the mode you select, specify a data type as follows:

Mode	What To Specify
Built-in	In the **Data type** field, select from the drop-down list of supported data types, as described in “Built-In Data Types” on page 7-66.
Expression	Enter an expression that evaluates to a data type in the **Data type** field. The following expressions are allowed: • Alias type from the MATLAB workspace, as described in “Typing Data by Using an Alias” on page 7-69. • `type` operator to specify the type of previously defined data, as described in “Deriving Data Types from Previously Defined Data” on page 7-68. • `fixdt` function to create a `Simulink.NumericType` object describing a fixed-point or floating-point data type For more information on how to build expressions in the Data properties dialog, see “Entering Expressions and Parameters for Data Properties” on page 7-42.

Mode	What To Specify
Fixed point	Specify the following information about the fixed point data: • Whether the data is signed or unsigned. • Word length • Scaling mode For information on how to specify these fixed point data properties, see "Fixed-Point Data Properties" on page 7-37.

Mode	What To Specify
Inherited	You cannot specify a value. The data type is inherited from previously-defined data, based on the scope you selected for the data object, as follows: • If scope is **Input**, data type is inherited from the Simulink input signal on the designated input port (see “Sharing Input and Output Data with Simulink” on page 7-46) • If scope is **Output**, data type is inherited from the Simulink output signal on the designated output port (see “Sharing Input and Output Data with Simulink” on page 7-46) **Note** Inheriting data types from output signals is not recommended. See “Guidelines for Inheriting Data and Event Properties” on page 7-77. • If scope is **Parameter**, data type is inherited from the associated parameter, which can be defined in Simulink or the MATLAB workspace (see “Sharing Stateflow Data with Simulink and MATLAB” on page 7-46) • If scope is **Data Store Memory**, data type is inherited from the Simulink data store to which the data object is bound (see “Sharing Global Data with Simulink” on page 7-53)
Bus object	In the **Bus object** field, enter the name of a `Simulink.Bus` object that you have defined in the base workspace to associate with the Stateflow bus object structure. **Note** Alternatively, you can inherit bus object properties from Simulink signals. For more information about Stateflow bus object structures, see Chapter 11, “Working with Structures and Bus Signals in Stateflow”.

Built-In Data Types

Stateflow provides the following built-in data types:

Entry	Description
`double`	64-bit double-precision floating point
`single`	32-bit single-precision floating point
`int32`	32-bit signed integer
`int16`	16-bit signed integer
`int8`	8-bit signed integer
`uint32`	32-bit unsigned integer
`uint16`	16-bit unsigned integer
`uint8`	8-bit unsigned integer
`boolean`	Boolean (1 = true; 0 = false)
`ml`	Typed internally with the MATLAB array `mxArray`. You can assign this type to local Stateflow data only. The `ml` 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. See “ml Data Type” on page 8-34.

Inheriting Data Types from Simulink

Stateflow data objects of scope **Input**, **Output**, **Parameter**, and **Data Store Memory** can inherit their data types from Simulink objects, as follows:

Scope:	Can inherit type from:
Input	Simulink input signal connected to corresponding input port in Stateflow

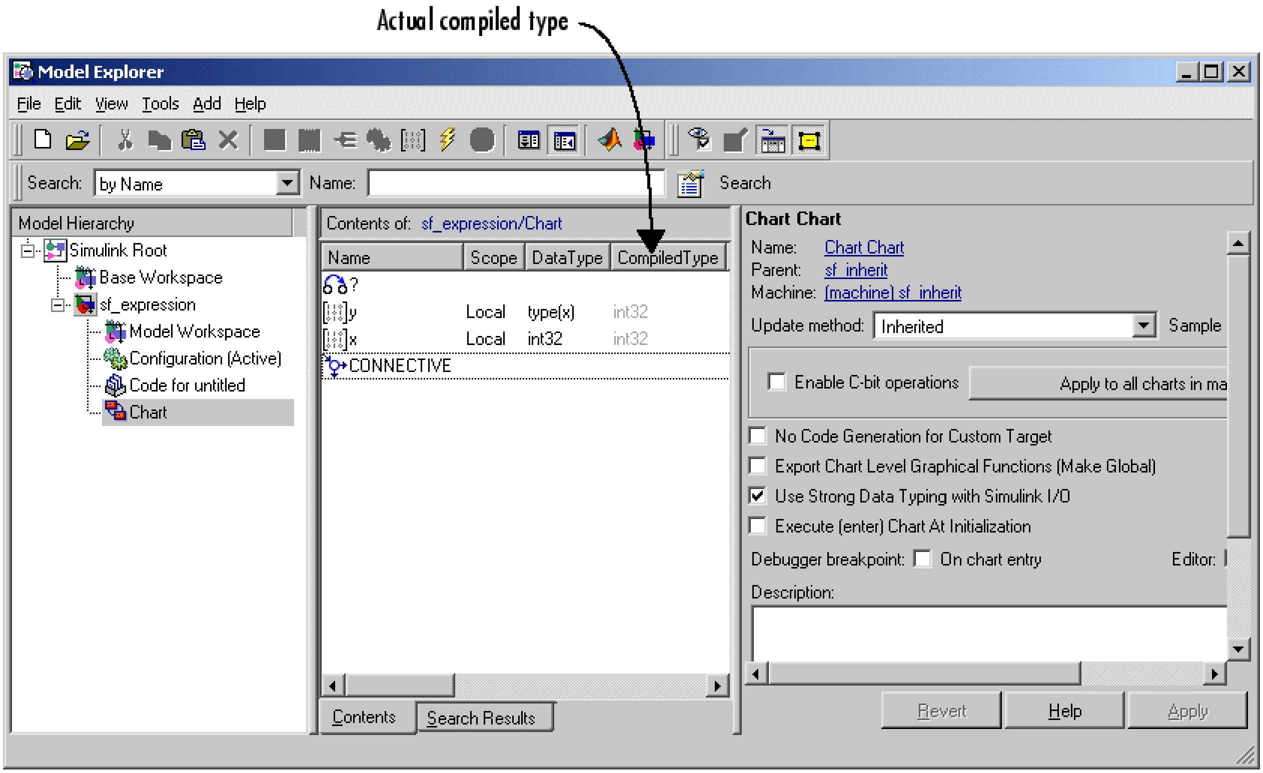
Scope:	Can inherit type from:
Output	Simulink output signal connected to corresponding output port in Stateflow **Note** Inheriting data types from output signals is not recommended. See “Guidelines for Inheriting Data and Event Properties” on page 7-77.
Parameter	Corresponding MATLAB workspace variable or Simulink parameter in a masked subsystem
Data Store Memory	Corresponding Simulink data store

To configure these objects to inherit data types, create the corresponding objects in Simulink and select **Inherited** as the **Data type mode** in the **Data** properties dialog, as described in “Specifying Modes and Types” on page 7-63.

To determine the data types that were inherited, build the Simulink model and look at the **Compiled Type** column for the Stateflow data object in the **Model Explorer**.

Deriving Data Types from Previously Defined Data

You can use the `type` operator to derive data types from previously defined Stateflow data. In the following example, the data type of the Stateflow local data object `y` is specified by the Stateflow operator `type(x)`, where `x` is defined as a local data object of type `int32`. After you build your model, the **Compiled Type** column of the **Model Explorer** displays the type of each data object in the compiled simulation application.



Actual compiled type

Contents of: sf_expression/Chart

Name	Scope	DataType	CompiledType
?			
y	Local	type(x)	int32
x	Local	int32	int32
CONNECTIVE			

Chart Chart

Name: Chart Chart

Parent: sf_inherit

Machine: (machine) sf_inherit

Update method: Inherited Sample

□ Enable C-bit operations Apply to all charts in ma

□ No Code Generation for Custom Target

□ Export Chart Level Graphical Functions (Make Global)

☑ Use Strong Data Typing with Simulink I/O

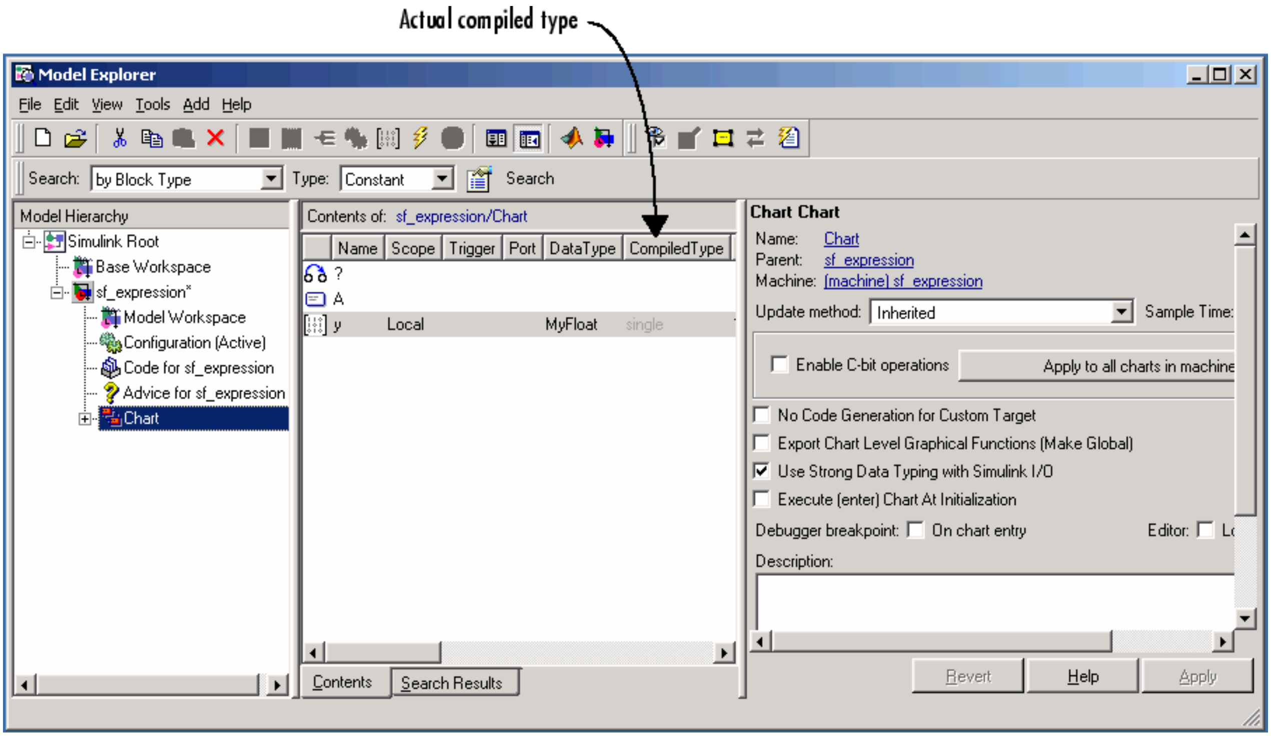
□ Execute (enter) Chart At Initialization

Debugger breakpoint: □ On chart entry Editor:

Description:

Typing Data by Using an Alias

You can specify the type of Stateflow data by using a Simulink data type alias (see `Simulink.AliasType` in the Simulink Reference documentation). After you build the model, the **Compiled Type** column of the **Model Explorer** displays the type used in the compiled simulation application. In the following example, Stateflow local data `y` is typed by the alias `MyFloat`, with `BaseType` set to `single`.



Search: by Block Type Type: Constant Search

Model Hierarchy
- Simulink Root
  - Base Workspace
  - sf_expression*
    - Model Workspace
    - Configuration (Active)
    - Code for sf_expression
    - Advice for sf_expression
    - Chart

Contents of: sf_expression/Chart

Name	Scope	Trigger	Port	DataType	CompiledType
?					
A					
y	Local			MyFloat	single

Chart Chart

Name: Chart
Parent: sf_expression
Machine: (machine) sf_expression
Update method: Inherited Sample Time:

□ Enable C-bit operations Apply to all charts in machine

□ No Code Generation for Custom Target
□ Export Chart Level Graphical Functions (Make Global)
☑ Use Strong Data Typing with Simulink I/O
□ Execute (enter) Chart At Initialization

Debugger breakpoint: □ On chart entry Editor: □ Lo

Description:

Strong Data Typing with Simulink I/O

By default, inputs to and outputs from Stateflow charts are of type `double`. Input signals from Simulink are converted to the type of the corresponding input data objects in Stateflow. Likewise, the data output objects are converted to `double` before they are exported as output signals to Simulink.

To interface directly with signals of data types other than `double` without the need for conversion, you can enable the option **Use Strong Data Typing with Simulink I/O** for the Stateflow chart (see “Specifying Chart Properties” on page 10-6). When this option is enabled, the Stateflow chart accepts input signals of any data type supported by Simulink, provided that the type of the input signal matches the type of the corresponding Stateflow input data object. Otherwise, you receive a type mismatch error.

For fixed-point data, always enable the **Use Strong Data Typing with Simulink IO** option to flag mismatches between input or output fixed-point data in Stateflow and their counterparts in Simulink.

Sizing Stateflow Data

You specify the size of Stateflow data by entering a value in the **Size** field of the **Data** properties dialog, as described in “Setting General Properties” on page 7-33.

You can enter size as a constant value or an expression. Stateflow input and output data objects can also inherit their sizes from the Simulink signals that connect to them.

- “Sizing Data by Expression” on page 7-72
- “Inheriting Input and Output Data Size from Simulink” on page 7-73

Sizing Data by Expression

You can use a mathematical expression to set the size of a data object to be a scalar, vector, or n-dimensional matrix, depending on its scope (see “Size” on page 7-36). Size expressions must resolve to a positive integer.

You set the **Size** property for two-dimensional arrays in `[row column]` format. One-dimensional data arrays in Stateflow are compatible with Simulink row or column vectors of the same size. For example, a Stateflow input or output data object of size `3` is compatible with a Simulink row vector of size `[1,3]`, or column vector of size `[3,1]`. To define a row vector of size 5, set the **Size** to `[1 5]`. To define a column vector of size 6, set the **Size** property to `[6 1]` or just `6`.

You can enter a MATLAB expression for each dimension in the **Size** field. Expressions can contain a mix of numeric constants, Stateflow constants, arithmetic operators, parameters, and calls to functions such as `size`, `min`, and `max`. Here are examples of valid size expressions:

```
k+1
size(x)
min(size(y),k)
```

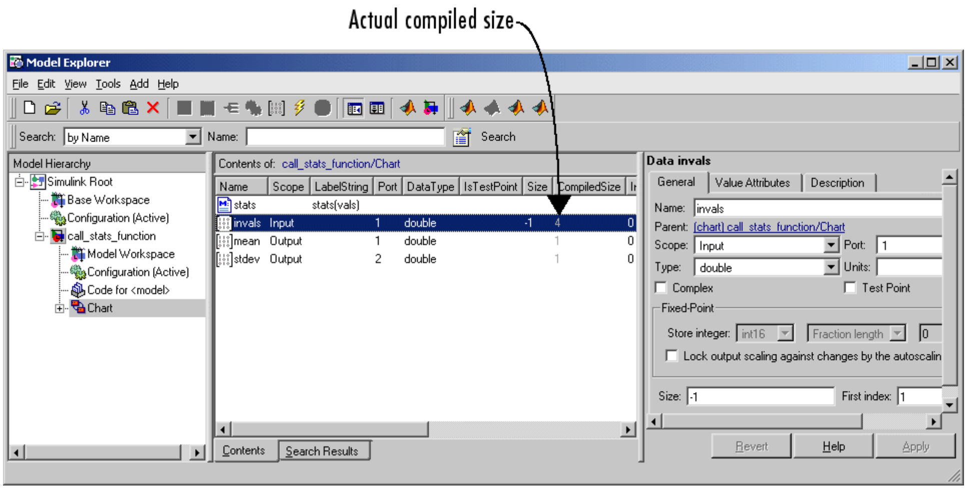
For more information about expressions, see “Entering Expressions and Parameters for Data Properties” on page 7-42.

Note You cannot size Stateflow input data with an expression that accepts frame-based data from Simulink.

Inheriting Input and Output Data Size from Simulink

To configure Stateflow input and output data objects to inherit size from the corresponding Simulink input and output signals, enter `-1` in the **Size** field for that data. This is the default setting for input and output data that you add from the Stateflow Editor (see “Adding Data” on page 7-27). After you build the model, the **Compiled Size** column of the **Model Explorer** displays the actual size used in the compiled simulation application.

In the following example, the input data `invals` is connected to a Constant block that specifies a four-element vector. The **Compiled Size** field displays the correct inherited size of 4 for `invals`.



Actual compiled size

Model Explorer

Search: by Name Name: Search

Model Hierarchy

- Simulink Root
  - Base Workspace
  - Configuration (Active)
  - call_stats_function
    - Model Workspace
    - Configuration (Active)
    - Code for <model>
    - Chart

Contents of: call_stats_function/Chart

Name	Scope	LabelString	Port	DataType	IsTestPoint	Size	CompiledSize	Ir
stats		stats(vals)						
invals	Input		1	double		-1	4	0
mean	Output		1	double			1	0
stdev	Output		2	double			1	0

Data invals

Name: invals
Parent: (chart) call_stats_function/Chart
Scope: Input Port: 1
Type: double Units:
□ Complex □ Test Point
Fixed-Point
Store integer: int16 Fraction length 0
□ Lock output scaling against changes by the autoscalin
Size: -1 First index: 1

Inheriting the size of input data is complete for all cases. The inherited size of output data is inferred from chart actions that store values in the specified output. If the expected size in Simulink matches the inferred size, inheritance is successful. In all other cases, a mismatch occurs during build time.

Note Stateflow cannot inherit frame-based data sizes from Simulink.

Defining Temporary Data

You can define temporary data in graphical, truth table, and Embedded MATLAB functions. Temporary data persists only while the function executes. For example, you can designate a loop counter to have **Temporary** scope if its value does not need to persist after the function completes.

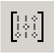
To define temporary data for a Stateflow function, follow these steps:

1. Select **Explore** from the **Tools** menu in the Stateflow Editor.

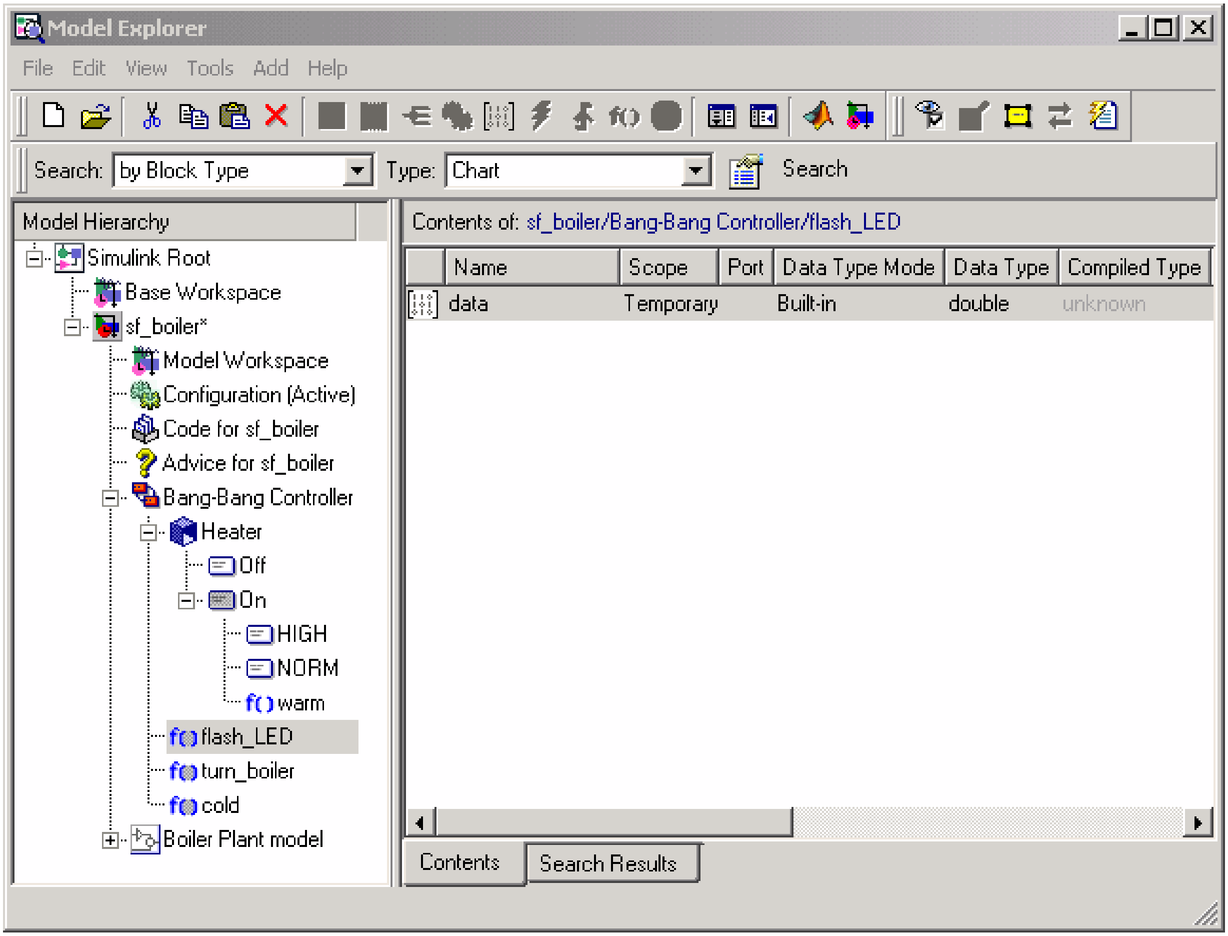
   The **Model Explorer** opens.

2. In the **Model Hierarchy** pane, select the graphical, truth table, or Embedded MATLAB function that will use the temporary data.

3. Select **Data** from the **Add** menu, or click the **Add Data** button:

Stateflow adds a default definition for the data in the data dictionary, with a scope set to **Temporary** by default, as in this example:



Search: by Block Type Type: Chart

Contents of: sf_boiler/Bang-Bang Controller/flash_LED

Name	Scope	Port	Data Type Mode	Data Type	Compiled Type
data	Temporary		Built-in	double	unknown

4 Change other properties of the data as needed, as described in “Setting Data Properties in the Data Dialog” on page 7-31.

Guidelines for Inheriting Data and Event Properties

Inheriting properties can sometimes produce unpredictable results. This section presents guidelines for inheriting properties when

- The object is output data
- The Stateflow block is in a library

Inheriting Output Data Properties

It is not recommended that Stateflow output data inherit properties from output signals because the values are back propagated from Simulink and may, therefore, be unpredictable.

In the Stateflow action language, inherited properties of outputs are determined solely by external information from Simulink and *not* from the code. By contrast, within the Embedded MATLAB subset — used in Truth tables and Embedded MATLAB functions — inherited properties of outputs are determined solely from the code and the properties of the inputs.

Inheriting Properties in Libraries

Stateflow blocks in libraries can inherit event and data properties. However, multiple instances of the same library in a model must inherit the same values for those properties.

Transferring Events and Data Across Models

When you copy a Stateflow Chart from one Simulink model to another, all data and event objects in the chart hierarchy are copied *except* those parented by the Stateflow machine. However, you can use the **Model Explorer** to transfer individual events and data objects from machine to machine.

To *copy* objects, follow these steps:

1. In the **Contents** pane of the **Model Explorer**, right–click the event or data object you want to copy and select **Copy** from the drop-down menu.

2. In the **Model Hierarchy** pane, right–click the destination Stateflow machine and select **Paste** from the drop-down menu.

To *move* objects, click the event or data object in the **Contents** pane of the **Model Explorer** and drag it to the destination Stateflow machine in the **Model Hierarchy** pane.

8

Using Actions in Stateflow

Stateflow attaches actions to a state or transition through its label. The actions in action language can be broadcast events, condition statements, function calls, variable assignments and operations, and so on. Many are very similar to statements in C or MATLAB. Stateflow also defines categories for the actions that you specify, known as action types. This chapter describes the action types of states and transitions and the actions that they contain in the following sections:

Defining Action Types

Stateflow attaches actions to states and transitions through the syntax of their labels. Each action is entered as an action of a particular type. States specify actions through five action types: entry, during, exit, bind, and on *event_name*. Transitions specify actions through four action types: event trigger, condition, condition action, and transition action. This section describes and gives examples of the action language types for states and transitions in the following topics:

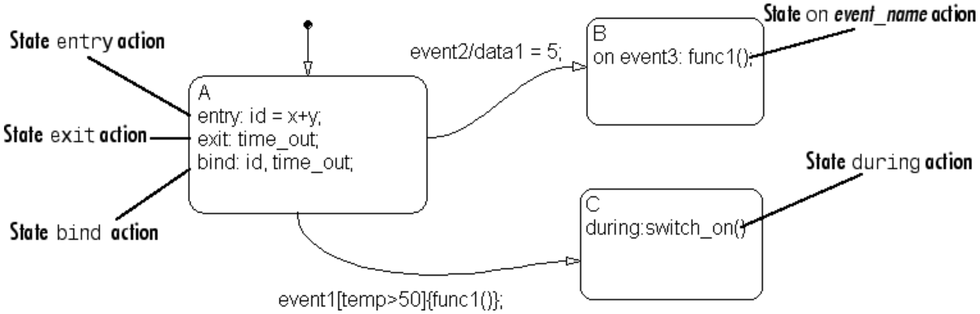
- "State Action Types" on page 8-3 — Introduces you to the notation and meaning of actions that accompany states.
- "Transition Action Types" on page 8-7 — Introduces you to the notation and meaning of actions that accompany transitions.
- "Example of Action Type Execution" on page 8-9 — Shows how the different action types interact in executing example Stateflow diagram.

State Action Types

States can have different action types, which include `entry`, `during`, `exit`, `bind`, and, `on` *`event_name`* actions. The actions for states are assigned to an action type using label notation with the following general format:

```
name/
entry:entry actions
during:during actions
exit:exit actions
bind:data_name, event_name
on event_name:on event_name actions
```

The following example shows examples of state action types:



After you enter the name in the state's label, enter a carriage return and specify the actions for the state. A description of each action type is given in the following topics:

Note The order that you use to enter action types in the label is irrelevant.

Entry Actions

Entry actions are preceded by the prefix `entry` or `en` for short, followed by a required colon (`:`), followed by one or more actions. Separate multiple actions with a carriage return, semicolon (`;`), or a comma (`,`). 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 `entry` actions only.

Entry actions are executed for a state when the state is entered (becomes active). In the preceding example in "State Action Types" on page 8-3, the entry action `id = x+y` is executed when the state A is entered by the default transition.

For a detailed description of the semantics of entering a state, see "Entering a State" on page 3-21 and "State Execution Example" on page 3-24.

Exit Actions

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

Exit actions for a state are executed when the state is active and a transition out of the state is taken.

For a detailed description of the semantics of exiting a state, see "Exiting an Active State" on page 3-23 and "State Execution Example" on page 3-24.

During Actions

During actions are preceded by the prefix `during` or `du` for short, followed by a required colon (`:`), followed by one or more actions. Separate multiple actions with a carriage return, semicolon (`;`), or a comma (`,`).

During actions are executed for a state when it is active and an event occurs and no valid transition to another state is available.

For a detailed description of the semantics of executing an active state, see "Executing an Active State" on page 3-23 and "State Execution Example" on page 3-24.

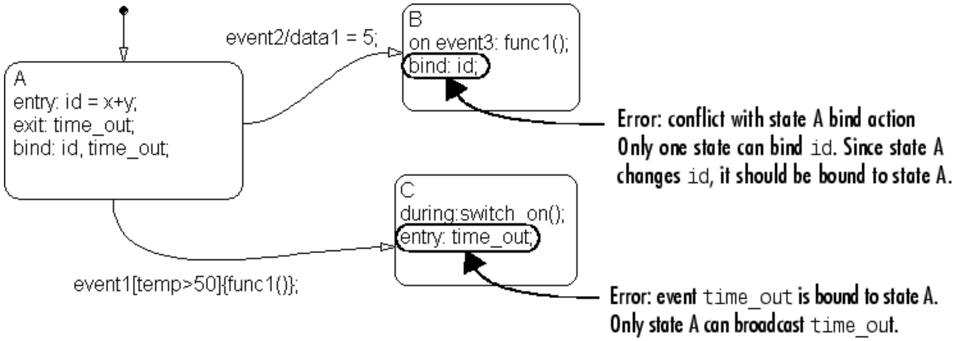
Bind Actions

Bind actions are preceded by the prefix `bind`, followed by a required colon (`:`), followed by one or more events or data. Separate multiple data/events with a carriage return, semicolon (`;`), or a comma (`,`).

Bind actions bind the specified data and events to a state. Data bound to a state can be changed by the actions of that state or its children. Other states and their children are free to read the bound data, but they cannot change it. Events bound to a state can be broadcast only by that state or its children. Other states and their children are free to listen for the bound event, but they cannot send it.

Bind actions are applicable to a Stateflow diagram whether the binding state is active or not. In the preceding example in "State Action Types" on page 8-3, the bind action `bind:  id, time_out` for state `A` binds the data `id` and the event `time_out` to state `A`. This forbids any other state (or its children) in the Stateflow diagram from changing `id` or broadcasting event `time_out`.

If another state includes actions that change data or send events that are bound to another state, a parsing error results. The following example demonstrates a few of these error conditions:


A
entry: id = x+y;
exit: time_out;
bind: id, time_out;
event2/data1 = 5;
B
on event3: func1();
bind: id;
C
during:switch_on();
entry: time_out;
event1[temp>50]{func1()};
Error: conflict with state A bind action
Only one state can bind id. Since state A changes id, it should be bound to state A.
Error: event time_out is bound to state A.
Only state A can broadcast time_out.

Binding a function-call event to a state also binds the function-call subsystem that it calls. In this case, the function-call subsystem is enabled when the binding state is entered and disabled when the binding state is exited. For a detailed description of this feature, see “Using Bind Actions to Control Function-Call Subsystems” on page 8-74.

On Event_Name Actions

On *event_name* actions are preceded by the prefix `on, followed by a unique event,` *event_name*, followed by one or more actions. Separate multiple actions with a carriage return, semicolon (`;`), or a comma (`,`). You can specify actions for more than one event by adding additional `on` *event_name* lines for different events. If you want different events to trigger different actions, enter multiple `on` *event_name* action statements in the state’s label, each specifying the action for a particular event or set of events, for example:

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

On *event_name* actions for a state are executed when the state is active and the event *event_name* is received by the state. This is also accompanied by the execution of any during actions for the state.

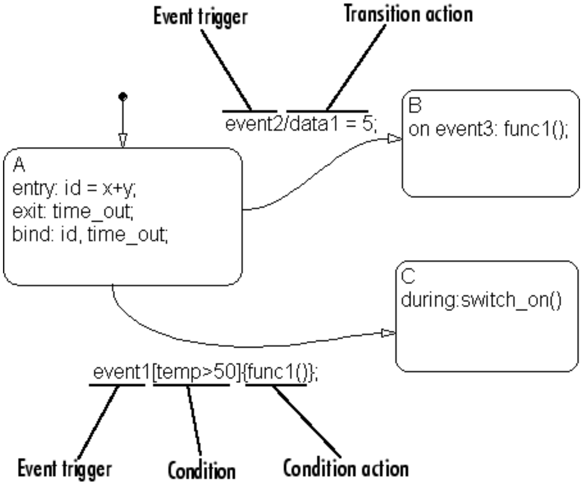
For a detailed description of the semantics of executing an active state, see “Executing an Active State” on page 3-23.

Transition Action Types

In "State Action Types" on page 8-3, you see how Stateflow attaches actions to the label for a state. Stateflow also attaches actions to a transition through its label. Transitions can have different action types, which include event triggers, conditions, condition actions, and transition actions. The actions for transitions are assigned to an action type using label notation with the following general format:

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

The following example shows examples of transition action types:



Event Triggers

In transition label syntax, event triggers appear first as the name of an event. They have no distinguishing special character to separate them from other actions in a transition label. In the example in "Transition Action Types" on page 8-7, 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. The absence of an event indicates that the transition is taken upon the occurrence of any event. Multiple events are specified using the OR logical operator (`|`).

Conditions

In transition label syntax, conditions are Boolean expressions enclosed in square brackets (`[]`). In the example in "Transition Action Types" on page 8-7, 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. The following are some guidelines for defining and using conditions:

- The condition expression must be a Boolean expression of some kind that evaluates to either 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
  - The `in(state_name)`condition function that is evaluated as true when the state specified as the argument is active. The full state name, including any ancestor states, must be specified to avoid ambiguity.

    Note A chart cannot use the `In` condition function to trigger actions based on the activity of states in other charts.

  - Temporal conditions (see "Using Temporal Logic in Actions" on page 8-51)
- The condition expression should not call a function that causes the Stateflow diagram 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 “Transition Action Types” on page 8-7, the transition from state A to state B has the condition action `func()`, 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.

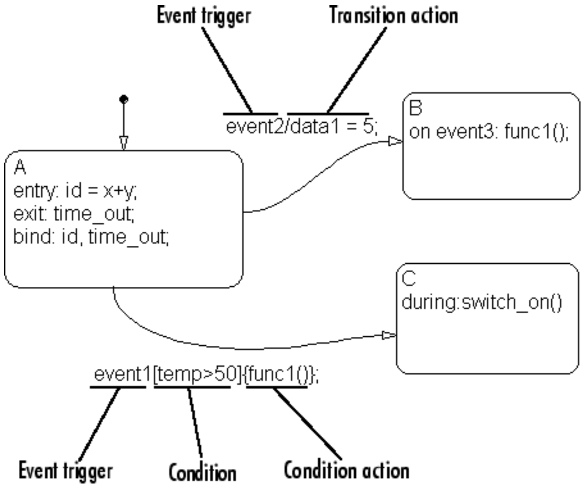
Transition Actions

In transition label syntax, transition actions are preceded with a forward slash (/). In the example in “Transition Action Types” on page 8-7, the transition from state A to state B has the transition action `data1 = 5`.

Transition actions are executed when the transition is actually taken. They are executed 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 is only executed when the entire transition path to the final destination is determined to be valid.

Example of Action Type Execution

In “State Action Types” on page 8-3 and “Transition Action Types” on page 8-7, you are introduced to the notation and meaning of the action language types in Stateflow. In this topic, you see how Stateflow action language types interact when you execute the following example Stateflow diagram:



If the Stateflow diagram is turned on, the following takes place:

1 The default transition to state A is taken.

2 The entry action `id = x+y` is executed.

3 The event `time_out` is bound to state A.

4 State A is active.

If state `A` is active and the Stateflow diagram receives the event `event2`, the following takes place:

1 The exit action broadcast of the event `time_out` is executed.

2 State A becomes inactive.

3 The transition action `data1 = 5` is executed.

4 State B becomes active.

If state `A` is active and the Stateflow diagram receives the event `event1`, the following takes place:

1. The condition `temp > 50` is evaluated.

If condition is	Then
True (temp > 50)	The remaining steps are executed and the transition is taken.
False (temp <= 50)	The remaining steps are *not* executed. The transition is *not* taken and State A remains active.

2. The condition action call to the function `func1()` is executed.

3. The exit action broadcast of the event `time_out` is executed.

4. State A becomes inactive.

5. The transition action `data1 = 5` is executed.

6. State B becomes active.

Using Operations in Actions

Stateflow maintains a set of allowable operations between Stateflow data in action language. The following sections categorize the operations you can use in Stateflow action language:

- "Binary and Bitwise Operations" on page 8-12 — Lists and describes the supported action language operations that require two operands.
- "Unary Operations" on page 8-15 — Lists and describes the supported action language operations that require one operand.
- "Unary Actions" on page 8-15 — Lists and describes the supported action language operations that require one operand and an operator to the right.
- "Assignment Operations" on page 8-16 — Lists and describes the supported action language operations that assign the results of an operation to an operand.
- "Pointer and Address Operations" on page 8-17 — Lists and describes the supported action language operations that point to the location of data.
- "Type Cast Operations" on page 8-17 — Lists and describes the supported action language operations that change the data type of an operand.

Binary and Bitwise Operations

The table that follows summarizes the interpretation of all binary operators in Stateflow action language. Table order gives relative operator precedence; highest precedence (10) is at the top of the table. Binary operators are evaluated left to right (left associative).

You can specify that the binary operators `&`, `^`, `|`, `&&`, and `||` are interpreted as bitwise operators in Stateflow generated C code for a chart or for all the charts in a model. See these individual operators in the table that follows for specific binary or bitwise operator interpretations.

Example	Precedence	Description
`a * b`	10	Multiplication
`a / b`	10	Division

Example	Precedence	Description
`a %% b`	10	Modulus
`a + b`	9	Addition
`a - b`	9	Subtraction
`a >> b`	8	Shift operand `a` right by `b` bits. Noninteger operands for this operator are first cast to integers before the bits are shifted.
`a << b`	8	Shift operand `a` left by `b` bits. Noninteger operands for this operator are first cast to integers before the bits are shifted.
`a > b`	7	Comparison of the first operand greater than the second operand
`a < b`	7	Comparison of the first operand less than the second operand
`a >= b`	7	Comparison of the first operand greater than or equal to the second operand
`a <= b`	7	Comparison of the first operand less than or equal to the second operand
`a == b`	6	Comparison of equality of two operands
`a ~= b`	6	Comparison of inequality of two operands
`a != b`	6	Comparison of inequality of two operands
`a <> b`	6	Comparison of inequality of two operands

Example	Precedence	Description
`a & b`	5	One of the following: • Bitwise AND of two operands Enabled when **Enable C-bit operations** is selected in chart properties dialog. See "Specifying Chart Properties" on page 10-6. • Logical AND of two operands Enabled when **Enable C-bit operations** is cleared in chart properties dialog.
`a ^ b`	4	One of the following: • Bitwise XOR of two operands Enabled when **Enable C-bit operations** is selected in chart properties dialog. See "Specifying Chart Properties" on page 10-6. • Operand `a` raised to power `b` Enabled when **Enable C-bit operations** is cleared in chart properties dialog.

Example	Precedence	Description
`a | b`	3	One of the following: - Bitwise OR of two operands Enabled when **Enable C-bit operations** is selected in chart properties dialog. See "Specifying Chart Properties" on page 10-6. - Logical OR of two operands Enabled when **Enable C-bit operations** is cleared in chart properties dialog.
`a && b`	2	Logical AND of two operands
`a || b`	1	Logical OR of two operands

Unary Operations

The following unary operators are supported in Stateflow action language. Unary operators have higher precedence than binary operators and are evaluated right to left (right associative).

Example	Description
`~a`	Logical NOT of `a` Complement of `a` (if `bitops` is enabled)
`!a`	Logical NOT of `a`
`-a`	Negative of `a`

Unary Actions

The following unary actions are supported in Stateflow action language.

Example	Description
`a++`	Increment a
`a--`	Decrement a

Assignment Operations

The following assignment operations are supported in Stateflow action language.

Example	Description
`a = expression`	Simple assignment
`a := expression`	Used primarily with fixed-point numbers. See "Assignment (=, :=) Operations" on page 9-25 for a detailed description.
`a += expression`	Equivalent to `a = a + expression`
`a -= expression`	Equivalent to `a = a - expression`
`a *= expression`	Equivalent to `a = a * expression`
`a /= expression`	Equivalent to `a = a / expression`

The following assignment operations are supported in Stateflow action language when **Enable C-bit operations** is selected in the properties dialog for the chart. See "Specifying Chart Properties" on page 10-6.

Example	Description
`a |= expression`	Equivalent to `a = a | expression` (bit operation). See operation `a | b` in "Binary and Bitwise Operations" on page 8-12.
`a &= expression`	Equivalent to `a = a & expression` (bit operation). See operation `a & b` in "Binary and Bitwise Operations" on page 8-12.
`a ^= expression`	Equivalent to `a = a ^ expression` (bit operation). See operation `a ^ b` in "Binary and Bitwise Operations" on page 8-12.

Pointer and Address Operations

The address operator is available for use with both custom code variables and Stateflow variables. The pointer operator is available for use with custom code variables only.

Note The action language parser uses a relaxed set of restrictions. As a result, many syntax errors are not trapped until compilation.

The following examples show syntax that is valid for use with *custom code* variables only.

```
varStruct.field = <expression>;
(*varPtr) = <expression>;
varPtr->field = <expression>;
myVar = varPtr->field;
varPtrArray[index]->field = <expression>;
varPtrArray[expression]->field = <expression>;
myVar = varPtrArray[expression]->field;
```

The following examples show syntax that is valid for use both with custom code variables and with Stateflow variables.

```
varPtr = &var;
ptr = &varArray[<expression>];
*(&var) = <expression>;
function(&varA, &varB, &varC);
function(&sf.varArray[<expression>]);
```

Type Cast Operations

Stateflow provides type cast operators to convert a value of one type to a value that can be represented in another type. Normally, you do not need to use type cast operators in actions because Stateflow checks whether the types involved in a variable assignment differ and compensates by inserting the required type cast operator of the target language (typically C) in the generated code. However, external (custom) code might require data in a different type from those currently available in Stateflow. In this case, Stateflow cannot determine the required type casts and you must explicitly use a Stateflow action language type cast operator to tell Stateflow the target language type cast operator to generate.

For example, you might have a custom code function that requires integer RGB values for a graphic plot. You might have these values in Stateflow data, but only in data of type `double`. To call this function, you must type cast the original data and assign the result to integers, which you use as arguments to the function.

In Stateflow, type cast operations have two forms: the MATLAB type cast form and the explicit form using the `cast` operator. These operators and the special `type` operator, which works with the explicit `cast` operator, are described in the topics that follow.

MATLAB Form Type Cast Operators

The MATLAB type casting form in Stateflow has the general form

```
<type_op>(<expression>)
```

`<type_op>` is a conversion type operator that can be `double`, `single`, `int32`, `int16`, `int8`, `uint32`, `uint16`, `uint8`, or `boolean`. `<expression>` is the expression to be converted. For example, you can cast the expression `x+3` to a 16-bit unsigned integer and assign its value to the data `y` as follows:

```
y = uint16(x+3)
```

Explicit Type Cast Operator

You can also type cast with the explicit `cast` operator, which has the following general form:

```
cast(<expression>,<type>)
```

As in the preceding example, the statement

```
y = cast(x+3,uint16)
```

tells Stateflow to cast the expression `x+3` to a 16-bit unsigned integer and assign it to `y`, which can be of any type.

type Operator

To make type casting more convenient, Stateflow also provides a type operator that works with the explicit type cast operator cast to let you assign types to data based on the types of other data.

The type operator returns the type of an existing Stateflow data according to the general form

```
type(<data>)
```

where <*data*> is the Stateflow data whose type you want to return.

The return value from a type operation can be used only in an explicit cast operation. For example, if you want to convert the data y to the same type as that of data z, use the following statement:

```
cast(y,type(z))
```

In this case, the data z can have any acceptable Stateflow type.

Using Special Symbols in Actions

Stateflow notation uses the symbols `inf`, `NaN`, `t`, `$`, `...`, `%`, `//`, `/*`, `;`, `F`, and hexadecimal notation to provide the user with special features in action language notation as described in the following topics:

- "Comment Symbols" on page 8-20
- "Hexadecimal Notation Symbols" on page 8-20
- "Infinity Symbol, inf" on page 8-21
- "Line Continuation Symbol, ..." on page 8-21
- "Literal Code Symbol, $" on page 8-21
- "MATLAB Display Symbol, ;" on page 8-21
- "Single-Precision Floating-Point Number Symbol, F" on page 8-21
- "Time Symbol, t" on page 8-21

Comment Symbols

Use the symbols %, //, and /* to represent comments in Stateflow action language as shown in the following examples:

```
% MATLAB comment line
// C++ comment line
/* C comment line */
```

You can optionally include comments in Stateflow generated code for a Real-Time Workshop target (see "Configuration Parameter Reference" in the Real-Time Workshop documentation) or a Stateflow custom target (see "Configuring a Custom Target in Stateflow" on page 14-22). Stateflow action language comments in generated code are represented with multibyte character code. This means that you can have comments in code with characters for non-English alphabets such as Japanese Kanji characters.

Hexadecimal Notation Symbols

Stateflow action language supports 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 Stateflow action language. Calculations like n/0, where n is any nonzero real value, result in inf.

Line Continuation Symbol, ...

Use the characters ... at the end of a line of action language to indicate that the expression continues on the next line.

Literal Code Symbol, $

Use $ characters to mark action language that you want the parser to ignore but you want to appear in the generated code. For example,

```
$
ptr -> field = 1.0;
$
```

The parser is completely disabled during the processing of anything between the $ characters. Frequent use of literals is discouraged.

MATLAB Display Symbol, ;

Omitting the semicolon after an expression displays the results of the expression in the MATLAB Command Window. If you use a semicolon, the results are not displayed.

Single-Precision Floating-Point Number Symbol, F

Use a trailing F to specify single-precision floating-point numbers in Stateflow action language. 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, it is assumed to be double-precision.

Time Symbol, t

Use the letter t to represent absolute time inherited from Simulink in simulation targets. For example, the condition [t - On_time > Duration] specifies that the condition is true if the value of `On_time` subtracted from the simulation time `t` is greater than the value of `Duration`.

Note The meaning of `t` for nonsimulation targets is undefined since it is dependent upon the specific application and target hardware.

Calling C Functions in Actions

This section describes the C functions that you can call directly in Stateflow action language. See the following topics:

- "Calling C Library Functions" on page 8-23 — Tells you how to call C functions from the math library of your compiler or from custom libraries that you provide.
- "Calling min and max Functions" on page 8-24 — Describes the special `min` and `max` macros that you can call.
- "Calling User-Written C Code Functions" on page 8-25 — Tells you how to call C functions you provide in custom code for the target you build.

Calling C Library Functions

You can call the following small subset of the C Math Library functions:

`abs`*	`acos`	`asin`	`atan`	`atan2`	`ceil`
`cos`	`cosh`	`exp`	`fabs`	`floor`	`fmod`
`labs`	`ldexp`	`log`	`log10`	`pow`	`rand`
`sin`	`sinh`	`sqrt`	`tan`	`tanh`	

*Stateflow extends the `abs` function beyond that of its standard C counterpart with its own built in functionality. See "Calling the abs Function" on page 8-24.

You can call the above C Math Library functions without doing anything special as long as you are careful to call them with the right data types. In case of a type mismatch, Stateflow replaces the input argument with a cast of the original argument to the expected type. For example, if you call the `sin` function with an integer argument, Stateflow replaces the argument with a cast of the original argument to a floating-point number of type `double`.

If you call other C library functions not specified above, be sure to include the appropriate `#include...` directive in the **Custom code included at the**

top of generated code field of the **Target Options** dialog. See the section "Specifying Custom Code Options for Stateflow Targets" on page 14-27.

Calling the abs Function

Stateflow extends the interpretation of its abs function 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, Stateflow evaluates abs(x) with the standard C function abs applied to x, or abs(x).
- If x is an integer of type other than int32, Stateflow evaluates abs(x) with the standard C abs function applied 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, Stateflow evaluates abs(x) with the standard C function fabs applied to x, or fabs(x).
- If x is a floating point number of type single, Stateflow evaluates abs(x) with the standard C function fabs applied to a cast of x as a double, or fabs((double)x).
- If x is a fixed-point number, Stateflow evaluates abs(x) with the standard C function fabs applied to a cast of the fixed-point number as a double, or fabs((double)V_x), where V_x is the real-world value of x.

If you want to use the abs function in Stateflow in the strict sense of standard C, be sure to cast its argument or return values to integer types. See "Type Cast Operations" on page 8-17.

Note If x is declared in Stateflow custom code, Stateflow evaluates abs(x) with the standard C abs function in all cases. For instructions on inserting custom code into Stateflow diagrams, see "Integrating Custom Code with Stateflow Targets" on page 14-27.

Calling min and max Functions

Although min and max are not C library functions, Stateflow enables them 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()`, Stateflow generates code for them with a mangled name of the following form: `<prefix>_min`. However, if you export `min()` or `max()` graphical functions to other Stateflow charts in the Stateflow machine, 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.

Calling User-Written C Code Functions

To install your own C code functions for use in Stateflow action language, do the following:

1. From the Tools menu, select the **Open** (**RTW** or **Simulation**) **Target** dialog.

2. When the **Open Target** dialog appears, select **Target Options**.

3. Enter the following:

- Include a header file containing the declarations of your C code functions in the **Custom code included at the top of generated code** field.
- Specify the source `file name` containing your C code functions in the **Custom source files** field.

See “Specifying Custom Code Options for Stateflow Targets” on page 14-27.

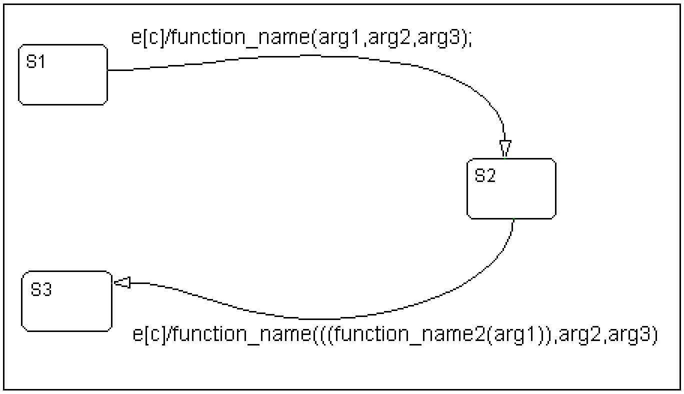
To use your own C code functions in Stateflow action language, follow these guidelines:

- Define a function by its name, any arguments in parentheses, and an optional semicolon.
- String parameters to user-written functions are passed between 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).

Function Call Transition Action Example

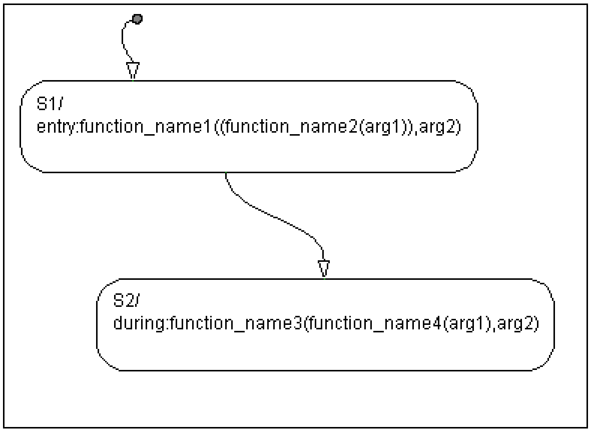
These are example formats of function calls using transition action notation.


S1
e[c]/function_name(arg1,arg2,arg3);
S2
S3
e[c]/function_name(((function_name2(arg1)),arg2,arg3)

If S1 is active, event e occurs, c is true, and the transition destination is determined, then a function call is made to function_name with arg1, arg2, and arg3. The transition action in the transition from S2 to S3 shows a function call nested within another function call.

Function Call State Action Example

These are example formats of function calls using state action notation.


S1/
entry:function_name1((function_name2(arg1)),arg2)
S2/
during:function_name3(function_name4(arg1),arg2)

When the default transition into S1 occurs, S1 is marked active and then its entry action, a function call to function_name1 with the specified arguments, is executed and completed. If S2 is active and an event occurs, the during action, a function call to function_name3 with the specified arguments, executes and completes.

Passing 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 data dictionary, the following rules apply.

- Do not use pointers to pass data items input from Simulink.

  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 IO** must be on (see “Specifying Chart Properties” on page 10-6).
- If the data type of x is boolean, the coder option **Use bitsets to store state-configuration** must be turned off (see “Configuring Real-Time Workshop for Stateflow” on page 14-13).
- If x is an array with its first index property set to 0 (see “Setting Data Properties in the Data Dialog” on page 7-31), then the function must be called 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.

Using MATLAB Functions and Data in Actions

You can call MATLAB functions and access MATLAB workspace variables in action language, using the `ml` namespace operator or the `ml` function. See the following sections:

- "ml Namespace Operator" on page 8-29 – Shows you how to use MATLAB workspace variables or call MATLAB functions through the `ml` namespace operator.
- "ml Function" on page 8-30 – Shows you how to use MATLAB functions through the `ml` function.
- "ml Expressions" on page 8-32 – Shows you how to mix ml namespace operator and `ml` function expressions along with Stateflow data in larger expressions.
- "ml Data Type" on page 8-34 — Shows you how to use the MATLAB data type to keep MATLAB data in Stateflow instead of in the MATLAB workspace.
- "Inferring Return Size for ml Expressions" on page 8-37 — Gives you the rules for providing enough information to infer the size of the values returned from the `ml` namespace operator and the ml function in larger action language expressions.

Caution Because MATLAB functions are not available in a target environment, do not use the `ml` namespace operator and the `ml` function if you plan to build an RTW target that includes code from Stateflow Coder.

ml Namespace Operator

The `ml` namespace operator uses standard dot (`.`) notation to reference MATLAB variables and functions in action language. For example, the statement `y = ml.x` returns the value of the MATLAB workspace variable `x` to the Stateflow data `y`. The statement `y = ml.matfunc(arg1, arg2)` passes the return value from the MATLAB function `matfunc` to Stateflow data `y`.

If the MATLAB function you call does not require arguments, you must still include the parentheses, as shown in the preceding examples. If the parentheses are omitted, Stateflow interprets the function name as a workspace variable, which, when not found, generates a run-time error during simulation.

In the following examples, `x`, `y`, and `z` are workspace variables and `d1` and `d2` are Stateflow data:

- `a = ml.sin(ml.x)`

  In this example, the `sin` function of MATLAB 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, `ml.x` is used instead of just `x`.

- `a = ml.sin(d1)`

  In this example, the `sin` function of MATLAB evaluates the sine of `d1`, which is assigned to Stateflow data variable `a`. Because `d1` is Stateflow data, you can access it directly.

- `ml.x = d1*d2/ml.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 literal string.

  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

You can use the `ml` function to specify calls to MATLAB functions through a string expression in the action language. The format for the `ml` function call uses standard function notation as follows:

```
ml(evalString, arg1,arg2,...);
```

evalString is a string 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 string literals in the following command:

```
ml.eval(ml.sprintf(evalString,arg1,arg2,...))
```

Stateflow assumes scalar return values from ml namespace operator and ml function calls when they are used as arguments in this context. See “Inferring Return Size for ml Expressions” on page 8-37.

In the following 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 sin function of MATLAB 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 sin function of MATLAB 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 string 'matfunc(%g, ''abcdefg'', x, %f)' is the evalString shown in the preceding format statement. Stateflow data d1 and d2 are inserted into that string with the format specifiers %g and %f, respectively. The string ''abcdefg'' is a string literal with two single pairs of quotation marks used to enclose it because it is part of the evaluation string, 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 in Stateflow as a 4-by-4 array before simulation. If its size is different, a size mismatch error is generated during run-time.

ml Expressions

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 is included 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 and Bitwise Operations" on page 8-12. To repeat a warning note in that section, be sure to use parentheses around power expressions with the ^ operator when you use them in conjunction with other arithmetic operators.

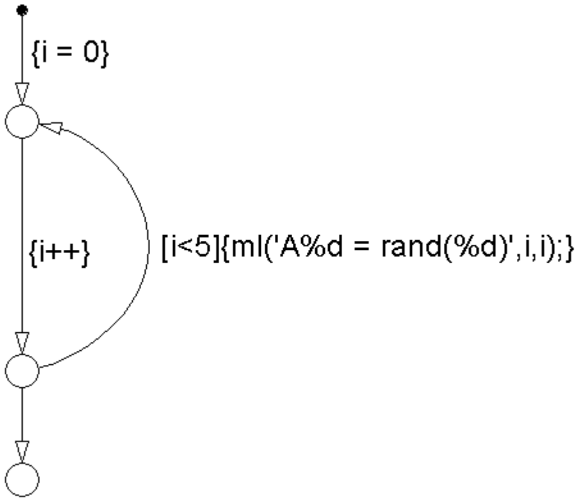
Stateflow checks expressions for data size mismatches in your action language during parsing of your charts and during run-time. Because the return values for `ml` expressions are not known till run-time, Stateflow must infer the size of their return values. See "Inferring Return Size for ml Expressions" on page 8-37.

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 example creates four new MATLAB matrices:

  This example demonstrates the use of a Stateflow `for` loop to create four new matrix workspace variables in MATLAB. 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 is taken and 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 is taken and execution stops.

  This results in 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 demonstrated by the following example:

  ```
  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 mxArray. This means that you can assign (store) any type of data available in Stateflow to a data of type ml. This includes any type of data defined in Stateflow or returned from MATLAB with the ml namespace operator or ml function.

The following features and limitations apply to Stateflow data of type ml.

- ml data can be initialized from the MATLAB workspace just like other data in Stateflow (see the **Initialize from** property in “Setting Data Properties in the Data Dialog” on page 7-31).
- Any numerical scalar or array of ml data in Stateflow can participate in any kind of unary operation and any kind of binary operation with any other data in Stateflow.

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 "Inferring Return Size for ml Expressions" on page 8-37.

Note The preceding feature does not apply to ml data storing MATLAB 64 bit integers. ml data can store 64 bit MATLAB integers but cannot be used in Stateflow action language.

- ml data cannot be defined with the scope **Constant** or specified as an array.

  These options are disabled in the data properties dialog and Stateflow Explorer for Stateflow data of type ml.
- ml data can be used in building a simulation target (sfun) but not in building an RTW target (rtw).
- If data of type ml contains an array, the elements of the array can be accessed through indexing with the following rules:

  a Only arrays with numerical elements can be indexed.

  b Numerical arrays can be indexed according to their dimension only.

  This means that only one-dimensional arrays can be accessed 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 string 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 string data of type ml*/
```

- ml data cannot have a scope outside Stateflow; that is, it cannot be scoped as **Input to 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 Stateflow. 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 Stateflow and use it for MATLAB computations in Stateflow action language.

As an example, in the following Stateflow action language 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 rand function in MATLAB, 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 ml.

In the second line of the example, mldata2, also of Stateflow data type ml, 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 ml data to hold the generated matrices:

```
ml.wsdata1 = ml.rand(3);
ml.wsdata2 = ml.transpose(ml.wsdata);
```

In this case, each workspace data must be accessed through the ml namespace operator.

Inferring Return Size for ml Expressions

Stateflow expressions using the ml namespace operator and the ml function are evaluated in the MATLAB workspace at run-time. This means that 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 ml namespace operator or the ml function call

  For example, the size of the return values from the expressions ml.var, ml.func(), or ml(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 ml
- Graphical functions that return Stateflow data of type ml

When any of these expressions is used in action language, Stateflow code generation must create temporary Stateflow data, invisible to the user, to hold their intermediate returns for evaluation of the full expression of which they are a part. Because the size of these return values is not known till run-time, Stateflow must employ context rules to infer their size for the 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 chosen to store it, a size mismatch error results. To prevent these run-time errors, use the following guidelines in constructing action language statements with MATLAB commands or ml data:

1. The return sizes of MATLAB commands or data in an expression must match the return sizes of peer expressions.

   For example, in the expression ml.func() * (x + ml.y), if x is a 3-by-2 matrix, then ml.func() and ml.y 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.

2. Expressions that return a scalar never produce an error.

You can combine matrices and scalars in larger expressions because MATLAB practices scalar expansion. For example, in the larger expression `ml.x + y,` if `y` is a 3-by-2 matrix and `ml.x` returns a scalar, the resulting value is determined by adding the scalar value of `ml.x` to every member of `y` to produce a matrix with the size of `y`, that is, a 3-by-2. The same rule applies to subtraction (`-`), multiplication (`*`), division (`/`), and any other binary operations.

3. MATLAB commands or Stateflow data of type `ml` can be members of the following independent levels of expression, for which the return size must be resolved:

   - Arguments

     The expression for each function argument is a larger expression for which the return size of MATLAB commands or Stateflow data of type `ml` must be determined. For example, in the expression `z + func(x + ml.y)`, the size of `ml.y` has nothing to do with the size of `z`, because `ml.y` is used at the function argument level. However, the return size for `func(x + ml.y)` must match the size of `z`, because they are both at the same expression level.

   - Array indices

     The expression for an array index is an independent level of expression that is required to be scalar in size. For example, in the expression `x + arr[y]`, the size of `y` has nothing to do with the size of `x` because `y` and `x` are at different levels of expression, and `y` must be a scalar.

4. The return size for an indexed array element access must be a scalar.

   For example, the expression `x[1][1]`, where `x` is a 3-by-2 array, must evaluate to a scalar.

5. MATLAB command or data elements used in an expression for the input argument for a MATLAB function called through the `ml` namespace operator are resolved for size using the rule for peer expressions (preceding rule 1) for the expression itself, because there is no size definition prototype available.

   For example, in the function call `ml.func(x + ml.y)`, if `x` is a 3-by-2 array, `ml.y` must return a 3-by-2 array or a scalar.

6 MATLAB command or data elements used for the input argument for a graphical function in an expression are resolved for size by the function's prototype.

For example, if the graphical function `gfunc` has the prototype `gfunc(arg1)`, where `arg1` is a 2-by-3 Stateflow data array, then the calling expression, `gfunc(ml.y + x)`, requires that both `ml.y` and `x` evaluate to 2-by-3 arrays (or scalars) during run-time.

7 `ml` function calls can take only scalar or string literal arguments. Any MATLAB command or data used to specify an argument for the `ml` function must return a scalar value.

8 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 `ml.x` or a single Stateflow data of type `ml`, then the sizes of both left-hand expression and right-hand expression are determined by the right-hand expression.

For example, in the expression `s = ml.func(x)`, where `x` is a 3-by-2 matrix and `s` is scalar data in Stateflow, `ml.func(X)` must return a scalar to match the left-hand expression, `s`. However, in the expression `ml.y = x + s`, where `x` is a 3-by-2 data array and `s` is scalar, the left-hand expression, workspace variable `y`, is assigned the size of a 3-by-2 array to match the size of the right-hand expression, `x+s`, a 3-by-2 array.

9 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.

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. For example, in the expression `s = ml.func()`, where `ml.func()` returns a 1-by-3 matrix, if `s` is a vector of size `3`, the assignment is valid.

10 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.

For example, in the expression `ml.x = ml.y + ml.z`, none of the preceding rules can be used to infer a common size among `ml.x`, `ml.y`, and `ml.z`. In this case, both `ml.y` and `ml.z` are assumed to return scalar values. And even if `ml.y` and `ml.z` return matching sizes at run-time, if they return nonscalar values, a size mismatch error results.

11 The preceding rules for resolving the size of member MATLAB commands or Stateflow data of type `ml` 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.

For example, the expression `x + ml.str`, where `ml.str` is a string workspace variable, produces a run-time error stating that `ml.str` is not a numeric type.

Note Member MATLAB commands or data of type `ml` in a larger expression are limited to numeric values (scalar or array) only if they participate in numeric expressions.

---

12 Stateflow has special cases in which it does no size checking to resolve the size of MATLAB command or data expressions that are members of larger expressions. In the cases shown, use of a singular MATLAB element such as `ml.var`, `ml.func()`, `ml(evalString, arg1, arg2,...)`, Stateflow data of type `ml`, or a graphical function returning a Stateflow data of type `ml`, does not require that size checking be enforced at run-time. In these cases, assignment of a return to the left-hand side of an assignment statement or to a function argument is made without consideration 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 `ml.x = ml.y`, `ml.y` is a MATLAB workspace variable of any size and type (structure, cell array, string, and so on).

- `An` assignment in which the left-hand side is a data of type `ml`

  For example, in the expression `m_x = ml.func()`, `m_x` is a Stateflow data of type `ml`.

- Input arguments of a MATLAB function

  For example, in the expression `ml.func(m_x, ml.x, gfunc())`, `m_x` is a Stateflow data of type `ml`, `ml.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 `ml`. Even though Stateflow does nothing to check the size of the input type, if the passed-in data is not of the expected type, an error results from the function call `ml.func()`.

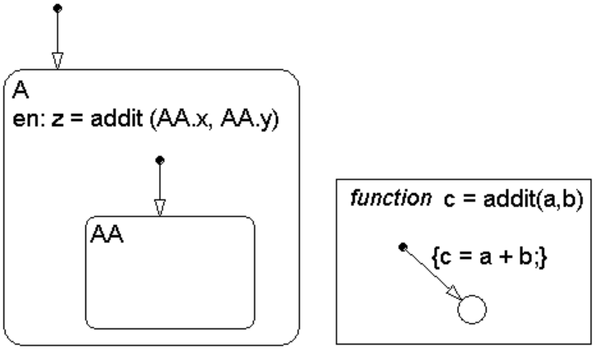
- Arguments for a graphical function that are specified as Stateflow data of type `ml` in its prototype statement

Note If inputs in the preceding cases are replaced with non-MATLAB numeric Stateflow data, a conversion to an `ml` type is performed.

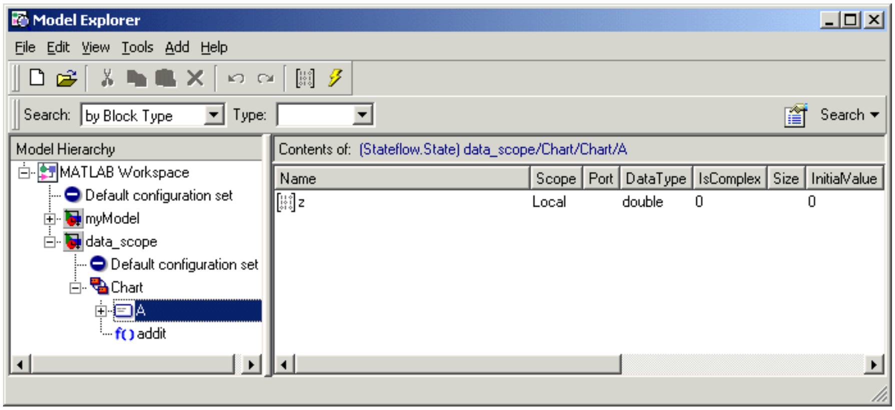
Using Data and Event Arguments in Actions

When you use data and event objects as arguments to functions that you call in action language, they are assumed to be defined at the same level in the hierarchy as the action language that references them. If they are not found at that level, Stateflow attempts to resolve the object name by searching up the hierarchy. Data or event object arguments that are parented anywhere else must have their path hierarchies defined explicitly.

In the following example, state A calls the graphical function `addit` to add the Stateflow data `x` and `y` and store the result in data `z`.

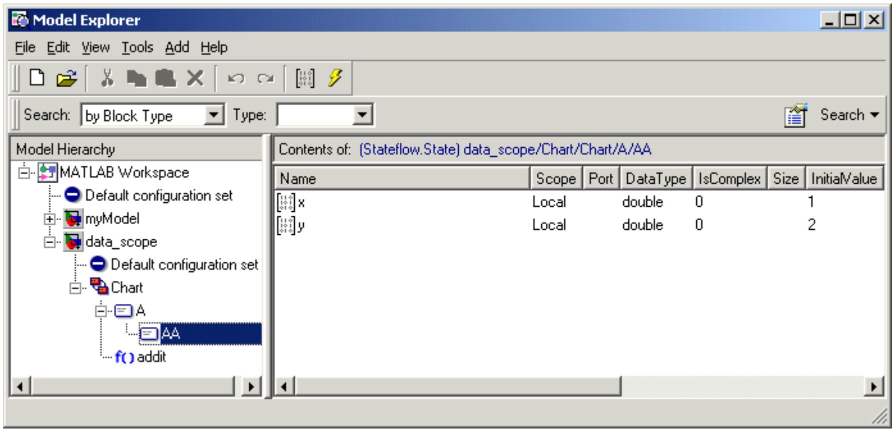


The following **Model Explorer** windows show the data `z` is defined for state A, but the data `x` and `y` are defined for state AA, a substate of A.



Contents of: (Stateflow.State) data_scope/Chart/Chart/A

Name	Scope	Port	DataType	IsComplex	Size	InitialValue
z	Local		double	0		0



Search: by Block Type Type:

Model Hierarchy

- MATLAB Workspace
  - Default configuration set
  - myModel
  - data_scope
    - Default configuration set
    - Chart
      - A
        - AA
      - f() addit

Contents of: (Stateflow.State) data_scope/Chart/Chart/A/AA

Name	Scope	Port	DataType	IsComplex	Size	InitialValue
x	Local		double	0		1
y	Local		double	0		2

The call to function `addit` from state `A` can resolve `z` because it is owned by `A`. However, it cannot resolve `x` and `y` by looking above state `A`. Therefore, the function call must reference `x` and `y` explicitly to their owner, state `AA`.

There are a variety of functions that you can call in Stateflow action language that use data as arguments. See the following sections:

- "Using Functions to Extend Actions" on page 6-29
- "Calling C Functions in Actions" on page 8-23
- "Using MATLAB Functions and Data in Actions" on page 8-29

Only the temporal logic operators take events as an argument. See "Using Temporal Logic in Actions" on page 8-51.

Using Arrays in Actions

This section tells you how to use Stateflow data arrays in action language. See the following topics:

- "Array Notation" on page 8-44 — Gives examples of array notation in action language.
- "Arrays and Custom Code" on page 8-45 — Shows you how to access arrays provided by custom code that you build into a Stateflow target.

Array Notation

Use C style syntax in the action language to access array elements.

```
local_array[1][8][0] = 10;

local_array[i][j][k] = 77;

var = local_array[i][j][k];
```

As an exception to this style, **scalar expansion** is available within the action language. This statement assigns a value of 10 to all the elements of the array `local_array`.

```
local_array = 10;
```

Scalar expansion is available for performing general operations. This statement is valid if the arrays `array_1`, `array_2`, and `array_3` have the same value for the **Sizes** property.

```
array_1 = (3*array_2) + array_3;
```

Note Use the same notation for accessing arrays in Stateflow, from Simulink, and from custom code.

Arrays and Custom Code

Stateflow action language provides the same syntax for Stateflow arrays and custom code arrays.

See also “Integrating Custom Code with Stateflow Targets” on page 14-27.

Note Any array variable that is referred to in a Stateflow chart but is not defined in the data dictionary is identified as a custom code variable.

Broadcasting Events in Actions

You can specify an event to be broadcast in the action language. Events have hierarchy (a parent) and scope. The parent and scope together define a range of access to events. It is primarily the event's parent that determines who can trigger on the event (has receive rights). See "Name" on page 7-10 for more information.

See the following sections for an understanding of broadcasting events in action language:

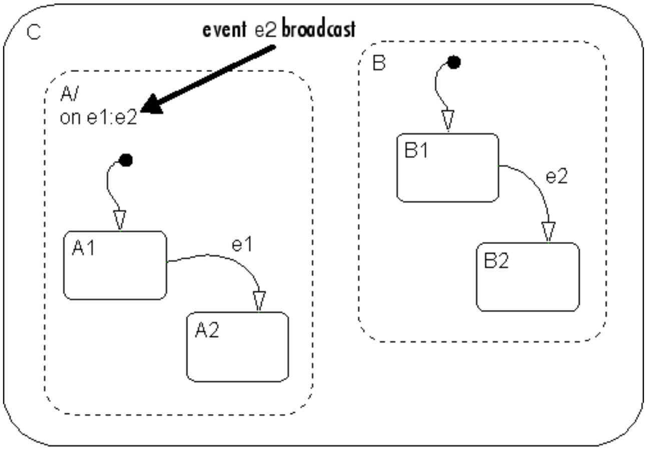
- "Event Broadcasting" on page 8-46 — Gives examples of using broadcast events to synchronize behavior between AND (parallel) states.
- "Directed Event Broadcasting" on page 8-48 — Shows you how to use the send function to send an event to a specific state.

Event Broadcasting

Broadcasting an event in the action language is most useful as a means of synchronization among AND (parallel) states. Recursive event broadcasts can lead to definition of cyclic behavior. Cyclic behavior can be detected only during simulation.

Event Broadcast State Action Example

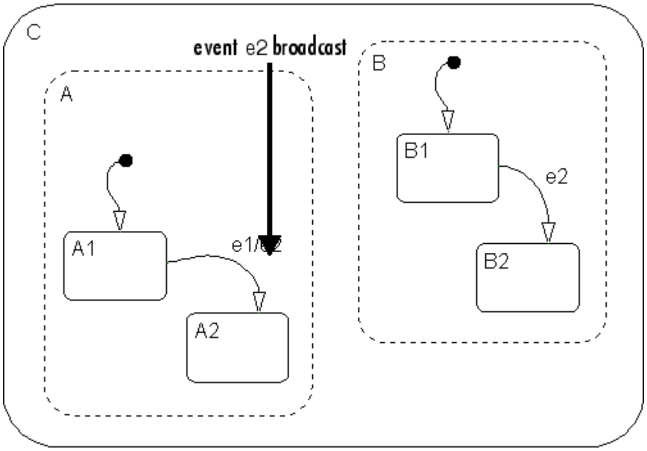
The following is an example of the state action notation for an event broadcast:



See "Event Broadcast State Action Example" on page 3-84 for information on the semantics of this notation.

Event Broadcast Transition Action Example

The following is an example of transition action notation for an event broadcast.



See "Event Broadcast Transition Action with a Nested Event Broadcast Example" on page 3-87 for information on the semantics of this notation.

Directed Event Broadcasting

You can specify a directed event broadcast in actions. Using a directed event broadcast, you can broadcast a specific event to a specific receiver state in the same chart. The receiving state must be active at the time the broadcast is executed to receive and potentially act on the directed event broadcast.

Directed event broadcasting is a more efficient means of synchronization among parallel (AND) states. Using directed event broadcasting improves the efficiency of the generated code. As is true in event broadcasting, recursive event broadcasts can lead to definition of cyclic behavior.

Note An action in one chart cannot broadcast events to states defined in another chart.

Directed Event Broadcasting Using send

The format of the directed event broadcast with send is as follows:

```
send(event_name,state_name)
```

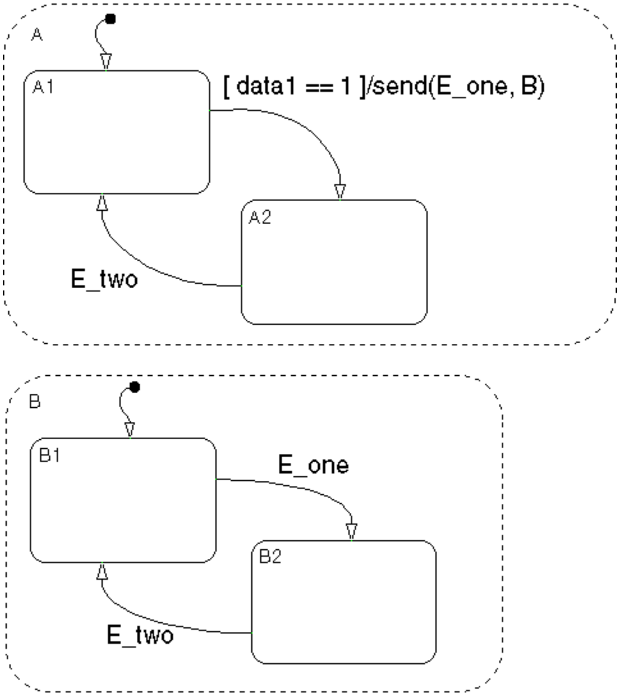
where event_name is broadcast to state_name and any offspring of that state in the hierarchy. The event sent must be visible to both the sending state and the receiving state (state_name).

The state_name argument can include a full hierarchy path to the state. For example, if the state A contains the state A1, send an event e to state A1 with the following broadcast:

```
send(e, A.A1)
```

Note Do not use the chart name in the full hierarchy path to a state. Formal chart names include the subsystem they are in. For example, in the demo model fuelsys the chart control logic is in the subsystem fuel rate controller. This means that the formal name for the chart control logic is fuel rate controller/control logic. This name includes the forward slash character ('/'), which is not a valid character in Stateflow identifiers.

This is an example of a directed event broadcast using the `send(event_name,state_name)` transition action as a transition action.



In this example, event `E_one` must be visible in both `A` and `B`. See "Directed Event Broadcast Using Send Example" on page 3-96 for information on the semantics of this notation.

Directed Event Broadcasting Using Qualified Event Names

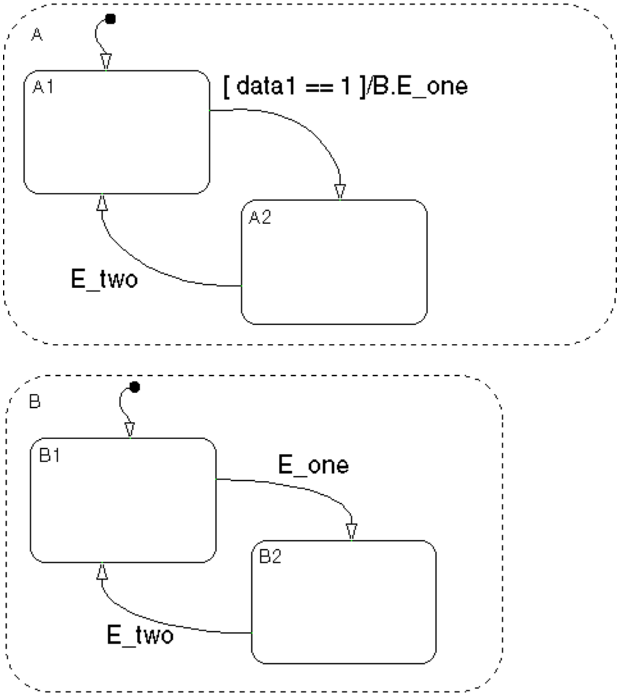
The format of the direct event broadcast using qualified event names is as follows:

```
state_name.event_name
```

where `event_name` is broadcast to its owning state (`state_name`) and any offspring of that state in the hierarchy. The event sent is visible only to the receiving state (`state_name`).

The state_name argument can also include a full hierarchy path to the receiving state. Again, do not use the chart name in the full path name of the state.

The following example illustrates the use of a qualified event name in a directed event broadcast.



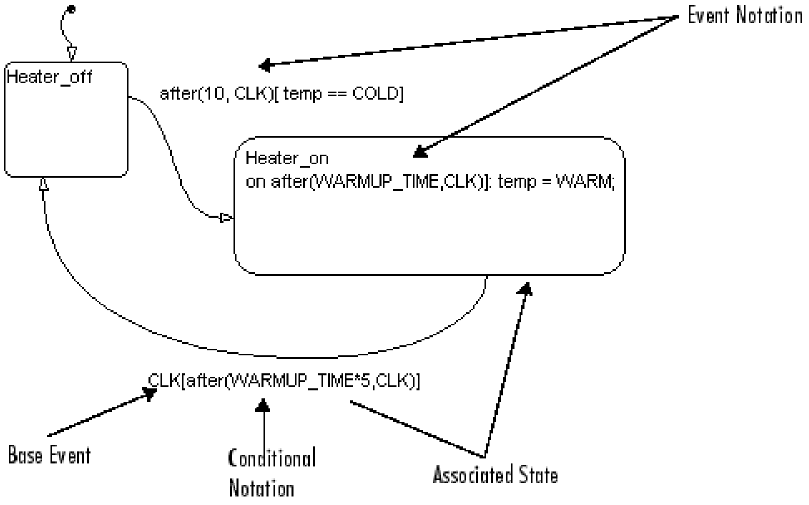
In this example, event E_one is visible only to state B. See “Directed Event Broadcasting Using Qualified Event Names Example” on page 3-98 for information on the semantics of this notation.

Using Temporal Logic in Actions

Temporal logic operators are Boolean operators that operate on recurrence counts of Stateflow events. See the following subsections for individual descriptions of each temporal logic operator:

Rules for Using Temporal Logic Operators

The following diagram illustrates the use of temporal logic operators in action language:


Event Notation
Heater_off
after(10, CLK)[temp == COLD]
Heater_on
on after(WARMUP_TIME,CLK)]: temp = WARM;
CLK[after(WARMUP_TIME*5,CLK)]
Base Event
Conditional Notation
Associated State

The following rules apply generally to the use of temporal logic operators:

- The recurring event on which a temporal operator operates is called the *base event*. Any Stateflow event can serve as a base event for a temporal operator.

  Note Temporal logic operators can also operate on recurrences of implicit events, such as state `entry` or `exit` events or data `change` events. See "Defining Implicit Events" on page 7-24.

- For a chart with no Simulink input events, you can use the `wakeup` (or `tick`) event to denote the implicit event of a chart waking up.
- Temporal logic operators can appear only in conditions on transitions originating from states and in state actions.

  Note This means you cannot use temporal logic operators as conditions on default transitions or flow graph transitions.

  The state on which the temporally conditioned transition originates or in whose `during` action the condition appears is called the temporal operator's *associated state.*
- You must use event notation (see "Temporal Logic Events" on page 8-58) to express temporal logic conditions on events in state `during` actions.

after Temporal Logic Operator

The `after` operator checks whether an event occurs after a specified time.

Syntax

```
after(n, E)
```

where `E` is the base event for the `after` operator and `n` is one of the following:

- A constant integer greater than 0

- An expression that evaluates to an integer value greater than or equal to 0

Description

The `after` operator is true if the base event `E` has occurred `n` times since activation of its associated state. Otherwise, it is false. In a chart with no input events, `after(n,wakeup)` (or `after(n,tick)`) evaluates to true after the chart has woken up `n` times.

Note The `after` operator resets its counter for `E` to 0 each time the associated state is activated.

Example

The following example illustrates use of the `after` operator in a transition expression.

```
CLK[after(10, CLK) && temp == COLD]
```

This example permits a transition out of the associated state only if there have been 10 occurrences of the `CLK` event since the state was activated and the `temp` data item has the value `COLD`.

The next example illustrates usage of event notation for temporal logic conditions in transition expressions.

```
after(10, CLK)[temp == COLD]
```

This example is semantically equivalent to the first example.

The next example illustrates setting a transition condition for any event visible in the associated state while it is activated.

```
[after(10, CLK)]
```

This example permits a transition out of the associated state on any event after 10 occurrences of the `CLK` event since activation of the state.

The next two examples underscore the semantic distinction between an after condition on its own base event and an after condition on a nonbase event.

```
CLK[after(10,CLK)]
ROTATE[after(10,CLK)]
```

The first expression says that the transition must occur *as soon as* 10 CLK events have occurred after activation of the associated state. The second expression says that the transition can occur *no sooner than* 10 CLK events after activation of the state, but possibly later, depending on when the ROTATION event occurs.

The next example illustrates usage of an after event in a state's during action.

```
Heater_on
on after(5*BASE_DELAY, CLK): status('heater on');
```

This example causes the Heater_on state to display a status message each CLK cycle, starting 5*BASE_DELAY clock cycles after activation of the state. Note the use of event notation to express the after condition in this example. Use of conditional notation is not allowed in state during actions.

before Temporal Logic Operator

The before operator checks whether an event occurs before a specified time.

Syntax

```
before(n, E)
```

where E is the base event for the before operator and n is one of the following:

- A constant integer greater than 0
- An expression that evaluates to an integer value greater than or equal to 0

Description

The before operator is true if the base event E has occurred fewer than ntimes since activation of its associated state. Otherwise, it is false. In a chart with no input events, before(n,wakeup) or before(n,tick) evaluates to true before the chart has woken up n times.

Note The before operator resets its counter for E to 0 each time the associated state is activated.

Example

The following example illustrates the use of the before operator in a transition expression.

```
ROTATION[before(10, CLK)]
```

This expression permits a transition out of the associated state only on occurrence of a ROTATION event but *no later than* 10 CLK cycles after activation of the state.

The next example illustrates usage of a before event in a state's during action.

```
Heater_on
on before(MAX_ON_TIME, CLK): temp++;
```

This example causes the Heater_on state to increment the temp variable once per CLK cycle until the MAX_ON_TIME limit is reached.

at Temporal Logic Operator

The at operator checks for a specific ordinal occurrence of an event.

Syntax

```
at(n, E)
```

where E is the base event for the at operator and n is one of the following:

- A constant integer greater than 0
- An expression that evaluates to an integer value greater than or equal to 0

Description

The `at` operator is true only at the `n`th occurrence of the base event `E` since activation of its associated state. Otherwise, it is false. In a chart with no input events, `at(n,wakeup)` (or `at(n,tick)`) evaluates to true when the chart wakes up for the `n`th time.

Note The `at` operator resets its counter for `E` to 0 each time the associated state is activated.

Example

The following example illustrates the use of the `at` operator in a transition expression:

```
ROTATION[at(10, CLK)]
```

This expression permits a transition out of the associated state only if a `ROTATION` event occurs *exactly* `10 CLK` cycles after activation of the state.

The next example illustrates usage of an `at` event in a state's `during` action.

```
Heater_on
on at(10, CLK): status('heater on');
```

This example causes the `Heater_on` state to display a status message 10 `CLK` cycles after activation of the associated state.

every Temporal Logic Operator

The`every` operator checks for every ordinal occurrence of an event.

Syntax

```
every(n, E)
```

where `E` is the base event for the `every` operator and `n` is one of the following:

- A constant integer greater than 0

- An expression that evaluates to an integer value greater than or equal to 0

Description

The every operator is true at every nth occurrence of the base event E since activation of its associated state. Otherwise, it is false. In a chart with no input events, every(n,wakeup) (or every(n,tick)) evaluates to true whenever the chart wakes up an integer multiple n times.

Note The every operator resets its counter for E to 0 each time the associated state is activated. As a result, this operator is useful only in state during actions.

Example

The following example illustrates the use of the every operator in a state.

```
Heater_on
on every(10, CLK): status('heater on');
```

This example causes the Heater_on state to display a status message every 10 CLK cycles after activation of the associated state.

in Temporal Logic Operator

The in operator checks for active states.

Syntax

```
in(S)
```

where S is a fully-qualified state.

Description

The in operator is true and returns 1 whenever state S is active; otherwise, it returns zero.

Example

The following example illustrates the use of the `in` operator in a state during action:

```
du: numfans = in(FAN1.On) + in(FAN2.On);
```

This example checks whether the states `FAN1.On` and `FAN2.On` are active. The boolean expression sums the values returned by each `in` operator and, therefore, indicates whether 0, 1, or 2 fans are operating in any given time step.

Conditional and Event Notation

Stateflow treats the following notations as equivalent,

```
E[tlo(n, E) && C]
tlo(n, E)[C]
```

where *`tlo`* is a temporal logic operator (`after`, `before`, `at`, `every`), `E` is the operator's base event, `n` is the operator's occurrence count, and `C` is any conditional expression. For example, the following expressions are functionally equivalent in Stateflow:

```
CLK[after(10, CLK) && temp == COLD]
after(10, CLK)[temp == COLD]
```

The first notation is referred to as the conditional notation for temporal logic operators and the second notation as the event notation.

Note You can use conditional and event notation interchangeably in transition expressions. However, you must use the event notation in state `during` actions.

Temporal Logic Events

Although temporal logic does not introduce any new events into a Stateflow model, it is useful to think of the change of value of a temporal logic condition as an event. For example, suppose that you want a transition to occur from state `A` exactly 10 clock cycles after activation of the state. One way to achieve this would be to define an event called ALARM and to broadcast this event 10 CLK events after state A is entered. You would then use ALARM as the event that triggers the transition out of state A.

An easier way to achieve the same behavior is to set a temporal logic condition on the CLK event that triggers the transition out of state A.

```
CLK[after(10, CLK)]
```

Note that this approach does not require creation of any new events. Nevertheless, conceptually it is useful to think of this expression as equivalent to creation of an implicit event that triggers the transition. Hence, Stateflow supports the equivalent event notation (see “Temporal Logic Events” on page 8-58).

```
after(10, CLK)
```

Note that the event notation allows you to set additional constraints on the implicit temporal logic "event," for example,

```
after(10, CLK)[temp == COLD]
```

This expression says, "Exit state A if the temperature is cold but no sooner than 10 clock cycles."

Using Change Detection in Actions

Stateflow provides operators for automatically detecting changes in Stateflow chart data. This topic describes the heuristics of change detection in Stateflow and how to use change detection operators.

- “About Change Detection” on page 8-60
- “Running a Model That Demonstrates Change Detection” on page 8-61
- “How Change Detection Works” on page 8-64
- “Change Detection Operators” on page 8-67
- “Change Detection Example” on page 8-71

About Change Detection

Stateflow can detect changes in the following types of chart data from one time step to the next:

- Inputs
- Outputs
- Local variables
- Data bound to Simulink data store memory

  (For more information, see “Sharing Global Data with Simulink” on page 7-53.)

For each of these types of data, Stateflow provides operators that detect the following changes:

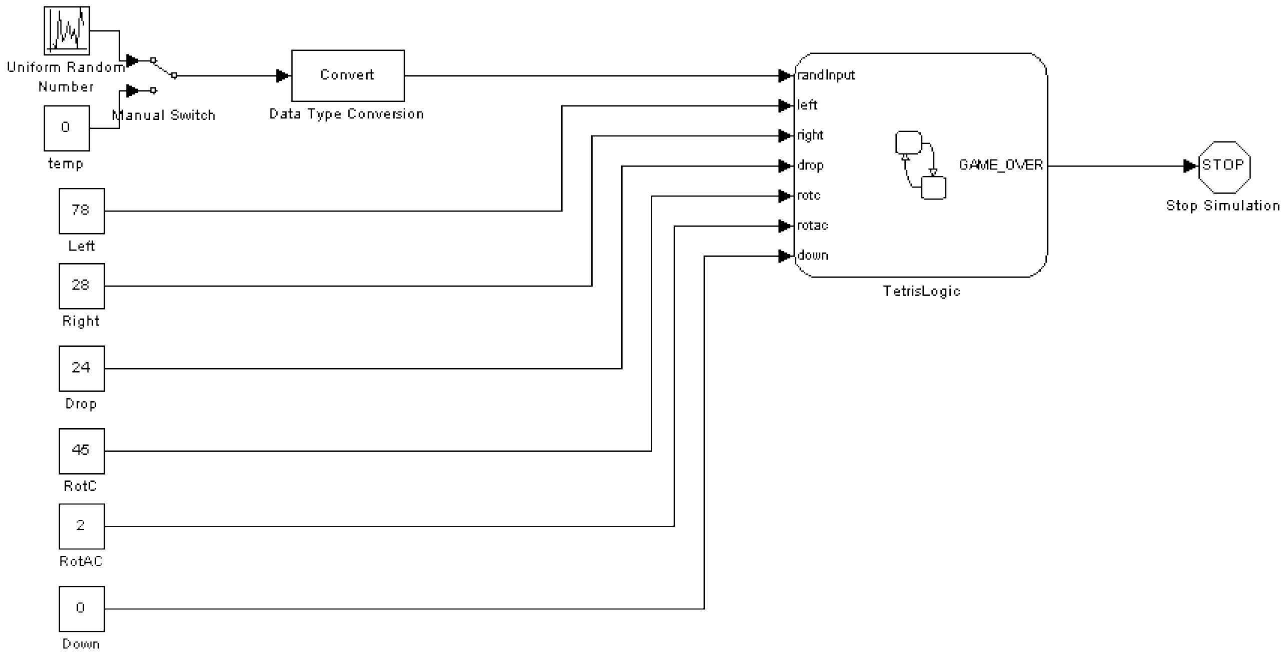
Type of Change	Operator
Data changes value from the beginning of the last time step to the beginning of the current time step.	See “hasChanged Operator” on page 8-68.

Type of Change	Operator
Data changes from a specified value at the beginning of the last time step to a different value at the beginning of the current time step.	See "hasChangedFrom Operator" on page 8-69.
Data changes to a specified value at the beginning of the current time step from a different value at the beginning of the last time step.	See "hasChangedTo Operator" on page 8-70.

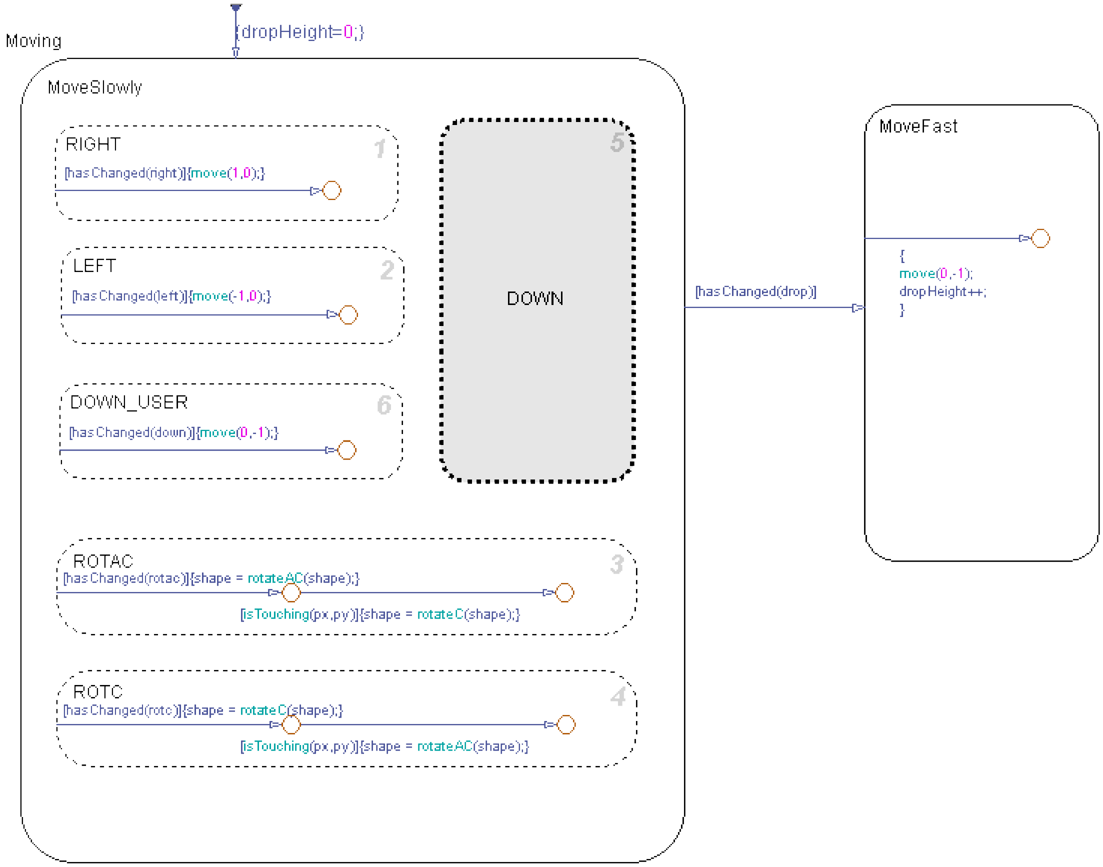
Change detection operators return 1 if the data value changes or 0 if there is no change. See "Change Detection Operators" on page 8-67.

Running a Model That Demonstrates Change Detection

Stateflow ships with a model `sf_tetris2` that demonstrates how you can detect asynchronous changes in inputs — in this case, user keystrokes — to manipulate a Tetris shape as it moves through the playing field. The Stateflow chart TetrisLogic implements this logic:



TetrisLogic contains a subchart called Moving that calls the operator `hasChanged` to determine when users press any of the Tetris control keys, and then moves the shape accordingly. Here is a look inside the subchart:


{dropHeight=0;}
Moving
MoveSlowly
RIGHT
1
[hasChanged(right)]{move(1,0);}
LEFT
2
[hasChanged(left)]{move(-1,0);}
DOWN_USER
6
[hasChanged(down)]{move(0,-1);}
5
DOWN
ROTAC
3
[hasChanged(rotac)]{shape = rotateAC(shape);}
[isTouching(px,py)]{shape = rotateC(shape);}
ROTC
4
[hasChanged(rotc)]{shape = rotateC(shape);}
[isTouching(px,py)]{shape = rotateAC(shape);}
[hasChanged(drop)]
MoveFast
{
move(0,-1);
dropHeight++;
}

To run the demo model from MATLAB, follow these steps:

1 At the MATLAB command prompt, type:

```
demos
```

The MATLAB Help Browser opens the Demos tab in the Help Navigator pane.

2 In the Help Navigator pane, navigate to **Simulink > Stateflow > General Applications**.

3 In the right contents pane, click **Tetris**.

A description of the Tetris demo model appears.

4 In the upper right corner of the contents pane, click the link **Open this model**.

The model opens on your desktop.

Tip You can also open the model by typing `sf_tetris2` at the MATLAB command prompt.

How Change Detection Works

Stateflow detects changes in chart data by evaluating values at time step boundaries. That is, Stateflow compares the value at the beginning of the previous execution step with the value at the beginning of the current execution step. To detect changes, Stateflow automatically double-buffers these values in local variables, as follows:

Local Buffer:	Stores:
var_name`_prev`	Value of data at the beginning of the last time step
var_name`_start`	Value of data at the beginning of the current time step

Note Double-buffering occurs once per time step except if multiple input events occur in the same time step. Then, double-buffering occurs once per input event (see “Handling Changes When Multiple Input Events Occur” on page 8-67).

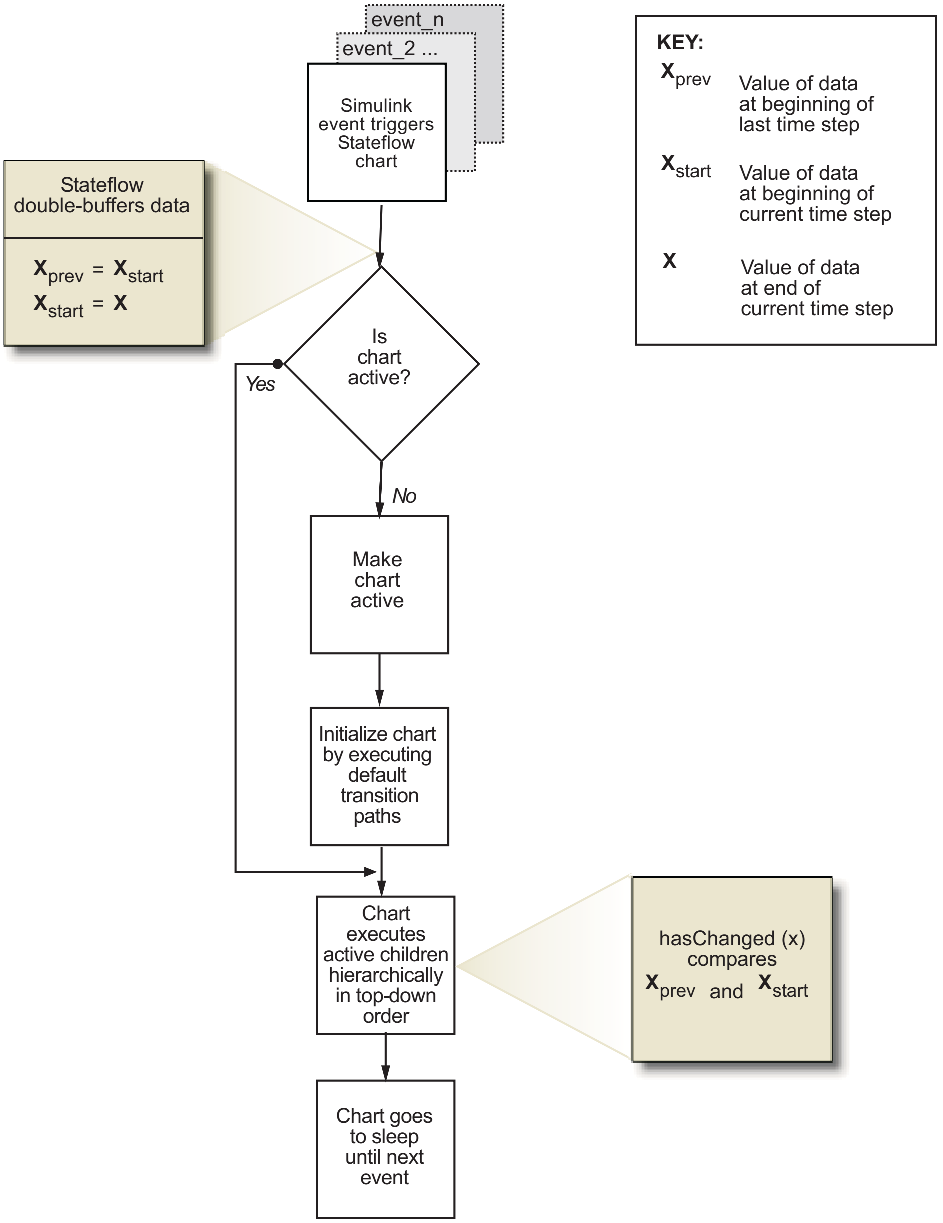
When you invoke change detection operations in an action in a Stateflow chart, Stateflow performs the following operations:

1 Double-buffers data values *after* a Simulink event triggers the chart, but *before* the chart begins execution.

2 Compares values in `_prev` and `_start` buffers. If the values match, the change detection operator returns 0 (no change); otherwise, it returns 1 (change).

The following diagram places these tasks in the context of the chart life cycle:

Where Change Detection Occurs in the Chart Life Cycle


event_n
event_2 ...
Simulink event triggers Stateflow chart
KEY:
X_{prev} Value of data at beginning of last time step
X_{start} Value of data at beginning of current time step
X Value of data at end of current time step
Stateflow double-buffers data
$X_{prev} = X_{start}$
$X_{start} = X$
Is chart active?
Yes
No
Make chart active
Initialize chart by executing default transition paths
Chart executes active children hierarchically in top-down order
hasChanged (x) compares X_{prev} and X_{start}
Chart goes to sleep until next event

That fact that buffering occurs before chart execution has implications for change detection in the following scenarios:

- "Handling Transient Changes in Local Variables" on page 8-67
- "Handling Changes When Multiple Input Events Occur" on page 8-67

Handling Transient Changes in Local Variables

Stateflow attempts to filter out transient changes in local chart variables by evaluating their values only at time boundaries (see "How Change Detection Works" on page 8-64). This behavior means that Stateflow evaluates the specified local variable only once at the end of the execution step and, therefore, returns a consistent result. That is, the return value 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 a local variable `temp` changes from its value at the previous time step, but then reverts to the original value. In this case, the operator `hasChanged(temp)` returns 0 for the next time step, indicating that no change occurred. For more information, see "Change Detection Operators" on page 8-67.

Handling Changes When Multiple Input Events Occur

When multiple input events occur in the same time step, Stateflow updates the `_prev` and `_start` buffers once per event. In this way, Stateflow detects changes between input events, even if the changes occur more than once in a given time step.

Change Detection Operators

Change detection operators check for changes in chart inputs, outputs, and local variables, and in Stateflow data that is bound to Simulink data store memory.

You can invoke change detection operators wherever you call built-in functions in Stateflow — in state actions, transition actions, condition actions, and conditions. There are three change detection operators:

hasChanged Operator (p. 8-68)	Detects any change since the last time step
hasChangedFrom Operator (p. 8-69)	Detects whether data changes from a specified value
hasChangedTo Operator (p. 8-70)	Detects whether data changes to a specified value

hasChanged Operator

The `hasChanged` operator detects any change in Stateflow data since the last time step, using the following heuristic:

$$hasChanged(x) = \begin{cases} 1 \; if \; x_{prev} \neq x_{start} \\ 0 \; otherwise \end{cases}$$

where x_{start} represents the value at the beginning of the current time step and x_{prev} represents the value at the beginning of the previous time step.

Syntax.

```
hasChanged ( u )
hasChanged ( m [ expr ] )
hasChanged ( s [ expr ] )
```

where `u` is a scalar or matrix variable, `m` is a matrix, and `s` is aggregate data.

The arguments *u*, *m*, and *s* must be one of the following data types:

- Input, output, or local variable in a Stateflow chart
- Stateflow data that is bound to Simulink data store memory

The arguments cannot be expressions or custom code variables.

Description. `hasChanged ( u )` returns `1` if *u* changes value since the last time step. If *u* is a matrix, `hasChanged` returns `1` if *any* element of *u* changes value since the last time step.

`hasChanged ( m [ expr ] )` returns 1 if the value at location *expr* of matrix *m* changes value since the last time step. *expr* can be an arbitrary expression that evaluates to a scalar value.

`hasChanged ( s [ expr ] )` returns 1 if the value at location *expr* of aggregate data *s* has changed since the last time step. *s* must be a fully qualified name, such as `u.foo.bar`, which resolves to an aggregate data type such as a structure or bus signal. *expr* can be an arbitrary expression that evaluates to a scalar value.

All forms of `hasChanged` return zero if Stateflow writes to the data, but does not change its value.

hasChangedFrom Operator

The `hasChangedFrom` operator detects when Stateflow data changes *from* a specified value since the last time step, using the following heuristic:

$$hasChangedFrom(x, x_0) = \begin{cases} 1 \; if \; x_{prev} \neq x_{start} \; and \; x_{prev} = x_0 \\ 0 \; otherwise \end{cases}$$

where x_{start} represents the value at the beginning of the current time step and x_{prev} represents the value at the beginning of the previous time step.

Syntax.

```
hasChangedFrom ( u , v )
hasChangedFrom ( m [ expr ], v )
hasChangedFrom ( s [ expr ], v )
```

where *u* is a scalar or matrix variable, *m* is a matrix, and *s* is aggregate data.

The arguments *u*, *m*, and *s* must be one of the following data types:

- Input, output, or local variable in a Stateflow chart
- Stateflow data that is bound to Simulink data store memory

Note The first arguments *u*, *m*, and *s* cannot be expressions or custom code variables. The second argument *v* can be an expression. However, if the first argument is a matrix variable, then *v* must resolve to either a scalar value or a matrix value with the same dimensions as the first argument.

Description. `hasChangedFrom ( u, v )` returns 1 if *u* changes from the value specified by *v* since the last time step. If *u* is a matrix variable whose elements all equal the value specified by *v*, `hasChangedFrom` returns 1 if one or more elements of the matrix changes to a different value in the current time step.

`hasChangedFrom ( m [ expr ], v)` returns 1 if the value at location *expr* of matrix *m* changes from the value specified by *v* since the last time step. *expr* can be an arbitrary expression that evaluates to a scalar value.

`hasChangedFrom ( s [ expr ] )` returns 1 if the value at location *expr* of aggregate data *s* changes from the value specified by *v* since the last time step. *s* must be a fully qualified name, such as `u.foo.bar`, which resolves to an aggregate data type such as a structure or bus signal. *expr* can be an arbitrary expression that evaluates to a scalar value.

hasChangedTo Operator

The `hasChangedTo` operator detects when Stateflow data changes to a specified value since the last time step, using the following heuristic:

$$hasChangedTo(x, x_0) = \begin{cases} 1\ if\ x_{prev} \neq x_k\ and\ x_{start} = x_0 \\ 0\ otherwise \end{cases}$$

where x_{start} represents the value at the beginning of the current time step and x_{prev} represents the value at the beginning of the previous time step.

Syntax.

```
hasChangedTo ( u , v )
hasChangedTo ( m [ expr ], v )
hasChangedTo ( s [ expr ], v )
```

where *u* is a scalar or matrix variable, *m* is a matrix, and *s* is aggregate data.

The arguments *u*, *m*, and *s* must be one of the following data types:

- Input, output, or local variable in a Stateflow chart
- Stateflow data that is bound to Simulink data store memory

Note The first arguments *u*, *m*, and *s* cannot be expressions or custom code variables. The second argument *v* can be an expression. However, if the first argument is a matrix variable, then *v* must resolve to either a scalar value or a matrix value with the same dimensions as the first argument.

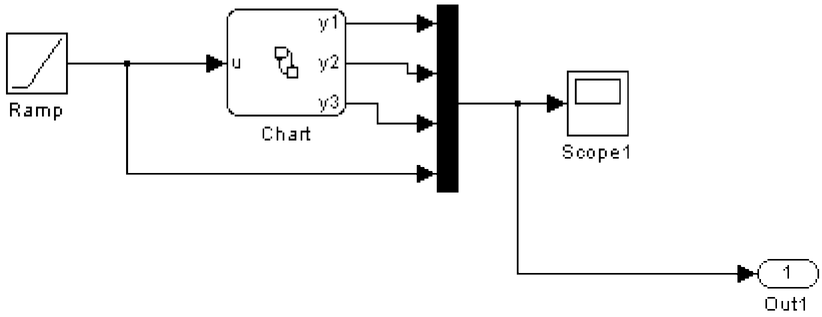
Description. `hasChangedTo ( u, v )` returns 1 if *u* changes to the value specified by *v* in the current time step. If *u* is a matrix variable, `hasChangedTo` returns 1 if any its of its elements changes value so that all elements of the matrix equal the value specified by *v* in the current time step.

`hasChangedTo ( m [ expr ], v)` returns 1 if the value at location *expr* of matrix *m* changes to the value specified by *v* in the current time step. *expr* can be an arbitrary expression that evaluates to a scalar value.

`hasChangedTo ( s [ expr ] )` returns 1 if the value at location *expr* of aggregate data *s* changes to the value specified by *v* in the current time step. *s* must be a fully qualified name, such as `u.foo.bar`, which resolves to an aggregate data type such as a structure or bus signal. *expr* can be an arbitrary expression that evaluates to a scalar value.

Change Detection Example

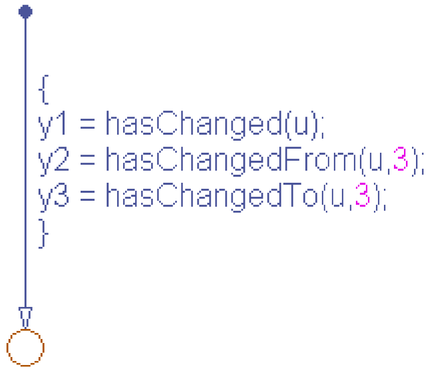
The following model shows how to use the `hasChanged`, `hasChangedFrom`, and `hasChangedTo` operators to detect specific changes in an input signal. In this example, a Ramp block sends a discrete, increasing time signal to a Stateflow chart, as follows:



The model uses a fixed-step solver with a step size of 1. The signal increments by 1 at each time step. The Stateflow chart analyzes the input signal for the following changes at each time step:

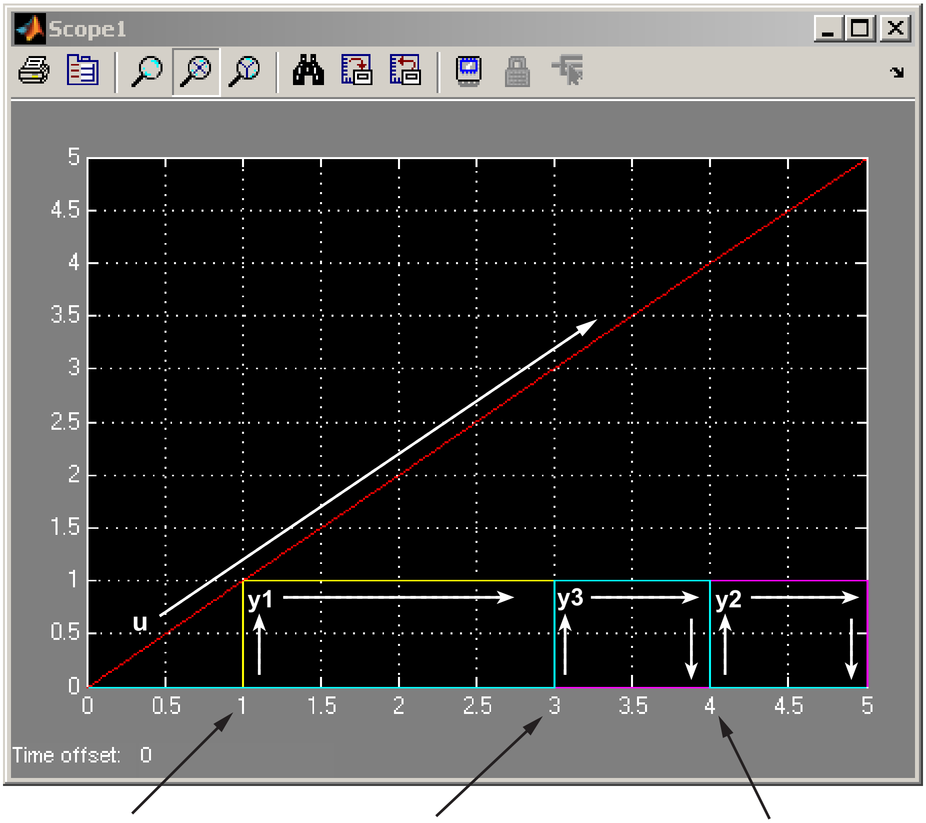
- Any change from the previous time step
- Change **to** the value 3
- Change **from** the value 3

To check the signal, the Stateflow chart calls three change detection operators in a transition action, and outputs the return values as y1, y2, and y3, as follows:



```
{
y1 = hasChanged(u);
y2 = hasChangedFrom(u,3);
y3 = hasChangedTo(u,3);
}
```

During simulation, the outputs y1, y2, and y3 represent changes in the input signal, as shown in this scope:



y1
transitions to 1 at T1;
stays at 1
because u keeps
increasing

y3
transitions to 1 at T3
when u changes to 3;
transitions back to 0
at T4 when u increases
from 3 to 4

y2
transitions to 1 at T4
when u changes from 3 to 4;
transitions back to 0
at T5 when u increases
from 4 to 5

Using Bind Actions to Control Function-Call Subsystems

Bind actions in a state bind specified data and events to that state. 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 it triggers. The function-call subsystem enables when the state with the bound event is entered and disables when that state is exited. This means that the execution of the function-call subsystem is fully bound to the activity of the state that calls it.

Examine the effects of binding a function-call subsystem trigger event in the following topics:

- "Binding a Function-Call Subsystem to a State" on page 8-74
- "Example of How to Bind a Function-Call Subsystem to a State" on page 8-78
- "Simulating a Bound Function-Call Subsystem" on page 8-80
- "Using Stateflow Logic with Binding" on page 8-83
- "Avoiding Muxed Trigger Events with Binding" on page 8-87

Binding a Function-Call Subsystem to a State

By default, a function-call subsystem is controlled by the Stateflow 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 is deactivated. 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 8-5).

Bind actions 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.

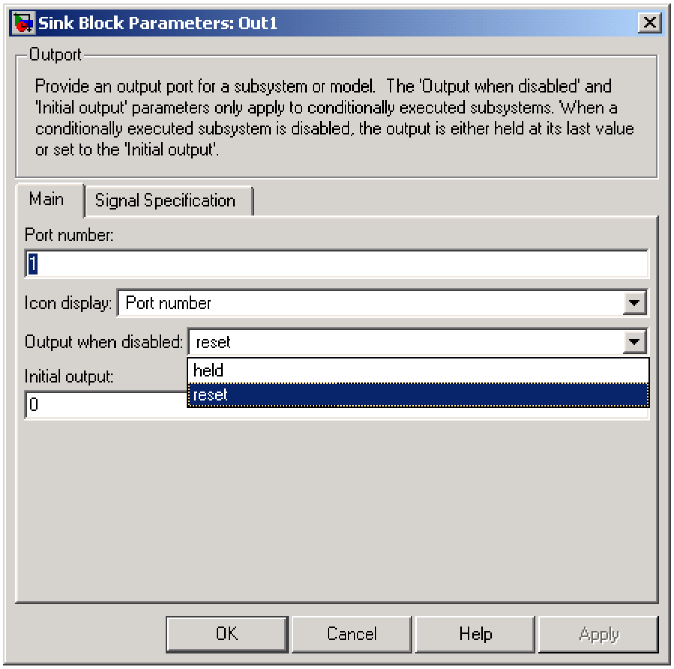
When you bind a function-call subsystem to a state, you can fine-tune the behavior of the subsystem when it is enabled and disabled, as described in the following sections:

- "Handling Outputs When the Subsystem is Disabled" on page 8-75
- "Controlling Behavior of States When the Subsystem is Enabled" on page 8-76

Handling Outputs When the Subsystem is Disabled

Although function-call subsystems do not execute while they are 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 outport block of the subsystem to open its **Block Parameters** dialog, as in this example:



Sink Block Parameters: Out1

Outport

Provide an output port for a subsystem or model. The 'Output when disabled' and 'Initial output' parameters only apply to conditionally executed subsystems. When a conditionally executed subsystem is disabled, the output is either held at its last value or set to the 'Initial output'.

Port number: 1

Icon display: Port number

Output when disabled: reset

Initial output: 0

2 Select an option for the field **Output when disabled**, as follows:

Select:	To:
held	Maintain most recent output value
reset	Reset output to its initial value

3 Click **OK** to record the settings.

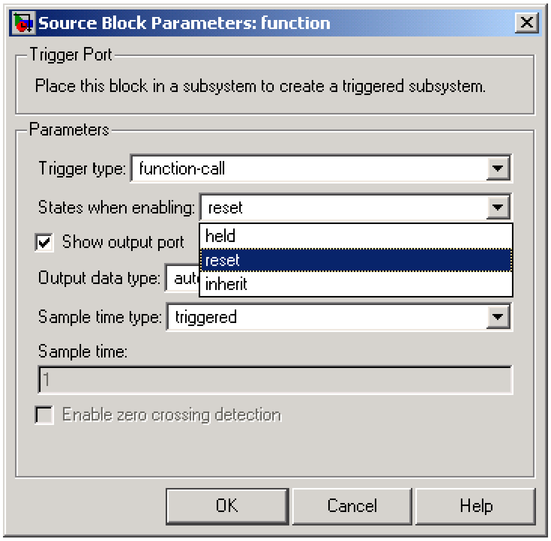
Note Setting **Output when disabled** is meaningful only when the function-call subsystem is bound to a state, as described in "Binding a Function-Call Subsystem to a State" on page 8-74.

Controlling 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 its **Block Parameters** dialog, as in this example:



Source Block Parameters: function

Trigger Port

Place this block in a subsystem to create a triggered subsystem.

Parameters

Trigger type: function-call

States when enabling: reset

☑ Show output port

Output data type: aut

Sample time type: triggered

Sample time:

1

□ Enable zero crossing detection

2 Select an option for the field **States when enabling**, as follows:

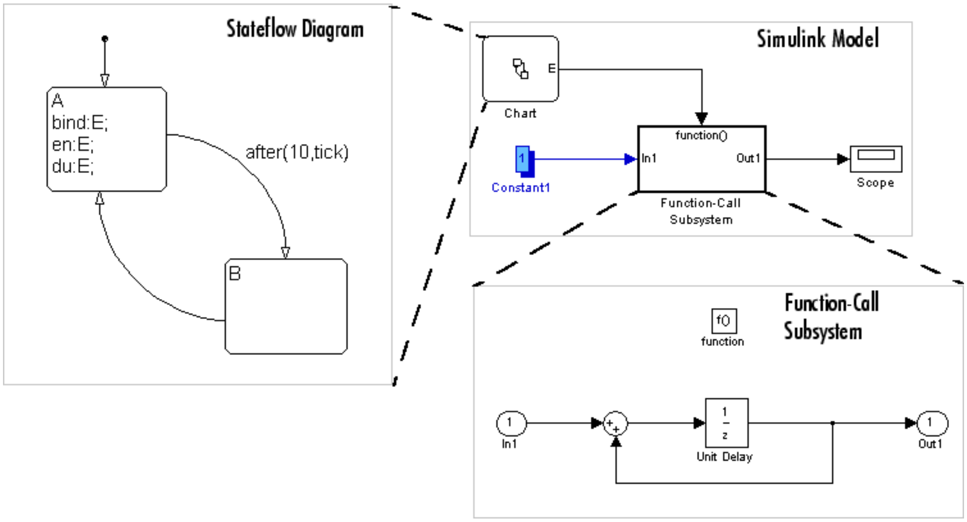
Select:	To:
held	Maintain most recent values of the states of the subsystem that contains the trigger port
reset	Revert to the initial conditions of the states of the subsystem that contains this trigger port
inherit	Inherit this setting from the the function-call initiator's parent subsystem. If the 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 “Binding a Function-Call Subsystem to a State” on page 8-74.

Example of How to Bind a Function-Call Subsystem to a State

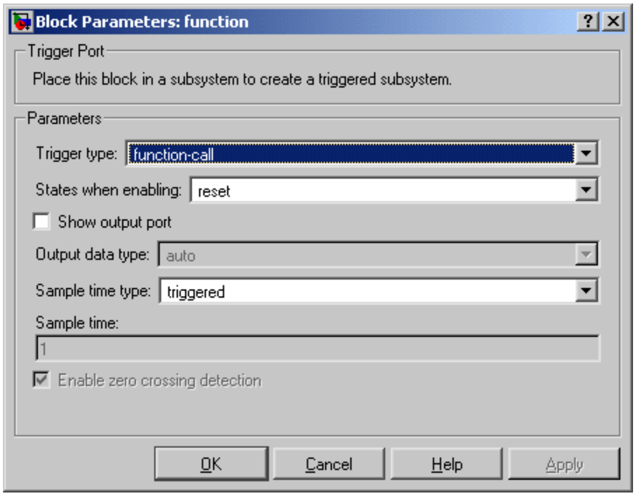
The control of a Stateflow state that binds a function-call subsystem trigger is best understood through the creation and execution of an example model. In the following example, a Simulink model triggers a function-call subsystem with a function-call trigger event `E` bound to state `A` of a Stateflow diagram.



The function subsystem contains a trigger port block, an input port, an output port, and a simple block diagram. The block diagram increments a count by 1 each time, using a Unit Delay block to store the count.

The Stateflow diagram contains two states, `A` and `B`, and connecting transitions, along with some actions. Notice that event `E` is bound to state A with the binding action `bind:E`. Event `E` is defined for the Stateflow diagram in the example with a scope of **Output to Simulink** and a trigger type of **Function Call**.

The **Block Parameters** for the trigger port are configured as follows:



Block Parameters: function

Trigger Port

Place this block in a subsystem to create a triggered subsystem.

Parameters

Trigger type: function-call

States when enabling: reset

□ Show output port

Output data type: auto

Sample time type: triggered

Sample time:

1

☑ Enable zero crossing detection

Notice that the **States when enabling** field is set to the default value **reset**. This resets the state values for the function-call subsystem to zero when it is enabled.

Notice also that the **Sample time type** field is set to the default value **triggered**. This sets the function-call subsystem to execute only when it is triggered by a calling event while it is enabled.

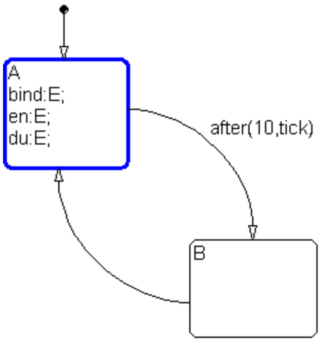
Setting **Sample time type** to **periodic** enables the **Sample time** field below it, which defaults to 1. These settings force the function-call subsystem to execute for each time step specified in the **Sample time** field while it is enabled. To accomplish this, the state that binds the calling 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. Therefore, for fixed step sampling, the sample time you enter in the **Sample time** field must be an integer multiple of the fixed step size. For variable step sampling, there are no limits on what you enter in the **Sample time** field.

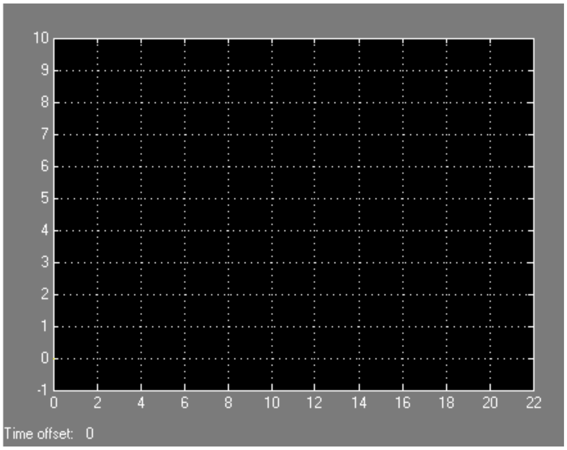
Simulating a Bound Function-Call Subsystem

To see the control that a state can have over the function-call subsystem whose trigger event it binds, begin simulating the example model in "Example of How to Bind a Function-Call Subsystem to a State" on page 8-78. For the purposes of display, the simulation parameters for this model specify a fixed-step solver with a fixed-step size of 1. Take note of model behavior in the following steps, which record the simulating Stateflow diagram and the output of the subsystem.

1 The default transition to state `A` is taken.

2 State `A` becomes active as shown.



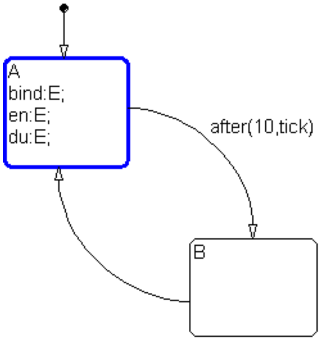


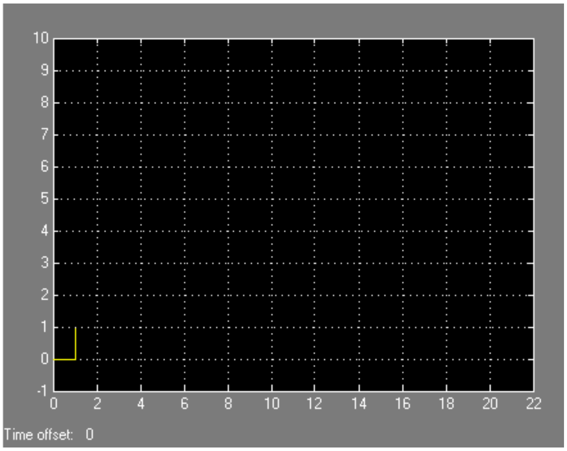
When state `A` becomes active, it executes its bind and entry actions. The binding action, `bind:E`, binds event `E` to state `A`. This enables the function-call subsystem and resets its state variables to 0.

State `A` also executes its entry action, `en:E`, which sends an event `E` to trigger the function-call subsystem and execute its block diagram. The block diagram increments a count by 1 each time using a Unit Delay block. Since the previous content of the Unit Delay block is 0 after the reset, the starting output point is 0 and the current value of 1 is held for the next call to the subsystem.

3 The next update event from Simulink tests state A for an outgoing transition.

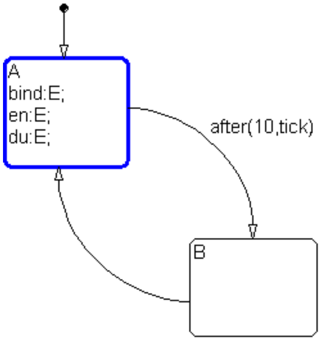
The temporal operation on the transition to state `B`, `after(10, tick)`, allows the transition to be taken only after ten update events are received. This means that for the second update, the during action of state `A`, `du:E`, is executed, which sends an event to trigger the function-call subsystem. The held content of the Unit Delay block, 1, is output to the scope as shown.

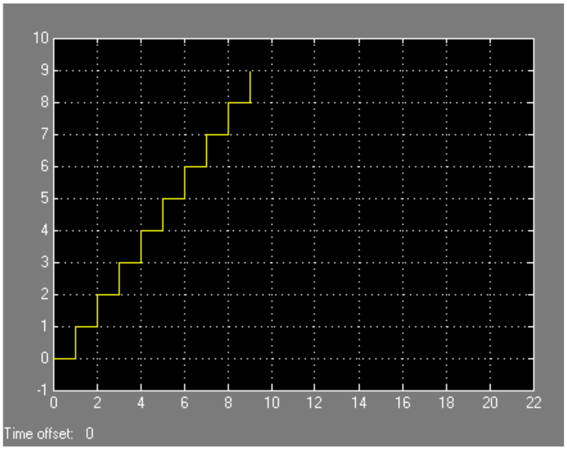




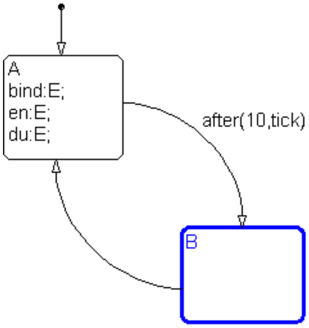
The subsystem also adds 1 to the held value to produce the value 2, which is held by the Unit Delay block for the next triggered execution.

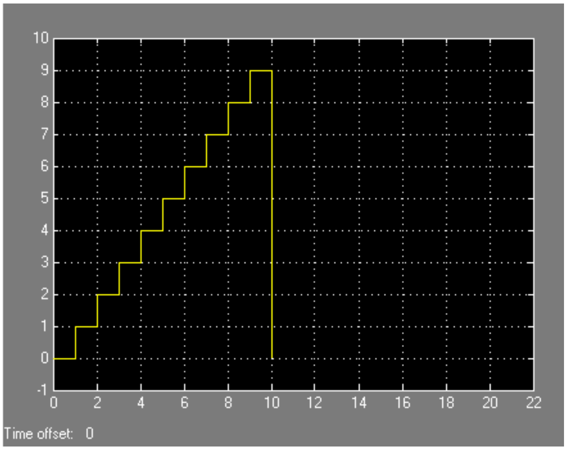
4 The next eight update events repeat step 2, which increment the subsystem output by 1 each time as shown.





5 On the 11th update event, the transition to state B is taken as shown.

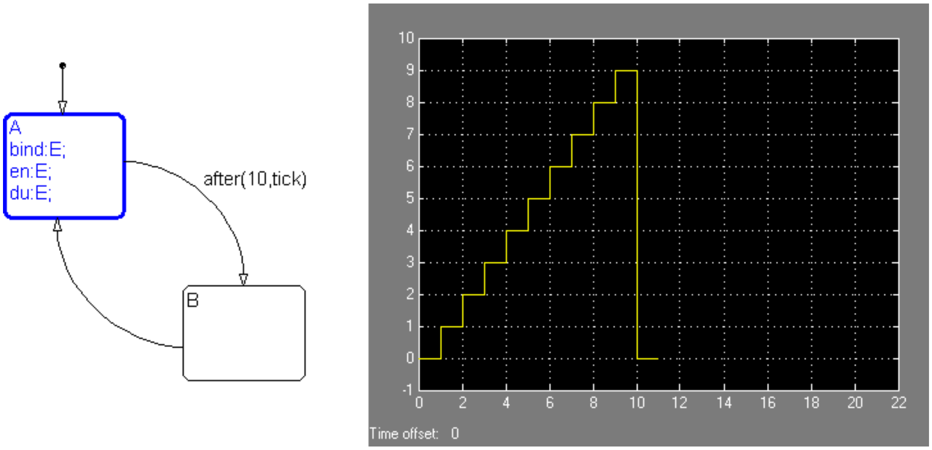




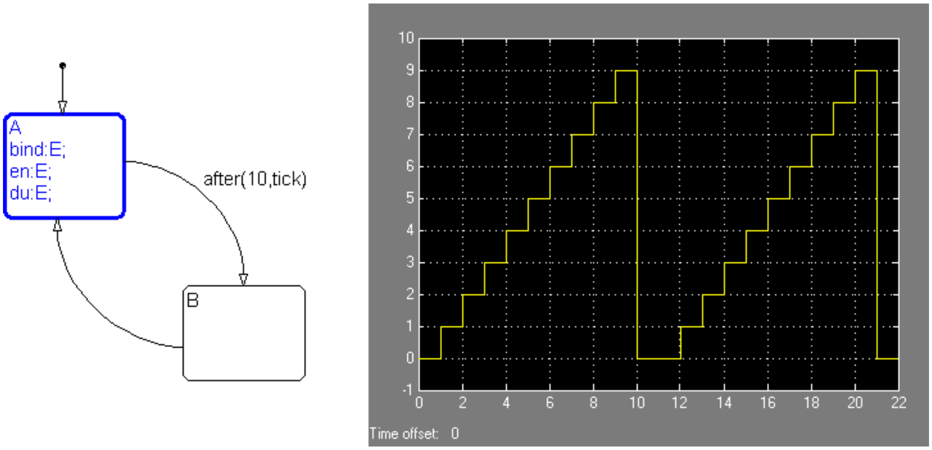
This makes state `B` active. Since the binding state `A` is no longer active, the function-call subsystem is disabled, and its output drops to 0.

6 When the next sampling event occurs, the transition from state `B` to state `A` is taken.

Once again, the binding action, `bind: E`, enables the subset and resets its output to 0 as shown.



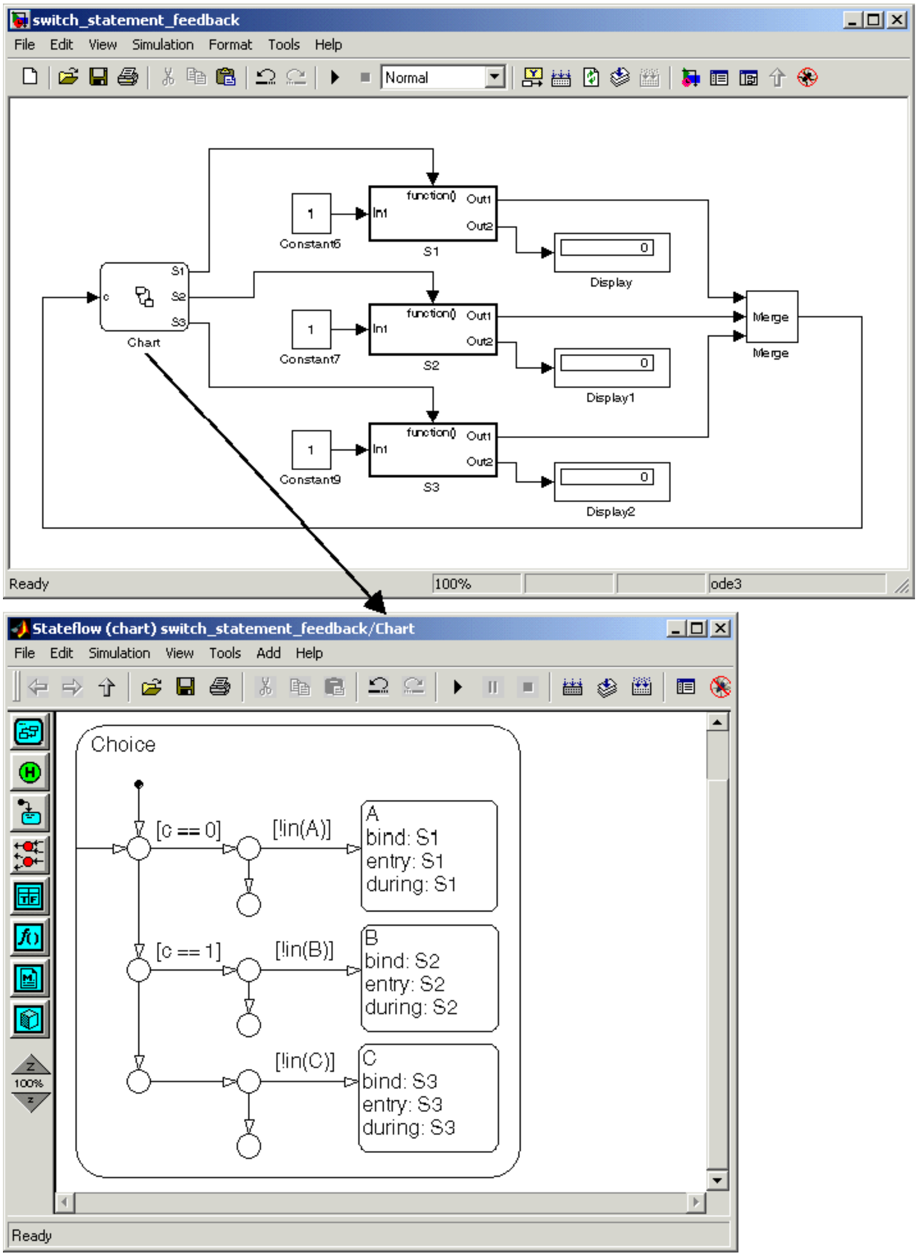
7 With the next 10 update events, steps 2 through 5 repeat, producing the following output:



Using Stateflow Logic with Binding

You can use Stateflow logic to control function-call subsystems that model C-like `switch`, `if-else`, `for`, and `while` statements in Simulink. Although you can model switch behavior in a Stateflow diagram, the generated code approximates the switch logic by using `if-else` statements.

For example, the following model demonstrates a Simulink `switch` statement with subsystems controlled by bind actions:


switch_statement_feedback
File Edit View Simulation Format Tools Help
Normal
function() Out1 Out2
In1
1
Constant6
S1
Display
0
S1 S2 S3
c
Chart
Constant7
S2
Display1
Merge
Merge
Constant9
S3
Display2
Ready
100%
ode3
Stateflow (chart) switch_statement_feedback/Chart
File Edit Simulation View Tools Add Help
Choice
[c == 0]
[!in(A)]
A
bind: S1
entry: S1
during: S1
[c == 1]
[!in(B)]
B
bind: S2
entry: S2
during: S2
[!in(C)]
C
bind: S3
entry: S3
during: S3
100%
Ready

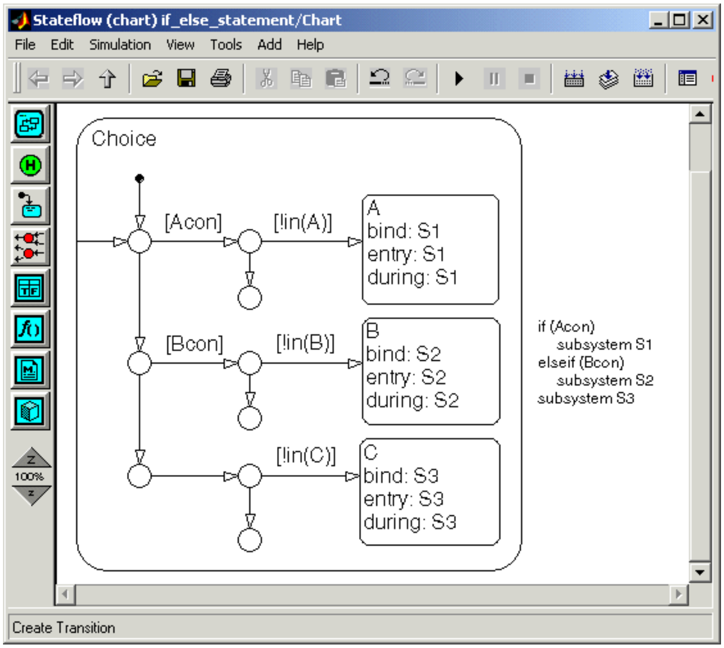
In this model, the Stateflow diagram controls three subsystems, S1, S2, and S3, through the bind actions for three states, A, B, and C, respectively. In this example, the value of the case argument c determines the subsystem to execute. State A becomes active and stays active when c is 0. State B becomes active and stays active when c is 1. State C becomes active and stays active when c has any other value.

When state A is active, the event S1 is bound to state A, which enables subsystem S1. The entry and during actions for A broadcast the event S1 whenever the model is updated for sampling. This means that while A is active, the subsystem S1 is executed for each sample time. The same applies to subsystem S2 for state B, and to subsystem S3 for state C.

The generated code for this model does not contain switch statements. Instead, it uses if-else logic, as represented by the following pseudocode:

```
if (c==0)
   if (!in(A))
      subsystem S1
else if (c==1)
   if(!in(B))
      subsystem S2
else
   if (!in(C))
       subsystem S3
```

You can modify the previous Stateflow diagram to control a Simulink model with an if-else statement, as shown.



```
if (Acon)
    subsystem S1
elseif (Bcon)
    subsystem S2
subsystem S3
```

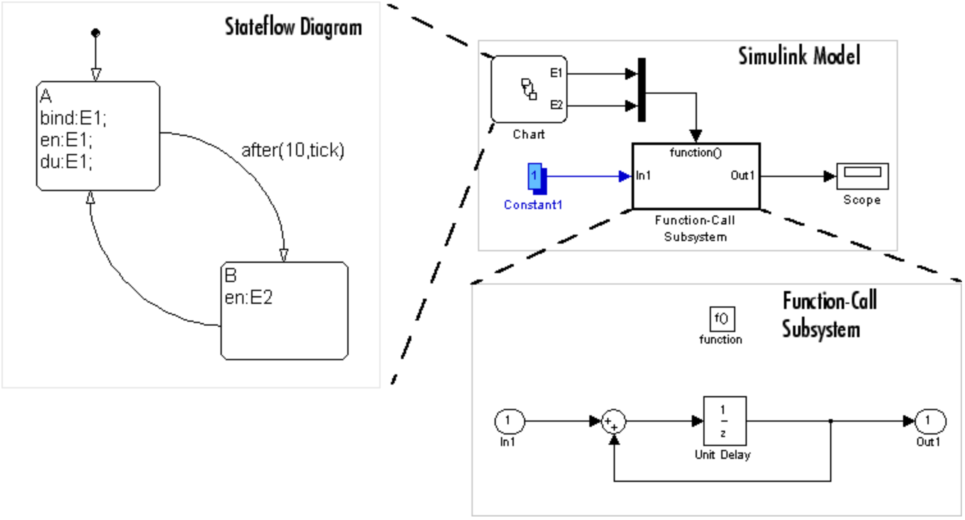
In this example, State A becomes active and stays active when the condition Acon is true. State B becomes active and stays active when the condition Bcon is true and the condition Acon is false. State C becomes active and stays active when both conditions Acon and Bcon are false. This creates the following if-else statement in Simulink:

```
if (Acon)
      subsystem S1
elseif (Bcon)
      subsystem S2
subsystem S3
```

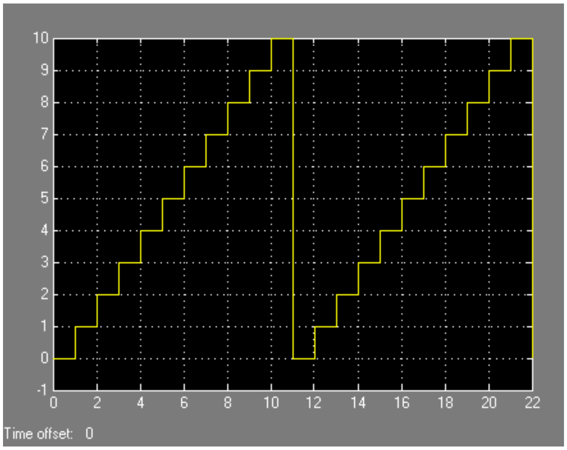
Avoiding Muxed Trigger Events with Binding

The simulated example in “Simulating a Bound Function-Call Subsystem” on page 8-80 shows how binding events gives control of a function-call subsystem to a single state in a Stateflow diagram. This control can be undermined if you allow other events to trigger the function-call subsystem through a mux.

For example, the following Simulink diagram defines two function-call events to trigger a function-call subsystem through a mux:



In the Stateflow diagram, E1 is bound to state A, but E2 is not. This means that state B is free to send the triggering event E2 in its entry action. When you simulate this model, you receive the following output:



Notice that broadcasting `E2` in state `B` changes the output, which now rises to a height of 10 before the binding action in state `A` resets the data.

Note Binding is not recommended when users provide multiple trigger events to a function-call subsystem through a mux. Muxed trigger events can interfere with event binding and cause undefined behavior.

Using Fixed-Point Data in Stateflow

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. The following topics describe fixed-point data in Stateflow. Be sure to read “Tips for Using Fixed-Point Data in Stateflow” on page 9-9 when you are ready to begin using it.

What Is Fixed-Point Data?

This section presents a high-level overview of fixed-point arithmetic. Use this section to understand the theory of fixed-point numbers and their operations with the following topics:

- "Fixed-Point Numbers" on page 9-2
- "Fixed-Point Operations" on page 9-3

For more discussion on the theory of fixed-point numbers, see "Fixed-Point Numbers" in the Simulink Fixed Point documentation.

Fixed-Point Numbers

Fixed-point numbers use integers and integer arithmetic to represent real numbers and arithmetic with the following encoding scheme:

$$V \approx \tilde{V} = SQ + B$$

where

- V is a precise real-world value that you want to approximate with a fixed-point number.
- $\tilde{V}$ is the approximate real-world value that results from fixed-point representation.
- Q is an integer that encodes $\tilde{V}$. It is referred to as the *quantized integer.*

  Q is the actual stored integer value used in representing the fixed-point number; that is, if a fixed-point number changes, its quantized integer, Q, changes – S and B remain unchanged.
- S is a coefficient of Q referred to as the *slope*.
- B is an additive correction referred to as the *bias*.

Fixed-point numbers encode real quantities (for example, 15.375) using the stored integer Q. You set Q's value by solving the preceding equation $\tilde{V} = SQ + B$ for Q and rounding the result to an integer value as follows:

$Q = round((V - B)/S)$

For example, suppose you want to represent the number 15.375 in a fixed-point type with the slope S = 0.5 and the bias B = 0.1. This means that

$Q = round((15.375 — 0.1)/0.5) = 30$

However, because Q is rounded to an integer, you have lost some precision in representing the number 15.375. If you calculate the number that Q actually represents, you now get a slightly different answer.

$$V = \tilde{V} = SQ + B = 0.5 \cdot 30 + 0.1 = 15.1$$

So using fixed-point numbers to represent real numbers with integers involves the loss of some precision. However, if you choose S and B correctly, you can minimize this loss to acceptable levels.

Fixed-Point Operations

Now that you can express fixed-point numbers as $\tilde{V} = SQ + B$, you can define operations between two fixed-point numbers.

The general equation for an operation between fixed-point operands is as follows:

```
c = a <op> b
```

where `a`, `b`, and `c` are all fixed-point numbers, and `<op>` refers to one of the binary operations: addition, subtraction, multiplication, or division.

The general form for a fixed-point number `x` is $S_x Q_x + B_x$ (see “Fixed-Point Numbers” on page 9-2). Substituting this form for the result and operands in the preceding equation yields the following:

$(S_c Q_c + B_c) = (S_a Q_a + B_a)$ <op> $(S_b Q_b + B_b)$

The values for S_c and B_c are usually chosen by Stateflow for each operation (see “Promotion Rules for Fixed-Point Operations” on page 9-19) and are based on the values for S_a, S_b, B_a and B_b which are entered for each fixed-point data (see “Specifying Fixed-Point Data in Stateflow” on page 9-7).

Note Stateflow also offers a more precise means for choosing the values for S_c and B_c when you use the := assignment operator (that is, `c := a <op> b`). See “Assignment (=, :=) Operations” on page 9-25 for more detail.

Using the values for S_a, S_b, S_c, B_a, B_b, and B_c, you can solve the preceding equation for Q_c for each binary operation as follows:

- The operation `c=a+b` implies that

$$Q_c = ((S_a/S_c)Q_a + (S_b/S_c)Q_b + (B_a + B_b - B_c)/S_c)$$

- The operation `c=a-b` implies that

$$Q_c = ((S_a/S_c)Q_a - (S_b/S_c)Q_b - (B_a - B_b - B_c)/S_c)$$

- The operation `c=a*b` implies that

$$Q_c = ((S_aS_b/S_c)Q_aQ_b + (B_aS_b/S_c)Q_a + (B_bS_a/S_c)Q_a + (B_aB_b - B_c)/S_c)$$

- The operation `c=a/b` implies that

$$Q_c = ((S_aQ_a + B_a)/(S_c(S_bQ_b + B_b)) - (B_c / S_c))$$

The fixed-point approximations of the real number result of the operation `c = a <op> b` are given by the preceding solutions for the value Q_c. In this way, all fixed-point operations are performed using only the stored integer Q for each fixed-point number and integer operation.

Using Fixed-Point Data in Stateflow

In “What Is Fixed-Point Data?” on page 9-2 you learn the theory behind fixed-point numbers. In this section you learn how Stateflow implements these numbers in the following topics:

- “How Stateflow Defines Fixed-Point Data” on page 9-5 — Describes the parameters that Stateflow uses to define fixed-point data.
- “Specifying Fixed-Point Data in Stateflow” on page 9-7 — Tells you where and how to specify fixed-point data in Stateflow.
- “Fixed-Point Context-Sensitive Constants” on page 9-8 — Tells you how to specify fixed-point constants that take their data type from the context in which they are used.
- “Tips for Using Fixed-Point Data in Stateflow” on page 9-9 — Gives you guidelines for using fixed-point data in Stateflow.
- “Overflow Detection for Fixed-Point Types” on page 9-11 — Tells you how to detect errors that result from exceeding the numeric capacity of fixed-point numbers.
- “Sharing Fixed-Point Data with Simulink” on page 9-12 — Tells you how to specify fixed-point data in Simulink that it shares with Stateflow as input from Simulink and output to Simulink data

How Stateflow Defines Fixed-Point Data

The preceding example in “What Is Fixed-Point Data?” on page 9-2 does not answer the question of how the values for the slope, S, the quantized integer, Q, and the bias, B, are implemented in Stateflow as integers. These values are implemented through the following:

- Stateflow defines a fixed-point data’s type from values that you specify.

  You specify values for S, B, and the base integer type for Q. The available base types for Q are the unsigned integer types `uint8`, `uint16`, and `uint32`, and the signed integer types `int8`, `int16`, and `int32`. For specific instructions on how to enter fixed-point data, see “Specifying Fixed-Point Data in Stateflow” on page 9-7.

Notice that 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.

- Stateflow implements an integer variable for the Q value of each fixed-point data in generated code.

  This is the only part of a fixed-point number that varies in value. The quantities S and B are constant and appear only as literal numbers or expressions in generated code.

- The slope, S, is factored into an integer power of two, E, and a coefficient, F, such that $S = F*2^{E}$ and $1 \leq F< 2$.

  The powers of 2 are implemented as bit shifts, which are more efficient than multiply instructions. Setting $F = 1$ avoids the computationally expensive multiply instructions for values of $F > 1$. This is referred to as *binary-point-only* scaling, which is implemented with bit shifts only, and is highly recommended.

- Operations for fixed-point types are implemented with solutions for the quantized integer as described in “Fixed-Point Operations” on page 9-3.

  To generate efficient code, the fixed-point promotion rules choose values for S_c and B_c that conveniently cancel out difficult terms in the solutions. See “Addition (+) and Subtraction (-)” on page 9-23 and “Multiplication (*) and Division (/)” on page 9-23.

  Stateflow provides a special assignment operator (:=) and context-sensitive constants to help you maintain as much precision as possible in your fixed-point operations. See “Assignment (=, :=) Operations” on page 9-25 and “Fixed-Point Context-Sensitive Constants” on page 9-8.

- Any remaining numbers, such as the fractional slope, F, that cannot be expressed as a pure integer or a power of 2, are converted into fixed-point numbers.

  These remaining numbers can be computationally expensive in multiplication and division operations. That is why the practice of using binary-point-only scaling in which $F = 1$ and $B = 0$ is recommended.

- During simulation, Stateflow detects when the result of a fixed-point operation *overflows* the capacity of its fixed-point type. See “Overflow Detection for Fixed-Point Types” on page 9-11.

Specifying Fixed-Point Data in Stateflow

You can specify fixed-point data in Stateflow as follows:

1. Add data to Stateflow as described in “Adding Data Using the Stateflow Editor” on page 7-27.

2. Set the properties for the data in the data properties dialog as described in “Fixed-Point Data Properties” on page 7-37.

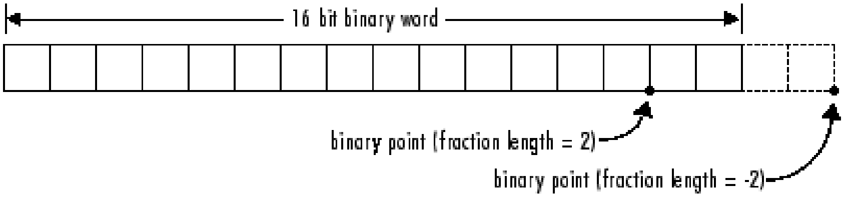
   For fixed-point data, set the following fields:

   - In the **Data type mode** field, select **Fixed point**.

     The Data properties dialog changes dynamically to display the fields **Signed**, **Word length** and **Scaling mode**.

   - In the **Word length** field, specify the size in bits of the word that will hold the quantized integer. Word length can be any integer between 0 and 32.

   - In the **Scaling mode** field, specify whether you want to scale fixed point data to avoid overflow conditions and minimize quantization errors. If you select binary point scaling, enter an integer value in the **Fraction length** field to indicate the binary point location. A positive value moves the binary point left of the rightmost bit (least significant bit) by that amount; a negative value moves the binary point further right of the rightmost bit by that amount, as in this example:


16 bit binary word
binary point (fraction length = 2)
binary point (fraction length = -2)

   - To enter separate slope and bias values (see note below), select the **Slope and bias** scaling option. The slope must be greater than zero.

Note It is recommended that you use binary-point-only scaling whenever possible to simplify the implementation of fixed-point data in generated code. Operations with fixed-point data using binary-point-only scaling are performed with simple bit shifts and eliminate the expensive code implementations required for separate slope and bias values.

You can also specify a fixed-point constant indirectly in action language by using a fixed-point context-sensitive constant. See “Fixed-Point Context-Sensitive Constants” on page 9-8.

Fixed-Point Context-Sensitive Constants

You can conveniently use fixed-point constants without using the data properties dialog or Stateflow Explorer, by using context-sensitive constants. Context-sensitive constants are constants that infer their types from the context in which they occur. They are written like ordinary constants, but have the suffix `C` or `c`. For example, the numbers 4.3C and 123.4c are valid fixed-point context-sensitive constants you can use in action language operations.

The following rules apply to context-sensitive constants:

- If any type in the context is a double then the context-sensitive constant is cast to type double.
- In an addition or subtraction operation, the type of the context-sensitive constant is the type of the other operand.
- In a multiplication or division operation with a fixed-point number, they obtain the best possible precision for a fixed-point result.

  In Simulink Fixed Point, this functionality is provided by the function `fixptbestexp`.
- In a cast, the context is the type to which the constant is being cast.
- As an argument in a function call, the context is the type of the formal argument. In an assignment, the context is the type of the left-hand operand.

- Context-sensitive constants may not be used on the left-hand side of an assignment.
- Both operands of a binary operation cannot be context-sensitive constants.

Note Both operands of a binary operation cannot be context-sensitive constants.

While fixed-point context-sensitive constants can be used in context with any types (for example, `int32` or `double`), the primary motivation for using them is with fixed-point numbers. The algorithm that computes the type to assign to a fixed-point context-sensitive constant depends on the operator, the types in the context, and the value of the constant. It provides a "natural" type, providing maximum accuracy without overflow.

Tips for Using Fixed-Point Data in Stateflow

Once you specify fixed-point data (see “Specifying Fixed-Point Data in Stateflow” on page 9-7), you can use it just as you would any data in Stateflow. However, because of the limitations of fixed-point numbers, it is a good idea to follow these guidelines when using them:

1. Develop and test your application 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. You need this while you are building your application.

2. Once your application works well, start substituting fixed-point data for double-precision data during the simulation phase, as follows:

   a. Set the integer word size for the simulation environment to the integer size of the intended target environment.

      Stateflow uses this integer size in generated code to select result types for your fixed-point operations. See “Setting the Integer Word Size for a Target” on page 9-21.

   b. Add the suffix ’C’ to literal numeric constants.

This suffix casts a literal numeric constant in the type of its context. For example, if `x` is fixed-point data, the expression `y = x/3.2C` first converts the numerical constant 3.2 to the fixed-point type of `x` and then performs the division with a fixed-point result. See "Fixed-Point Context-Sensitive Constants" on page 9-8 for more information.

Note If you do not use context-sensitive constants with fixed-point types, noninteger numeric constants (for example, constants that have a decimal point) can force fixed-point operations to produce floating-point results.

---

3. When you simulate, use overflow detection.

   See "Overflow Detection for Fixed-Point Types" on page 9-11 for instructions on how to set overflow detection in simulation.

4. If you encounter overflow errors in fixed-point data, you can do one of the following to add range to your data.

   - Increase the number of bits in the overflowing fixed-point data.

     For example, change the base type for Q from `int16` to `int32`.

   - Increase the range of your fixed-point data by increasing the power of 2 value, E.

     For example, you might want to increase E from -2 to -1. This decreases the available precision in your fixed-point data.

5. If you encounter problems with model behavior stemming from inadequate precision in your fixed-point data, you can do one of the following to add precision to your data:

   - Increase the precision of your fixed-point data by decreasing the value of the power of 2 binary point E.

     For example, you might want to decrease E from -2 to -3. This decreases the available range in your fixed-point data.

   - If you decrease the value of E, you might also want to increase the number of bits in the base data type for Q to prevent overflow.

For example, change the base type for *Q* from `int16` to `int32`.

6. If you cannot avoid overflow for lack of precision, consider using the := assignment operator in place of the = operator for assigning the results of multiplication and division operations.

   You can use the := operator to increase the range and precision of the result of fixed-point multiplication and division operations at the possible expense of computational efficiency. See “Assignment Operator :=” on page 9-26.

Overflow Detection for Fixed-Point Types

Overflow occurs when the magnitude of a result assigned to a data exceeds the numeric capacity of that data. You enable Stateflow to detect overflow of integer and fixed-point operations during simulation with the following steps:

1. In the Stateflow diagram editor, from the Tools menu, **select Open Simulation Target**.

   The **Stateflow Target Builder** dialog opens with `sfun` entered in the **Target Name** field.

2. Select **Coder Options**.

   The **Stateflow sfun Coder Options** dialog opens.

3. Select both the **Enable debugging/animation** and **Enable overflow detection (for debugging)** options.

   For descriptions of these options, see “Configuring a Simulation Target for Stateflow” on page 14-10.

4. Select **OK** to close the **Stateflow sfun Coder Options** dialog.

5. In the **Stateflow Target Builder** dialog, select **Build** to build the simulation target.

6. In the Stateflow diagram editor toolbar, select Debug to open the **Debugging** window.

7. In the **Debugging** window, select **Data Range**.

See “Setting Error Checking in the Debugging Window” on page 15-6 for a description of this option.

8 In the Debugging window, select **Start** to begin simulating the model.

Simulation breaks execution when an overflow occurs.

Sharing Fixed-Point Data with Simulink

If you plan on sharing fixed-point data with Simulink, use one of the following methods:

- Define the data that you input from Simulink or output to Simulink identically in both Stateflow and Simulink.

  This means that the values that you enter for the **Stored Integer** and **Scaling** fields in the shared data’s properties dialog in Stateflow (see “Specifying Fixed-Point Data in Stateflow” on page 9-7) must match similar fields that you enter for fixed-point data in Simulink. See “Fixed-Point "Bang-Bang Control" Example” on page 9-13 for an example of this method of sharing input from Simulink data using a Gateway In block in Simulink.

  For some Simulink blocks, you can specify the type of input or output data directly. For example, you can set fixed-point output data directly in the block parameters dialog of the Simulink Constant block when you select **Specify via dialog** for the **Output data type mode** field (under **Show additional parameters**).

- Define the data as **Input from Simulink** or **Output to Simulink** in the data’s properties dialog in Stateflow and instruct the sending or receiving block in Simulink to inherit its type from Stateflow.

  Many blocks allow you to set their data types and scaling through inheritance from the driving block, or through back propagation from the next block. This can be a good way to set the data type of a Simulink block to match the data type of the Stateflow port it connects to.

  For example, you can set the Simulink Constant block to inherit its type from the Stateflow **Input to Simulink** port that it supplies by selecting **Inherit via back propagation** for the **Output data type mode** field in its block parameters dialog (under **Show additional parameters**).

Fixed-Point "Bang-Bang Control" Example

In this section you open and explore a Stateflow fixed-point demo model that shows you how Stateflow fixed-point data is used in the following topics:

- "Opening the Fixed-Point "Bang-Bang Control" Example" on page 9-13
- "Exploring the Fixed-Point "Bang-Bang Control" Example" on page 9-14

Opening the Fixed-Point "Bang-Bang Control" Example

Stateflow includes demo models with applications of fixed-point data. For this example, load the `sf_boiler` demo model ("Bang-Bang control using Temporal Logic") into Simulink with the following steps:

1. In the MATLAB window, in the **Help** menu, select **Demos**.

2. In the left pane of the resulting **Help** dialog, click the + sign in front of **Simulink** to expand that node.

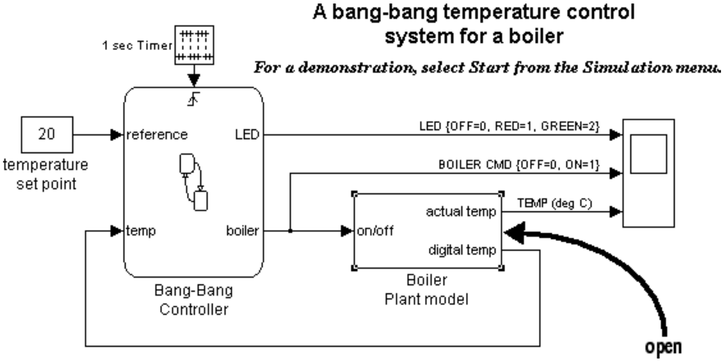
3. Continue by expanding the **Stateflow** node under the **Simulink** node.

4. Continue by expanding the **Examples** node under the **Stateflow** node.

5. Double-click the demos node under the **Stateflow** node.

6. Double-click the node marked **Bang-Bang control using Temporal Logic**.

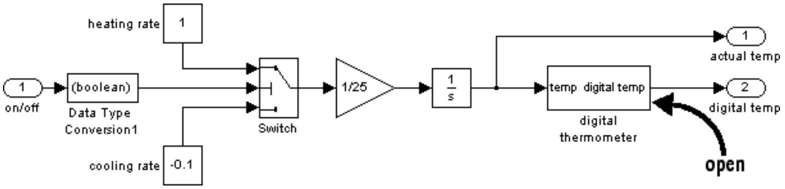
   A Simulink window opens as shown.



Exploring the Fixed-Point "Bang-Bang Control" Example

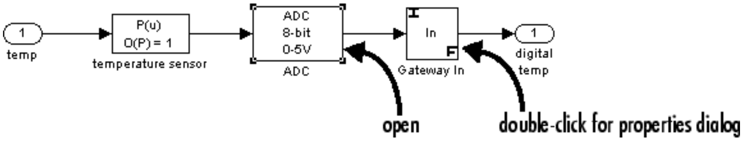
The Stateflow block performs almost all the logic of the bang-bang boiler model with the exception of the Boiler Plant model subsystem block.

1 Double-click the Boiler Plant model subsystem block.



The Boiler Plant model block simulates the temperature reaction of the boiler to periods of heating or cooling dictated by the Stateflow block. Depending on the Boolean value coming from the Controller, a temperature increment (+1 for heating, -0.1 for cooling) is added to the previous boiler temperature. The resulting boiler temperature is sent to the digital thermometer subsystem block.

2 Double-click the digital thermometer subsystem block.



The digital thermometer subsystem produces an 8 bit fixed-point representation of the input temperature with the blocks described in the sections that follow.

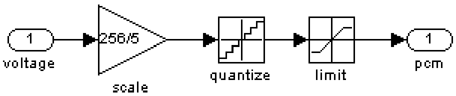
temperature sensor Block

The temperature sensor block converts input boiler temperature *(T)* to an intermediate analog voltage output T_{volts} with a first-order polynomial that results in the following output:

$$T_{\mathrm{volts}} = 05*T + 75$$

ADC Block

Double-click the ADC block to reveal the following contents:



The ADC subsystem digitizes the analog voltage from the temperature sensor block by multiplying the analog voltage by 256/5, rounding it to its integer floor, and limiting it to a maximum of 255 (the largest unsigned 8 bit integer value). Using the value for the output T_{volts} from the temperature sensor block, the new digital coded temperature output by the ADC block, $T_{digital}$, is given by the following equation:

$$T_{digital} = (265/5)*T_{volts} = (256*0.05/5)*T+(256/5)*0.75$$

Gateway In Block

An examination of the Block Parameters dialog for the Gateway In block shows that it informs the rest of the model that $T_{digital}$ is now a fixed-point number with a slope value of 5/265/0.05 and an intercept value of -0.75/0.05. The Stateflow block Bang-Bang Controller receives this output and interprets it as a fixed-point number through the Stateflow data `temp`, which is scoped as **Input from Simulink** and set as an unsigned 8 bit fixed-point data with the same values for *S* and *B* set in the Gateway In block.

The values for S and B are determined from the general expression for a fixed-point number, which is as follows:

$$V = S*Q + B$$

Therefore,

$$Q = (V - B)/S = (1/S)*V + (-1/S)*B$$

Since $T_{digital}$ is now a fixed-point number, it is now the quantized integer Q of a fixed-point type. This means that $T_{digital} = Q$ of its fixed-point type and results in the following identity:

$$(1/S)*V + (-1/S)*B = (256*0.05/5)*T + (256/5)*0.75$$

Since T is the real-world value for the environment temperature, the above equation implies the following identifications:

$$V = T$$

and

$$1/S = (256*0.05)/5$$

$$S = 5/(265*0.05) = 0.390625$$

and

$$(-1/S)*B = (256/5)*0.75$$

$$B = -(256/5)*0.75*5/(256*0.05) = -0.75/0.05 = 15$$

By setting T_{digital} to be a fixed-point data both as the output of the Gateway In block in Simulink and the input of the Stateflow Bang-Bang Controller block, Stateflow interprets and processes this data automatically in an 8 bit environment with no need for any explicit conversions.

Operations with Fixed-Point Data

This section lists the supported operations for fixed-point data in Stateflow and describes the data conversions required in order to perform these operations in the following topics:

- “Supported Operations with Fixed-Point Operands” on page 9-17
- “Promotion Rules for Fixed-Point Operations” on page 9-19
- “Assignment (=, :=) Operations” on page 9-25
- “Fixed-Point Conversion Operations” on page 9-30
- “Autoscaling of Stateflow Fixed-Point” on page 9-31

Supported Operations with Fixed-Point Operands

Stateflow supports the operations listed in the topics that follow.

Binary Operations

Stateflow supports the following binary operations with the listed precedence:

Example	Precedence	Description
`a * b`	10	Multiplication
`a / b`	10	Division
`a + b`	9	Addition
`a - b`	9	Subtraction
`a > b`	7	Comparison, greater than
`a < b`	7	Comparison, less than
`a >= b`	7	Comparison, greater than or equal to
`a <= b`	7	Comparison, less than or equal to
`a == b`	6	Comparison, equality
`a ~= b`	6	Comparison, inequality
`a != b`	6	Comparison, inequality
`a <> b`	6	Comparison, inequality

Example	Precedence	Description
`a & b`	5	One of the following: • Bitwise AND Enabled when **Enable C-bit operations** is selected in the chart properties dialog. See “Specifying Chart Properties” on page 10-6. Operands are cast to integers before the operation is performed. • Logical AND Enabled when **Enable C-bit operations** is cleared in chart properties dialog.
`a | b`	3	One of the following: • Bitwise OR Enabled when **Enable C-bit operations** is selected in chart properties dialog. See “Specifying Chart Properties” on page 10-6. Operands are cast to integers before the operation is performed. • Logical OR Enabled when **Enable C-bit operations** is cleared in chart properties dialog.
`a && b`	2	Logical AND
`a || b`	1	Logical OR

Unary Operations and Actions

Stateflow supports the following unary operations and actions:

Example	Description
`~a`	Unary minus
`!a`	Logical not
`a++`	Increment
`a--`	Decrement

Assignment Operations

Stateflow supports the following assignment operations:

Example	Description
`a = expression`	Simple assignment
`a := expression`	See “Assignment Operator :=” on page 9-26.
`a += expression`	Equivalent to `a = a + expression`
`a -= expression`	Equivalent to `a = a - expression`
`a *= expression`	Equivalent to `a = a * expression`
`a /= expression`	Equivalent to `a = a / expression`
`a |= expression`	Equivalent to `a = a | expression` (bit operation). See operation `a | b` in “Binary Operations” on page 9-17.
`a &= expression`	Equivalent to `a = a & expression` (bit operation). See operation `a & b` in “Binary Operations” on page 9-17.

Promotion Rules for Fixed-Point Operations

Operations with at least one fixed-point operand require rules for selecting the type of the intermediate result for that operation. For example, in the action statement `c = a + b`, where `a` or `b` is a fixed-point number, an intermediate result type for `a + b` must first be chosen before the result is calculated and assigned to `c`.

The rules for selecting the numeric types used to hold the results of operations with a fixed-point number are referred to as the *fixed-point promotion rules*.

The primary goal of these rules is to maintain good computational efficiency with reasonable usability.

Note You can use the := assignment operator to override the fixed-point promotion rules in the interest of obtaining greater accuracy. However, in this case, greater accuracy might require more computational steps. See "Assignment Operator :=" on page 9-26.

The following topics describe the process of selecting an intermediate result type for all binary operations with at least one fixed-point operand:

Default Selection of the Number of Bits of the Result Type

A fixed-point number with S = 1 and B = 0 is treated as an integer. In operations with integers, the C language promotes any integer input with fewer bits than the type `int` to the type `int` and then performs the operation.

The type `int` is the *integer word size* for C on a given platform. Result word size is increased to the integer word size because processors can perform operations at this size efficiently.

Stateflow maintains consistency with the C language by using the following default rule to assign the number of bits for the result type of an operation with fixed-point numbers:

When both operands are fixed-point numbers, the number of bits in the result type is the maximum number of bits in the input types or the number of bits in the integer word size for the target machine, whichever is larger.

Note The preceding rule is a default rule for selecting the bit size of the result for operations with fixed-point numbers. This rule is overruled for specific operations as described in the sections that follow.

Setting the Integer Word Size for a Target. The preceding default rule for selecting the bit size of the result for operations with fixed-point numbers relies on the definition of the integer word size for your target. You can set the integer word size for the targets that you build in Simulink with the following procedure:

1. Right-click inside the root Simulink model and select **Configuration Parameters**.

   The **Configuration Parameters** dialog opens.

2. Select **Hardware Implementation** in the left navigation panel.

   The right panel displays configuration parameters for embedded hardware (simulation and code generation) and emulation hardware (code generation only).

3. To set integer word size for embedded hardware, follow these steps:

   - In the drop-down menu for the **Device type** field, select **Custom**.
   - In the **int** field, enter a word size in bits.

4. To set integer word size for emulation hardware, follow these steps:

   - If no configuration fields appear, click the button **Configure current execution hardware device** and uncheck **None**.
   - In the drop-down menu for the **Device type** field, select **Custom**.
   - In the **int** field, enter a word size in bits.

5. Click **OK** to accept the changes.

When you build any target after making this change, Stateflow uses this integer size in generated code to select result types for your fixed-point operations.

Note It is recommended that you set all the available sizes because they affect code generation, although they do not affect the implementation of the fixed-point promotion rules in generated code.

Unary Promotions

Only the unary minus (-) operation requires a promotion of its result type. The word size of the result is given by the default procedure for selecting the bit size of the result type for an operation involving fixed-point data. See “Default Selection of the Number of Bits of the Result Type” on page 9-20. The bias, B, of the result type is the negative of the bias of the operand.

Binary Operation Promotion for Integer Operand with Fixed-Point Operand

Integers as operands in binary operations with fixed-point numbers are treated as fixed-point numbers of the same word size with slope, S, equal to 1, and a bias, B, equal to 0. The operation now becomes a binary operation between two fixed-point operands. See “Binary Operation Promotion for Two Fixed-Point Operands” on page 9-22.

Binary Operation Promotion for Double Operand with Fixed-Point Operand

When one operand is of type `double` in a binary operation with a fixed-point type, the result type is `double`. In this case, the fixed-point operand is cast to type `double`, and the operation is performed.

Binary Operation Promotion for Single Operand with Fixed-Point Operand

When one operand is of type `single` in a binary operation with a fixed-point type, the result type is `single`. In this case, the fixed-point operand is cast to type `single`, and the operation is performed.

Binary Operation Promotion for Two Fixed-Point Operands

Operations with both operands of fixed-point type produce an intermediate result of fixed-point type. The resulting fixed-point type is chosen through the application of a set of operator-specific rules. The procedure for producing an intermediate result type from an operation with operands of different fixed-point types is summarized in the following topics:

- “Setting the Integer Word Size for a Target” on page 9-21
- “Addition (+) and Subtraction (-)” on page 9-23

- "Multiplication (*) and Division (/)" on page 9-23
- "Relational Operations (>, <, >=, <=, ==, -=, !=, <>)" on page 9-23
- "Logical Operations (&, |, &&, ||)" on page 9-24

Addition (+) and Subtraction (-). The output type for addition and subtraction is chosen so that the maximum positive range of either input can be represented in the output while preserving maximum precision. The base word type of the output follows the rule in "Default Selection of the Number of Bits of the Result Type" on page 9-20. 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.

Note Mixing signed and unsigned operands might yield unexpected results and is not recommended.

Multiplication (*) and Division (/). The output type for multiplication and division is chosen to yield the most efficient code implementation. Nonzero biases are not supported for multiplication and division by Stateflow (see note).

The slope for the result type of the product of the multiplication of two fixed-point numbers is the product of the slopes of the operands. Similarly, the slope of the result type of the quotient of the division of two fixed-point numbers is the quotient of the slopes. The base word type is chosen to conform to the rule in "Default Selection of the Number of Bits of the Result Type" on page 9-20.

Note Because nonzero biases are computationally very expensive, they are not supported for multiplication and division by Stateflow.

Relational Operations (>, <, >=, <=, ==, -=, !=, <>). Stateflow supports the following relational (comparison) operations on all fixed-point types: >, <, >=, <=, ==, -=, !=, <>. See "Supported Operations with Fixed-Point Operands" on page 9-17 for an example and description of these operations. Stateflow requires that both operands in a comparison have equal biases (see note).

Comparing fixed-point values of different types can yield unexpected results because Stateflow must convert each operand to a common type for comparison. Because of rounding or overflow errors during the conversion, values that do not appear equal might be equal and values that appear to be equal might not be equal.

Note To preserve precision and minimize unexpected results, Stateflow requires both operands in a comparison operation to have equal biases.

For example, compare the following two unsigned 8 bit fixed-point numbers, a and b, in an 8 bit target environment:

Fixed-Point Number a	Fixed-Point Number b
$S_a = 2^{-4}$	$S_b = 2^{-2}$
$B_a = 0$	$B_b = 0$
$V_a = 43.8125$	$V_b = 43.75$
$Q_a = 701$	$Q_b = 175$

By rule, the result type for comparison is 8 bit. Converting b, the least precise operand, to the type of a, the most precise operand, could result in overflow. Consequently, a is converted to the type of b. Because the bias values for both operands are 0, the conversion is made as follows:

$$S_b\ (newQ_a) = S_aQ_a$$

$$newQ_a = (S_aS_b)\ Q_a = (2^{-4}/2^{-2})\ 701 = 701/4 = 175$$

Although they represent different values, a and b are considered equal as fixed-point numbers.

Logical Operations (&, |, &&, ||). If a is a fixed-point number used in a logical operation, it is interpreted with the equivalent substitution `a != 0.0C` where `0.0C` is an expression for zero in the fixed-point type of a (see “Fixed-Point Context-Sensitive Constants” on page 9-8). For example, if a is a fixed-point number in the logical operation `a && b`, this operation is equivalent to the following:

```
(a != 0.0C) && b
```

The preceding operation is not a check to see whether the quantized integer for a, Q_a, is not 0. If the real-world value for a fixed-point number a is 0, this implies that $V^a = S_a Q_a + B_a = 0.0$. Therefore, the expression `a != 0`, for fixed-point number a, is actually equivalent to the following expression:

$$Q_a\ ! = -B_a / S_a$$

For example, if a fixed-point number, a, has a slope of 2^{-2}, and a bias of 5, the test `a != 0` is equivalent to the test `if` Q_a ! = -20.

Assignment (=, :=) Operations

Stateflow supports the assignment operations `LHS = RHS` and `LHS := RHS` between a left-hand side (`LHS`) and a right-hand side (`RHS`). These are described in the following topics:

- "Assignment Operator =" on page 9-25.
- "Assignment Operator :=" on page 9-26
- ":= Multiplication Example" on page 9-26
- ":= Division Example" on page 9-28
- ":= Assignment and Context-Sensitive Constants" on page 9-29

Assignment Operator =

An assignment statement of the type LHS = RHS is equivalent to casting the right-hand side to the type of the left-hand side. Stateflow supports any assignment between fixed-point types and therefore, implicitly, any cast.

A cast converts the stored integer Q from its original fixed-point type while preserving its value as accurately as possible using the online conversions (see "Fixed-Point Conversion Operations" on page 9-30). Assignments are most efficient when both types have the same bias, and slopes that are equal or both powers of 2.

Assignment Operator :=

Ordinarily, Stateflow uses the fixed-point promotion rules to choose the result type for an operation. Using the := assignment operator overrides this behavior by using the type of the `LHS` as the result type of the `RHS` operation.

This type of assignment is particularly useful in retaining useful range and precision in the result of a multiplication or division that ordinary assignment might not retain. It is less useful with addition or subtraction but can avoid overflow or the loss of memory to store a result even in these cases.

Use of the := assignment operator is governed by the following rules:

- The `RHS` can contain at most one binary operator.
- If the `RHS` contains anything other than a multiplication (*), division (/), addition (+), or subtraction (-) operation, or a constant, then the := assignment behaves exactly like regular assignment (=).
- Constants on the `RHS` of an `LHS := RHS` assignment are converted to the type of the left-hand side using offline conversion (see “Fixed-Point Conversion Operations” on page 9-30). Ordinary assignment always casts the `RHS` using online conversions.

For examples contrasting the `LHS := RHS` and the `LHS = RHS` assignment operations, see the following:

- “:= Multiplication Example” on page 9-26
- “:= Division Example” on page 9-28

Caution Using the := assignment operator to produce a more accurate result might generate code that is less efficient than the code generated using the normal fixed-point promotion rules.

:= Multiplication Example

The following example contrasts the := and = assignment operators for multiplication. Here, the := operator is used to avoid overflow in the results of the multiplication `c = a * b` in which `a` and `b` are of two fixed-point operands.

The operands and result for this operation are 16 bit unsigned integers with the following assignments:

Fixed-Point Number a	Fixed-Point Number b	Fixed-Point Number c
$S_a = 2^{-4}$	$S_b = 2^{-4}$	$S_c = 2^{-5}$
$B_a = 0$	$B_b = 0$	$B_c = 0$
$V_a = 20.1875$	$V_b = 15.3125$	$V_c = ?$
$Q_a = 323$	$Q_b = 245$	$Q_c = ?$

where S is the slope, B is the bias, V is the real-world value, and Q is the quantized integer.

c = a*b. In this case, first calculate an intermediate result for `a*b` in the fixed-point type given by the rules in the section "Fixed-Point Operations" on page 9-3, and then cast that result into the type for `c`.

The intermediate value is calculated as follows:

$$Q_{iv} = Q_a Q_b$$

$$= 323 \cdot 245 = 79135$$

Because the maximum value of a 16 bit unsigned integer is $2^{16} - 1 = 65535$, the preceding result overflows its word size. An operation that overflows its type produces an undefined result.

You can capture overflow errors like the preceding example during simulation with the Debugger window. See "Overflow Detection for Fixed-Point Types" on page 9-11.

c := a*b. In this case, calculate `a*b` directly in the type of `c`. Use the solution for Q_c given in "Fixed-Point Operations" on page 9-3 with the requirement of zero bias, which is as follows:

$$Q_c = ((S_a S_b / S_c) Q_a Q_b)$$

$$= (2^{-4} \cdot 2^{-4}/2^{-5})(323 \cdot 245)$$

$$= 79135/8 = 9892 \text{ (rounded to floor)}$$

No overflow occurs in this case, and the approximate real-world value is as follows:

$$\tilde{V}_c = S_c Q_c = 2^{-5} \cdot 9892 = 9892/32 = 309.125$$

This value is very close to the actual real-world result of 309.121.

:= Division Example

The following example contrasts the := and = assignment operators for division. The := operator is used to obtain more precise results for the division of two fixed-point operands, `b` and `c`, in the statement `c := a/b`.

This example uses the following fixed-point numbers, where *S* is the slope, *B* is the bias, *V* is the real-world value, and *Q* is the quantized integer:

Fixed-Point Number a	Fixed-Point Number b	Fixed-Point Number c
$S_a^{-4} = 2$	$S_b^{-3} = 2$	$S_c^{-6} = 2$
$B_a = 0$	$B_b = 0$	$B_c = 0$
$V_a = 2$	$V_b = 3$	$V_c = ?$
$Q_a = 32$	$Q_b = 24$	$Q_c = ?$

c = a/b. In this case, first calculate an intermediate result for `a/b` in the fixed-point type given by the rules in the section "Fixed-Point Operations" on page 9-3, and then cast that result into the type for `c`.

The intermediate value is calculated as follows:

$$Q_{iv} = Q_a/Q_b$$

$$= 32/24 = 1$$

The intermediate value is then cast to the result type for `c` as follows:

$$S_bQ_c = S_{iv}Q_{iv}$$

$$Q_c = (S_{iv}/S_c)Q_{iv}$$

The slope of the intermediate value for a division operation is calculated as

$$S_{iv} = S_a/S_b = 2^{-4-3}/2 = 2^{-1}$$

Substitution of this value into the preceding result yields the final result.

$$Q_c = 2^{-1}/2^{-6} = 2^5 = 32$$

In this case, the approximate real-world value is $\tilde{V}c = 32/64 = 0.5$, which is not a very good approximation of the actual result, $2/3 \overset{\sim}{=} 0.667$.

c := a/b. In this case, calculate `a/b` directly in the type of `c`. Use the solution for Q_c given in “Fixed-Point Operations” on page 9-3 with the simplification of zero bias, which is as follows:

$$Q_c = (S_aQ_a) / (S_c(S_bQ_b))$$

$$= (S_a/(S_b \cdot S_c)) \cdot Q_a/Q_b$$

$$= (2^{-4}/(2^{-3} \cdot 2^{-6})) \cdot 32/24$$

$$= 2^5 \cdot 32/24 = 42$$

In this case, the approximate real-world value $\tilde{V}c$ = 42/64 = 0.6563, a much better approximation to the precise result, 2/3 = 0.667.

:= Assignment and Context-Sensitive Constants

In a := assignment operation, the type of the left-hand side (`LHS`) determines part of the context used for inferring the type of a right-hand side (`RHS`) context-sensitive constant.

The following rules apply to `RHS` context-sensitive constants in assignments with the := operator:

- If the `LHS` is a floating-point data (type `double` or `single`) , the `RHS` context-sensitive constant becomes a floating-point constant.
- For addition and subtraction, the type of the LHS determines the type of the context-sensitive constant on the RHS.
- For multiplication and division, the type of the context-sensitive constant is chosen independent of the LHS.

Fixed-Point Conversion Operations

Stateflow converts real numbers into fixed-point data during data initialization and as part of casting operations in the application. These conversions compute a quantized integer, *Q*, from a real number input. Stateflow uses offline conversions to initialize data and online conversions for casting operations in the running application. The topics that follow describe each conversion type and give examples of the results.

Offline Conversions for Initialized Data

Offline conversions are performed during code generation, and are designed to maximize accuracy. They round the resulting quantized integer to its nearest integer value. If the conversion overflows, the result saturates the value for *Q*.

Offline conversions are performed for the following operations:

- Initialization of data (both variables and constants) in the data dictionary
- Initialization of constants or variables from the MATLAB workspace

Online Conversions for Casting Operations

Online conversions are performed for casting operations that take place during execution of the application. Designed to maximize computational efficiency, they are faster and more efficient than offline conversions, but less precise. Instead of rounding *Q* to its nearest integer, online conversions round to the floor (with the possible exception of division, which might round to 0, depending on the C compiler you have). If the conversion overflows the type converted to, the result is undefined.

Offline and Online Conversion Examples

The following examples show the difference in the results of offline and online conversions of real numbers to a fixed-point type defined by a 16 bit word size, a slope (*S*) equal to 2^{-4}, and a bias (*B*) equal to 0:

		Offline Conversion	**Online Conversion**		
V	***V/S***	***Q***	$\tilde{V}$	***Q***	$\tilde{V}$
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

In the preceding example,

- *V* is the real-world value represented as a fixed-point value.
- *V*/*S* is the floating-point computation for the quantized integer *Q*.
- *Q* is the rounded value of *V*/*S*.
- $\tilde{V}$ is the approximate real-world value resulting from *Q* for each conversion.

Autoscaling of Stateflow Fixed-Point

Simulink autoscales Stateflow fixed-point data with the Simulink autoscaling tool. See “Automatic Scaling” in Simulink Fixed Point documentation for instructions on autoscaling fixed-point data in Simulink.

You can prevent Stateflow fixed-point data from being autoscaled by selecting the **Lock output scaling against changes by the autoscaling tool** check box in the **Data** dialog for a fixed-point data. Selecting this option prevents Simulink from replacing the current fixed-point type with a Simulink chosen type in the autoscaling tool. See “Setting Data Properties in the Data Dialog” on page 7-31 for a description of the properties for data.

Defining Interfaces to Simulink and MATLAB

Each Stateflow chart is a block in a Simulink diagram that sits on top of MATLAB. You can share data with MATLAB and Simulink and also determine how and when Simulink executes your charts through Stateflow interfaces with the following sections:

Overview of Stateflow Interfaces

Each Stateflow block interfaces to its Simulink model. Take an overview look at Stateflow interfaces to Simulink and MATLAB with the following topics:

- "Stateflow Interfaces" on page 10-3 — Lists the interfaces that Stateflow has to Simulink blocks, MATLAB data, and external code sources.
- "Typical Tasks to Define Stateflow Interfaces" on page 10-4 — Describes the tasks used to define Stateflow interfaces.
- "Where to Find More Information on Events and Data" on page 10-4 — Gives you references to further information on defining Stateflow interfaces in the Stateflow documentation.

Stateflow Interfaces

Each Stateflow block interfaces to its Simulink model. Each Stateflow block can interface to sources external to the Simulink model (data, events, custom code). Events and data are the Stateflow objects that define the interface from the Stateflow block's point of view.

Events can be local to the Stateflow block or can be propagated to and from Simulink and sources external to Simulink. Data can be local to the Stateflow block or can be shared with and passed to the Simulink model and to sources external to the Simulink model.

The Stateflow interfaces includes the following:

- Physical connections between Simulink blocks and the Stateflow block
- Event and data information exchanged between the Stateflow block and external sources
- The properties of a Stateflow chart
- Graphical functions exported from a chart

  See "Exporting Graphical Functions" on page 6-41 for more details.
- The MATLAB workspace

  See "Using MATLAB Functions and Data in Actions" on page 8-29 for more details.

- Definitions in external code sources

Typical Tasks to Define Stateflow Interfaces

Defining the interface for a Stateflow block in a Simulink model involves some or all the tasks described in the following topics:

- Specify the update method for a Stateflow block in a Simulink model.

  This task is described in “Setting the Stateflow Block Update Method” on page 10-15.

- Define the input and output data and events that you need.

  See the following topics for detailed information:

  - “Defining Input Events” on page 7-13
  - “Defining Output Events” on page 7-14
  - “Sharing Input and Output Data with Simulink” on page 7-46

- Add and define any nonlocal data and events your Stateflow diagram must interact with.

- Define relationships with any external sources.

  See the topics “MATLAB Workspace Interfaces” on page 10-30 and “Interface to External Sources” on page 10-31.

The preceding task list could be a typical sequence. You might find that another sequence better complements your model development.

See “Implementing Simulink Update Interfaces” on page 10-17 for examples of implemented interfaces to Simulink.

Where to Find More Information on Events and Data

The following references are relevant to defining the interface for a Stateflow Chart block in Simulink:

- “Defining Input Events” on page 7-13
- “Defining Output Events” on page 7-14
- “Importing Events from Stateflow External Code” on page 7-22

- “Exporting Events to Stateflow External Code” on page 7-21
- “Sharing Input and Output Data with Simulink” on page 7-46
- “Sharing Stateflow Data with External Modules” on page 7-60
- “Sharing Stateflow Data with External Modules” on page 7-60

Specifying Chart Properties

Part of the interface for a Stateflow block to its Simulink model is set when you specify the properties for the chart of a Stateflow block. You can specify properties for individual charts or for all charts in a model as described in the following topics:

- "Setting Properties for Individual Charts" on page 10-6
- "Setting Properties for All Charts in the Model" on page 10-12

Setting Properties for Individual Charts

To specify properties for an individual Stateflow chart, follow these steps:

1. Double-click on a Stateflow block to open its diagram in the Stateflow diagram editor.

2. Right-click an open area of the Stateflow diagram.

3. From the resultant context menu, select **Properties**.

   The properties dialog for the chart appears, as shown:

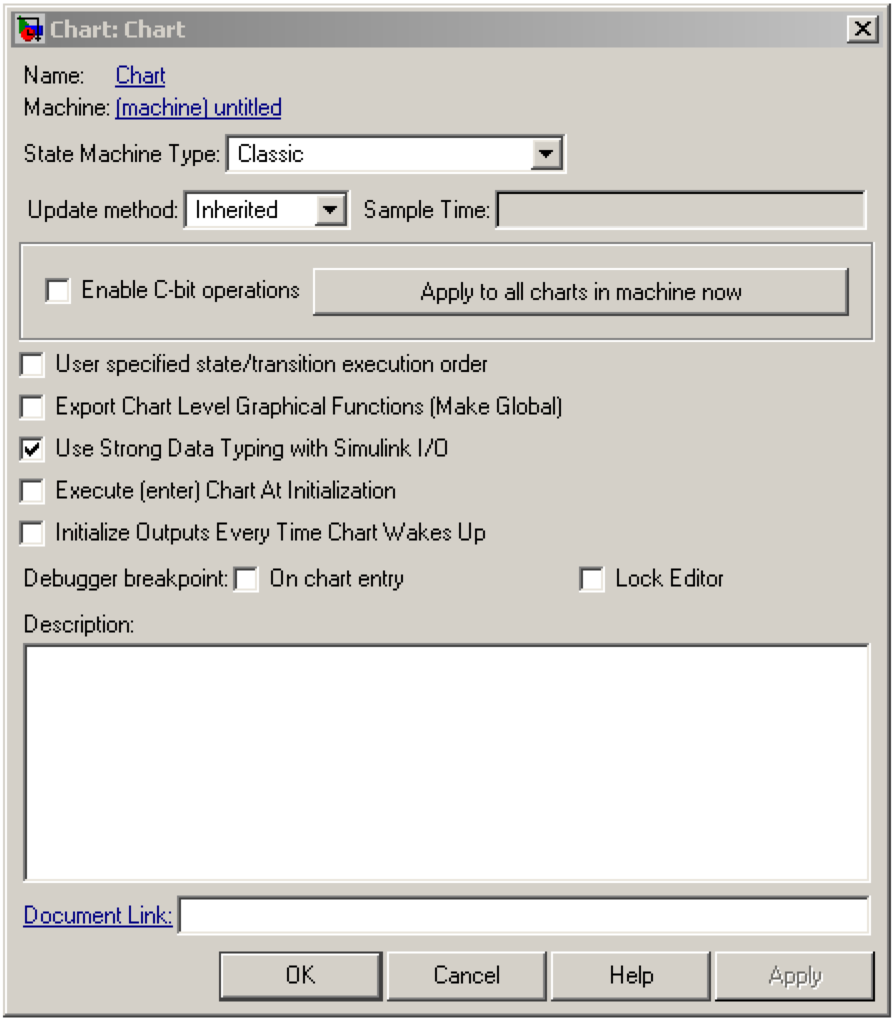


Chart: Chart

Name: Chart

Machine: (machine) untitled

State Machine Type: Classic

Update method: Inherited Sample Time:

□ Enable C-bit operations

□ User specified state/transition execution order

□ Export Chart Level Graphical Functions (Make Global)

☑ Use Strong Data Typing with Simulink I/O

□ Execute (enter) Chart At Initialization

□ Initialize Outputs Every Time Chart Wakes Up

Debugger breakpoint: □ On chart entry □ Lock Editor

Description:

Document Link:

4 Enter properties for the chart based on the following descriptions:

Field	Description
Name	Stateflow diagram name; read-only; click this hypertext link to bring the chart to the foreground.
Machine	Simulink subsystem name; read-only; click this hypertext link to bring the Simulink subsystem to the foreground.
State Machine Type	Type of state machine to create. Choose from: • **Classic**: Default state machine. Provides full set of Stateflow semantics (see Chapter 3, "Stateflow Semantics") . • **Mealy**: State machine in which output is a function of inputs *and* state. • **Moore**: State machine in which output is a function *only* of state. Mealy and Moore charts use a subset of Stateflow semantics. For more information, see Chapter 5, "Building Mealy and Moore Charts in Stateflow".
Update method	Method by which a simulation updates (wakes up) a chart in Simulink. Choose from **Inherited**, **Discrete**, or **Continuous**. For more information, see "Setting the Stateflow Block Update Method" on page 10-15.
Sample Time	If **Update method** is **Sampled**, enter a sample time.

Field	Description
Enable C-bit operations	Select this box to recognize C bitwise operators (~, &, |, ^, >>, and so on) in action language statements and encode them as C bitwise operations. If this box is not selected, the following occurs: • & and | are interpreted as logical operators. • ^ is interpreted as the power operator (for example, 2^3 = 8). • The remaining expressions (>>, <<, and so on) result in parse errors. To specify this interpretation for all charts in the model (machine), select the **Apply to all charts in machine now** button.
User specified state/transition execution order	Select this box to switch to explicit ordering of parallel states and transitions. In this mode, you have complete control of the order in which parallel states are executed and transitions originating from a source are tested for execution. For more information, see “Execution Order for Parallel States” on page 3-27 and “Transition Testing Order” on page 3-11.
Export Chart Level Graphical Functions	Exports graphical functions defined at the chart’s root level. See “Exporting Graphical Functions” on page 6-41 for more information.

Field	Description
Use Strong Data Typing with Simulink I/O	If this option is selected, the Chart block for this chart can accept input signals of any data type supported by Simulink, provided that the type of the input signal matches the type of the corresponding chart input data item (see “Sharing Input and Output Data with Simulink” on page 7-46). If the types do not match, a type mismatch error occurs. If this item is cleared, the chart accepts and outputs only signals of type `double`. In this case, Stateflow converts Simulink input signals to the data types of the corresponding chart input data items. Similarly, Stateflow converts chart output data (see “Sharing Input and Output Data with Simulink” on page 7-46) to type `double` if this option is not selected. For fixed-point data, see the note following this table.
Execute (enter) Chart at Initialization	Select this option if you want a chart’s state configuration to be initialized at time 0 instead of at the first occurrence of an input event (see “Executing a Chart at Initialization” on page 3-7).

Field	Description
Initialize Outputs Every Time Chart Wakes Up	Interprets the initial value of outputs every time a chart wakes up, not only at time 0. When you set an initial value for an output data object, the output will be reset to that value. Outputs are reset whenever a chart is triggered, whether by function call, edge trigger, or clock tick. Enable this option to • Ensure all outputs are defined in every chart execution • Prevent latching of outputs (carrying over values of outputs computed in previous executions) • Give all chart outputs a meaningful initial value
Debugger breakpoint: On chart entry	Select to set a debugging breakpoint on entry to this chart.
Editor: Locked	Select to mark the Stateflow diagram as read-only and prohibit any write operations.
Description	Textual description/comment.
Document Link	Enter a Web URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

Note For fixed-point data, the **Use Strong Data Typing with Simulink I/O** option is always on. Therefore, if an input or output fixed-point data in Stateflow does not match its counterpart data in Simulink, a mismatch error results.

1 Select one of the following buttons:

   - **Apply** to save the changes
   - **Cancel** to cancel any changes since the last apply
   - **OK** to save the changes and close the dialog box
   - **Help** to display the Stateflow online help in an HTML browser window

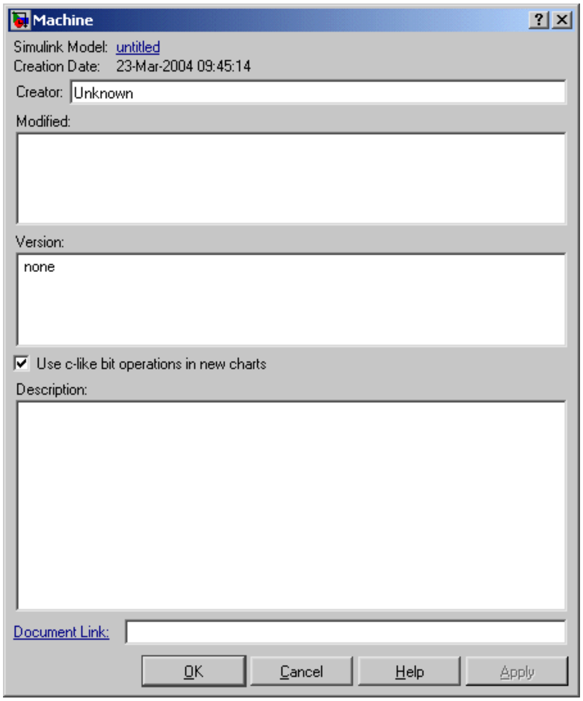
Setting Properties for All Charts in the Model

You can set some properties for all charts in the model by setting properties for the Stateflow machine for a model. The Stateflow machine for a model represents all of the Stateflow blocks in a model.

To set properties for the Stateflow machine, do the following:

1 In the **Chart** properties dialog for a particular Stateflow chart, select the **Machine** link at the top of the dialog.

   The **Machine properties** dialog box appears.



See “Setting Properties for Individual Charts” on page 10-6 for instructions on accessing the **Chart** properties dialog for a Stateflow chart.

2 Enter information in the fields provided as described below.

Field	Description
Simulink Model	Name of the Simulink model that defines this Stateflow machine, which is read-only. You change the model name in Simulink when you save the model under a chosen file name.
Creation Date	Date on which this machine was created.
Creator	Name of the person who created this Stateflow machine.
Modified	Time of the most recent modification of this Stateflow machine.

Field	Description
Version	Version number of this Stateflow machine.
Enable C-like bit operations	If you select this box, all new charts recognize C bitwise operators (~, &, |, ^, >>, and so on) in action language statements and encode these operators as C bitwise operations. You can enable or disable this option for individual charts or all charts in the model in an individual chart's property dialog box. See "Setting Properties for Individual Charts" on page 10-6 for a detailed explanation of this property.
Description	Brief description of this Stateflow machine, which is stored with the model that defines it.
Document Link	MATLAB expression that, when evaluated, displays documentation for this Stateflow machine.

3 Click one of the following:

- **Apply** saves the changes.
- **Cancel** closes the dialog without making any changes.
- **OK** saves the changes and closes the dialog box.
- **Help** displays the Stateflow online help in an HTML browser window.

Setting the Stateflow Block Update Method

Stateflow blocks are Simulink subsystems. Simulink events wake up subsystems for execution. To specify a wakeup method for a chart, set the chart's **Update method** property in the **Chart** dialog for the chart (see "Specifying Chart Properties" on page 10-6). Choose from the following wakeup methods:

- **Inherited**

  This is the default update method. Specifying this method causes input from the Simulink model to determine when the chart wakes up during a simulation.

  If you define input events for the chart, the Stateflow block is explicitly triggered by a signal on its trigger port originating from a connected Simulink block. This trigger input event can be set in the Stateflow Explorer to occur in response to a Simulink signal that is **Rising**, **Falling**, or **Either** (rising and falling), or in response to a **Function Call**. See "Defining Input Events" on page 7-13.

  If you do not define input events, the Stateflow block implicitly inherits triggers from the Simulink model. These implicit events are the sample times (discrete or continuous) of the Simulink signals providing inputs to the chart. If you define data inputs (see "Sharing Input and Output Data with Simulink" on page 7-46), 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 its parent subsystem's execution behavior.

- **Discrete**

  Simulink awakens (samples) the Stateflow block at the rate you specify as the block's **Sample Time** property. An implicit event is generated by Simulink at regular time intervals corresponding to the specified rate. The sample time is in the same units as the Simulink simulation time. Note that other blocks in the Simulink model can have different sample times.

- **Continuous**

  Simulink wakes up (samples) the Stateflow block at each step in the simulation, as well as at intermediate time points that can be requested by the Simulink solver. This method is consistent with the continuous method in Simulink.

See “Interface to External Sources” on page 10-31 for more information.

Implementing Simulink Update Interfaces

Stateflow diagrams execute when they are updated by the Simulink model during simulation. A Stateflow diagram can be updated when it is triggered or sampled by the Simulink model. This section summarizes all the settings necessary for implementing any of the following possible Simulink updates for a Stateflow chart block:

- “Defining a Triggered Stateflow Block” on page 10-17 — Provides an example of a triggered Stateflow block in a Simulink model.
- “Defining a Sampled Stateflow Block” on page 10-18 — Provides an example of a sampled Stateflow block in a Simulink model.
- “Defining an Inherited Stateflow Block” on page 10-19 — Provides an example of a Stateflow block that inherits its sample time in a Simulink model.
- “Defining a Continuous Stateflow Block” on page 10-20 — Provides an example of a continuously sampled Stateflow block in a Simulink model.
- “Defining Function Call Output Events” on page 10-22 — Provides an example of a Stateflow block that triggers a subsystem in a Simulink model with a function call.
- “Defining Edge-Triggered Output Events” on page 10-26 — Provides an example of a Stateflow block that triggers a subsystem in a Simulink model with a signal edge.

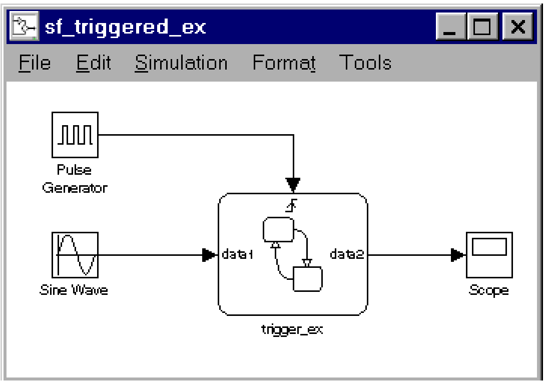
Defining a Triggered Stateflow Block

These are essential conditions that define an edge-triggered Stateflow block:

- The chart **Update method** (set in the **Chart Properties** dialog box) is set to **Triggered or Inherited**. (See “Specifying Chart Properties” on page 10-6.)
- The chart has an **Input from Simulink** event defined and an edge-trigger type specified. (See “Defining Input Events” on page 7-13.)

Triggered Stateflow Block Example

A Pulse Generator block connected to the trigger port of the Stateflow block is an example of an edge-triggered Stateflow block.



The **Input from Simulink** event has a **Rising Edge** trigger type. If more than one **Input from Simulink** event is defined, the sample times are determined by Simulink 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.

Defining a Sampled Stateflow Block

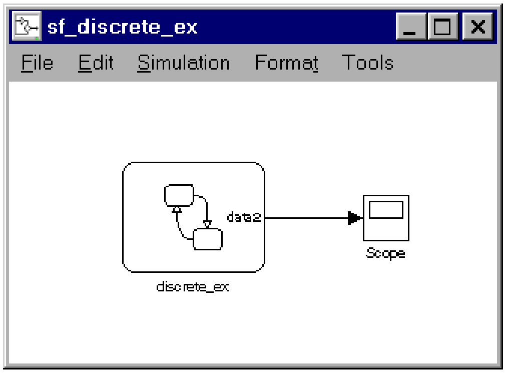
There are two ways you can define a sampled Stateflow block. Setting the chart **Update method** (set in the **Chart Properties** dialog box) to **Sampled** and entering a **Sample Time** value define a sampled Stateflow block. (See "Specifying Chart Properties" on page 10-6.)

Alternatively, you can add and define an **Input from Simulink** data object. Data is added and defined using either the graphics editor **Add** menu or the Explorer. (See "Sharing Input and Output Data with Simulink" on page 7-46.) The chart sample time is determined by Simulink to be consistent with the rate of the incoming data signal.

The **Sample Time** (set in the **Chart Properties** dialog box) takes precedence over the sample time of any **Input from Simulink** data.

Sampled Stateflow Block Example

You specify a discrete sample rate to have Simulink trigger a Stateflow block that is not explicitly triggered via the trigger port. You can specify a **Sample Time** in the Stateflow diagram's **Chart properties** dialog box. The Stateflow block is then called by Simulink at the defined, regular sample times.



The outputs of a sampled Stateflow block are held after the execution of the block.

Defining an Inherited Stateflow Block

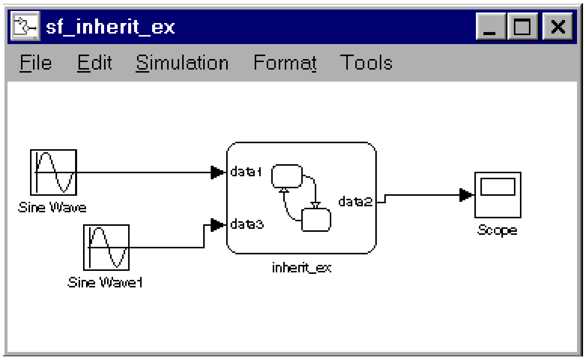
These are essential conditions that define an inherited trigger Stateflow block:

- The chart **Update method** (set in the **Chart Properties** dialog box) is set to **Triggered** or **Inherited**. (See "Specifying Chart Properties" on page 10-6)
- The chart has an **Input from Simulink** data object defined (added and defined using either the graphics editor **Add** menu or the Explorer). (See "Sharing Input and Output Data with Simulink" on page 7-46.) The chart sample time is determined by Simulink to be consistent with the rate of the incoming data signal.

Inherited Stateflow Block Example

Simulink can trigger a Stateflow block that is not explicitly triggered by a trigger port or a specified discrete sample time. In this case, the Stateflow block is called by Simulink at a sample time determined by Simulink.

In this example, more than one **Input from Simulink** data object is defined. The sample times are determined by Simulink 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.

Defining a Continuous Stateflow Block

To define a continuous Stateflow block, set the chart **Update method** in the **Chart** dialog to **Continuous**. See “Specifying Chart Properties” on page 10-6.

Considerations in Choosing Continuous Update

The availability of intermediate data makes it possible for the solver to back up in time to precisely locate a zero crossing. Refer to the Using Simulink documentation for further information on zero crossings. Use of the intermediate time point information can provide increased simulation accuracy.

To support the **Continuous** update method, Stateflow keeps an extra copy of all its data.

In most cases, including continuous-time simulations, the **Inherited** method provides consistent results. The timing of state and output changes of the Stateflow block is entirely consistent with that of the continuous plant model.

There are situations, such as the following, when changes within the Stateflow block must be felt immediately by the plant and a **Continuous** update is needed:

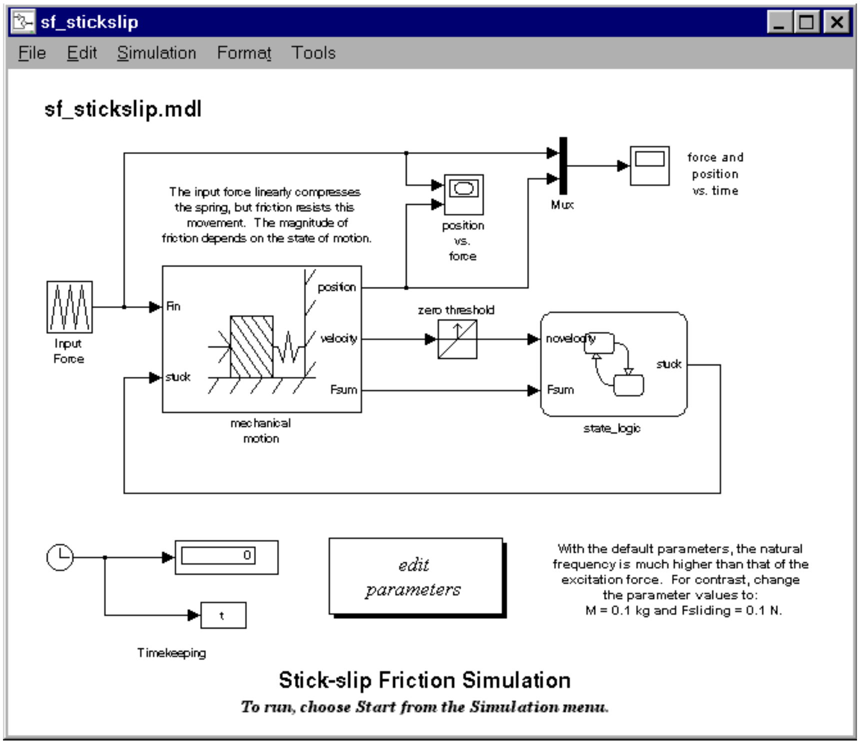
- Data output to Simulink that is a direct function of data input from Simulink and then updated by the Stateflow diagram (state **during** actions in particular)
- Models in which Stateflow states correspond to intrinsic physical states, such as the onset of static friction or the polarity of a magnetic domain

  These states are in contrast to states that are assigned, for example, as modes of control strategy.

Continuous Stateflow Block Example

Simulink awakens (samples) the Stateflow block at each step in the simulation, as well as at intermediate time points that might be requested by the Simulink solver. This method is consistent with the continuous method in Simulink.

In the following example (provided in the Examples/Stick-Slip Friction Demonstration block), the chart **Update method** (set in the **Chart Properties** dialog box) is set to **Continuous**.



The input force linearly compresses the spring, but friction resists this movement. The magnitude of friction depends on the state of motion.

With the default parameters, the natural frequency is much higher than that of the excitation force. For contrast, change the parameter values to: M = 0.1 kg and Fsliding = 0.1 N.

Stick-slip Friction Simulation

To run, choose Start from the Simulation menu.

Defining Function Call Output Events

This topic shows you how to trigger a function-call subsystem in Simulink with a Function Call output event in a Stateflow diagram. It assumes that you already have in place a programmed function-call subsystem and a Stateflow block in the Simulink model. Use the following steps to connect the Stateflow block to the function-call subsystem and trigger it during simulation.

1 In the Stateflow diagram editor, from the **Add** menu, select **Event**.

   A pop-up menu of different event scopes appears.

2 From the pop-up menu select **Output to Simulink.**

   The **Event** dialog appears with a default name of `event` and a **Scope** of **Output to Simulink**.

3 In the **Event** dialog, in the **Trigger** field, select **Function Call**.

4 Name the event appropriately and select **OK** to close the dialog.

An output port with the name of the event you add appears on the right side of the Stateflow block.

5 From the Simulink library browser **Ports & Subsystems** library, place a function-call subsystem in the Simulink model.

You can also create a function-call subsystem by adding a subsystem to the model and adding a Trigger port to the subsystem. In the **Triggerport parameters** dialog for the Trigger block, set the **Trigger type** field to **function-call**.

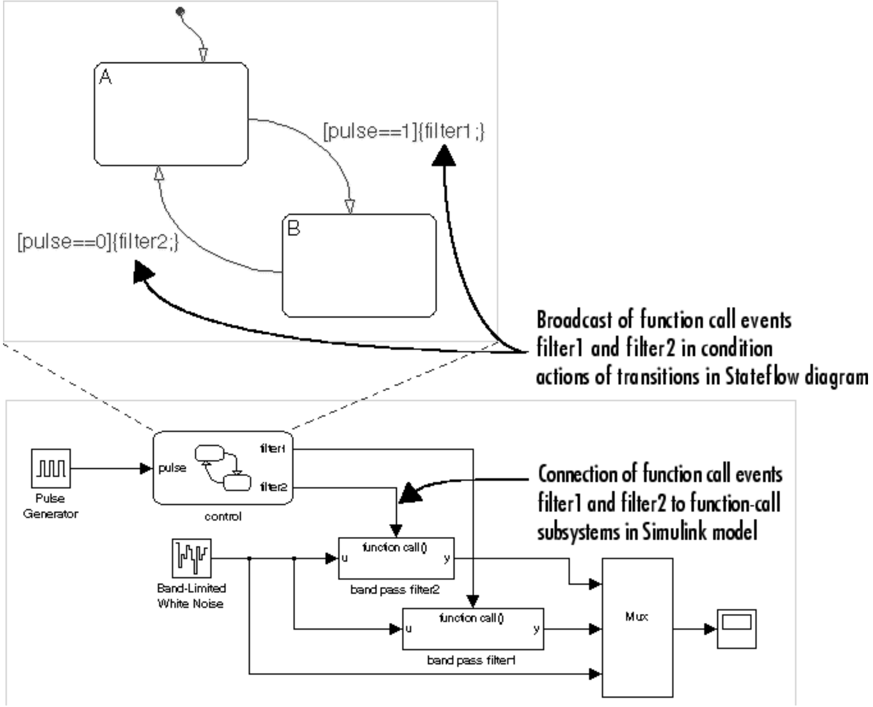
6 Connect the output port on the Stateflow block for the **Function Call** trigger **Output to Simulink** event you add to the function-call trigger input port of the subsystem.

You should avoid placing any other blocks in the connection lines between the Stateflow block and the function-call subsystem for Stateflow blocks that have feedback loops from a block triggered by a function call event.

Note You cannot connect a function-call output event from Stateflow to a Simulink Demux block in order to trigger multiple subsystems.

7 To execute the function-call subsystem, include an event broadcast of the function call output event in the actions of the Stateflow diagram as shown in the following example.

Function Call Output Events Example

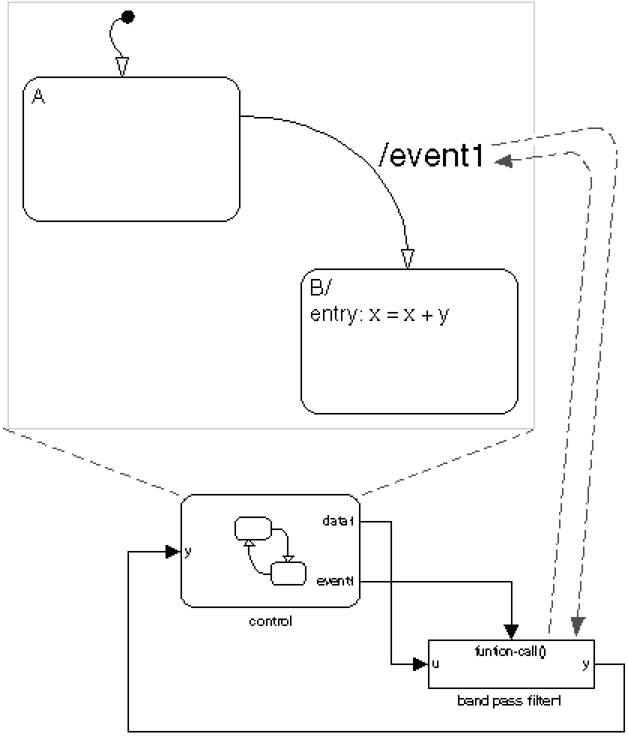

A
[pulse==1]{filter1;}
B
[pulse==0]{filter2;}
Broadcast of function call events filter1 and filter2 in condition actions of transitions in Stateflow diagram
Pulse Generator
pulse
filter1
filter2
control
Connection of function call events filter1 and filter2 to function-call subsystems in Simulink model
Band-Limited White Noise
function call()
u
y
band pass filter2
function call()
u
y
band pass filter1
Mux

The control Stateflow block has one data input called `pulse` and two function call output events called `filter1` and `filter2`. A pulse generator provides input data to the control block. Each function call output event is attached to a subsystem in the Simulink model that is set to trigger by a function call.

Each transition in the control chart has a condition based on the size of the input pulse. When taken, each transition broadcasts a function call output event that determines whether to make a function call to `filter1` or `filter2`. If the **Output to Simulink** function call event `filter1` is broadcast, the `band pass filter1` subsystem executes. If the **Output to Simulink** function call event `filter2` is broadcast, the `band pass filter2` subsystem executes. When either of these subsystems is finished executing, control is returned to the control Stateflow block for the next execution step. In this way, the Stateflow block controls the execution of `band pass filter1` and `band pass filter2`.

Function Call Semantics Example

In this example the transition from state A to state B (in the Stateflow diagram) has a transition action that specifies the broadcast of `event1`. `event1` is defined in Stateflow to be an **Output to Simulink** with a **Function Call** trigger type. The Stateflow block output port for `event1` is connected to the trigger port of the `band pass filter1` Simulink block. The `band pass filter1` block has its **Trigger type** field set to **Function Call**.



This sequence is followed when state A is active and the transition from state A to state B is valid and is taken:

1. State A exit actions execute and complete.

2. State A is marked inactive.

3. The transition action is executed and completed.

In this case the transition action is a broadcast of `event1`. Because `event1` is an event output to Simulink with a function call trigger, the `band pass filter1` block executes and completes, and then returns to the next statement in the execution sequence. The value of `y` is fed back to the Stateflow diagram.

4. State `B` is marked active.

5. State `B` entry actions execute and complete (`x = x + y`). The value of `y` is the updated value from the `band pass filter1` block.

6. The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

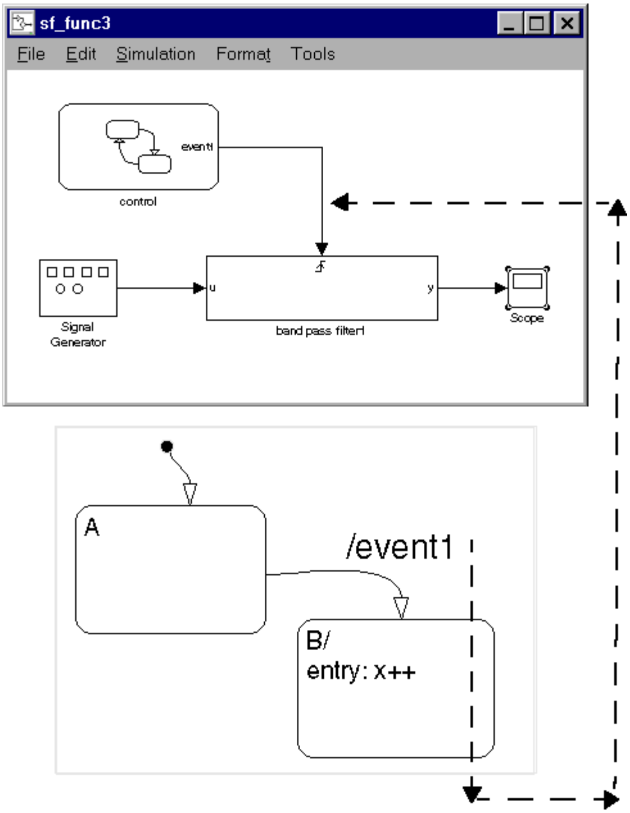
Defining Edge-Triggered Output Events

Simulink controls the execution of edge-triggered subsystems with output events. These are essential conditions that define this use of triggered output events:

- The chart has an **Output to Simulink** event with the trigger type **Either Edge**. See “Defining Output Events” on page 7-14.
- The Simulink block connected to the edge-triggered **Output to Simulink** event has its own trigger type set to the equivalent edge triggering.

Edge-Triggered Semantics Example

In this example the transition from state `A` to state `B` (in the Stateflow diagram) has a transition action that specifies the broadcast of `event1`. `event1` is defined in Stateflow to be an **Output to Simulink** with an **Either edge** trigger type. The Stateflow block output port for `event1` is connected to the trigger port of the `band pass filter1` Simulink block. The `band pass filter1` block has its **Trigger type** field set to **Either edge**.



This sequence is followed when state A is active and the transition from state A to state B is valid and is taken:

1 State A exit actions execute and complete.

2 State A is marked inactive.

3 The transition action, an edge-triggered **Output to Simulink** event broadcast, is registered (but not executed). Simulink is controlling the execution and execution control does not shift until the Stateflow block completes.

4 State B is marked active.

5. State `B` entry actions execute and complete (`x = x++`).

6. The Stateflow diagram goes back to sleep, waiting to be awakened by another event.

7. The `band pass filter1` block is triggered, executes, and completes.

Creating Chart Libraries

A Stateflow chart library is a Simulink block library that contains Stateflow Chart blocks (and, optionally, other types of Simulink blocks as well). Just as Simulink libraries serve as repositories of commonly used blocks, chart libraries serve as repositories of commonly used charts.

You create a chart library in the same way you create other types of Simulink libraries. First, create an empty chart library by selecting **Library** from the **New** submenu of Simulink's **File** menu. Then create or copy Chart blocks into the library just as you would create or copy Chart blocks into a Stateflow model.

You use chart libraries in the same way you use other types of Simulink libraries. To include a chart from a library in your Stateflow model, copy or drag the chart from the library to the model. Simulink creates a link from the instance in your model to the instance in the library. This allows you to update all instances of the chart simply by updating the library instance.

Note Events parented by a library Stateflow machine are invalid. Stateflow allows you to define such events but flags them as errors when parsing a model.

MATLAB Workspace Interfaces

The MATLAB workspace is an area of memory normally accessible from the MATLAB command line. It maintains a set of variables built up during a MATLAB session.

Examining the MATLAB Workspace in MATLAB

Two commands, `who` and `whos`, show the current contents of the workspace. The `who` command gives a short list, while `whos` also gives size and storage information.

To delete all the existing variables from the workspace, enter `clear` at the MATLAB command line.

See the MATLAB online or printed documentation for more information.

Interfacing the MATLAB Workspace in Stateflow

Stateflow charts have the following access to the MATLAB workspace:

- You can access MATLAB data or MATLAB functions in Stateflow action language with the `ml` namespace operator or the `ml` function.

  See “Using MATLAB Functions and Data in Actions” on page 8-29 for more information.

- You can use the MATLAB workspace to initialize chart data at the beginning of a simulation.

  See “Entering Expressions and Parameters for Data Properties” on page 7-42.

- You can save chart data to the workspace at the end of a simulation.

  See “Save final value to base workspace” on page 7-40 for more information.

Interface to External Sources

Any source of data, events, or code that is outside a Stateflow diagram, its Stateflow machine, or its Simulink model, is considered external to that Stateflow diagram. Stateflow can interface data and events from external sources to your Stateflow chart, as described in the following topics:

- "Exported Events" on page 10-31 — Describes events that a Stateflow chart exports to locations outside itself.
- "Imported Events" on page 10-33 — Describes events that a Stateflow chart imports from locations outside itself.
- "Exported Data" on page 10-35 — Describes data that a Stateflow chart exports to locations outside itself.
- "Imported Data" on page 10-36 — Describes data that a Stateflow chart imports from locations outside itself.

See Chapter 7, "Defining Events and Data" for information on defining events and data.

You can include external source code in the **Target Options** section of the **Target Builder** dialog box. (See "Integrating Custom Code with Stateflow Targets" on page 14-27.)

Exported Events

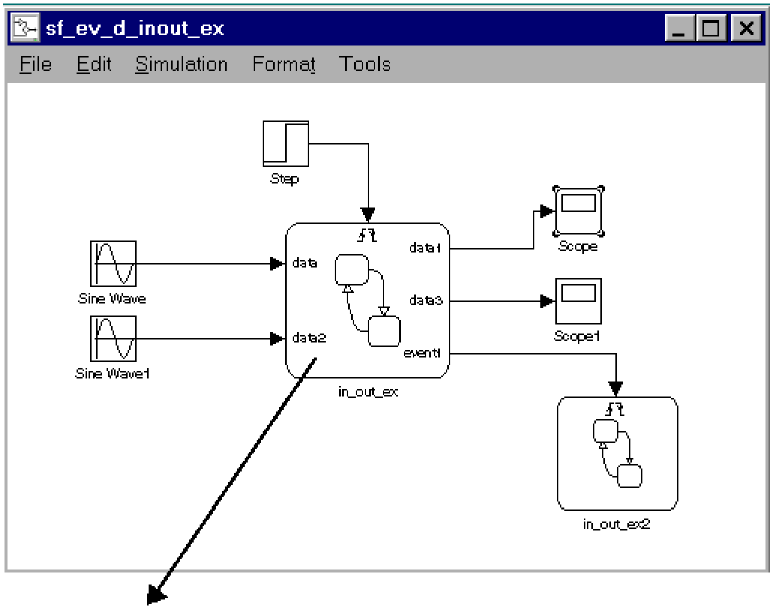
You might want an external source (outside the Stateflow diagram, its Stateflow machine, and its Simulink model) to be able to broadcast an event. By defining an event's scope to be **Exported**, you make that event available to external sources for broadcast purposes. Exported events must be parented by the Stateflow machine, because the machine has the highest level in the Stateflow hierarchy and can interface to external sources. The Stateflow machine also retains the ability to broadcast the exported event. Exporting the event does not imply anything about what the external source does with the information. It is the responsibility of the external source to include the **Exported** event (in the manner appropriate to the source) to make use of the right to broadcast the event.

If the external source for the event is another Stateflow machine, then that machine must define the event as an **Exported** event and the other machine must define the same event as **Imported**. Stateflow generates the appropriate export and import event code for both machines.

Consider a real-world example to clarify when to define an **Exported** event. You have purchased a communications pager. There are a few people you want to be able to page you, so you give those people your personal pager number. These people now know your pager number and can call that number and page you at any time. You do not usually page yourself, but you can do so. Telling someone the pager number does not mean they have heard and recorded the number. It is the other person's responsibility to retain the number.

Exported Event Example

This example shows the format required in the external code source (custom code) to take advantage of an **Exported** event generated in Stateflow.



e is added and defined as an Exported event. Stateflow generates the following code for the Exported event:

```
void broadcast_e (void)
{
/* code based on
   event definition
*/
 } ...
```

e is imported in the external code source.

External code source

```
void func_example(void)
{
extern void broadcast_e (void);
 ...
external_broadcast_e();
 ...
 }
```

Imported Events

You might want to broadcast an event that is defined externally (outside the Stateflow diagram, its Stateflow machine, and its Simulink model). By defining an event's scope to be **Imported**, you can broadcast the event anywhere within the hierarchy of that machine (including any offspring of the machine).

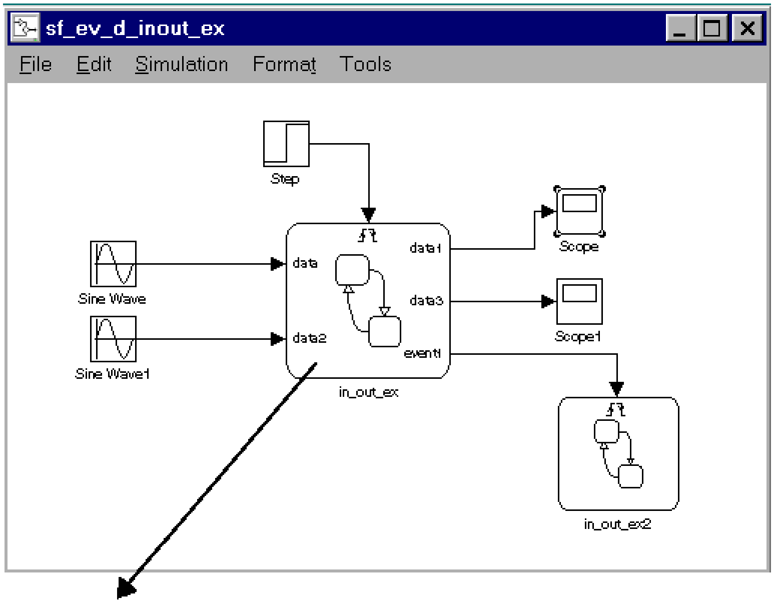
An imported event's parent is external. However, the event needs an adoptive parent to resolve symbols for code generation. An imported event's adoptive parent must be the Stateflow machine, because the machine has the highest level in the Stateflow hierarchy and can interface to external sources. It is the responsibility of the external source to make the imported event available (in the manner appropriate to the source).

If the external source is another Stateflow machine, the source machine must define the same event as **Exported**. Stateflow generates the appropriate import and export event code for both machines.

The preceding pager example for exported events can clarify the use of imported events. For example, someone buys a pager and tells you that you might want to use this number to page them in the future and they give you the pager number to record. You can then use that number to page that person.

Imported Event Example

The following example shows the format required in an external code source (custom code) to generate an **Imported** event in Stateflow.



e is added and defined as an Imported event.

Stateflow generates the following code for the Imported event:

```
extern void broadcast_e (void);
```

e is exported in the external code source.

External code source

```
void broadcast_e (void)
{
 ...
 }
```

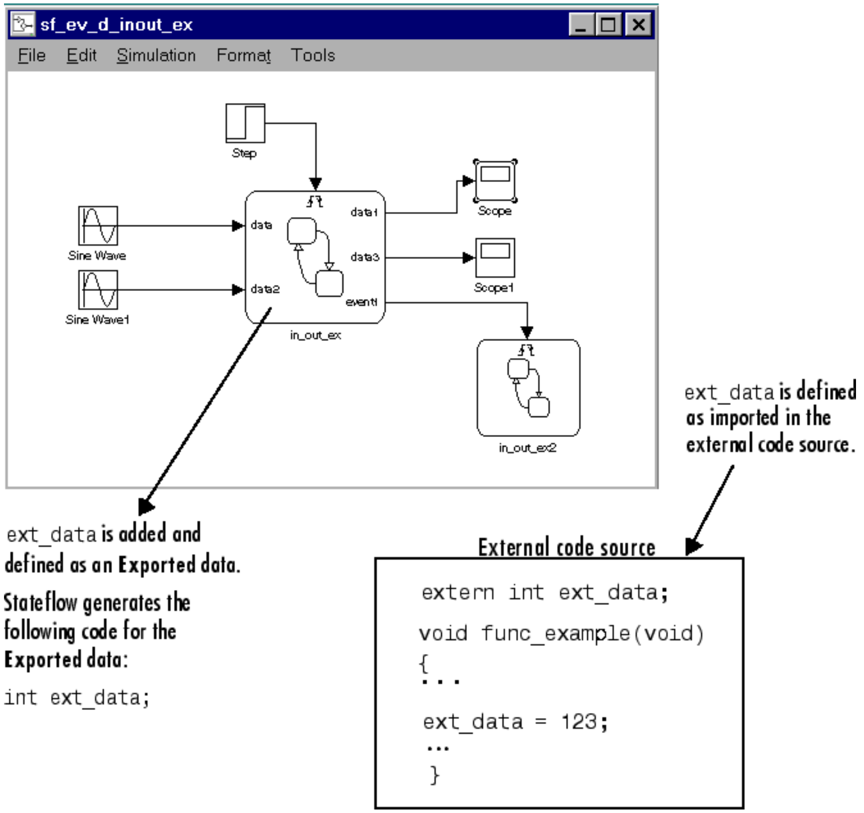
Exported Data

You might want an external source (outside the Stateflow diagram, its Stateflow machine, and its Simulink model) to be able to access a data object. By defining a data object's scope as **Exported**, you make it accessible to external sources. Exported data must be parented by the Stateflow machine, because the machine has the highest level in the Stateflow hierarchy and can interface to external sources. The Stateflow machine also retains the ability to access the exported data object. Exporting the data object does not imply anything about what the external source does with the data. It is the responsibility of the external source to include the exported data object (in the manner appropriate to the source) to make use of the right to access the data.

If the external source is another Stateflow machine, then that machine defines an exported data object and the other machine defines the same data object as imported. Stateflow generates the appropriate export and import data code for both machines.

Exported Data Example

The following example shows the format required in the external code source (custom code) to import a Stateflow exported data object:



ext_data is defined as imported in the external code source.

ext_data is added and defined as an Exported data.

Stateflow generates the following code for the Exported data:

```
int ext_data;
```

External code source

```
extern int ext_data;
void func_example(void)
{
. . .
ext_data = 123;
...
 }
```

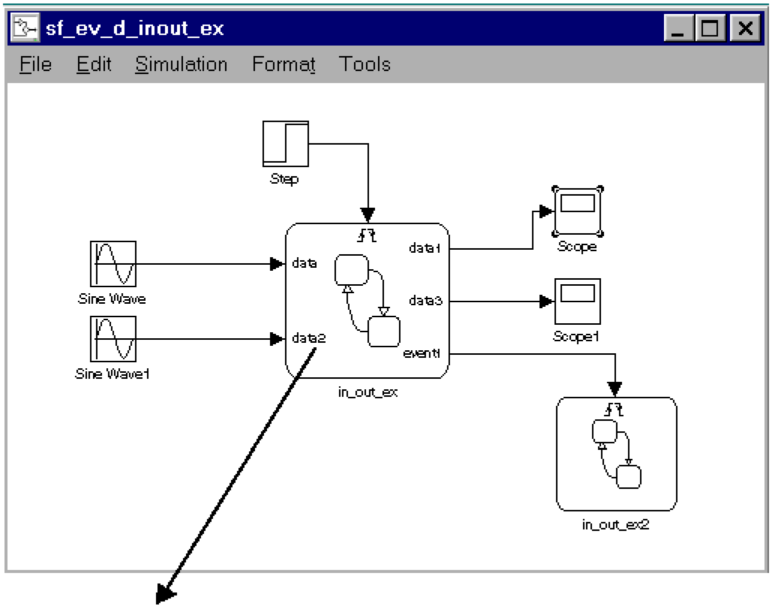
Imported Data

Similarly, you might want to access a data object that is externally defined outside the Stateflow diagram, its Stateflow machine, and its Simulink model. If you define the data's scope as **Imported**, the data can be accessed anywhere within the hierarchy of the Stateflow machine (including any offspring of the machine). An imported data object's parent is external. However, the data object needs an adoptive parent to resolve symbols for code generation. An imported data object's adoptive parent must be the Stateflow machine, because the machine has the highest level in the Stateflow hierarchy and can interface to external sources. It is the responsibility of the external source to make the imported data object available (in the manner appropriate to the source).

If the external source for the data is another Stateflow machine, that machine must define the same data object as **Exported**. Stateflow generates the appropriate import and export data code for both machines.

Imported Data Example

This example shows the format required to retrieve imported data from an external code source (custom code).



`ext_data` is added and defined as an imported data Stateflow generates the following code for the imported data:

```
extern int ext_data;
```

`ext_data` is defined as exported in the external code source.

External code source

```
int ext_data;
void func_example(void)
{
 ...
}
```

Working with Structures and Bus Signals in Stateflow

Stateflow provides a structure data type that you can use to interface Stateflow charts and truth tables with Simulink bus signals, and to define local and temporary structures.

About Stateflow Structures

The Stateflow structure is a data type that you define as a `Simulink.Bus` object. This section describes the elements and uses of the Stateflow structure.

- “Elements of Stateflow Structures” on page 11-2
- “What You Can Do with Structures” on page 11-2
- “Example of Stateflow Structures” on page 11-3

Elements of Stateflow Structures

The elements of the Stateflow structure data type are called fields. They can be any combination of

- Individual signals of mixed data types
- Composite signals, such as muxed signals or buses

To be consistent with Simulink, there are restrictions on the use of Stateflow structures with arrays:

- Stateflow structures cannot contain arrays of buses.
- Stateflow data array objects cannot contain structures.

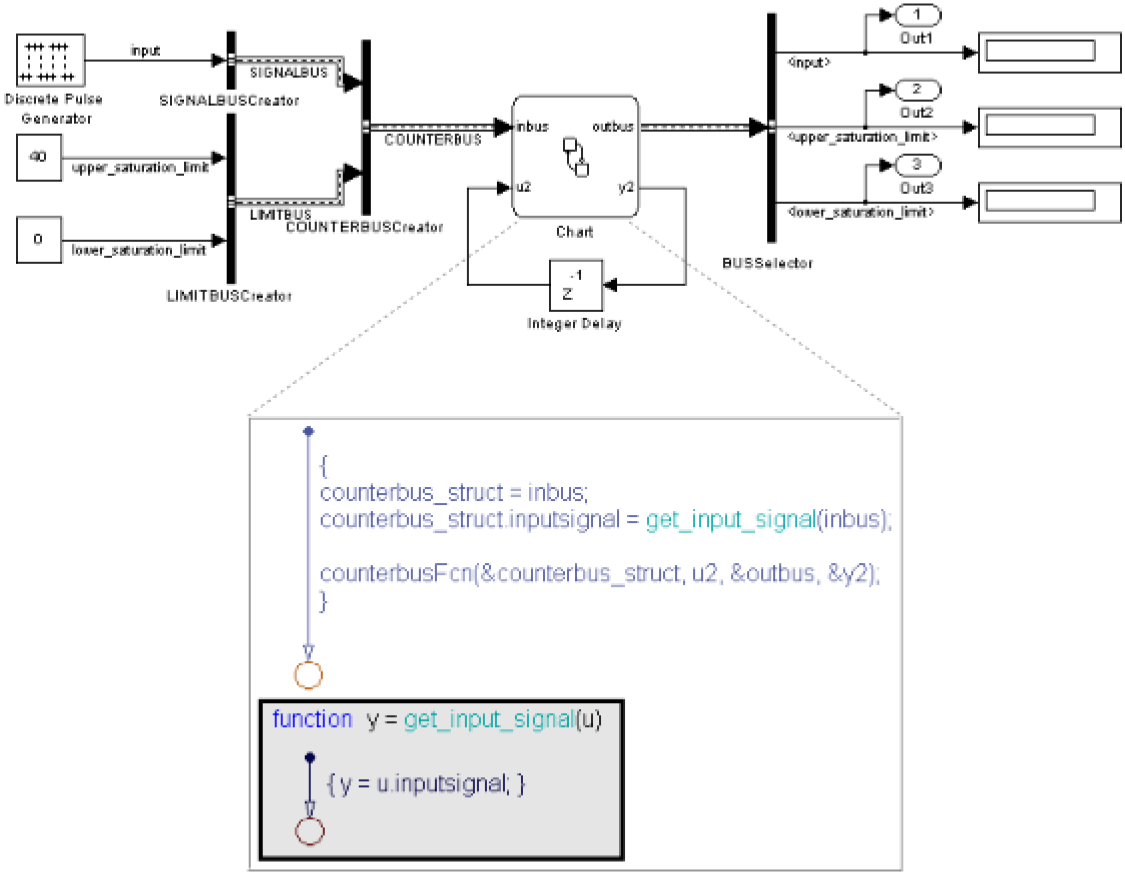
What You Can Do with Structures

With the Stateflow structure data type, you can create

- Inputs and outputs for accessing Simulink bus signals from Stateflow charts, Truth Table blocks, and Embedded MATLAB function blocks (see “Defining Structure Inputs and Outputs” on page 11-7)
- Local structure data in Stateflow charts, truth tables, graphical functions, Embedded MATLAB functions, and boxes (see “Defining Local Structures” on page 11-12)
- Temporary structure data in Stateflow graphical functions, truth tables, and Embedded MATLAB functions (see “Defining Temporary Structures” on page 11-14)

Example of Stateflow Structures

The model sfbus_demo provides examples of structures in a Stateflow chart and graphical function, as follows:



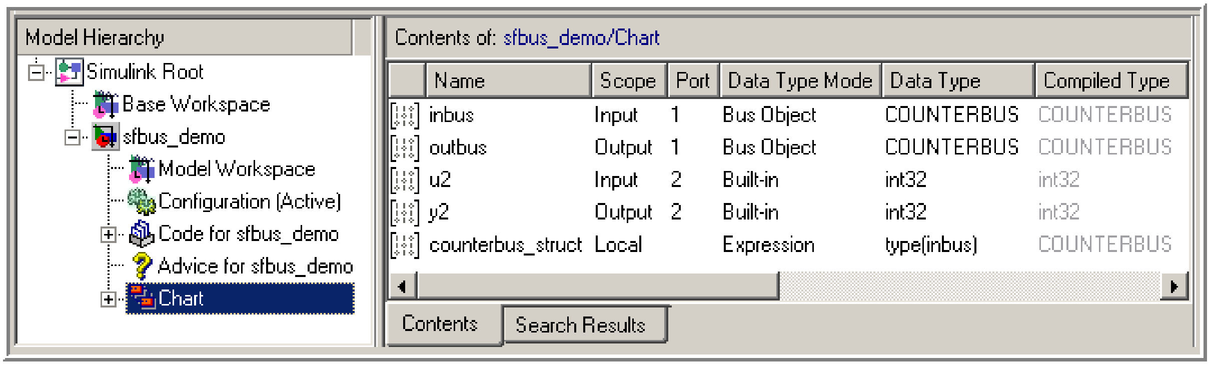
```
{
counterbus_struct = inbus;
counterbus_struct.inputsignal = get_input_signal(inbus);

counterbusFcn(&counterbus_struct, u2, &outbus, &y2);
}
```

```
function  y = get_input_signal(u)

{ y = u.inputsignal; }
```

In this model, the Stateflow chart receives a bus input signal using the structure `inbus` at input port 1 and outputs a bus signal from the structure `outbus` at output port 1. The input signal comes from the Simulink Bus Creator block `COUNTERBUSCreator`, which bundles signals from two other Bus Creator blocks: `SIGNALBUSCreator` and `LIMITBUSCreator`. The structure `outbus` connects to a Simulink Bus Selector block `BUSSelector`. The Stateflow chart also contains a local structure `counterbus_struct` and a graphical function `get_input_signal` that contains an input structure `u` and output structure `y`.

Structure Definitions in sfbus_demo Stateflow Chart

Here are the definitions of the structures in the Stateflow chart of the `sfbus_demo` model, as they appear in the Model Explorer:



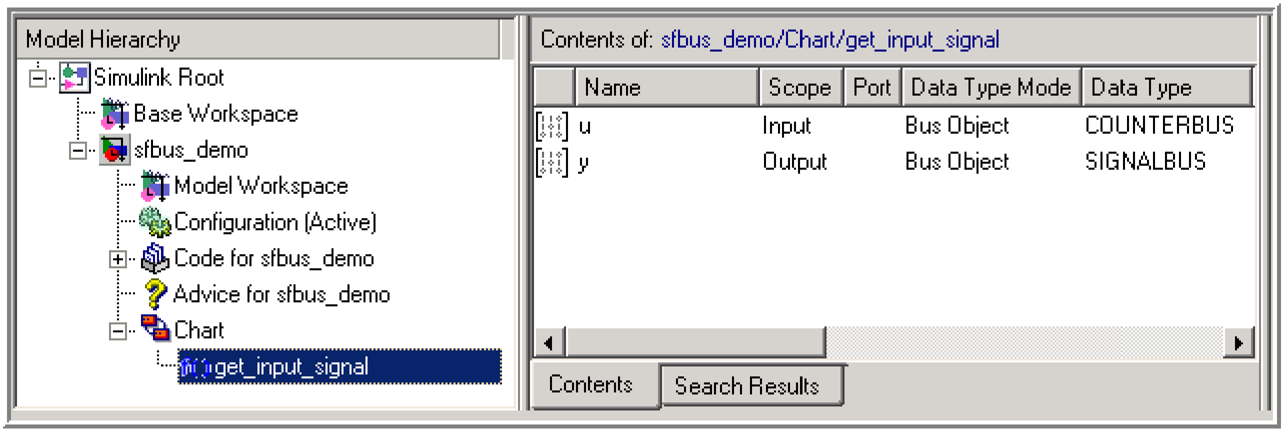
Contents of: sfbus_demo/Chart

Name	Scope	Port	Data Type Mode	Data Type	Compiled Type
inbus	Input	1	Bus Object	COUNTERBUS	COUNTERBUS
outbus	Output	1	Bus Object	COUNTERBUS	COUNTERBUS
u2	Input	2	Built-in	int32	int32
y2	Output	2	Built-in	int32	int32
counterbus_struct	Local		Expression	type(inbus)	COUNTERBUS

Note The local structure `counterbus_struct` is defined using the `type` operator in an expression, as described in "Defining Structure Types with Expressions" on page 11-15.

Structure Definitions in sfbus_demo Stateflow Graphical Function

Here are the definitions of the structures in the graphical function `get_input_signal` as they appear in the Model Explorer:

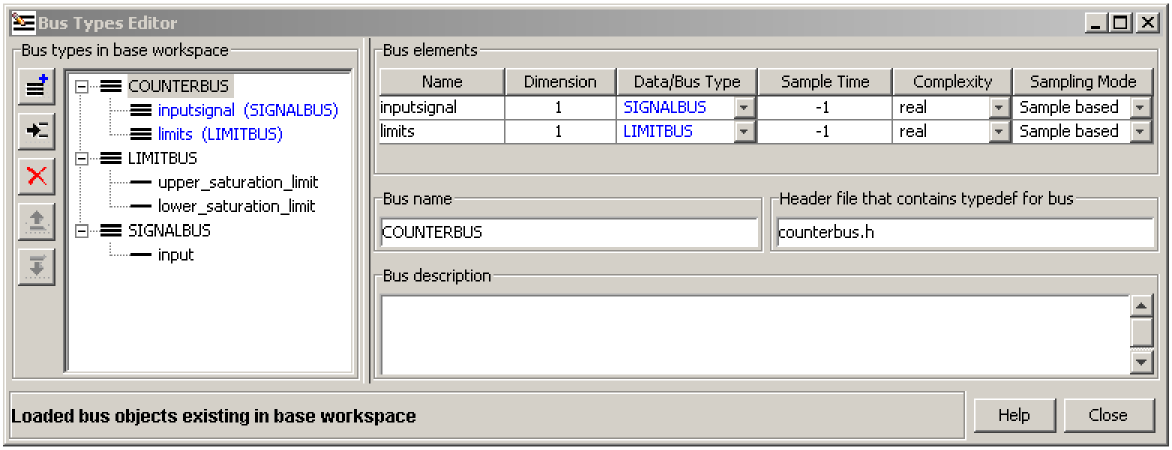


Contents of: sfbus_demo/Chart/get_input_signal

Name	Scope	Port	Data Type Mode	Data Type
u	Input		Bus Object	COUNTERBUS
y	Output		Bus Object	SIGNALBUS

Simulink Bus Objects Define Stateflow Structures

Each Stateflow structure must be defined by a `Simulink.Bus` object in the base workspace. This means that the structure shares the same properties as the bus object, including number, name, and type of fields. For example, the `sfbus_demo` model defines the following bus objects in the base workspace:



Bus elements

Name	Dimension	Data/Bus Type	Sample Time	Complexity	Sampling Mode
inputsignal	1	SIGNALBUS	-1	real	Sample based
limits	1	LIMITBUS	-1	real	Sample based

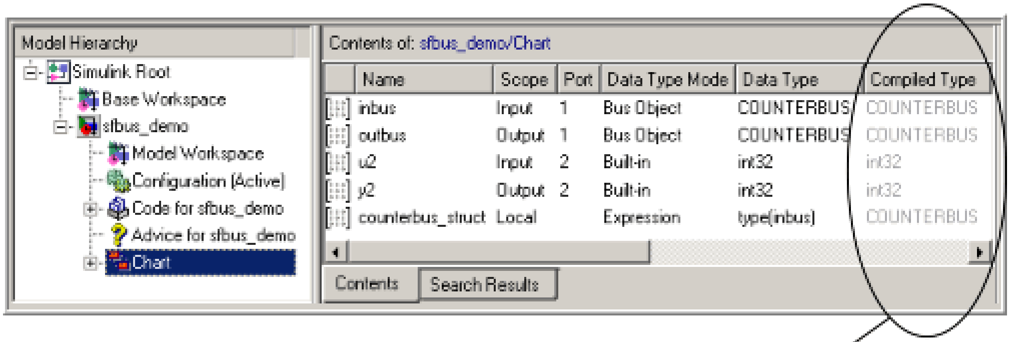
Bus name: COUNTERBUS

Header file that contains typedef for bus: counterbus.h

Bus description:

Loaded bus objects existing in base workspace

You can find the bus object that defines a Stateflow structure by looking in the Data Type and Compiled Type columns in the Contents pane of the Model Explorer. For example, the structures `inbus`, `outbus`, and `counterbus_struct` are all defined in `sfbus_demo` by the same Simulink bus object, `COUNTERBUS`, as shown in this view of the Model Explorer:



Contents of: sfbus_demo/Chart

Name	Scope	Port	Data Type Mode	Data Type	Compiled Type
inbus	Input	1	Bus Object	COUNTERBUS	COUNTERBUS
outbus	Output	1	Bus Object	COUNTERBUS	COUNTERBUS
u2	Input	2	Built-in	int32	int32
y2	Output	2	Built-in	int32	int32
counterbus_struct	Local		Expression	type(inbus)	COUNTERBUS

Simulink.Bus object COUNTERBUS defines the properties of structures inbus, outbus, and counterbus_struct

Based on these definitions, `inbus`, `outbus`, and `counterbus_struct` have the same properties as `COUNTERBUS`. For example, these Stateflow structures in `sfbus_demo` reference their fields by the same names as the elements in `COUNTERBUS`, as follows:

Structure	First Field	Second Field
`inbus`	`inbus.inputsignal`	`inbus.limits`
`outbus`	`outbus.inputsignal`	`outbus.limits`
`counterbus_struct`	`counterbus_struct.inputsignal`	`counterbus_struct.limits`

To learn how to define structures in Stateflow using `Simulink.Bus` objects, see “Defining Structures in Stateflow” on page 11-7.

If you define a custom structure in C for your Stateflow chart, you must make sure that the structure’s `typedef` declaration in your header file matches the properties of the `Simulink.Bus` object that defines the structure, as described in “Integrating Custom Structures in Stateflow” on page 11-22.

Defining Structures in Stateflow

This section explains how to define structures in Stateflow.

- “Rules for Defining Structure Data Types in Stateflow” on page 11-7
- “Defining Structure Inputs and Outputs” on page 11-7
- “Defining Local Structures” on page 11-12
- “Defining Temporary Structures” on page 11-14
- “Defining Structure Types with Expressions” on page 11-15

Rules for Defining Structure Data Types in Stateflow

Follow these rules when defining structures in Stateflow:

- You must define each structure used in Stateflow as a `Simulink.Bus` object in the base workspace.
- You cannot define structures for Stateflow machines.

Note The *Stateflow machine* is the object that contains all other Stateflow objects in a Simulink model (see “Stateflow Hierarchy of Objects” on page 1-21).

- Stateflow structures cannot have scopes defined as Constant, Parameter, or Data Store Memory.

Defining Structure Inputs and Outputs

This section describes how to define structure inputs and outputs in Stateflow that you can connect to Simulink bus signals.

- “Interfacing Stateflow Structures with Simulink Bus Signals” on page 11-8
- “Working with Virtual and Nonvirtual Buses” on page 11-12

Interfacing Stateflow Structures with Simulink Bus Signals

Stateflow structure inputs can be driven by any Simulink bus signal that has matching properties. Similarly, Stateflow can output structures to Simulink blocks that accept bus signals. To create inputs and outputs in Stateflow, follow these steps:

1. Create a Simulink bus object in the base workspace to define the structure type for your Stateflow chart.

   For information about how to create Simulink bus objects, see `Simulink.Bus` in the Simulink Reference documentation.

2. Open the Model Explorer and perform these tasks:

   a. Add a data object, as described in “Using the Model Explorer to Create Data Objects” in the Simulink User’s Guide.

   b. Double-click the data object to open its properties dialog box and enter the following information in the General tab fields:

      - **Name** — Name of the structure data.
      - **Scope** — Select **Input** or **Output**.
      - **Data type mode** — Select **Inherited**, **Bus Object**, or **Expression** according to these guidelines:

Data Type Mode	Works with Scope	Requirements
Inherited	**Input**	If the data type mode is **Inherited**: – There must be a Simulink bus signal in your model that connects to the Stateflow structure input. – The Simulink bus signal must be a nonvirtual bus (see "Working with Virtual and Nonvirtual Buses" on page 11-12). – You must specify a `Simulink.Bus` object in the base workspace with the same properties as the bus signal in your model that connects to the Stateflow structure input. The following properties must match: Number, name, and type of inputs Dimension Sample Time Complexity Sampling Mode – If your input signal comes from a Bus Creator block, you must check the option **Specify properties via bus object** in the Bus Creator properties dialog box. When you enable this option, Simulink verifies that the properties of the `Simulink.Bus` object in the base workspace match the properties of the Simulink bus signal.

Data Type Mode	Works with Scope	Requirements
Bus Object	**Input** or **Output**	If the data type mode is **Bus Object**, you must specify a `Simulink.Bus` object in the base workspace to define the Stateflow structure input or output. **Note** You are not required to specify a bus signal in your Simulink model that connects to the Stateflow structure input or output. However, if you do specify a bus signal, its properties must match the `Simulink.Bus` object that defines the Stateflow structure input or output.
Expression	**Input** or **Output**	If the data type mode is **Expression**, you must derive the data type from an existing structure in your Stateflow chart.

- Additional fields — Depending on the data type mode that you select, you may need to enter information in additional fields in the Data properties dialog box, as follows:

Field	When it Appears	What to Specify
Bus object	When you select **Bus Object** as the data type mode	Enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.
Data type	When you select **Expression** as the data type mode	Enter an expression according to these guidelines: – For structure inputs, you can use the Stateflow`type` operator to assign the type of your structure based on the type of another structure defined in the Stateflow chart, as described in "Defining Structure Types with Expressions" on page 11-15 **Note** You cannot use the `type` operator for structure outputs (structures of scope **Output**) – For structure inputs or outputs, you can enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.

c Click **Apply**.

Working with Virtual and Nonvirtual Buses

Simulink supports virtual and nonvirtual buses. Virtual buses read their inputs from noncontiguous memory, while nonvirtual buses read their inputs from data structures stored in contiguous memory (see "Virtual and Nonvirtual Buses" in the Simulink User's Guide).

Stateflow supports nonvirtual buses only. When Simulink builds models that contain Stateflow structure inputs and outputs, it uses a hidden converter block to convert bus signals for use with Stateflow, as follows:

- Converts incoming virtual bus signals to nonvirtual buses for Stateflow structure inputs
- Converts outgoing nonvirtual bus signals from Stateflow to virtual bus signals, if necessary

Even though this conversion process allows Stateflow to accept virtual and nonvirtual buses as input, Stateflow structures cannot inherit properties from virtual bus input signals. If the input to Stateflow is a virtual bus, you must set the data type mode of the Stateflow bus input to **Bus Object**, as described in "Interfacing Stateflow Structures with Simulink Bus Signals" on page 11-8.

Defining Local Structures

To define local structures in Stateflow, follow these steps:

1. Create a Simulink bus object in the base workspace to define the structure type for your Stateflow chart.

   For information about how to create Simulink bus objects, see `Simulink.Bus` in the Simulink Reference.

2. Open the Model Explorer and perform these tasks:

   a. Add a data object, as described in "Using the Model Explorer to Create Data Objects" in the Simulink User's Guide.

   b. Double-click the data object to open its properties dialog box and enter the following information in the General tab fields:

Field	What to Specify
Name	Enter a name for the structure data.
Scope	Select **Local**.
Data type mode	Select **Bus Object** or **Expression**.

c Additional fields — Depending on the data type mode that you select, you may need to enter information in additional fields in the Data properties dialog box, as follows:

Field	When it Appears	What to Specify
Bus object	When you select **Bus Object** as the data type mode	Enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.
Data type	When you select **Expression** as the data type mode	Enter any of the following expressions: • Use the Stateflow`type` operator to assign the type of your structure based on the type of another structure defined in the Stateflow chart, as described in "Defining Structure Types with Expressions" on page 11-15 • Enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.

d Click **Apply**.

Defining Temporary Structures

You can define temporary structures in Stateflow truth tables, graphical functions, and Embedded MATLAB functions. Follow these steps:

1. Create a Simulink bus object in the base workspace to define the structure type for your Stateflow chart.

   For information about how to create Simulink bus objects, see `Simulink.Bus` in the Simulink Reference.

2. Open the Model Explorer and perform these tasks:

   a. Add a data object, as described in "Using the Model Explorer to Create Data Objects" in the Simulink User's Guide.

   b. Double-click the data object to open its properties dialog box and enter the following information in the General tab fields:

Field	What to Specify
Name	Enter a name for the structure data.
Scope	Select **Temporary**.
Data type mode	Select **Bus Object** or **Expression**.

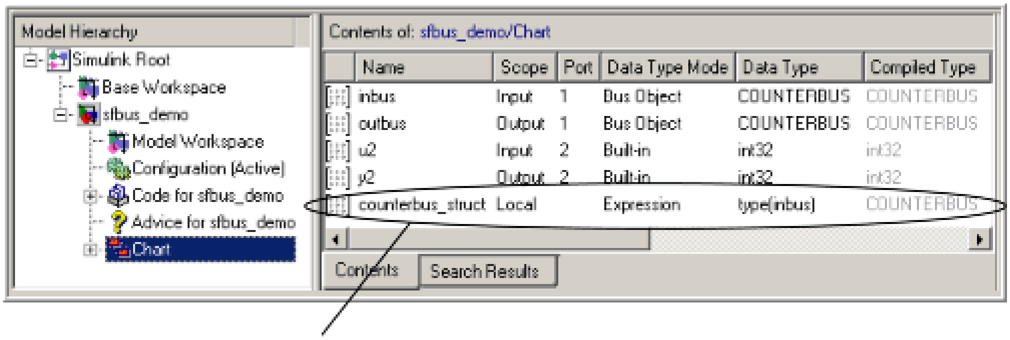
   c. Additional fields — Depending on the data type mode that you select, you may need to enter information in additional fields in the Data properties dialog box, as follows:

Field	When it Appears	What to Specify
Bus object	When you select **Bus Object** as the data type mode	Enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.
Data type	When you select **Expression** as the data type mode	Enter any of the following expressions: • Use the Stateflow`type` operator to assign the type of your structure based on the type of another structure defined in the Stateflow chart, as described in "Defining Structure Types with Expressions" on page 11-15 • Enter the name of the `Simulink.Bus` object in the base workspace that defines the Stateflow structure.

d Click **Apply**.

Defining Structure Types with Expressions

You can define structure types with expressions that call the Stateflow `type` operator. This operator assigns the type of your structure based on the type of another structure defined in the Stateflow chart. For example, the model sfbus_demo contains a local structure whose type is defined using a `type` operator expression, as follows:



Contents of: sfbus_demo/Chart

Name	Scope	Port	Data Type Mode	Data Type	Compiled Type
inbus	Input	1	Bus Object	COUNTERBUS	COUNTERBUS
outbus	Output	1	Bus Object	COUNTERBUS	COUNTERBUS
u2	Input	2	Built-in	int32	int32
y2	Output	2	Built-in	int32	int32
counterbus_struct	Local		Expression	type(inbus)	COUNTERBUS

Stateflow structure counterbus_struct
derives its type from Stateflow structure inbus

In this case, the structure `counterbus_struct` derives its type from structure `inbus`, which is defined by the `Simulink.Bus` object `COUNTERBUS`. Therefore, the structure `counterbus_struct` is also defined by the bus object `COUNTERBUS`.

To learn how to use the Stateflow type operator, see “Deriving Data Types from Previously Defined Data” on page 7-68.

Structure Operations

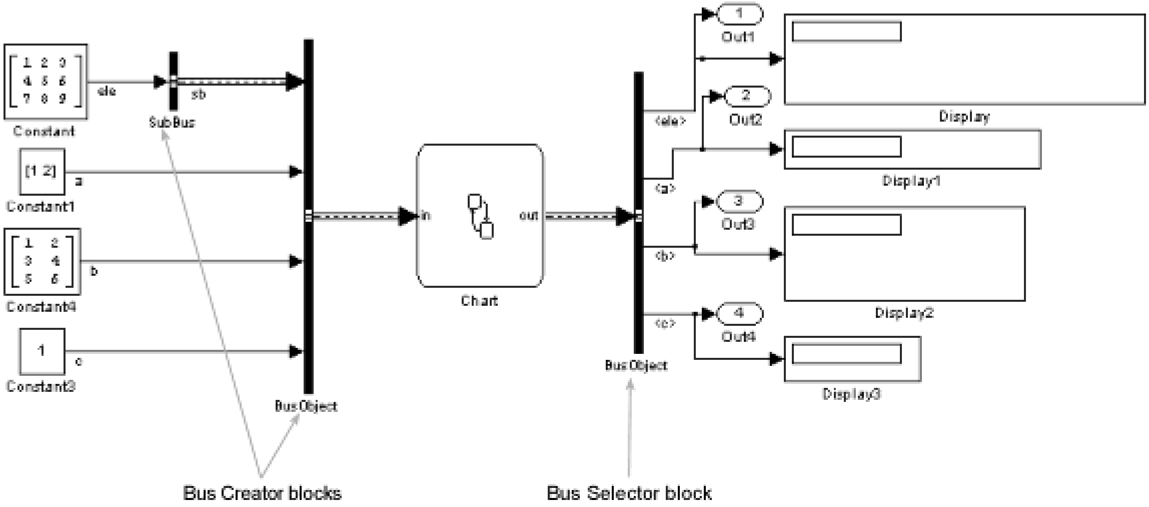
You can perform the following operations with Stateflow structures:

- "Indexing Sub-Structures and Fields" on page 11-17
- "Assigning Values" on page 11-19
- "Getting Addresses" on page 11-20

Indexing Sub-Structures and Fields

You index substructures and fields of Stateflow structures by using dot notation. With dot notation, the first text string identifies the parent object, and subsequent text strings 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). By default, 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, consider the following model:



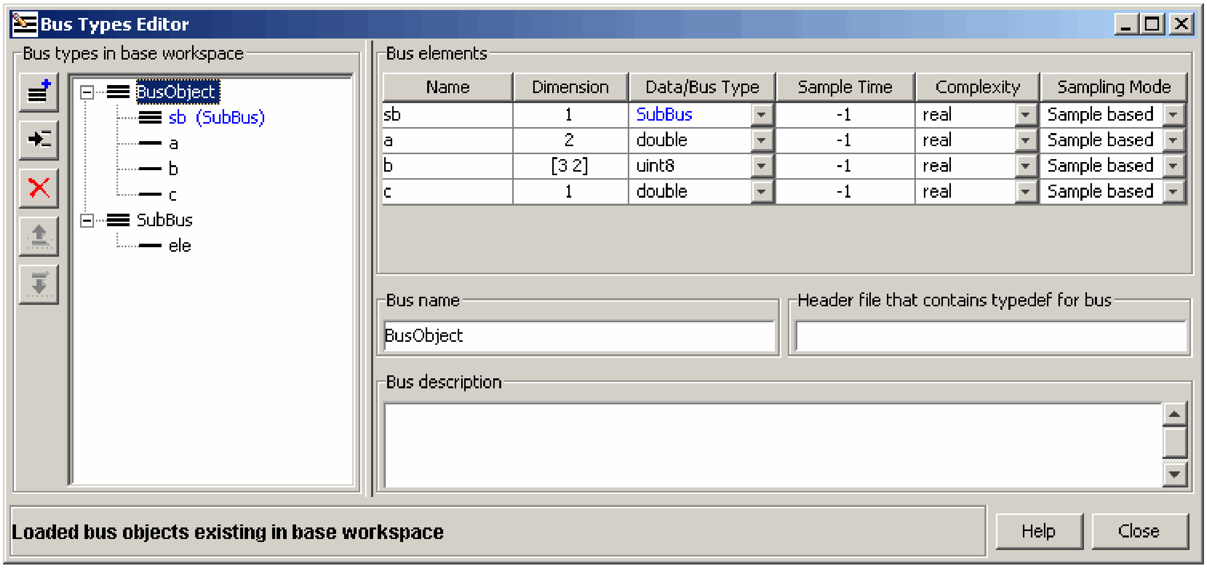
Bus Creator blocks

Bus Selector block

In this example, the following structures are defined in the Stateflow chart:

Name of Structure	Scope	Defined By Simulink.Bus Object
in	Input	BusObject
out	Output	BusObject
subbus	Local	SubBus

The Simulink.Bus objects that define these structures have the following elements:



Bus Types Editor

Bus types in base workspace

- BusObject
  - sb (SubBus)
  - a
  - b
  - c
- SubBus
  - ele

Bus elements

Name	Dimension	Data/Bus Type	Sample Time	Complexity	Sampling Mode
sb	1	SubBus	-1	real	Sample based
a	2	double	-1	real	Sample based
b	[3 2]	uint8	-1	real	Sample based
c	1	double	-1	real	Sample based

Bus name: BusObject

Header file that contains typedef for bus:

Bus description:

Loaded bus objects existing in base workspace

By default, Stateflow structures in and out have the same fields —sb, a, b, and c — as the elements of Simulink.Bus object BusObject. Similarly, the Stateflow structure subbus has the same field ele as the element of Simulink.Bus object SubBus. Based on these specifications, the following table shows how Stateflow resolves symbols in dot notation for indexing fields of the structures in this example:

Dot Notation	Symbol Resolution
in.c	Field c of input structure in
in.a[1]	Second value of the vector field a of input structure in
out.sb	Substructure sb of output structure out
in.sb.ele[2][3]	Value in row 2, column 3 of field ele of substructure sb of input structure in
subbus.ele[1][1]	Value in row 1, column 1 of field ele of local structure subbus

Assigning Values

You can assign values to any Stateflow structure *except* input structures — that is, a structures with scope equal to **Input**. Here are the guidelines for assigning values to output, local, and temporary structures:

Operation	Conditions
Assign one structure to another structure	You must define both structures with the same Simulink.Bus object in the base workspace
Assign one structure to a substructure of a different structure and vice versa	You must define the structure with the same Simulink.Bus object in the base workspace as the substructure
Assign a field of one structure to a field of another structure	The fields must have the same type and size **Note** In this case, you do not need to define the Stateflow structures with the same Simulink.Bus object in the base workspace.

For example, the following table presents valid and invalid structure assignments based on the specifications for the model sfbus_demo, as described in "Example of Stateflow Structures" on page 11-3:

Assignment	Valid or Invalid?	Rationale
outbus = inbus;	Valid	Both `outbus` and `inbus` are defined by the same `Simulink.Bus` object, `COUNTERBUS`.
inbus = outbus;	Invalid	You cannot write to input structures.
inbus.limits = outbus.limits;	Invalid	You cannot write to fields of input structures.
counterbus_struct = inbus;	Valid	Both `counterbus_struct` and `inbus` are defined by the same`Simulink.Bus` object, `COUNTERBUS`.
counterbus_struct.inputsignal = inbus.inputsignal;	Valid	Both `counterbus_struct.inputsignal` and `inbus.inputsignal` have the same type and size because they each reference field `inputsignal`, a substructure of the `Simulink.Bus` object `COUNTERBUS`.
outbus.limits.upper_saturation_limit = inbus.inputsignal.input;	Valid	The field `upper_saturation_limit` from `limits`, a substructure of `COUNTERBUS`, has the same type and size as the field `input` from `inputsignal`, a different substructure of `COUNTERBUS`.
outbus.limits = inbus.inputsignal;	Invalid	The substructure `limits` is defined by a different `Simulink.Bus` object than the substructure `inputsignal`.

Getting Addresses

When you write custom functions that take structure pointers as arguments, you must pass the structures by address. To get addresses of Stateflow structures and structure fields, use the `&` operator, as in the following examples:

- `&in` — Address of Stateflow structure `in`
- `&in.b` — Address of field `b` in Stateflow structure `in`

The model sfbus_demo contains a custom C function counterbusFcn that takes structure pointers as arguments, defined as follows in a custom header file:

```
...
extern void counterbusFcn
            (COUNTERBUS *u1, int u2, COUNTERBUS *y1, int *y2);
...
```

To call this function, you must pass addresses to two structures defined by the Simulink.Bus object COUNTERBUS, as in this example:

```
counterbusFcn(&counterbus_struct, u2, &outbus, &y2);
```

See “Example of Stateflow Structures” on page 11-3 for a description of the structures defined in sfbus_demo.

Integrating Custom Structures in Stateflow

You can define custom structures in C code, which you can then integrate with your Stateflow chart for simulation and Real-Time Workshop® (RTW) code generation. Follow these steps:

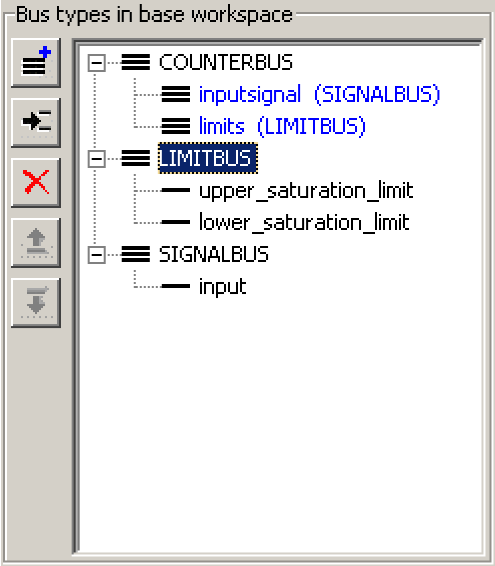
1 Define your structure in C, creating custom source and header files.

The header file must contain the `typedef` statements for your structures. For example, the model sfbus_demo uses custom structures, defined in a custom header file as follows:

```
...
#include "tmwtypes.h"

typedef struct {
  int input;
} SIGNALBUS;

typedef struct {
  int upper_saturation_limit;
  int lower_saturation_limit;
} LIMITBUS;

typedef struct {
  SIGNALBUS inputsignal;
  LIMITBUS limits;
} COUNTERBUS;
...
```

2 Define a `Simulink.Bus` object in the base workspace that matches each custom structure `typedef`.

For example, the model sfbus_demo, defines the following `Simulink.Bus` objects to match each `typedef` in the custom header file:

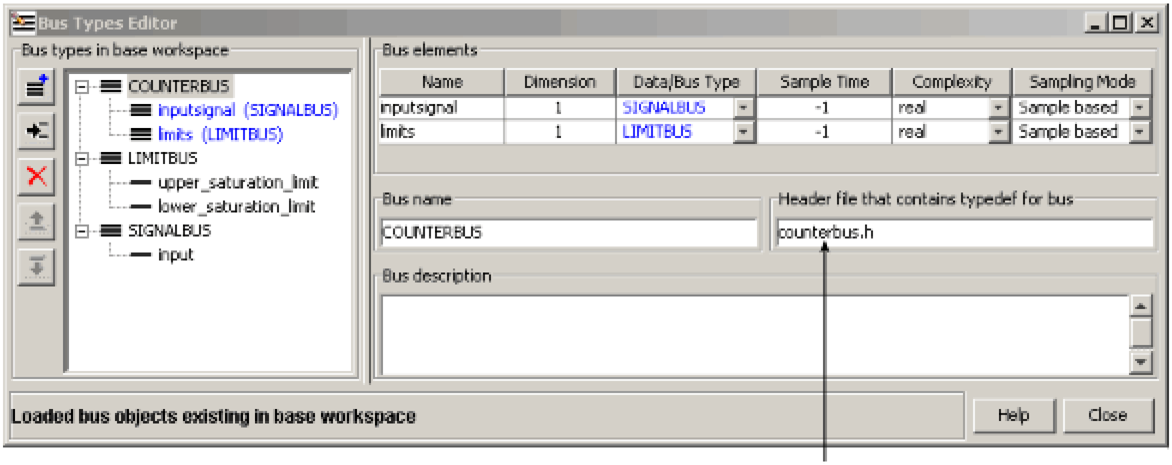


Bus types in base workspace

- COUNTERBUS
  - inputsignal (SIGNALBUS)
  - limits (LIMITBUS)
- LIMITBUS
  - upper_saturation_limit
  - lower_saturation_limit
- SIGNALBUS
  - input

3 Open the Bus Editor and for each bus object in the base workspace defined in custom code, add the name of the header file that contains the matching `typedef`.

For example, the model sfbus_demo specifies the custom header file **counterbus.h** for the bus object `COUNTERBUS`:



- COUNTERBUS
  - inputsignal (SIGNALBUS)
  - limits (LIMITBUS)
- LIMITBUS
  - upper_saturation_limit
  - lower_saturation_limit
- SIGNALBUS
  - input

Name	Dimension	Data/Bus Type	Sample Time	Complexity	Sampling Mode
inputsignal	1	SIGNALBUS	-1	real	Sample based
limits	1	LIMITBUS	-1	real	Sample based

Bus name: COUNTERBUS

Header file that contains typedef for bus: counterbus.h

Loaded bus objects existing in base workspace

Custom header file

4 Configure Stateflow to include your custom C code, as follows:

To Include Custom C Code:	Do this:
In code generated for simulation	Follow the instructions in “Specifying Custom Code Options for Stateflow Targets” on page 14-27.
In code generated for real-time applications using RTW	Follow these steps: **1** Open the Simulink model that contains the Stateflow chart that uses your custom C structures. The Model Editor opens on your desktop. **2** In the Model Editor, select **Simulation > Configuration Parameters**. The Configuration Parameters dialog box opens on your desktop. **3** In the Configuration Parameters dialog box, select **Custom Code** under Real-Time Workshop in the Select tree on the left side of the dialog box. Custom code options appear in the right pane of the dialog box. **4** Follow instructions in “Custom Code Options” in the Real-Time Workshop User’s Guide.

5 Build your model and fix errors (see “Debugging Structures in Stateflow” on page 11-26).

6 Run your model.

Debugging Structures in Stateflow

You debug structures as you would other data in Stateflow, as described in Chapter 15, “Debugging and Testing”. Using the Stateflow debugger, you can examine the values of structure fields during simulation, either from the graphical debugging window or from the command line, as described in “Watching Data Values with Debuggers” on page 15-26. To view the values of structure fields at the command line, use dot notation to index into the structure, as described in “Indexing Sub-Structures and Fields” on page 11-17.

Truth Table Functions

Stateflow uses functions to capture programming steps that you call repeatedly in a Stateflow diagram. In truth tables, you specify logical behavior with conditions, decisions, and actions. For purely logical behavior, truth tables are easier to program, easier to maintain, and easier for others to read than graphical functions. Truth tables also help you complete your function by telling you whether you have specified enough or too many decisions for the conditions you specify. To learn how to construct successful truth tables, see the following sections:

What Is a Truth Table?

Stateflow uses truth table functions to realize logical decision-making behavior that you call in an action language. Stateflow truth tables contain conditions, decisions, and actions arranged like the following:

Condition	Decision 1	Decision 2	Decision 3	Default Decision
x == 1	T	F	F	-
y == 1	F	T	F	-
z == 1	F	F	T	-
Action	t = 1	t = 2	t = 3	t = 4

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, that is referred to as a decision.

You evaluate a truth table one decision at a time, starting with Decision 1. If one of the decisions is true, you perform its action and truth table execution is complete. For example, if conditions 1 and 2 are false and condition 3 is true, Decision 3 is true and the variable `t` is set equal to 3. The remaining decisions are not tested and evaluation of the truth table is finished.

The last decision in the preceding example, Default Decision, covers all possible remaining decisions. If Decisions 1, 2, and 3 are false, then the Default Decision is automatically true and its action (t = 4) is executed. You can see this behavior when you examine the following equivalent pseudocode for the evaluation of the preceding truth table example:

Description	Pseudocode

Decision 1
Decision 1 Action
	`if ((x == 1) & !(y == 1) & !(z == 1))`
	`t = 1;`

Decision 2
Decision 2 Action
	`elseif (!(x == 1) & (y == 1) !(z == 1))`
	`t = 2;`

Decision 3
Decision 3 Action
	`elseif (!(x == 1) & !(y == 1) (z == 1))`
	`t = 3;`

Default Decision
Default Decision Action
	`else`
	`t = 4;`
	`endif`

Language Options for Stateflow Truth Tables

You implement truth tables by specifying conditions and actions using an action language. The programming language options for Stateflow truth tables are

- Stateflow Classic (the default)
- Embedded MATLAB

Stateflow Classic Truth Tables

Stateflow Classic truth tables allow you to specify conditions and actions using the Stateflow action language, which supports basic C constructs and provides access to MATLAB functions using the `ml` namespace operator or `ml` function. For more information about the Stateflow action language, see Chapter 8, “Using Actions in Stateflow”.

Stateflow Classic is the default language for Stateflow truth tables.

Embedded MATLAB Truth Tables

Embedded MATLAB truth tables allow you to specify conditions and actions using the Embedded MATLAB action language. Embedded MATLAB truth tables offer several advantages over Stateflow classic truth tables:

- The Embedded MATLAB language provides a richer syntax for specifying control flow logic in truth table actions. It provides `for` loops, `while` loops, nested `if` statements, and `switch` statements.
- You can call MATLAB functions directly in truth table actions. Also, you can call Embedded MATLAB library functions (for example MATLAB `sin` and `fft` functions) and generate code for these functions using Real-Time Workshop.
- You can create temporary or persistent variables during simulation or in code directly without having to define them in the Model Explorer.
- Embedded MATLAB uses a better debugging scheme. It is easier to set breakpoints on lines of code, step through code, and watch data values through tool tips.

- You can use persistent variables in truth table actions. This feature allows you to define data that persists across multiple calls to the truth table function during simulation.
- You get more comprehensive model coverage. Embedded MATLAB truth tables generate coverage reports on branches in conditions *and* actions. Stateflow classic truth tables provide coverage reports for conditions only. For more information, see "Model Coverage for Truth Tables" on page 12-58.

Selecting a Language for Stateflow Truth Tables

To specify an action language for your Stateflow truth table, follow these steps:

1. Double-click the truth table to open the Truth Table Editor.
2. Select **Language** from the **Settings** menu.
3. Choose a language from the drop-down menu.

Migrating from Stateflow Classic to Embedded MATLAB Truth Tables

When you migrate from a Stateflow Classic truth table to an Embedded MATLAB truth table, you must verify that the code used to program the actions conforms to Embedded MATLAB syntax. Inconsistencies between the two languages include

- In Embedded MATLAB, indices are one-based; in the Stateflow action language, you can specify the first index.
- In Embedded MATLAB, the syntax for *not equal to* is `~=`; in the Stateflow action language, the equivalent syntax is `!=`.

You can check for syntax errors by using the Run Diagnostics command in the Truth Table Editor, as described in "Checking Truth Tables for Errors" on page 12-45.

Using Truth Tables

Here is the recommended workflow for using truth tables in Simulink models:

1. Add a truth table to your Simulink model using one of the methods described in "Building a Simulink Model with a Stateflow Truth Table" on page 12-8.

2. Specify properties of the truth table function, as described in "Specifying Properties of Truth Table Functions in Stateflow" on page 12-15.

3. Select an action language and program the conditions and actions in the truth table, as described in "Programming a Truth Table" on page 12-24.

4. Debug the truth table for syntax errors and for error during simulation, as described in "Debugging a Truth Table" on page 12-45.

5. Check coverage of conditions and actions in the truth table, as described in "Model Coverage for Truth Tables" on page 12-58.

6. Simulate the model and check the generated content for the truth tables, as described in "How Stateflow Realizes Truth Tables" on page 12-63.

Building a Simulink Model with a Stateflow Truth Table

There are several ways to add a Stateflow truth table to a Simulink model:

Procedure	Action Languages Supported	How To Do It
Add a Truth Table block directly to the model	Embedded MATLAB only	See Appendix C, "The Truth Table Block".
Add a Stateflow block that calls a truth table function	Stateflow Classic and Embedded MATLAB	See "Adding a Stateflow Block that Calls a Truth Table Function" on page 12-8.

Once you build a model in this section, finish it by programming the truth table with its behavior in "Programming a Truth Table" on page 12-24.

Note The Stateflow diagram you create in this section contains the least amount of Stateflow programming possible. This might appeal to Simulink users who know little about Stateflow but want to use it to execute a truth table function.

Adding a Stateflow Block that Calls a Truth Table Function

This section describes how to add a Stateflow block to your Simulink model, then create a Stateflow diagram that calls a truth table function. The following topics are covered:

- "Creating a Simulink Model" on page 12-9
- "Creating a Stateflow Truth Table" on page 12-12
- "Specifying Properties of Truth Table Functions in Stateflow" on page 12-15
- "Calling a Truth Table in a Stateflow Action" on page 12-17
- "Creating Truth Table Data in Stateflow and Simulink" on page 12-20

Once you build a model in this section, finish it by programming the truth table with its behavior in “Programming a Truth Table” on page 12-24.

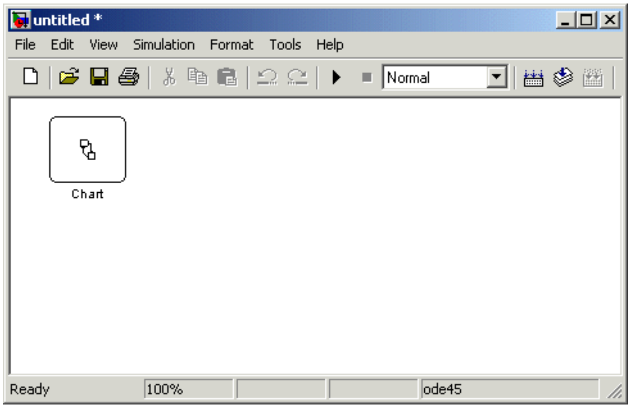
Creating a Simulink Model

To execute a truth table, you first need a Simulink model that calls a Stateflow block. Later, you will create a Stateflow diagram for the Stateflow block that calls a truth table function. In this section, you create a Simulink model that calls a Stateflow block with the following procedure:

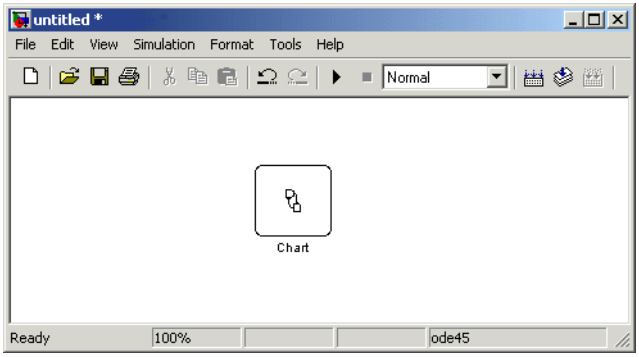
1 At the MATLAB prompt, enter the following command:

```
sfnew
```

An untitled Simulink model with a Stateflow block appears as shown.



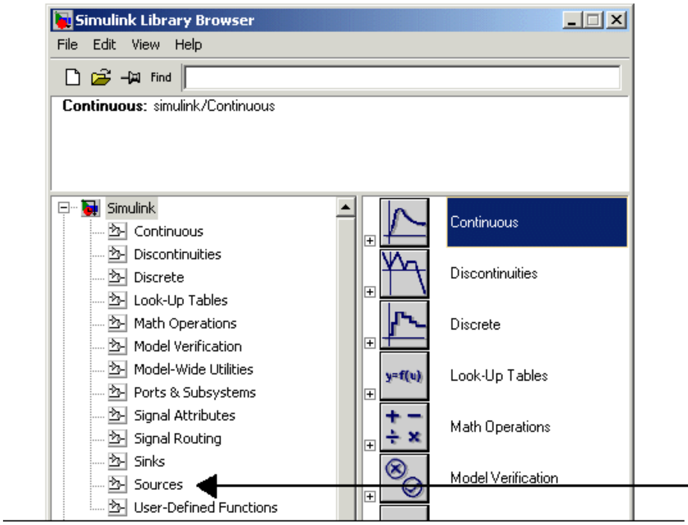
2 Click and drag the Stateflow block to the center of the Simulink window as shown.



This makes room for the blocks you add in the steps that follow.

3 In the Simulink window, from the **View** menu, select **Library browser**.

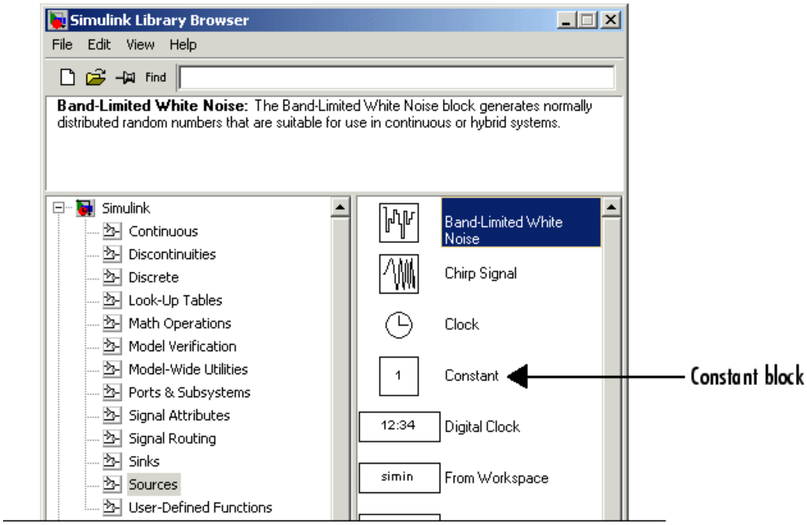
The **Simulink Library Browser** window opens with the **Simulink** node expanded.



Sources library

4 Under the **Simulink** node, select the **Sources** library.

The right pane of the **Simulink Library Browser** window displays the block members of the **Sources** library.



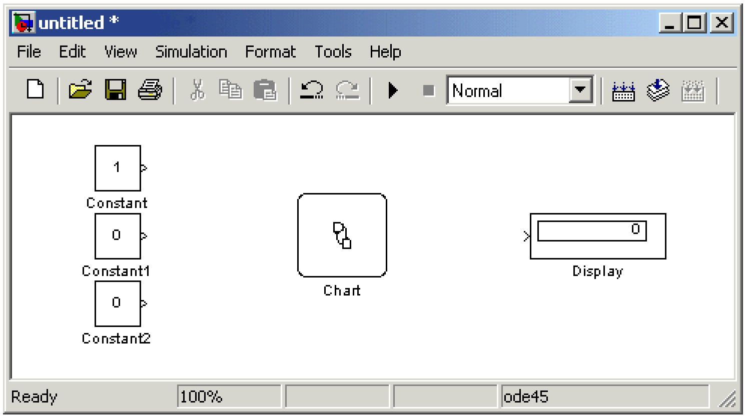
Band-Limited White Noise: The Band-Limited White Noise block generates normally distributed random numbers that are suitable for use in continuous or hybrid systems.

Constant block

5 From the right pane of the Simulink Library Browser window, click and drag the Constant block to the left of the Stateflow block in the Simulink model.

6 Add two more Constant blocks to the left of the Chart block and a Display block (from the Sinks library) to the right of the Chart block.

Your model should now have the following appearance:



7 In the Simulink model window, double-click the top Constant block.

8 In the resulting **Block Parameters** dialog, change the **Constant value** field to 1 and select **OK** to close the dialog.

9 In the Simulink model window, from the **Simulation** menu, select **Configuration Parameters**.

The **Configuration Parameters** dialog opens.

10 Set

- Solver Options **Type** field to `Variable-step`
- **Stop Time** to `inf`

11 Click **OK** to accept these values and close the **Configuration Parameters** dialog.

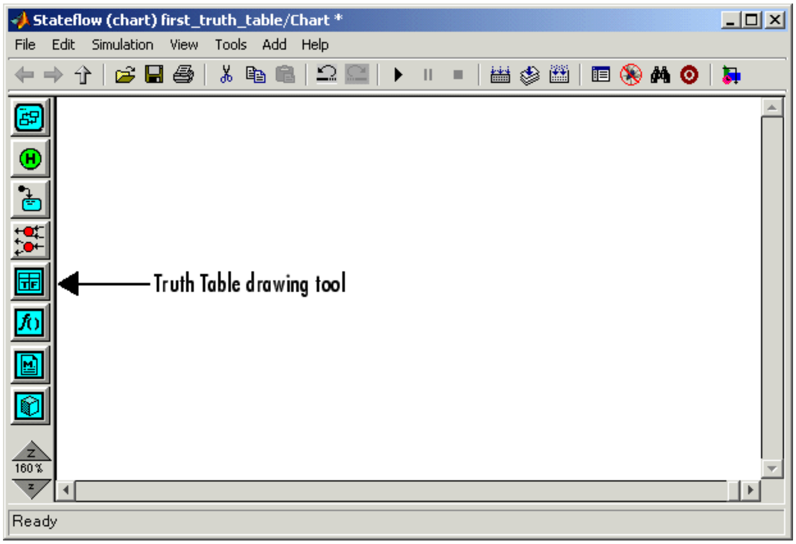
12 Save the model as `first_truth_table.mdl`.

Creating a Stateflow Truth Table

You created a Simulink model in “Creating a Simulink Model” on page 12-9 that contains a Stateflow block. Now you need to open the Stateflow diagram for the block and specify a truth table for it in the following steps:

1 In the Simulink model, double-click the Stateflow block named Chart.

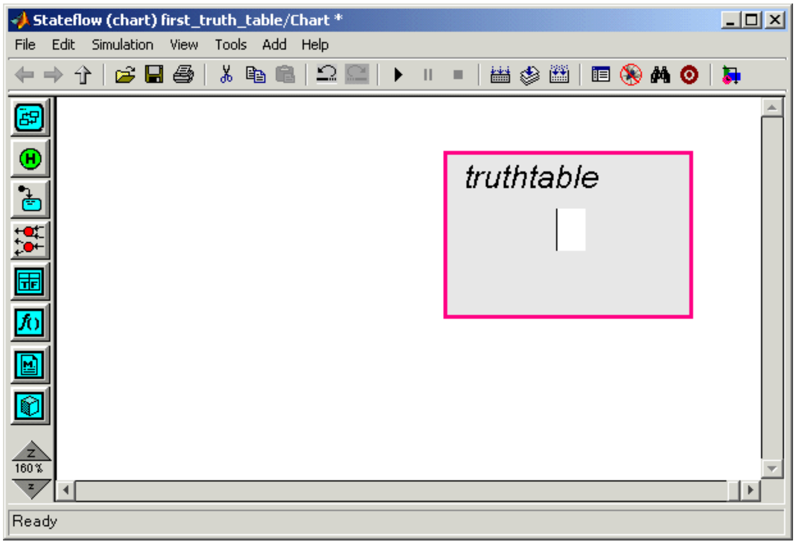
An empty Stateflow diagram editor appears.


Stateflow (chart) first_truth_table/Chart *
File Edit Simulation View Tools Add Help
Truth Table drawing tool
160%
Ready

2 In the Stateflow diagram editor, select the Truth Table drawing tool:

3 Move the cursor into the empty diagram area and notice that the cursor takes on the shape of a box.

4 Click to place a new truth table as shown.

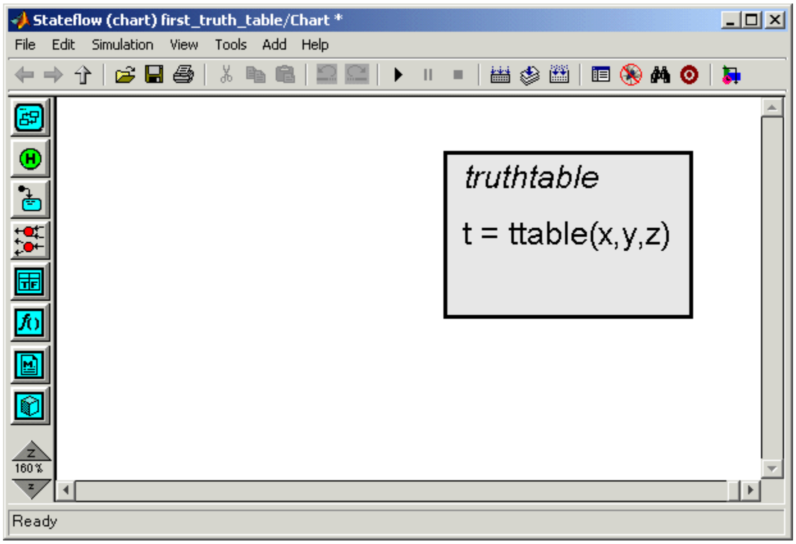

Stateflow (chart) first_truth_table/Chart *
File Edit Simulation View Tools Add Help
truthtable
160%
Ready

A shaded box appears with the title **truthtable** and a flashing text cursor in the middle of the box.

5 Enter the label text

```
t = ttable(x,y,z)
```

and click outside the truth table box.


Stateflow (chart) first_truth_table/Chart *
File Edit Simulation View Tools Add Help
truthtable
t = ttable(x,y,z)
160%
Ready

The signature label you enter for the truth table defines its name (ttable), its arguments (x, y, and z), and its return value (t). Argument and return values can each be a scalar value or a matrix of values. Multiple return values are not allowed.

Note If you need to change the truth table label at any time, click the label to place an editing cursor in the text of the label.

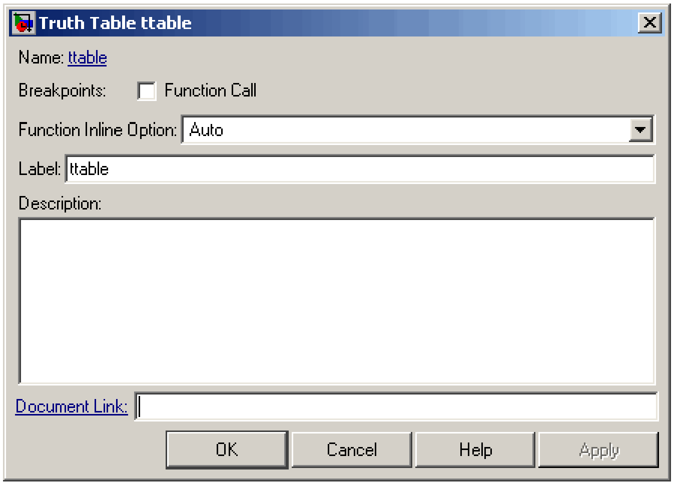
Specifying Properties of Truth Table Functions in Stateflow

After you add a truth table function to a Stateflow chart, you can specify its properties by following these steps:

1 Right-click the truth table function box.

2 Select **Properties** from the resulting submenu.

The **Truth Table Properties** dialog box for the truth table function appears, as shown:



Truth Table ttable

Name: ttable

Breakpoints: □ Function Call

Function Inline Option: Auto

Label: ttable

Description:

Document Link:

The fields in the **Truth Table Properties** dialog box are as follows:

Field	Description
Name	Function name; read-only; click this hypertext link to bring the truth table function to the foreground in its native Stateflow chart.
Breakpoints	Select **Function Call** to set a breakpoint to pause execution during simulation when the truth table function is called.

Field	Description
Function Inline Option	This option controls the inlining of the truth table function in generated code through the following selections: • **Auto** Stateflow decides whether or not to inline the truth table function based on an internal calculation. • **Inline** Stateflow inlines the truth table function as long as it is not exported to other charts and is not part of a recursion. A recursion exists if the function calls itself either directly or indirectly through another called function. • **Function** The function is not inlined.
Label	You can specify the signature label for the function through this field. See "Creating a Stateflow Truth Table" on page 12-12 for more information.
Description	Textual description/comment.
Document Link	Enter a URL address or a general MATLAB command. Examples are `www.mathworks.com`, `mailto:email_address`, and `edit/spec/data/speed.txt`.

Calling a Truth Table in a Stateflow Action

In "Creating a Stateflow Truth Table" on page 12-12, you created the truth table function `ttable` with the signature

```
t = ttable(x,y,z)
```

Now you need to specify a call to the truth table function in the Stateflow diagram. Later, when the diagram executes during simulation, it calls the truth table.

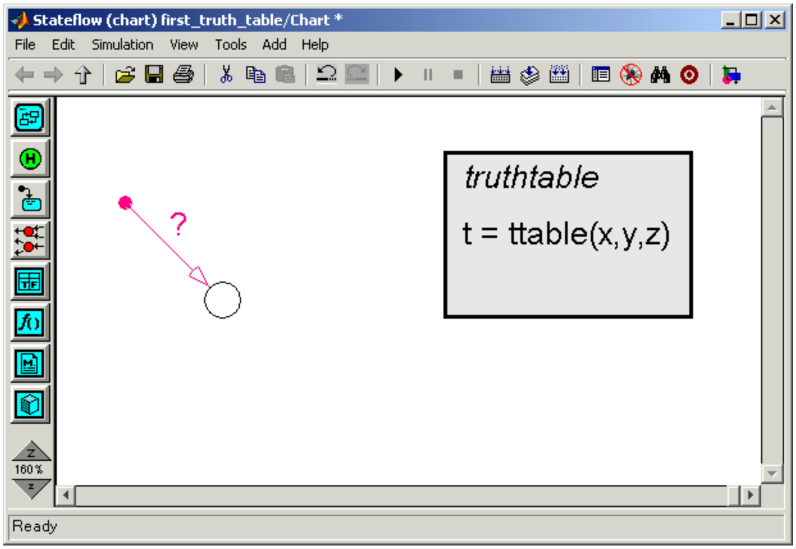
You can call truth table functions from the actions of any state or transition. You can also call truth tables from other functions, including graphical functions and other truth tables. Also, if you export a truth table, you can call it from any Stateflow chart in the model.

Use the following steps to call the `ttable` function from the default transition of its own Stateflow diagram.

1 Select the Default Transition button from the drawing toolbar.

2 Move the cursor to a location left of the truth table function and notice that the cursor takes on the shape of a downward-pointing arrow.

3 Click to place a default transition into a terminating junction.



4 Click the question mark character (?) that appears on the highlighted default transition.

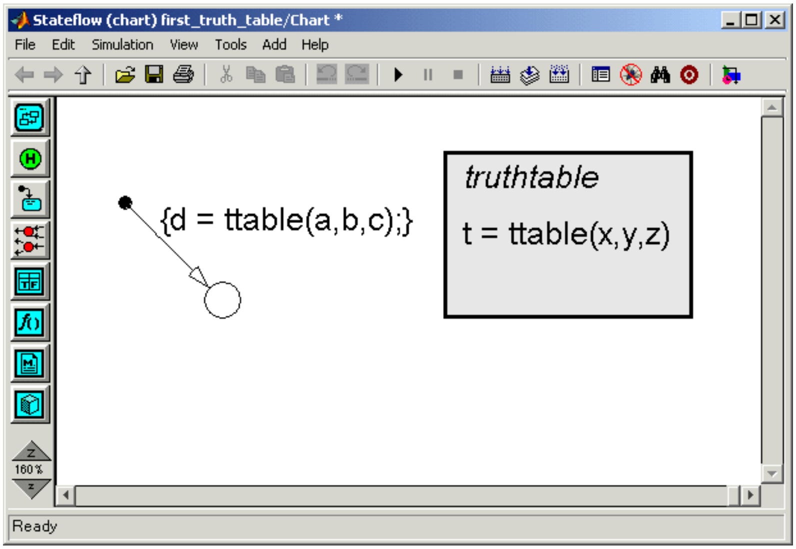
A blinking cursor in a text field appears for entering the label of the default transition.

5 Enter the text

```
{d = ttable(a,b,c);}
```

and click outside the transition label to finish editing it.

You might want to adjust the label's position by clicking and dragging it to a new location. The finished Stateflow diagram should have the following appearance:


Stateflow (chart) first_truth_table/Chart *
File Edit Simulation View Tools Add Help
{d = ttable(a,b,c);}
truthtable
t = ttable(x,y,z)
160%
Ready

The label on the default transition that you entered provides a condition action that calls the truth table with arguments and a return value. When Simulink triggers the Stateflow block during simulation, the default transition is taken and a call to the truth table `ttable` is made.

The call to the truth table in Stateflow action language must match the truth table signature. This means that the type of the return value `d` must match the type of the signature return value `t`, and the type of the arguments `a`, `b`, and `c` must match the type of the signature arguments `x`, `y`, and `z`. You ensure this with a later step in this section when you create the data that you use in Stateflow.

6 From the **File** menu, select **Save** to save the model.

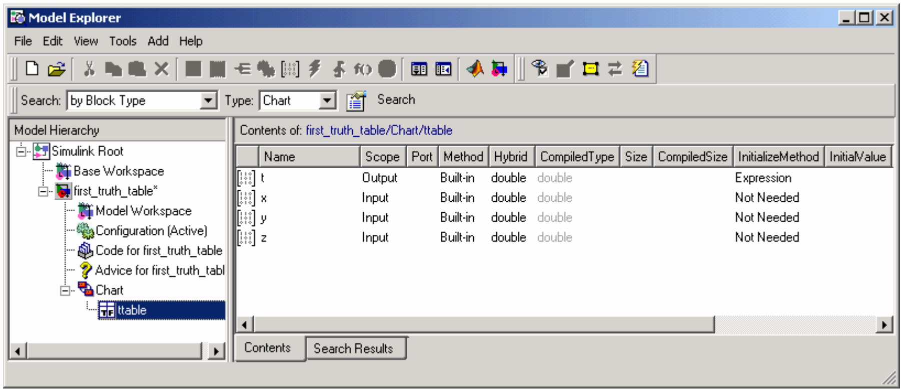
Creating Truth Table Data in Stateflow and Simulink

When you create a truth table with its own signature, you specify data for it in the form of a return value (`t`) and argument values (`x`, `y`, `z`). When you specify a call to a truth table, as you did in “Calling a Truth Table in a Stateflow Action” on page 12-17, you specify data that you pass to the return and argument values of the truth table (`d`, `a`, `b`, and `c`). Now you need to define this data for the Stateflow diagram in the following steps:

1 Double-click the truth table to open the Truth Table Editor.

2 In the Truth Table Editor, select the **Edit Data/Ports** button .

The **Model Explorer** window appears as shown.



Search: by Block Type Type: Chart

Contents of: first_truth_table/Chart/ttable

Name	Scope	Port	Method	Hybrid	CompiledType	Size	CompiledSize	InitializeMethod	InitialValue
t	Output		Built-in	double	double			Expression	
x	Input		Built-in	double	double			Not Needed	
y	Input		Built-in	double	double			Not Needed	
z	Input		Built-in	double	double			Not Needed	

Notice in the **Model Hierarchy** pane (left pane) that the node for the function `ttable` is highlighted and that the **Contents** pane (right pane) displays the output (`t`) and inputs (`x`, `y`, `z`) for `ttable`. By default, these data are defined as scalars of type `double`. If you want to redefine these data with a different array size and type, you do it in the **Model Explorer**. However, no changes are necessary for this example.

Notice also in the **Model Hierarchy** pane that the node above the function `ttable` is `Chart`, the name of the Stateflow diagram that contains the truth table `ttable`.

3 In the **Model Hierarchy** pane, select **Chart**.

Notice that `Chart` contains no data in the **Contents** pane. You need to add the return and argument data used in calling `ttable`.

4 From the **Add** menu, select **Data**.

A scalar data is added to the chart in the **Contents** pane of Explorer with the default name `data`. This data matches argument `x` in type and size.

Tip To verify that the properties match, right-click `data` in the **Contents** pane and select **Properties**. The property sheet shows that the type is **double** and the size is scalar (the default when there is no entry in the **Size** field).

---

5 In the **Contents** pane, double-click the entry `data` in the **Name** column.

A small text field opens with the name `data` highlighted.

6 In the text field, change the name to `a` and press **Enter**.

7 Click the entry `Local` under the **Scope** column.

A drop-down menu of selectable scopes appears with `Local` selected.

8 Select **Input**.

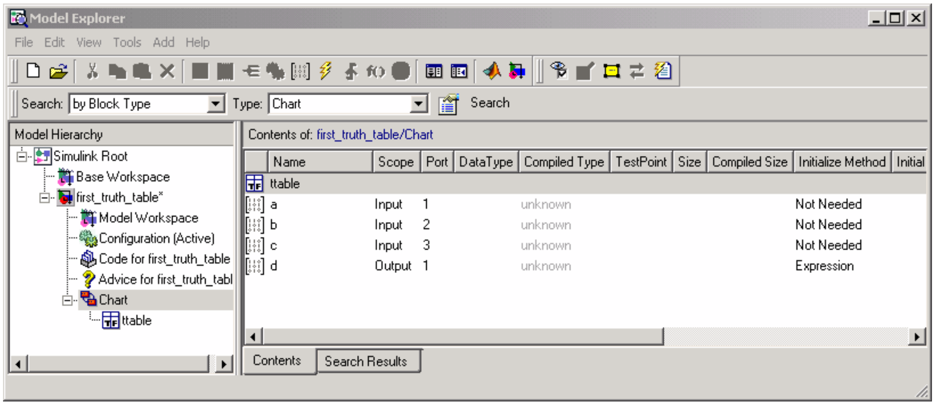
The scope **Input** means that Simulink provides the value for this data, which it passes to the Stateflow diagram through an input port on the Stateflow block.

You should now see the new data input `a` in the **Contents** pane.

9 Repeat steps 3 through 7 to add the data `b` and `c` with the scope **Input**, and data `d` with a scope of **Output**.

The scope **Output** means that the Stateflow chart provides this data and passes it to Simulink through an output port on the Stateflow block.

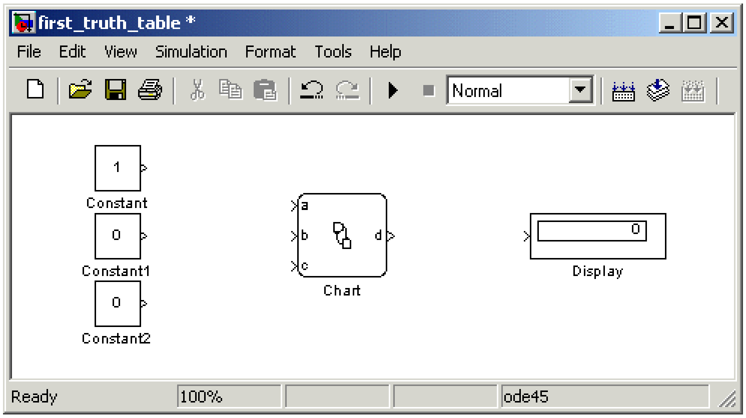
You should now see the following data in Stateflow Explorer:



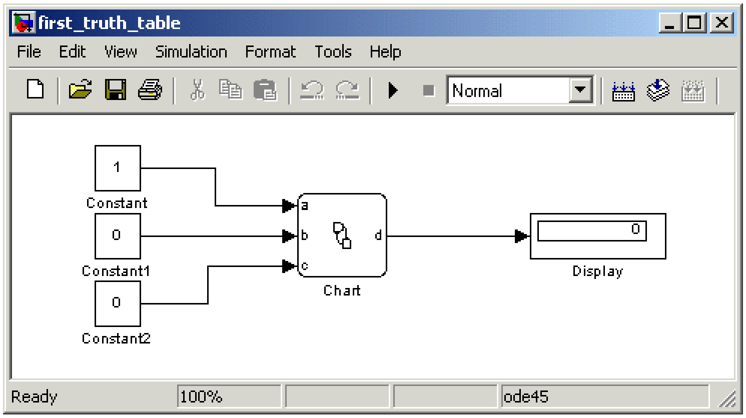
Contents of: first_truth_table/Chart

Name	Scope	Port	DataType	Compiled Type	TestPoint	Size	Compiled Size	Initialize Method	Initial
ttable									
a	Input	1		unknown				Not Needed	
b	Input	2		unknown				Not Needed	
c	Input	3		unknown				Not Needed	
d	Output	1		unknown				Expression	

The data a, b, c, and d match their counterparts x, y, z, and t in the truth table signature in size (scalar) and type (double), but have sources outside the Stateflow block. Notice that input ports for a, b, and c, and an output port for d appear on the Stateflow block in the Simulink model.



10 Complete connections to the Simulink diagram as shown.



11 From the **File** menu, select **Save** to save the model.

Programming a Truth Table

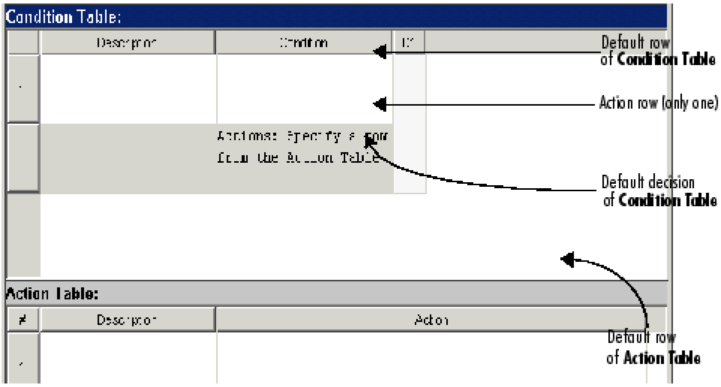
In “Building a Simulink Model with a Stateflow Truth Table” on page 12-8, you created a Simulink model with a Stateflow diagram that calls the truth table `ttable`. This truth table is empty and requires programming to specify its behavior. This section shows you how to program this truth table, covering the topics in the following steps:

1. “Opening a Truth Table for Editing” on page 12-24 — You open a truth table editor for a truth table object in the Stateflow diagram to begin programming it.
2. “Entering Truth Table Conditions” on page 12-25 — Shows you how to enter conditions in the **Condition Table** of a truth table.
3. “Entering Truth Table Decisions” on page 12-27 — Shows you how to enter decisions in the **Condition Table** of a truth table.
4. “Entering Truth Table Actions” on page 12-30 — Shows you how to enter actions for each decision in the **Action Table** of a truth table.
5. “Assigning Truth Table Actions to Decisions” on page 12-37 — Shows you how to assign actions that you entered in the **Action Table** to each decision in the **Condition Table**.
6. “Adding Initial and Final Actions” on page 12-42 — Shows you how to specify special initial and final actions in the **Action Table** of a truth table.

When you finish programming `ttable` in this section, the example model you start in “Building a Simulink Model with a Stateflow Truth Table” on page 12-8 is finished. Continue by debugging the truth table in “Debugging a Truth Table” on page 12-45.

Opening a Truth Table for Editing

After you create and label a truth table in a Stateflow diagram, you specify its logical behavior in the truth table editor. Double-click the truth table function to open its editor.



Actions: Specify a row from the Action Table

Default row of **Condition Table**

Action row (only one)

Default decision of **Condition Table**

Default row of **Action Table**

The truth table editor is titled in <*model name*>/<*truth table name*> format in its header. An empty default truth table contains a **Condition Table** and an **Action Table**, each with one row. The **Condition Table** also contains a single decision column, **D1**, and a single action row.

Selecting An Action Language

Select the language you want to use for programming conditions and actions in your truth table by following these steps:

1. In the Truth Table Editor, select **Language** from the **Settings** menu.
2. Choose a language from the drop-down menu.

Entering Truth Table Conditions

Conditions are the starting point for specifying logical behavior in a truth table. You open the truth table `ttable` for editing in “Opening a Truth Table for Editing” on page 12-24. In this topic, you start programming the behavior of `ttable` by specifying its conditions.

You enter conditions in the **Condition** column of the **Condition Table**. For each condition that you enter, you can also enter an optional description in the **Description** column. Use the following procedure to enter the conditions of the truth table `ttable`:

1. Click anywhere in the **Condition Table** to select it.

2 Click the Append Row button twice.

   Two rows are appended to the bottom of the **Condition Table**.

3 Click and drag the bar separating 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.

   The cell is highlighted and a flashing text cursor appears in the cell.

5 Enter the following text:

```
x is equal to 1
```

   Condition descriptions are optional, but are transferred as comments into the generated code for the truth table.

6 Press the **Tab** key to select the next cell on the right in the **Condition** column.

Tip You can use **Shift+Tab** to select the next cell on the left.

---

7 In the first row cell of the **Condition** column, enter the following text:

```
XEQ1:
```

   This is an optional label that you can include with the condition. In the generated code for a truth table, the condition label becomes the name of a temporary data variable that stores the outcome of its condition. If no label is entered, Stateflow names a temporary variable of its own.

   Condition 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 (_).

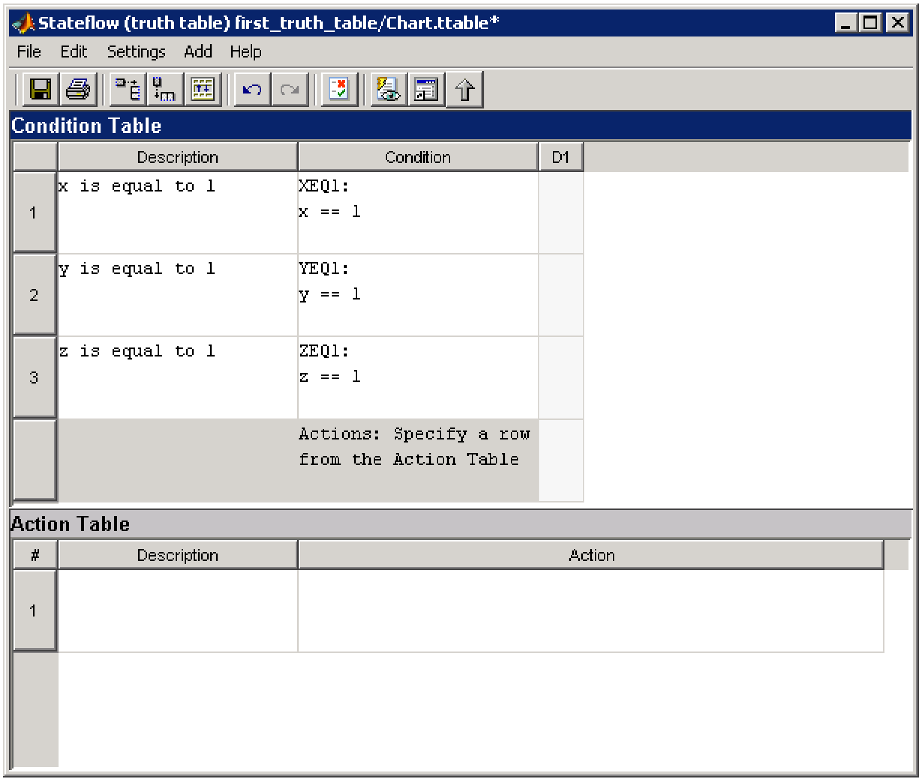
8 Press **Enter** and enter the following text:

```
x == 1
```

This is the actual condition. Each condition you enter must evaluate to zero (false) or nonzero (true). You can use optional brackets in the condition (for example, `[x == 1]`) as you would in Stateflow action language.

You can use data passed to the truth table function through its arguments in truth table conditions. 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 in Stateflow, including the Stateflow diagram.

9 Repeat the preceding steps to enter the remaining two conditions, as shown:



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		

Entering Truth Table Decisions

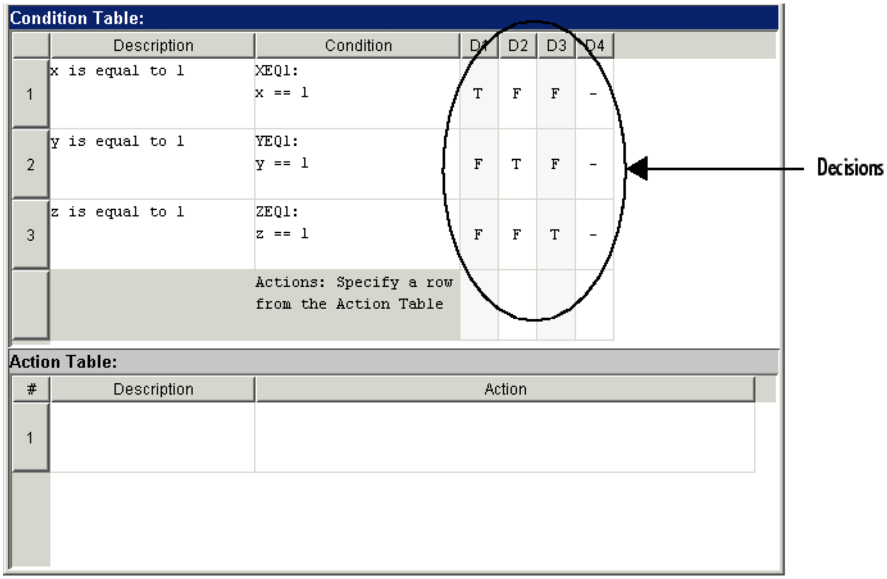
Each decision column (**D1**, **D2**, and so on) binds a group of condition outcomes together with an AND relationship into a decision. The allowed values for the condition outcomes in a decision are T (true), F (false), and - (true or false). In “Entering Truth Table Conditions” on page 12-25 you entered conditions for the truth table `ttable`. Continue by entering decisions in the decision columns with the following steps:

1. Click anywhere in the **Condition Table** to make sure it is selected.
2. Click the Append Column toolbar button three times to add three columns to the right end of the **Condition Table**.
3. Click the top cell in decision column **D1**.

   The cell is highlighted and a flashing text cursor appears in the cell.
4. Press the space bar until a value of T appears.

   Pressing the space bar toggles through the possible values of F, -, and T. You can also enter these characters directly. All other entries are rejected.
5. Press the down arrow key to advance to the next cell down in the **D1** column.

   In the decision columns, you can use the arrow keys to advance to another cell in any direction. You can also use **Tab** and **Shift+Tab** to advance left or right in these cells.
6. Enter the remaining values for the decision columns, as shown in the following:



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		

During execution of the truth table, decisions are tested in left to right order. The order of testing for individual condition outcomes within a decision is undefined. The current implementation of truth tables in Stateflow evaluates 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, you must not depend on a particular 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 remaining decisions not tested for in preceding decision columns to the left. You enter a default decision as the last decision column on the right with an entry of - for all conditions in the decision, where - represents any outcome for the condition.

In the preceding example, the following decisions are specified by the default decision column, **D4**:

Condition	Decision 4	Decision 5	Decision 6	Decision 7	Decision 8
x == 1	F	T	F	T	T
y == 1	F	F	T	T	T
z == 1	F	T	T	F	T

Note The default decision column must be the last column on the right in the **Condition Table**.

Entering Truth Table Actions

During execution of the truth table, decisions are tested in left to right order. When a decision is realized during execution of the truth table, the action in the **Action Table** specified in the **Actions** row for that decision column is executed and the truth table is exited.

In “Entering Truth Table Decisions” on page 12-27 you entered decisions in the truth table editor. The next step is to enter the 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**.

This section describes how to program truth table actions. It includes the following topics:

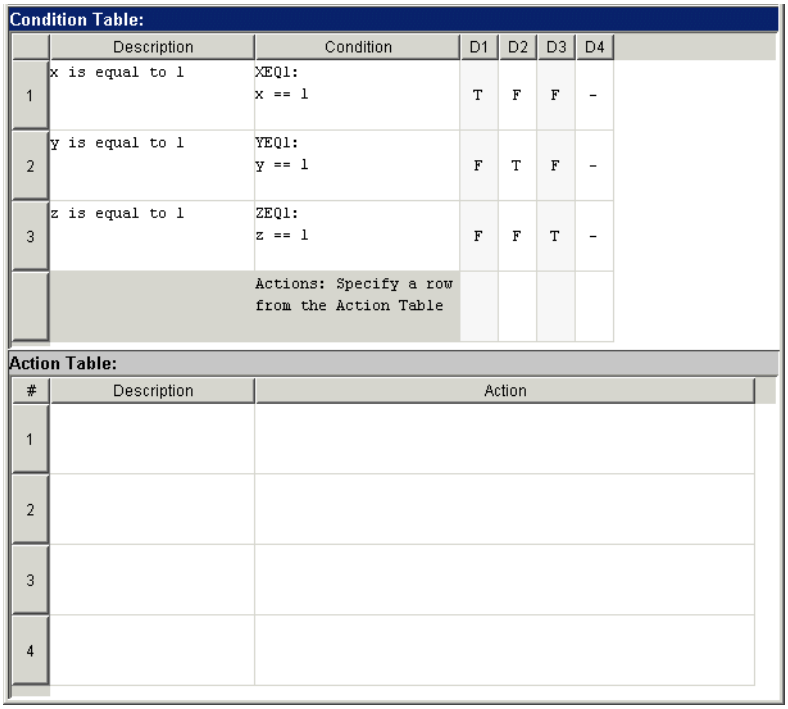
- “Setting Up the Action Table” on page 12-31 — Shows you how to set up the Action table in truth table `ttable`.
- “Programming Actions in Stateflow Classic Action Language” on page 12-32 — Provides sample code in Stateflow action language to program actions in `ttable`. Choose this section if you selected **Stateflow Classic** as the language for this truth table.
- “Programming Actions in Embedded MATLAB Action Language” on page 12-33 — Provides sample M-code to program actions in `ttable`. Choose this section if you selected **Embedded MATLAB** as the language for this truth table.

Setting Up the Action Table

1 Click anywhere in the **Action Table** to select it.

2 Click the Append Row toolbar button three times to add three rows to the bottom of the **Action Table**.

3 Click and drag the bottom border of the truth table editor window down to enlarge it and clearly show all rows of the **Action Table**, as shown.



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		
2		
3		
4		

4 Program the actions using the language you selected for the truth table:

If you selected	Use this procedure
Stateflow Classic	"Programming Actions in Stateflow Classic Action Language" on page 12-32
Embedded MATLAB	"Programming Actions in Embedded MATLAB Action Language" on page 12-33

Programming Actions in Stateflow Classic Action Language

Follow this procedure to program your actions in Stateflow action language:

1 Click the top cell in the **Description** column of the **Action Table.**

The cell is highlighted and a flashing text cursor appears in the cell.

2 Enter the following description:

```
set t to 1
```

Action descriptions are optional, but are carried into the generated code for the truth table as code comments.

3 Press **Tab** 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 (_).

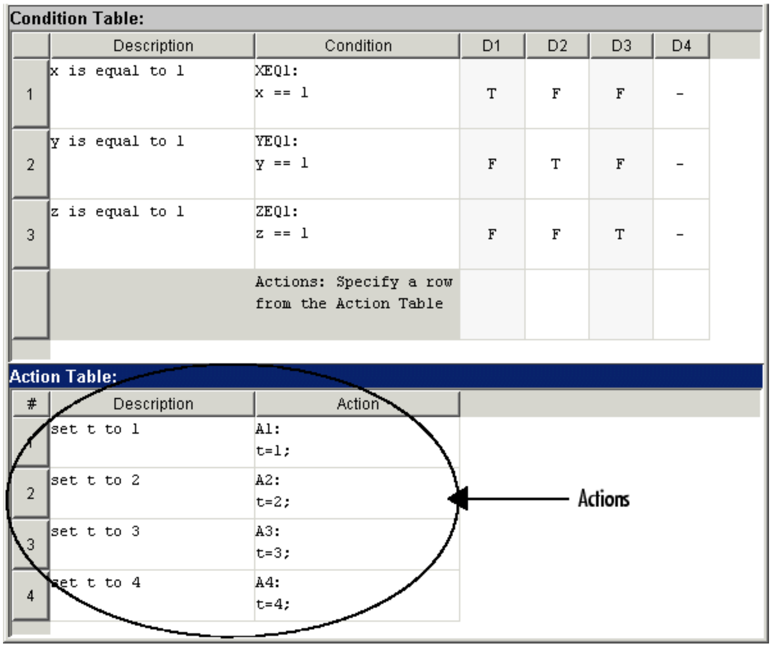
5 Press **Enter** and enter the following text:

```
t=1;
```

You can use data passed to the truth table function through its arguments and return value in truth table actions. The preceding action, `t=1`, sets the value of the return value `t`. You can also specify actions with data defined for a parent object of the truth table, including the Stateflow diagram. Truth table actions can also broadcast or send events that are defined for the truth table, or for a parent, such as the diagram (chart) itself.

If you omit the semicolon at the end of an action, the result of the action is echoed to the MATLAB window when it is executed during simulation. Use this as a debugging tool.

6 Enter the remaining actions in the **Action Table**, as shown in the following:



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	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

Now you are ready to assign actions to decisions, as described in “Assigning Truth Table Actions to Decisions” on page 12-37.

Programming Actions in Embedded MATLAB Action Language

If you selected Embedded MATLAB as your language, you can write M-code to program your actions. M-code allows you to add control flow logic and to call MATLAB functions directly. In the following procedure you will program an action in the truth table ttable, using the following features of the embedded MATLAB syntax:

- Persistent variables
- if ... else ... end control flows
- for loop
- Ability to call the MATLAB function plot directly

Follow these steps:

1 Click the top cell in the **Description** column of the **Action Table.**

The cell is highlighted and a flashing text cursor appears in the cell.

2 Enter the following description:

```
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.
```

Action descriptions are optional, but are carried into the generated code for the truth table as code comments.

3 Press **Tab** 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:

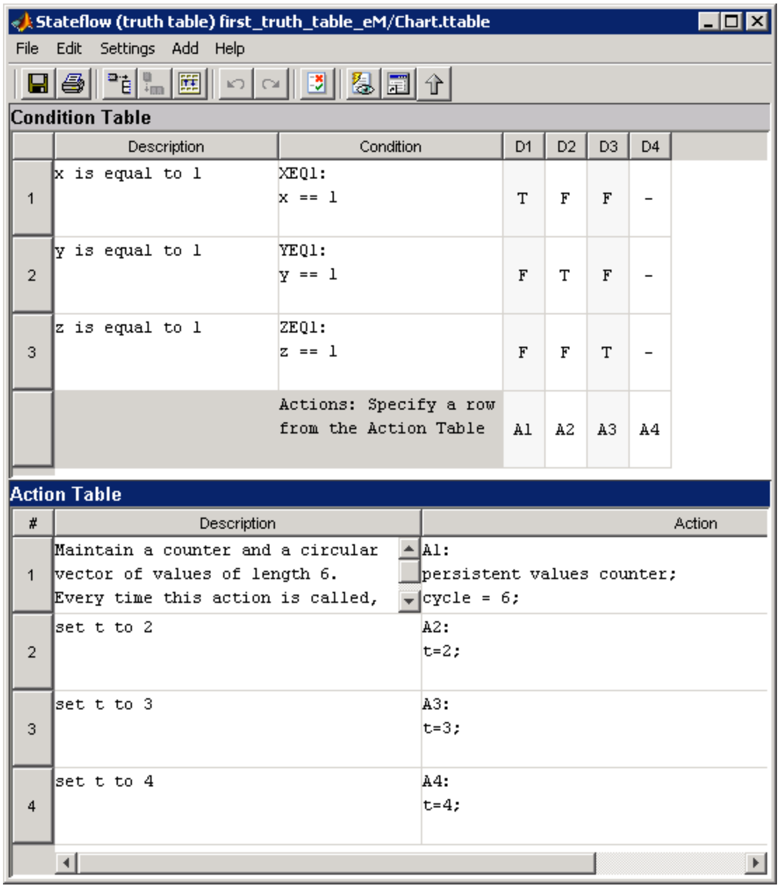
```
persistent values counter;
cycle = 6;
```

```
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 t takes the next value in values vector
t = values( mod(counter, cycle) + 1);
```

You can use data passed to the truth table function through its arguments and return value in truth table actions. The preceding action sets the return value `t` 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 Stateflow diagram. Truth table actions can also broadcast or send events that are defined for the truth table, or for a parent, such as the diagram (chart) itself.

If you omit the semicolon at the end of an action, the result of the action is echoed to the MATLAB window when it is executed during simulation. Use this as a debugging tool.

6 Enter the remaining actions in the **Action Table**, as shown:



Stateflow (truth table) first_truth_table_eM/Chart.ttable
File Edit Settings Add Help

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

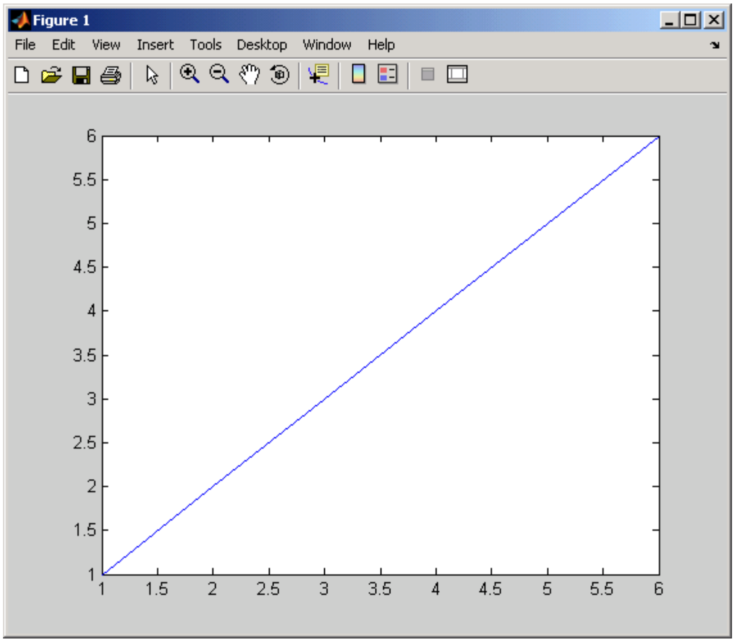
Action Table

#	Description	Action

1	Maintain a counter and a circular
	vector of values of length 6.
	Every time this action is called,
		A1:
		persistent values counter;
		cycle = 6;

2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

Note that if you simulate this model, condition `D1` will always be true, causing action `A1` to execute and display a plot of the content of the vector `values`, as follows:



Now you are ready to assign actions to decisions, as described in "Assigning Truth Table Actions to Decisions" on page 12-37.

Assigning Truth Table Actions to Decisions

You must assign at least one action from the **Action Table** to each decision in the **Condition Table**. This association allows Stateflow to determine what action to execute when a decision tests as true.

In this section, you will learn how to link actions to decisions.

Rules for Assigning Actions to Decisions

Stateflow allows you to be very creative in assigning actions. Here is a list of rules for assigning 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 be entered with the action in the **Action Table**.

- You must specify at least one action for each decision.

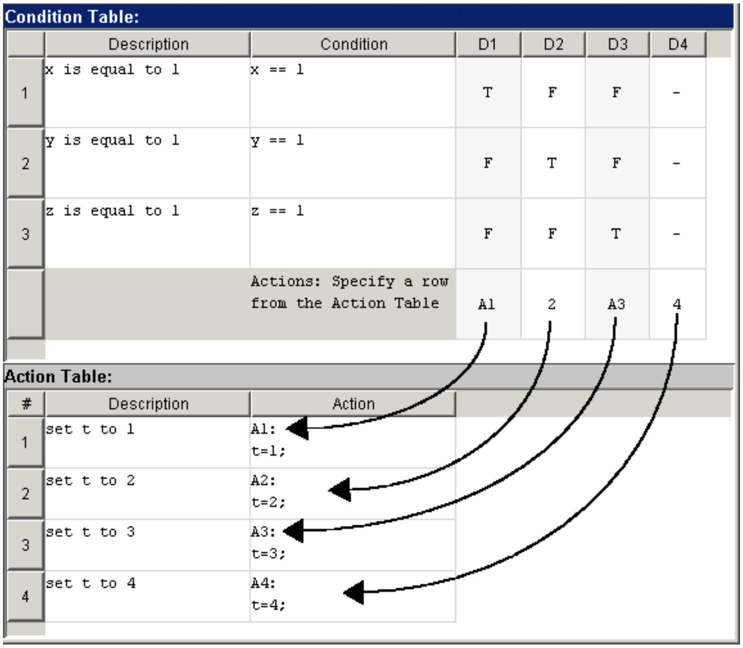
  Actions for decisions are not optional. Each decision must have at least one action specifier that points to an action in the **Action Table**. If you want to specify no action for a decision, specify a row that contains no action statements.

- You can specify multiple actions for a decision with multiple specifiers separated by a comma.

  For example, for the decision column **D1** you can specify A1, A2, A3 or 1, 2, 3 to execute the first three actions if 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.



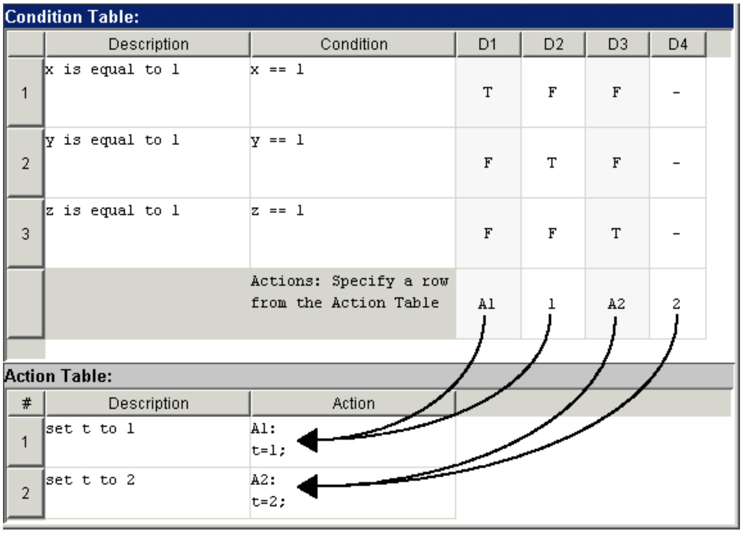
Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	A1	2	A3	4

Action Table:

#	Description	Action
1	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

- You can specify the same action for more than one decision, as shown.



Condition Table:

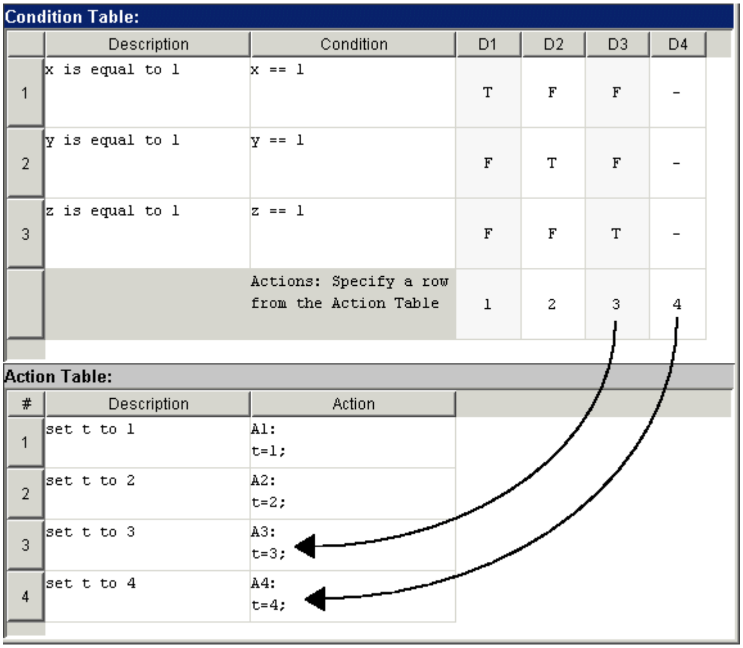
	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	A1	1	A2	2

Action Table:

#	Description	Action
1	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;

- Row number action specifiers in the **Actions** row of the **Condition Table** automatically adjust to changes in the row order of the **Actions Table**.

  In the following example, decisions **D3** and **D4** are assigned the actions in rows 3 and 4 of the **Action Table**, respectively.



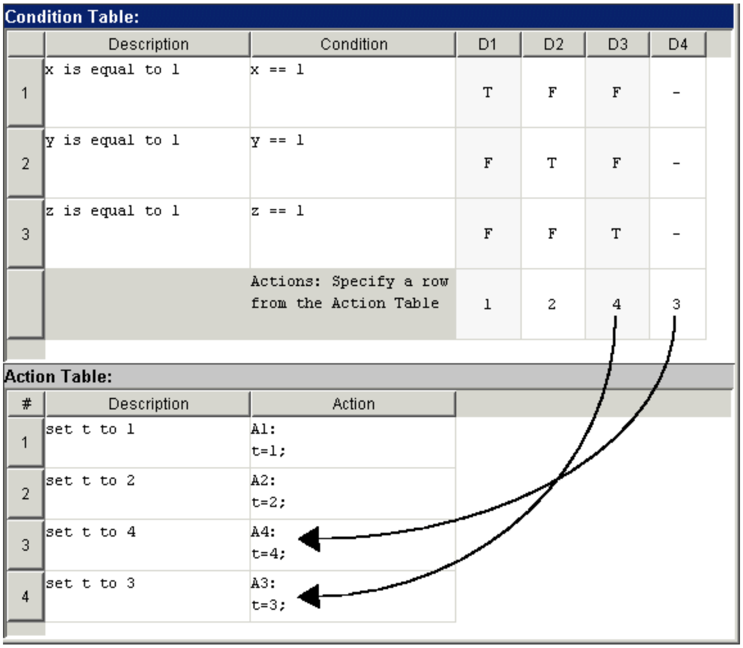
Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	1	2	3	4

Action Table:

#	Description	Action
1	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

Select row 4 in the **Action Table** and select the Move Row Up tool ⬆ to reverse rows 3 and 4, and notice the change in the action specifiers for columns **D3** and **D4**, as shown.



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	1	2	4	3

Action Table:

#	Description	Action
1	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 4	A4: t=4;
4	set t to 3	A3: t=3;

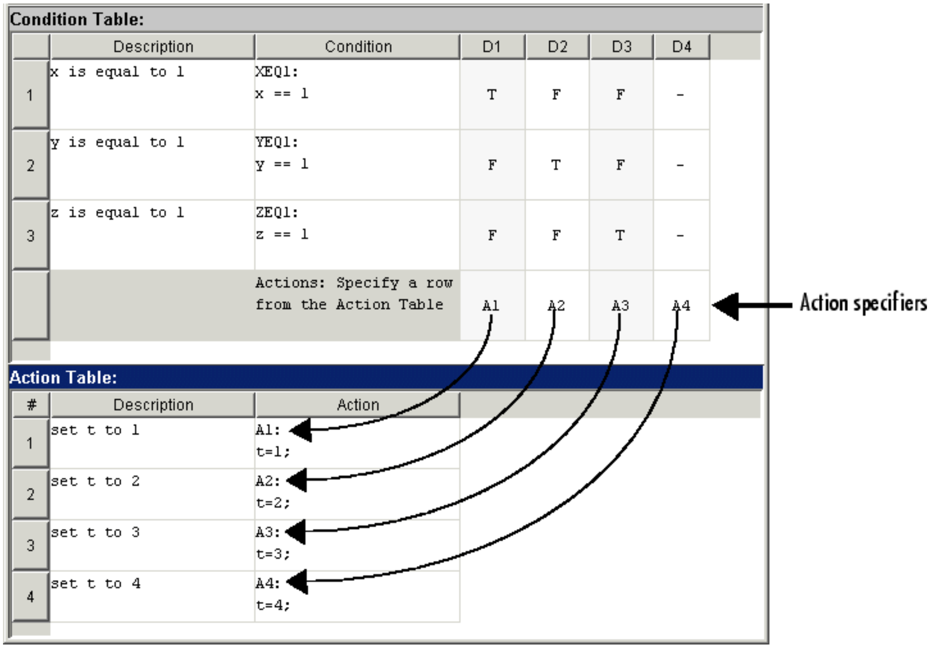
How to Assign Actions to Decisions

This section describes how to assign actions to decisions in the example 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**. Decision **D1** is assigned the action `t=1`, decision **D2** is assigned the action `t=2`, and so on. 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**, that links the action labeled `A1` in the **Action Table** to decision **D1**.

3. Enter the action specifiers for the remaining decision columns as shown in the following:



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	set t to 1	A1: t=1;
2	set t to 2	A2: t=2;
3	set t to 3	A3: t=3;
4	set t to 4	A4: t=4;

Now you are ready to perform the final step in programming a truth table, “Adding Initial and Final Actions” on page 12-42.

Adding Initial and Final Actions

In addition to the actions for decisions, Stateflow also lets you add initial and final actions to the truth table function. Initial actions specify an action that executes before any decisions are tested. Final actions specify an action that executes as the last action before the truth table is exited. To specify initial and final actions for a truth table, use the action labels `INIT` and `FINAL` in the **Action Table**.

Use the following procedure to add initial and final actions to display diagnostic messages in the MATLAB Command Window before and after the execution of the truth table `ttable`:

1 In the truth table editor for the truth table `ttable`, right-click row 1 of the **Action Table**.

A pop-up menu appears.

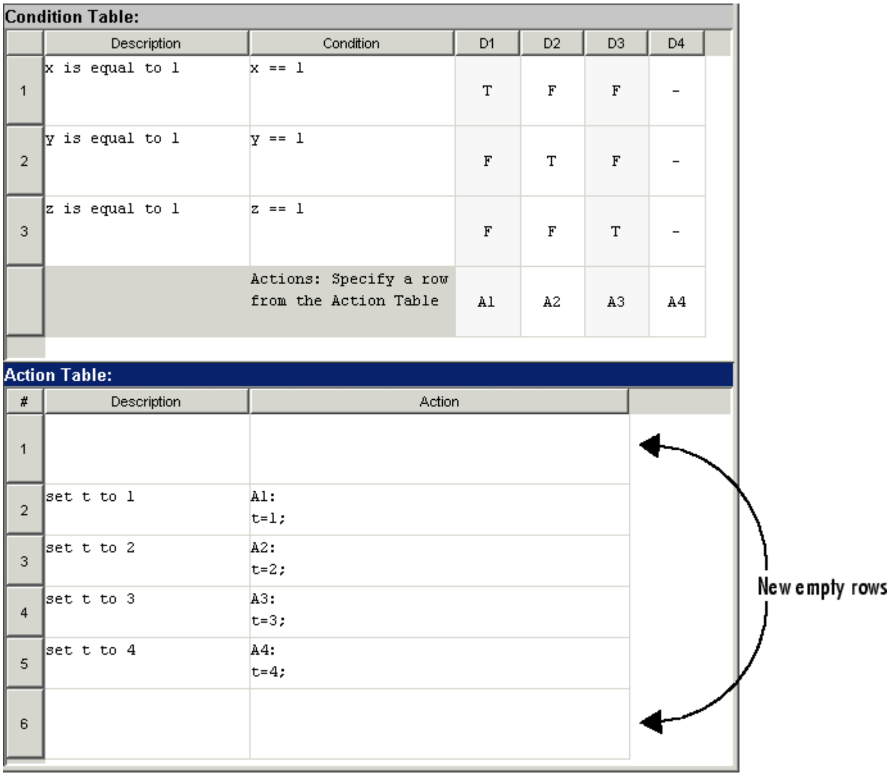
2 From the pop-up menu, select **Insert Row**.

A blank row is inserted at the beginning of the **Action Table**.

3 Click the Append Row tool .

A blank row is appended to the bottom of the **Action Table**.

4 Click and drag the bottom border of the truth table editor to expose all six rows of the **Action Table**, as shown.



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	A1	A2	A3	A4

Action Table:

#	Description	Action
1		
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		

New empty rows

5 Add the initial action in row 1 as follows:

Truth Table Type	Description	Action
Stateflow Classic	Initial action:Display message	`INIT:ml.disp('truth table ttable entered');`
Embedded MATLAB	Initial action:Display message	`INIT:disp('truth table ttable entered');`

6 Add the final action in row 6 as follows:

Truth Table Type	Description	Action
Stateflow Classic	Final action:Display message	`FINAL:`ml.disp('truth table ttable exited');
Embedded MATLAB	Final action:Display message	`FINAL:disp('truth table ttable exited');`

Even though the initial and final actions for the preceding truth table example are shown in the first and last rows of the **Action Table**, you can enter these actions in any row. You can also explicitly assign the initial and final actions to decisions by using the action specifier `INIT` or `FINAL` in the **Actions** row of the **Condition Table**.

Debugging a Truth Table

In “Programming a Truth Table” on page 12-24 you completed a Simulink model with a truth table by programming the truth table. Now you need to begin the process of debugging the truth table. Use the following topics to debug the truth table `ttable` in its Stateflow diagram.

1. “Checking Truth Tables for Errors” on page 12-45 — Shows you how to run diagnostics on truth tables to check for syntax errors.
2. “Debugging a Truth Table During Simulation” on page 12-46 — Shows you how to debug each condition and action of a truth table during simulation.

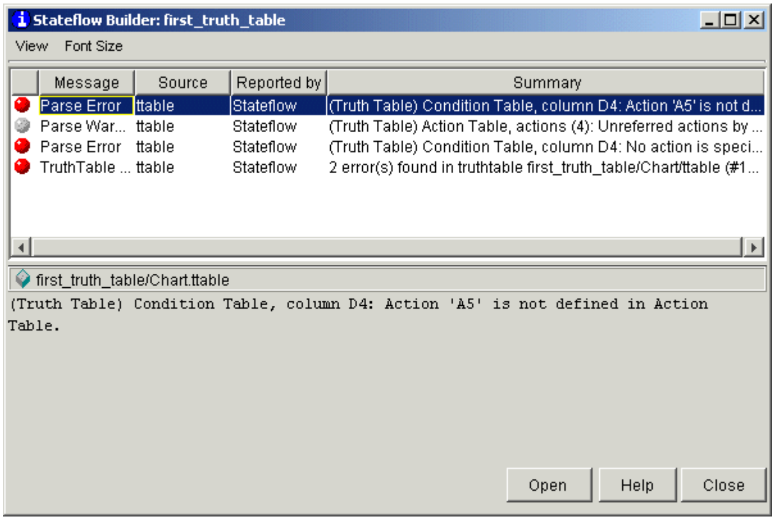
Checking Truth Tables for Errors

Once you completely specify your truth tables you need to 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 “Correcting Overspecified and Underspecified Truth Tables” on page 12-55.

To check for syntax errors, follow these steps:

1. Double-click the truth table to open its editor.
2. In the Truth Table Editor toolbar, click the Run Diagnostics button.

   If there are no errors or warnings, the **Builder** window appears and reports a message of success. If errors are found, the **Builder** window lists them. For example, if you change the action for decision column **D4** to an action that does not exist, the following **Builder** window appears:



	Message	Source	Reported by	Summary
●	Parse Error	ttable	Stateflow	(Truth Table) Condition Table, column D4: Action 'A5' is not d...
●	Parse War...	ttable	Stateflow	(Truth Table) Action Table, actions (4): Unreferred actions by ...
●	Parse Error	ttable	Stateflow	(Truth Table) Condition Table, column D4: No action is speci...
●	TruthTable ...	ttable	Stateflow	2 error(s) found in truthtable first_truth_table/Chart/ttable (#1...

first_truth_table/Chart.ttable

```
(Truth Table) Condition Table, column D4: Action 'A5' is not defined in Action
Table.
```

Stateflow highlights each detected error with a red button and each warning with a gray button. The first error message is highlighted in the top pane and the diagnostic message is displayed in the bottom pane.

Truth table diagnostics run automatically when you start simulation of the model with a new or modified truth table. If no errors are found, the **Builder** window does not appear and simulation commences immediately.

Debugging a Truth Table During Simulation

There are several ways to debug truth tables during simulation:

Method	Use With	How To Do It
Use Stateflow debugging tools to step through each condition and action, and monitor data values during simulation.	Stateflow Classic truth table and Embedded MATLAB truth table	See "Using Stateflow Debugging Tools" on page 12-47.
Use Embedded MATLAB debugging tools to step through embedded MATLAB code generated by the truth table.	Embedded MATLAB truth table only	See "Using Embedded MATLAB Debugging Tools" on page 12-54.

Using Stateflow Debugging Tools

When you use Stateflow debugging tools to debug truth tables, you must perform these tasks:

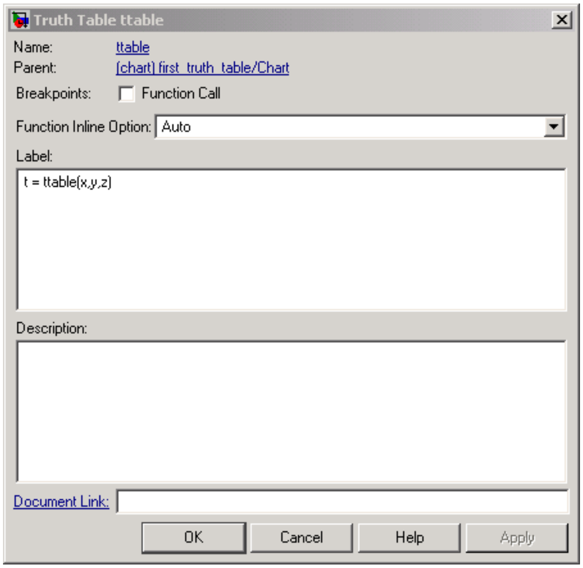
1. Specify a breakpoint for the call to the truth table.
2. Step through the conditions and actions.

Specifying a Breakpoint for the Call to a Truth Table. Before you debug the truth table during simulation, you must set a breakpoint for the truth table in its properties dialog. This breakpoint pauses execution during simulation so that you can debug each execution step of a truth table using the Stateflow Debugger.

Follow these steps:

1. In the Stateflow diagram editor, right-click the truth table.
2. In the resulting pop-up shortcut menu, select **Properties**.

   The **Truth Table** properties dialog appears, as shown.



Truth Table ttable

Name: ttable

Parent: (chart) first_truth_table/Chart

Breakpoints: □ Function Call

Function Inline Option: Auto

Label:

t = ttable(x,y,z)

Description:

Document Link:

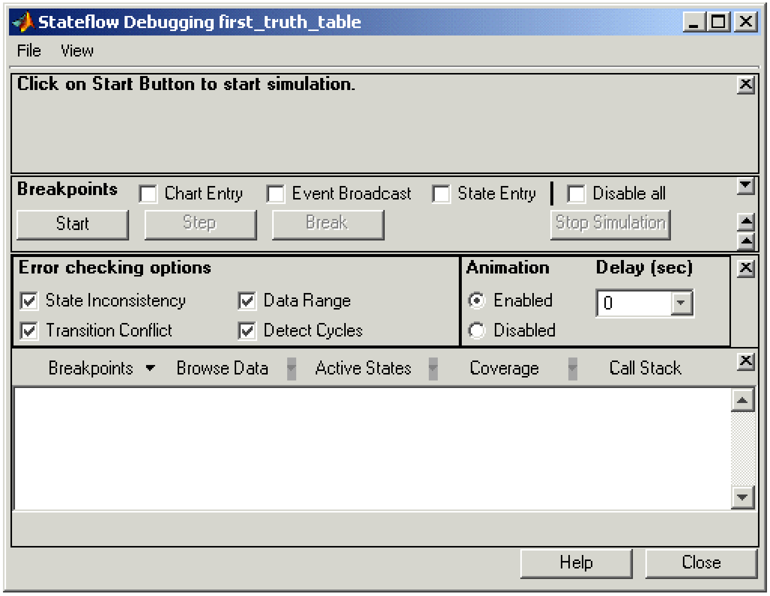
3 For **Breakpoints**, select **Function Call**.

This sets a breakpoint to occur when this truth table function is called in the Stateflow diagram during simulation.

4 Select **OK** to save settings and close the **Truth Table** properties dialog.

Stepping Through Conditions and Actions of a Truth Table. After setting a breakpoint for the truth table function call, you can step through the conditions and actions by following these steps:

1 Select the Debug button in the Stateflow diagram editor toolbar to start the **Stateflow Debugging** window as shown.



Click on Start Button to start simulation.

□ Chart Entry □ Event Broadcast □ State Entry □ Disable all

☑ State Inconsistency ☑ Data Range

☑ Transition Conflict ☑ Detect Cycles

● Enabled ○ Disabled

Delay (sec): 0

2 From the **Stateflow Debugging** window, select the **Start** button to begin simulation of your model.

When you simulate your model, Stateflow checks the truth tables automatically for syntactical errors if they have changed since the last simulation. If you receive errors or warnings, make corrections before you try to simulate again.

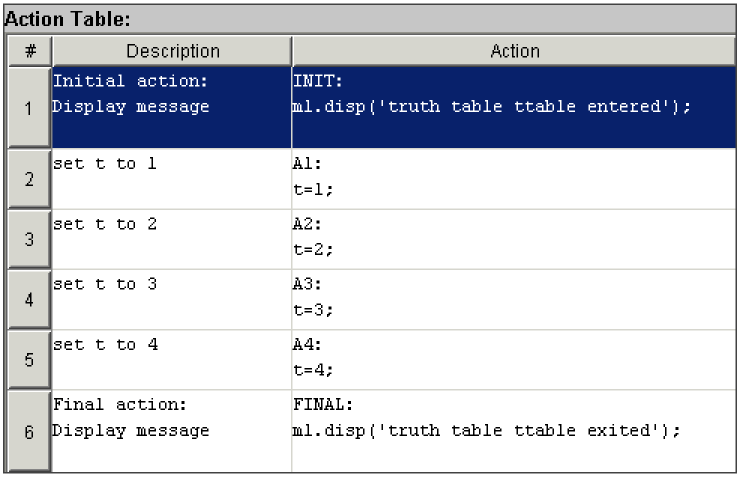
If Stateflow finds no syntactical errors in the truth table, Stateflow builds a simulation application and begins the simulation of your model.

3 Wait until the breakpoint for the call to the truth table is reached.

When this breakpoint is encountered, the truth table `ttable` appears and the **Start** button in the Stateflow Debugger changes to the **Continue** button.

4 In the **Stateflow Debugging** window, click the **Step** button three times to advance simulation through the call to the truth table.

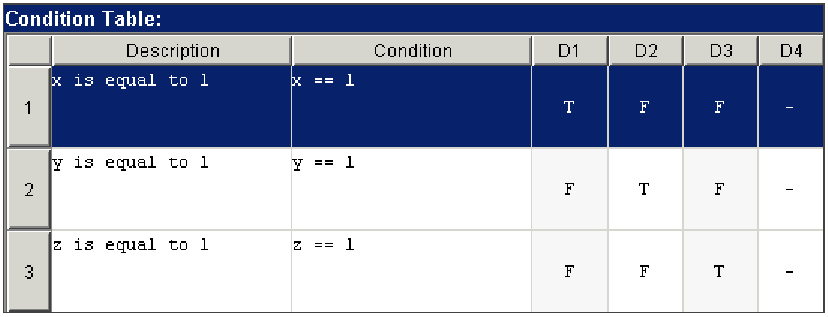
The `INIT` action of the truth table is highlighted prior to its execution.



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');

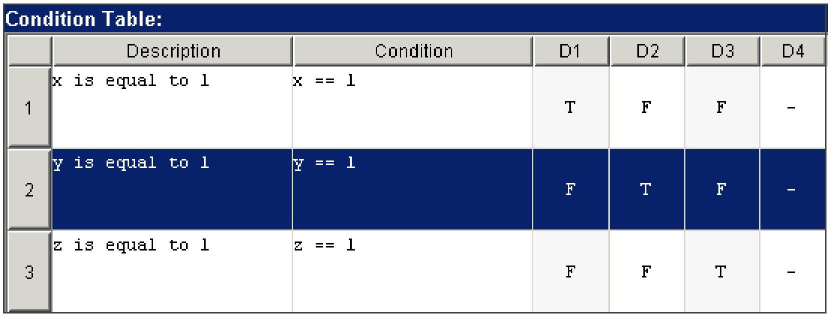
5 Click **Step** to execute the `INIT` action and advance truth table execution to the first condition, as shown.



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-

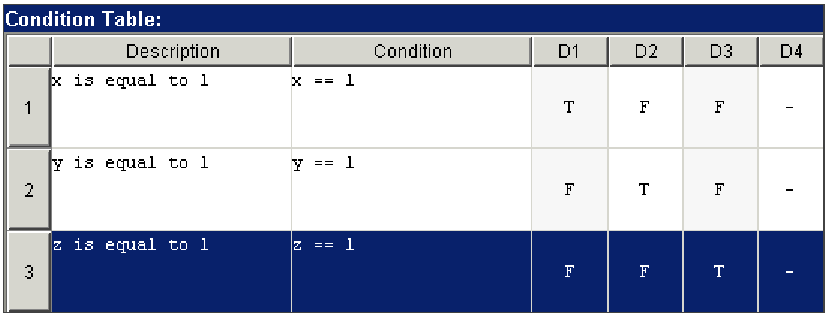
6 Click **Step** to evaluate the first condition and advance truth table execution to the second condition.



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-

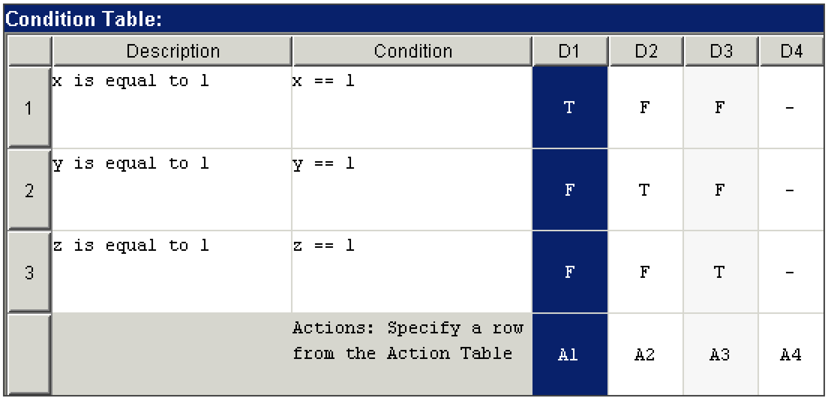
7 Click **Step** to evaluate the second condition and advance truth table execution to the third condition.



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-

8 Click **Step** to evaluate the third condition and advance truth table execution to the first decision.

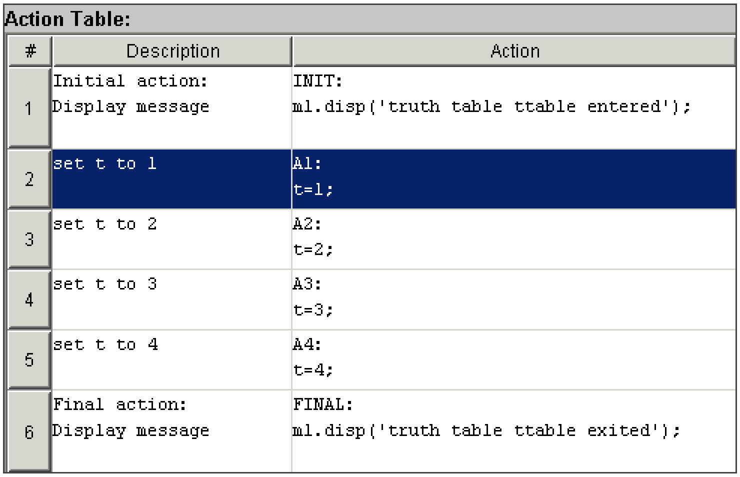


Condition Table:

	Description	Condition	D1	D2	D3	D4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-
		Actions: Specify a row from the Action Table	A1	A2	A3	A4

9 Click **Step** twice.

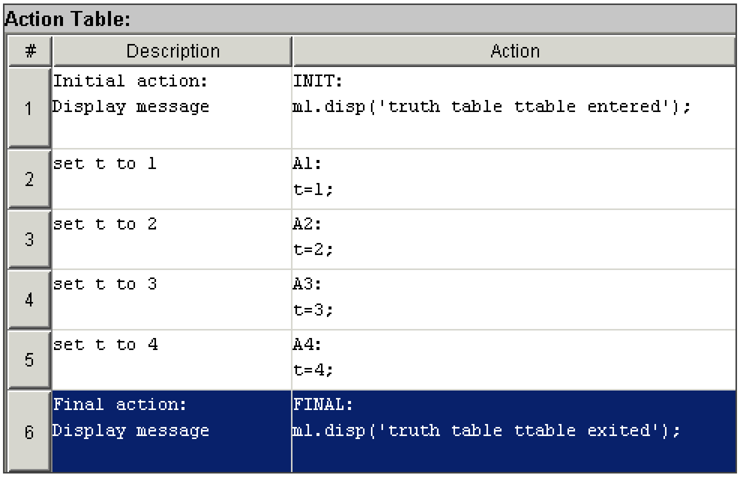
Because the first decision is true, truth table execution advances to its action, which is labeled `A1`.



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');

10 Click **Step** three times to execute action `A1` and advance to the `FINAL` action.

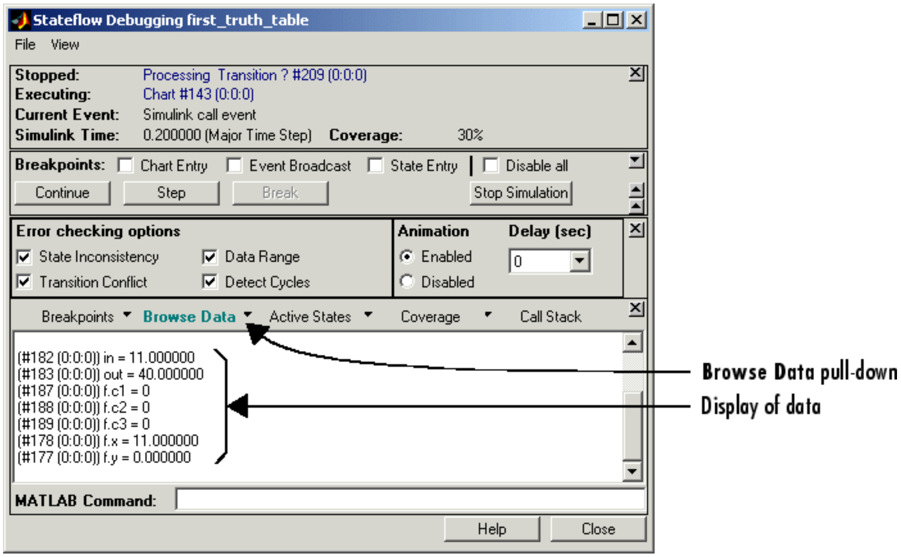


Action Table:

#	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');

11 In the **Stateflow Debugging** window, from the **Browse Data** pull-down, select **All Data (Current Chart)**.

A continuously updated display appears in the bottom pane of the **Stateflow Debugging** window, as shown.



Stateflow Debugging first_truth_table

Stopped: Processing Transition ? #209 (0:0:0)
Executing: Chart #143 (0:0:0)
Current Event: Simulink call event
Simulink Time: 0.200000 (Major Time Step) **Coverage:** 30%

Breakpoints: □ Chart Entry □ Event Broadcast □ State Entry □ Disable all

Error checking options
☑ State Inconsistency ☑ Data Range
☑ Transition Conflict ☑ Detect Cycles

Animation ● Enabled ○ Disabled **Delay (sec)** 0

```
(#182 (0:0:0)) in = 11.000000
(#183 (0:0:0)) out = 40.000000
(#187 (0:0:0)) f.c1 = 0
(#188 (0:0:0)) f.c2 = 0
(#189 (0:0:0)) f.c3 = 0
(#178 (0:0:0)) f.x = 11.000000
(#177 (0:0:0)) f.y = 0.000000
```

MATLAB Command:

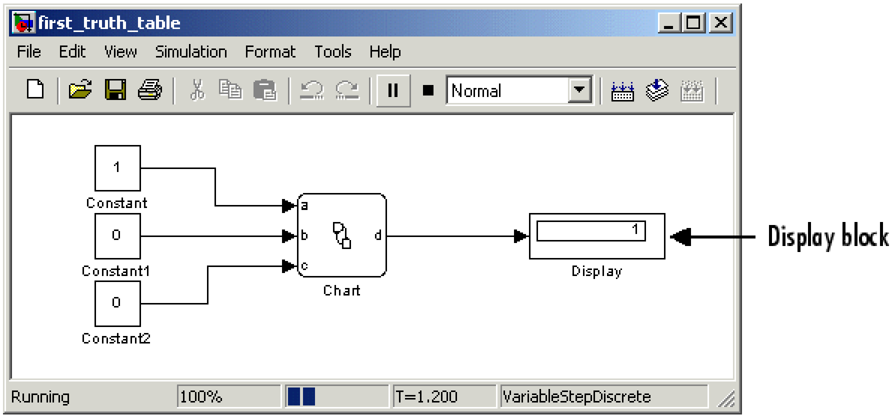
Browse Data pull-down

Display of data

You can use this display to monitor Stateflow data during simulation.

12 In the **Stateflow Debugging** window, click **Step**.

This executes the final action and exits the truth table. The Display block in the Simulink window should now display the number 1, as shown.



13 Change the values of the Constant blocks and continue stepping through the simulation.

For example, you might want to set the Constant1 block to 1 (sets b to 1) and the other Constant blocks to 0 (sets a and c to 0). Or you might want to set all the Constant blocks to 0. To enter a new value for a Constant block, double-click it. In the resulting **Block Parameters** dialog enter the new value in the **Constant value** field.

Using Embedded MATLAB Debugging Tools

Embedded MATLAB truth tables generate content as embedded MATLAB code, a format that offers advantages for debugging. You can set breakpoints on any line of generated code (whereas you cannot set breakpoints directly on a truth table). You can debug code generated by Embedded MATLAB truth tables the same way you debug an Embedded MATLAB function, as described in “Debugging an Embedded MATLAB Function”.

For more information about how to generate content for truth tables, see “How Stateflow Realizes Truth Tables” on page 12-63.

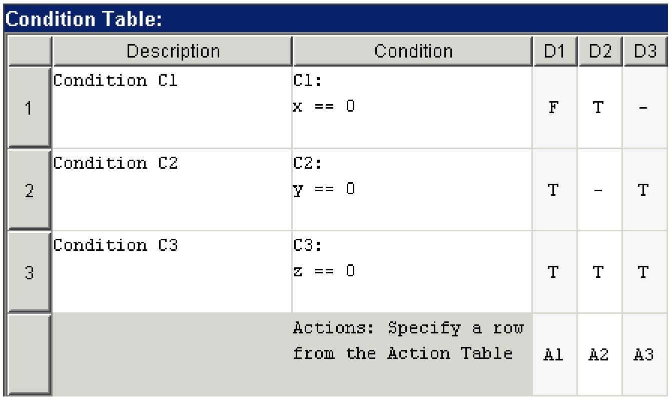
Correcting Overspecified and Underspecified Truth Tables

An *overspecified truth table* contains a decision that will never be executed because it is already specified in a previous decision in the **Condition Table**. An *underspecified truth table* lacks one or more possible decisions that might require an action to avoid undefined behavior in the application. Stateflow helps you correct overspecified and underspecified truth tables, as described in the following topics:

- "Defining an Overspecified Truth Table" on page 12-55 — Gives you an example of an overspecified truth table and a truth table that is not overspecified.
- "Defining an Underspecified Truth Table" on page 12-56 — Gives you an example of an underspecified truth table and a truth table that is not underspecified.

Defining an Overspecified Truth Table

An overspecified truth table contains at least one decision that will never be executed because it is already specified in a previous decision in the **Condition Table**. The following is the **Condition Table** of an overspecified truth table:

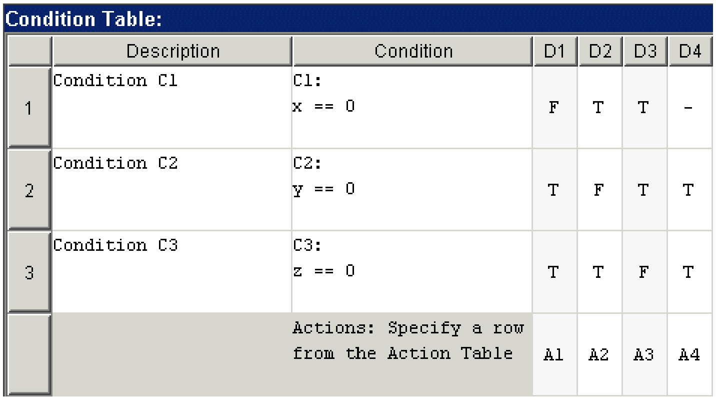


Condition Table:

	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 have already been specified by decisions **D1** (FTT) and **D2** (TTT and TFT). Therefore column **D3** is an overspecification.

The following is the **Condition Table** of a truth table that appears to be overspecified, but is not:



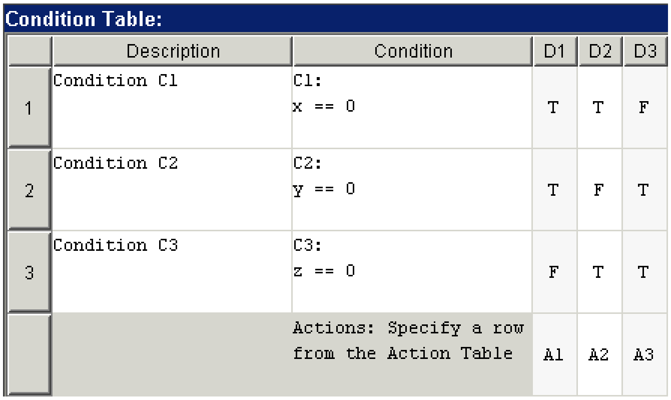
Condition Table:

	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 is specified by decision **D1**, but TTT is not specified in a previous decision column. Therefore, this **Condition Table** is not overspecified.

Defining an Underspecified Truth Table

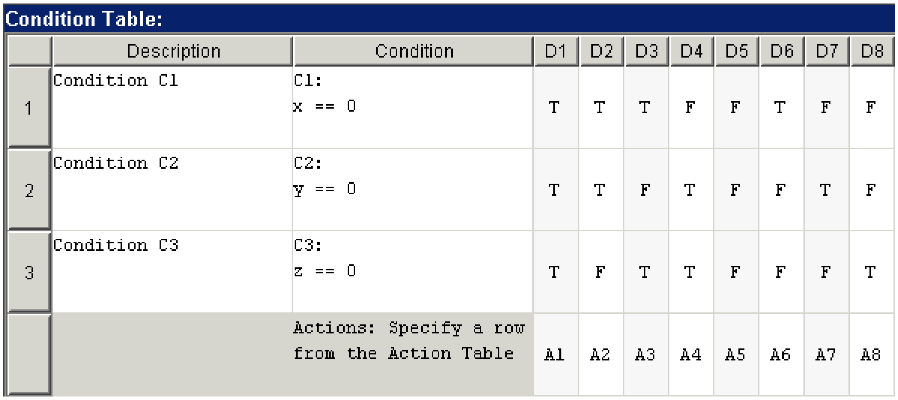
An underspecified truth table lacks one or more possible decisions that might require an action to avoid undefined behavior. The following is the **Condition Table** of an underspecified truth table:



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

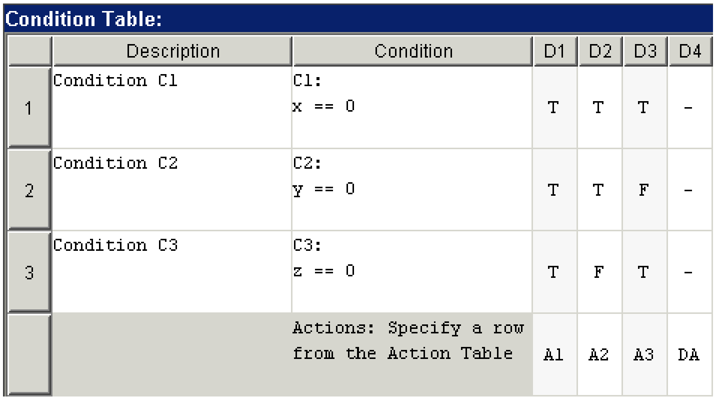
Complete coverage of the conditions in the preceding truth table requires a **Condition Table** with every possible decision, like the following example:



Condition Table:

	Description	Condition	D1	D2	D3	D4	D5	D6	D7	D8
1	Condition C1	C1: x == 0	T	T	T	F	F	T	F	F
2	Condition C2	C2: y == 0	T	T	F	T	F	F	T	F
3	Condition C3	C3: z == 0	T	F	T	T	F	F	F	T
		Actions: Specify a row from the Action Table	A1	A2	A3	A4	A5	A6	A7	A8

A possible workaround is to specify an action for all other possible decisions through a default decision, as in the following example:



Condition Table:

	Description	Condition	D1	D2	D3	D4
1	Condition C1	C1: x == 0	T	T	T	-
2	Condition C2	C2: y == 0	T	T	F	-
3	Condition C3	C3: z == 0	T	F	T	-
		Actions: Specify a row from the Action Table	A1	A2	A3	DA

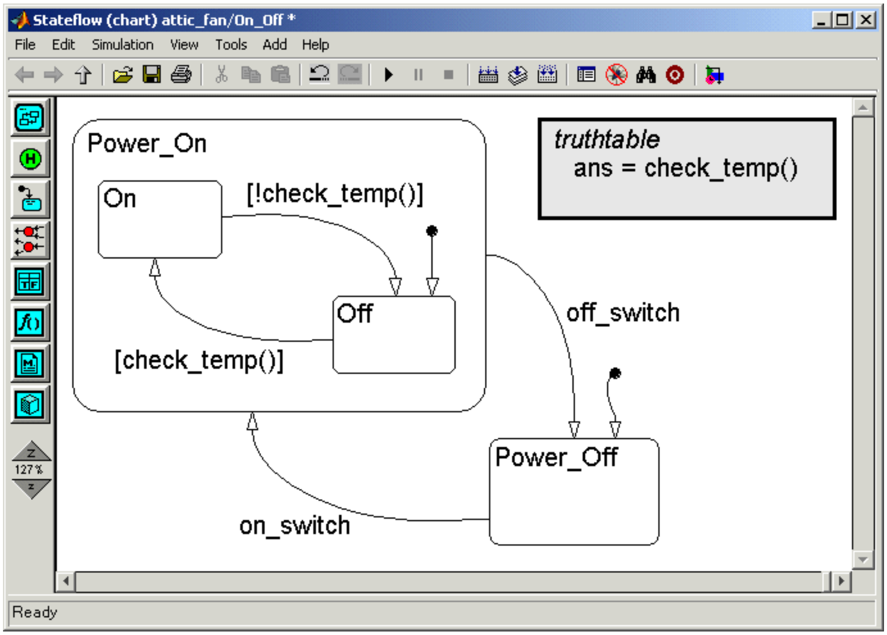
The last decision column is the default decision for the truth table. The default decision covers any remaining decisions not tested for in the preceding decision columns. See “The Default Decision Column” on page 12-29 for an example and more complete description of the default decision column for a **Condition Table**.

Model Coverage for Truth Tables

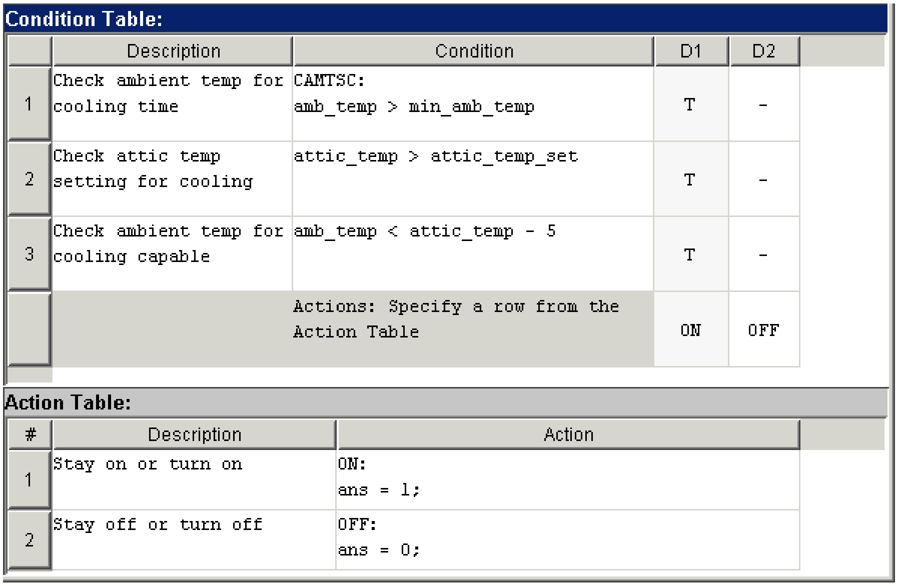
Stateflow reports model coverages for the decisions made by the objects in a Stateflow diagram during model simulation. The model coverage report includes coverage for the decisions made by truth table functions, as follows:

Type of Truth Table	Type of Coverage
Stateflow Classic	Stateflow generates coverage reports for conditions only.
Embedded MATLAB	Stateflow generates coverage reports for conditions and actions because the embedded MATLAB action languages lets you specify decision points in actions using control flow constructs such as loops and switch statements.

This section examines model coverage for an example Stateflow Classic truth table, `check_temp`, which is tested during simulation in the following Stateflow diagram:



The following shows the contents of the `check_temp` truth table:



Condition Table:

	Description	Condition	D1	D2
1	Check ambient temp for cooling time	CAMTSC: amb_temp > min_amb_temp	T	-
2	Check attic temp setting for cooling	attic_temp > attic_temp_set	T	-
3	Check ambient temp for cooling capable	amb_temp < attic_temp - 5	T	-
		Actions: Specify a row from the Action Table	ON	OFF

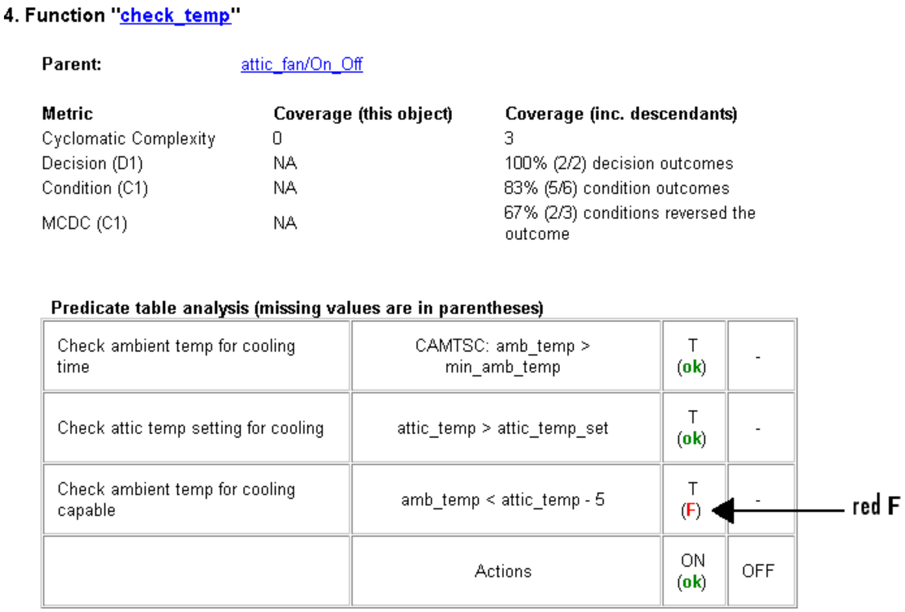
Action Table:

#	Description	Action
1	Stay on or turn on	ON: ans = 1;
2	Stay off or turn off	OFF: ans = 0;

You generate model coverage reports for a model during simulation. You first specify the creation of the reports in Simulink and then simulate the model. When simulation ends, a model coverage report appears in a browser window. See “Making Model Coverage Reports” on page 15-45 for information on how to set up a model coverage report.

Note The Model Coverage tool requires a Simulink Verification and Validation license.

The following is the part of a model coverage report that reports on the `check_temp` truth table:



4. Function "check_temp"

Parent: attic_fan/On_Off

Metric	Coverage (this object)	Coverage (inc. descendants)
Cyclomatic Complexity	0	3
Decision (D1)	NA	100% (2/2) decision outcomes
Condition (C1)	NA	83% (5/6) condition outcomes
MCDC (C1)	NA	67% (2/3) conditions reversed the outcome

Predicate table analysis (missing values are in parentheses)

Check ambient temp for cooling time	CAMTSC: amb_temp > min_amb_temp	T (ok)	-
Check attic temp setting for cooling	attic_temp > attic_temp_set	T (ok)	-
Check ambient temp for cooling capable	amb_temp < attic_temp - 5	T (F)	-
	Actions	ON (ok)	OFF

Coverage for the truth table function in the **Coverage (this object)** column shows no valid coverage values. The reason for this is that the container object for the truth table function, the chart, makes no decision on whether to execute the `check_temp` truth table or not.

Stateflow implements a Stateflow Classic truth table by generating a graphical function for it. The decision logic of the truth table is implemented internally in the transitions of the graphical function generated for the truth table. See "How Stateflow Realizes Truth Tables" on page 12-63 for a description of the generated graphical function for a truth table.

The transitions of the generated graphical function for a truth table contain the decisions and conditions of the truth table. Coverage for the descendants in the **Coverage (inc. descendants)** column includes coverage for these conditions and decisions, which are tested when the truth table function is called.

In the case of the `check_temp` truth table, the only decision covered in the model coverage report is the **D1** decision. There is no model coverage for the default decision, **D2**.

Note All logic that leads to taking a default decision is based on a false outcome for all preceding decisions. This means that no logic is required for the default decision, which receives no model coverage.

Coverages for the **D1** decision and its individual conditions in the `check_temp` truth table function are as follows:

- Decision coverage for the **D1** decision is 100% because this decision was tested both true and false during simulation.
- Condition coverage for the three conditions of the **D1** decision indicate that 5 of 6 possible T/F values were tested.

  Because each condition can have an outcome value of `T` or `F`, three conditions can have 6 possible values. During simulation, only 5 of 6 were tested. The **D1** decision coverage column shows that the last condition received partial condition coverage by not evaluating to false (F) during simulation. The missing occurrence of the false (F) condition outcome is indicated by the appearance of a red `F` character.
- MCDC coverage looks for decision reversals that occur because one condition outcome changes from `T` to `F` or from `F` to `T`. The **D1** decision reverses when any of the conditions changes from `T` to `F`. This means that the outcomes `FTT`, `TFT`, and `TTF` reverse this decision by a change in the value of one condition.

  The top two conditions for the D1 decision tested both true (`T`) and false (`F`) with a resulting reversal in the decision from true (`T`) to false (`F`). However, the bottom condition tested only a true (`T`) outcome but no false (`F`) outcome (appearance of red `F` character). Therefore, two of a possible three reversals were observed and coverage is 2/3 = 67%.
- The `(ok)` next to the `ON` action label indicates that its decision realized both true (`T`) and false (`F`) during simulation. Because the default decision is based on no logic of its own, it does not receive the `(ok)` mark.

How Stateflow Realizes Truth Tables

Stateflow realizes the logical behavior specified in a truth table by generating content as follows:

Type of Truth Table	Generated Content
Stateflow Classic	Graphical function
Embedded MATLAB	Embedded MATLAB code

This section describes the mechanics of truth table generation in Stateflow:

- "Viewing Generated Content" on page 12-63 — Describes how to view the generated content of truth tables.
- "How Stateflow Generates Graphical Functions for Truth Tables" on page 12-64 — Describes how Stateflow generates a graphical function to represent the logic of a Stateflow Classic truth table.
- "How Stateflow Generates Embedded MATLAB Code for Truth Tables" on page 12-68 — Describes how Stateflow generates Embedded MATLAB code to represent the logic of an Embedded MATLAB truth table.

Viewing Generated Content

Stateflow generates content for a truth table when you simulate your model. Stateflow regenerates content whenever a truth table changes. To view the generated content of a truth table, follow these steps:

1 Simulate the model that contains the truth table.

2 Double-click the truth table to open its editor.

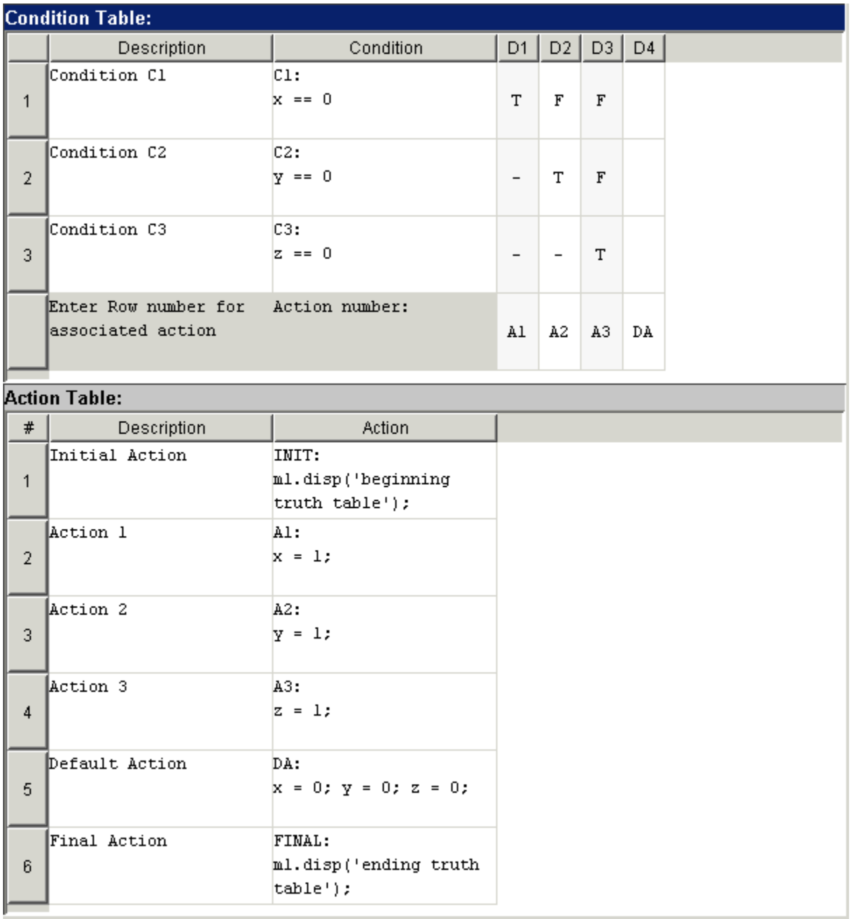
3 Select the **View Generated Content** button.

   Stateflow Classic truth tables display generated content as described in "How Stateflow Generates Graphical Functions for Truth Tables" on page 12-64.

How Stateflow Generates Graphical Functions for Truth Tables

This section describes how Stateflow translates the logic of a Stateflow Classic truth table into a graphical function.

In the following example, a Stateflow Classic truth table has three conditions, four decisions and actions, and initial and final actions:



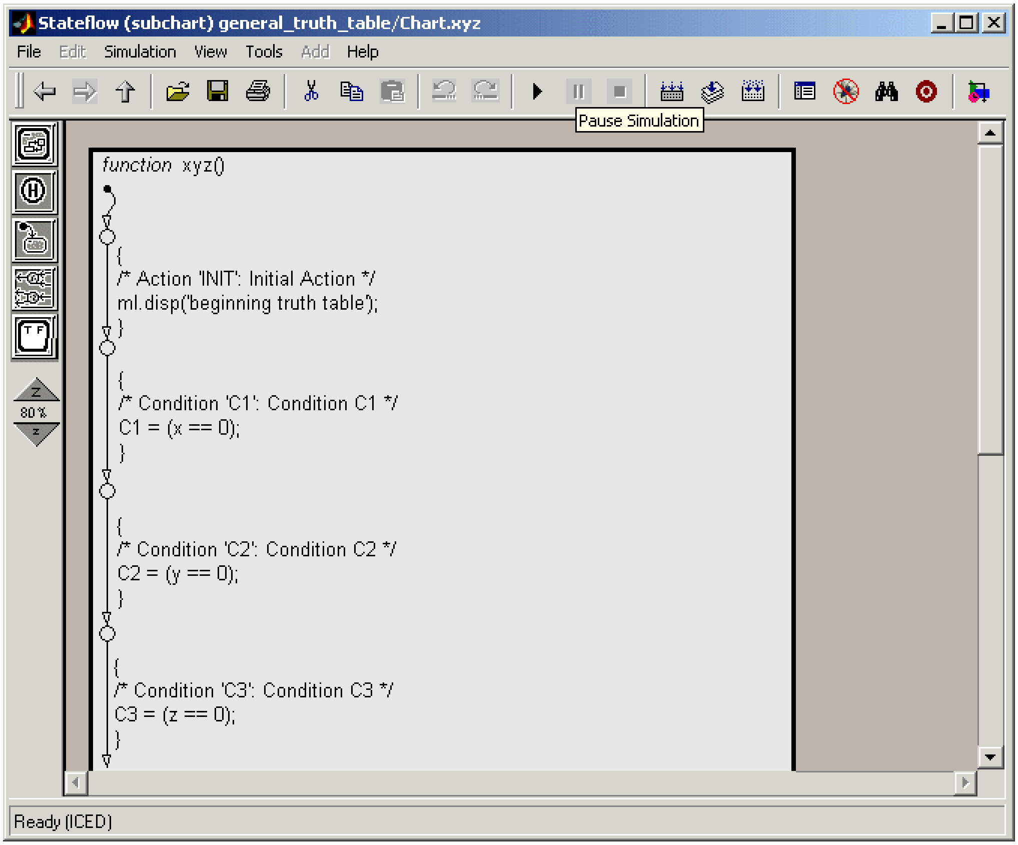
Condition Table:

	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	
	Enter Row number for associated action	Action number:	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 generates the following graphical function for the preceding truth table:



Stateflow (subchart) general_truth_table/Chart.xyz
File Edit Simulation View Tools Add Help
Pause Simulation
80 %
Ready (ICED)

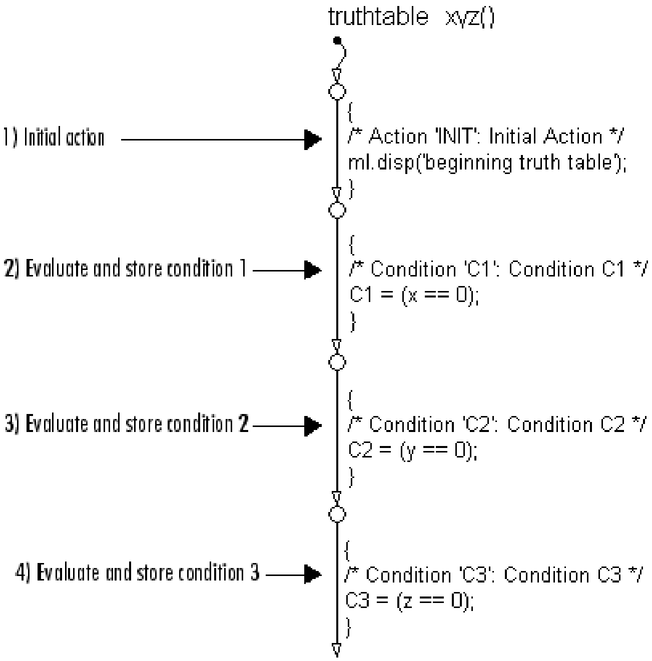
```
function xyz()
{
/* Action 'INIT': Initial Action */
ml.disp('beginning truth table');
}
{
/* Condition 'C1': Condition C1 */
C1 = (x == 0);
}
{
/* Condition 'C2': Condition C2 */
C2 = (y == 0);
}
{
/* Condition 'C3': Condition C3 */
C3 = (z == 0);
}
```

Stateflow uses the top half of the generated function to do the following:

- Perform initial actions
- Evaluate the conditions and store the results in temporary data variables.

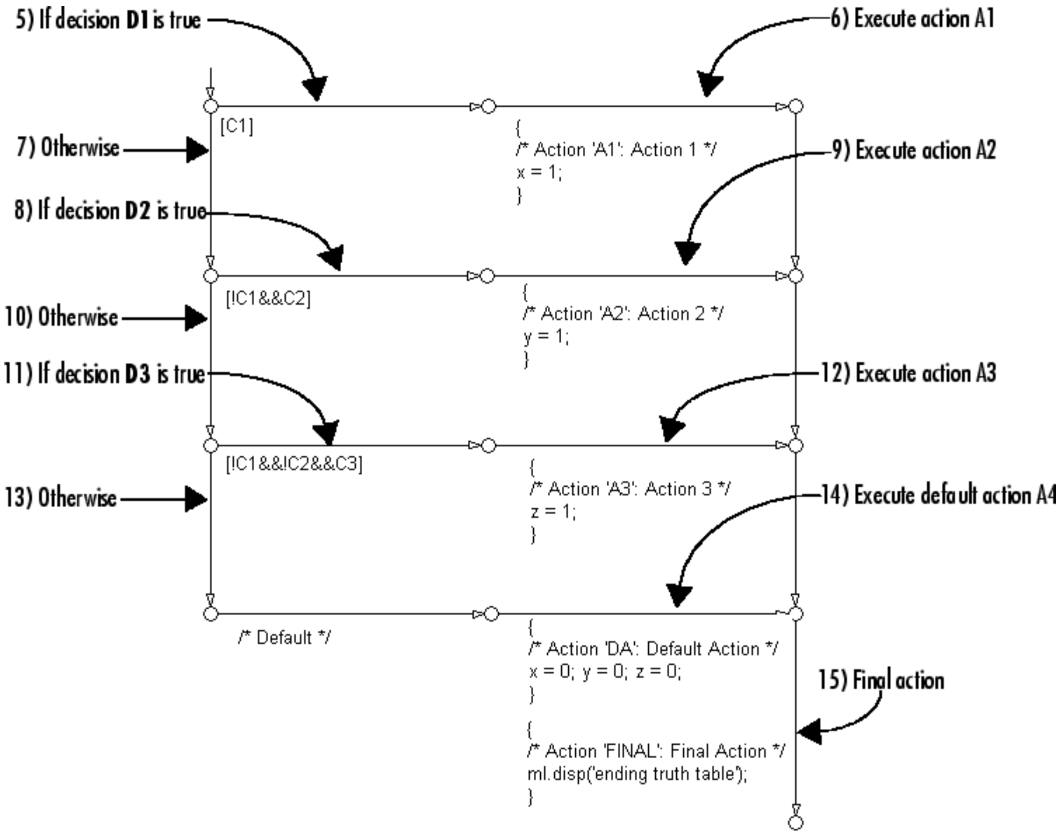
  The temporary data for storing conditions is based on the labels that you enter for the conditions. If no labels are specified, temporary data variables are named by Stateflow.

The following generated flow diagram for the `check_temp` truth table shows this process, which includes number steps to show the order of execution:


truthtable xyz()
1) Initial action
2) Evaluate and store condition 1
3) Evaluate and store condition 2
4) Evaluate and store condition 3

```
{
/* Action 'INIT': Initial Action */
ml.disp('beginning truth table');
}
{
/* Condition 'C1': Condition C1 */
C1 = (x == 0);
}
{
/* Condition 'C2': Condition C2 */
C2 = (y == 0);
}
{
/* Condition 'C3': Condition C3 */
C3 = (z == 0);
}
```

The stored values for the conditions are used in the bottom half of the function to make decisions on which action to perform. The following shows the remaining half of the generated function, along with numbered steps for showing the order of consideration for each condition and action:



```
{
/* Action 'A1': Action 1 */
x = 1;
}
```

```
{
/* Action 'A2': Action 2 */
y = 1;
}
```

```
{
/* Action 'A3': Action 3 */
z = 1;
}
```

```
{
/* Action 'DA': Default Action */
x = 0; y = 0; z = 0;
}
```

```
{
/* Action 'FINAL': Final Action */
ml.disp('ending truth table');
}
```

Each decision is implemented 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 is specified as a condition action that leads to the `FINAL` action and termination of the flow diagram

- A transition segment that flows to the next fork for an evaluation of the next decision

  This transition segment has no condition or action.

The preceding implementation continues from the first decision through the remaining decisions in left to right column order. When a specified decision is matched, the action specified for that decision is executed as a condition action of its transition segment. Once the action is performed, the flow diagram performs the final action for the truth table and terminates. This means that only one action results from a call to a truth table graphical function. This also implies that no data dependencies are possible between different decisions.

How Stateflow Generates Embedded MATLAB Code for Truth Tables

Stateflow generates the content of Embedded MATLAB truth tables as embedded MATLAB code that represents each action as a *nested* function inside the main truth table function. :

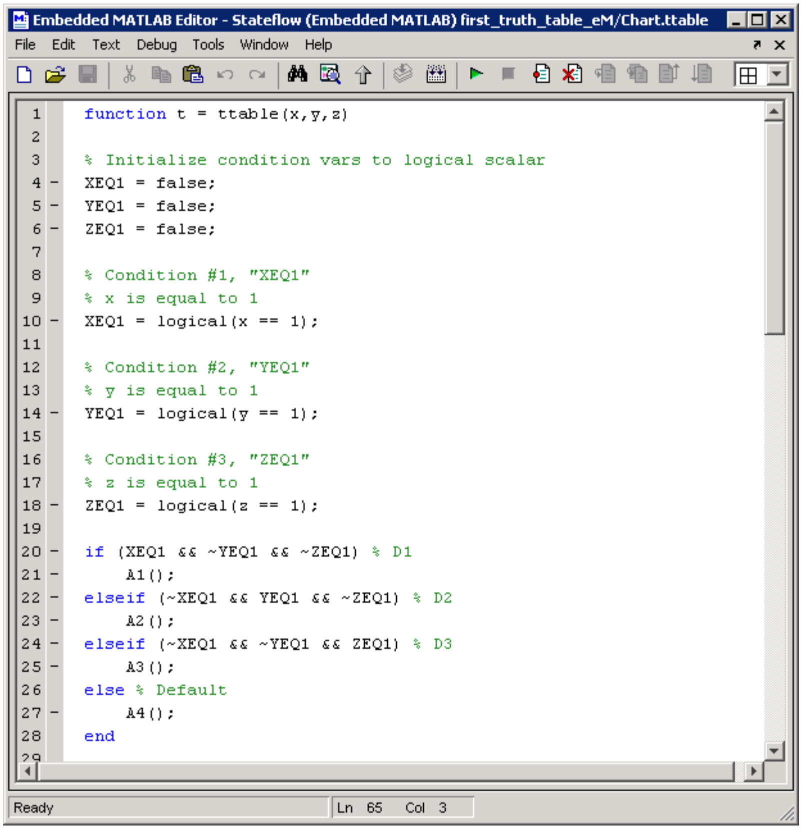
Nested functions offer several advantages over subfunctions:

- Nested functions are independent of each other. Therefore, variables are local to each function and not subject to name collisions.
- Nested functions can access all data from the main truth table function.

The generated content is displayed in an Embedded MATLAB Editor, which provides tools for simulation and debugging, as described in “Debugging an Embedded MATLAB Function”.

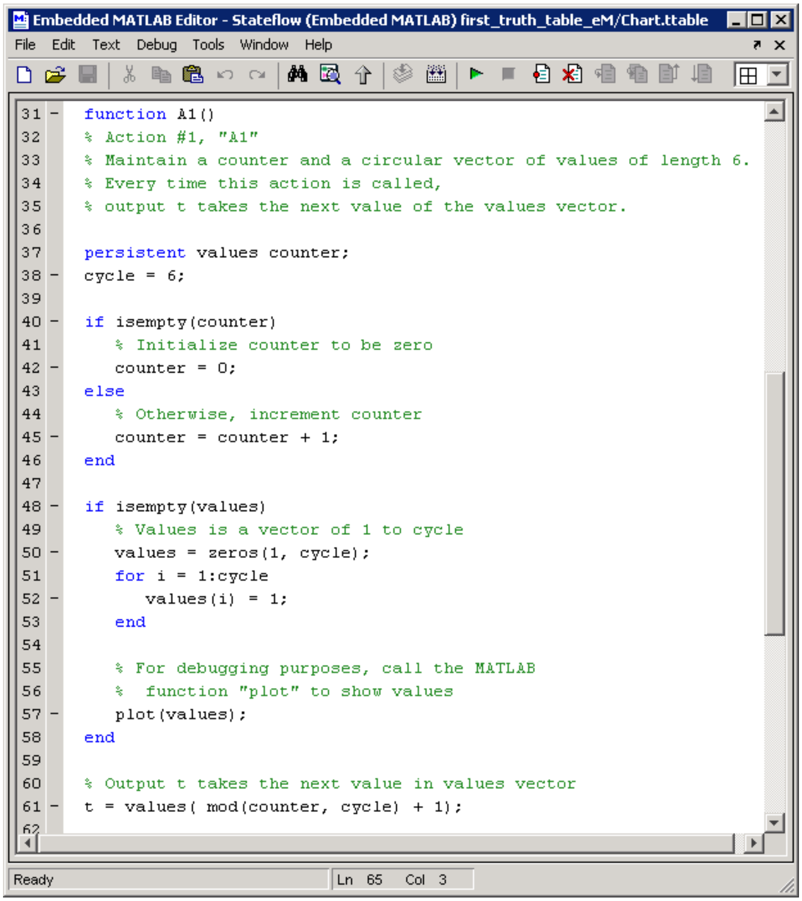
Here is the generated content for the Embedded MATLAB truth table described in “Programming Actions in Embedded MATLAB Action Language” on page 12-33:

- Main truth table function


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) first_truth_table_eM/Chart.ttable
File Edit Text Debug Tools Window Help
Ready
Ln 65 Col 3

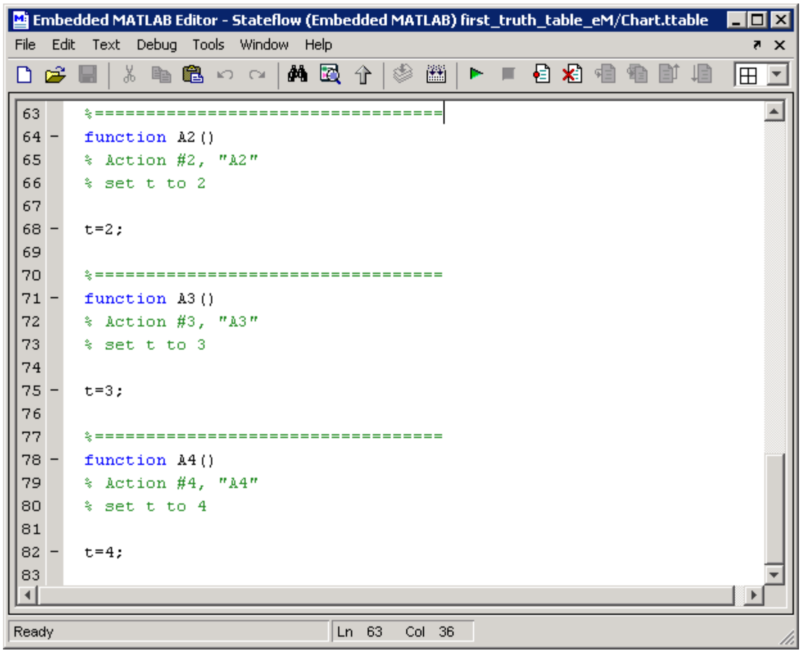
```
function t = ttable(x,y,z)

% 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


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) first_truth_table_eM/Chart.ttable
File Edit Text Debug Tools Window Help
Ready
Ln 65 Col 3

```
function A1()
% Action #1, "A1"
% Maintain a counter and a circular vector of values of length 6.
% Every time this action is called,
% output t takes the next value of the values 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) = 1;
   end

   % For debugging purposes, call the MATLAB
   %  function "plot" to show values
   plot(values);
end

% Output t takes the next value in values vector
t = values( mod(counter, cycle) + 1);
```

- Actions A2, A3, and A4


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) first_truth_table_eM/Chart.ttable
File Edit Text Debug Tools Window Help
Ready
Ln 63 Col 36

```
%==================================
function A2()
% Action #2, "A2"
% set t to 2

t=2;

%==================================
function A3()
% Action #3, "A3"
% set t to 3

t=3;

%==================================
function A4()
% Action #4, "A4"
% set t to 4

t=4;
```

Truth Table Editor Operations

This section describes the edit operations that you can perform in the truth table editor. Use the following topics to learn operations that you can do in the truth table editor:

- “Truth Table Editor Reference” on page 12-72— Identifies operations that you can perform in a truth table editor with tables and toolbar icon tables.
- “Searching and Replacing Text in Truth Tables” on page 12-75 — Shows you how the Stateflow Search & Replace tools work with Stateflow truth tables.
- “Using Row and Column Tooltip Identifiers” on page 12-77 — Shows you how row and column tooltips can help you navigate in big truth tables.

Truth Table Editor Reference

This section describes the operations you can perform in the Truth Table Editor.

Adding or Modifying Stateflow Data

	Edit Data/Ports lets you add or modify Stateflow data with the **Model Explorer** tool.

Appending Rows and Columns

	Append Column adds a column on the right end of the selected table.
	Append Row adds a row to the bottom of the selected table.

Compacting the Table

	Compact Table removes the empty rows and columns of the selected table.

Deleting Text, Rows, and Columns

To delete the contents of a cell, do the following:

1. Right-click the cell.
2. From the resulting pop-up menu, select **Delete Cell**.

To delete an entire row or column, do the following:

1. Right-click the row or column header.
2. From the resulting pop-up menu, select **Delete Row** or **Delete Column**.

   You can also click the row or column header to select the entire row or column and press the **Delete** key.

Diagnosing the Truth Table

	Run Diagnostics checks the truth table for syntax errors. See "Debugging a Truth Table" on page 12-45.

Viewing Generated Content

	View Generated Content displays the code generated for the truth table. Stateflow Classic truth tables generate graphical functions; Embedded MATLAB truth tables generate embedded MATLAB code. See "How Stateflow Realizes Truth Tables" on page 12-63.

Editing Tables

Both the default **Condition Table** and the default **Action Table** have one empty row. Click a cell to edit its text contents. Use **Tab** and **Shift+Tab** to move horizontally between cells. To add rows and columns to either table, see "Appending Rows and Columns " on page 12-72.

You set the Truth Table Editor to display only one of the two tables by double-clicking the header of the table to display. To revert to the display of both tables, double-click the header of the displayed table.

Cells for the numbered rows in decision columns like **D1** can take values of `T`, `F`, or `-`. Once you select one of these cells, you can use the spacebar to step through the `T`, `F`, and `-` values. In these cells you can use the left, right, up, and down arrow keys to advance to another cell in any direction.

Inserting Rows and Columns

To insert a blank row above an existing table row,

1. Right-click any cell in the row (including the row header).

2. From the resulting pop-up menu, select **Insert Row**.

To insert a blank decision column to the left of an existing decision column,

1. Right-click any cell in the existing decision column (including the column header).

2. From the resulting pop-up menu, select **Insert Column**.

Moving Rows and Columns

To move a condition or action row up or down:

1. Click the row header to select the row.

2. Drag the row to a new position.

   The Truth Table Editor renumbers the rows automatically.

To move a decision column up or down:

1. Click the column header to select the column.

2. Drag the column to a new position.

   The Truth Table Editor renumbers the decision columns automatically.

Printing Tables

🖨	**Print** makes a printed copy or an online viewable copy (HTML file) of the truth table.

Selecting and Deselecting Table Elements

- To select a cell for editing, click the cell.
- To select text in a cell, click and drag the cursor over the text.
- To select a row, click the header for the row.
- To select a decision column in the **Condition Table**, click the column header (**D1**, **D2**, and so on).
- To deselect a selected cell, row, or column, press **Esc**, or click another table, cell, row, or column.

Undoing and Redoing Edit Operations

↶	Select the **Undo** tool or press **Ctrl+Z** to reverse the effects of the preceding operation.
↷	Select the **Redo** tool or press **Ctrl+Y** to reverse the effects of the most recently undone edit operation.

Viewing the Stateflow Diagram for the Truth Table

⇧	**Go to Diagram Editor** displays the current truth table function in its native Stateflow diagram.

Searching and Replacing Text in Truth Tables

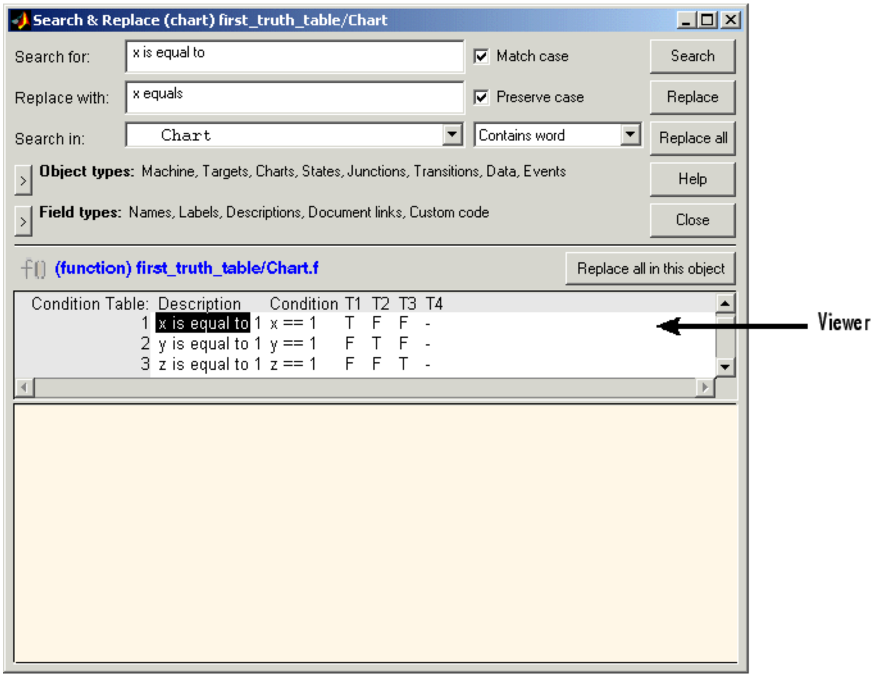
You can use the Search & Replace tool in Stateflow to search for text in the **Description**, **Condition**, and **Action** columns of a truth table and replace it with a substitute string. For example, you can search the model for the string `x is equal to` and replace it with the string `x equals` with the following procedure:

1 In the Stateflow diagram editor, select **Search & Replace** from the **Tools** menu.

2 In the resulting **Search & Replace** window, enter the text `x is equal to` in the **Search** field, and the text `x equals` in the **Replace** field.

3 Select the **Search** button.

You see something like the following in the **Search & Replace** window:



Search & Replace (chart) first_truth_table/Chart
Search
Replace
Replace all
Help
Close
Replace all in this object
Viewer

Search for: x is equal to ☑ Match case

Replace with: x equals ☑ Preserve case

Search in: Chart Contains word

Object types: Machine, Targets, Charts, States, Junctions, Transitions, Data, Events

Field types: Names, Labels, Descriptions, Document links, Custom code

(function) first_truth_table/Chart.f

Condition Table:	Description	Condition	T1	T2	T3	T4
1	x is equal to 1	x == 1	T	F	F	-
2	y is equal to 1	y == 1	F	T	F	-
3	z is equal to 1	z == 1	F	F	T	-

Notice that in the Viewer pane of the **Search & Replace** window the first occurrence of the string `x is equal to` is highlighted normally and the remaining matches are highlighted lightly.

4 Select **Replace** to replace the first match with `x equals`.

5 Select **Replace All** to replace all matches in the model (not just in the truth table) with `x equals`.

Note The Search & Replace tool is fully described in "Using the Stateflow Search & Replace Tool" on page 16-12.

Using Row and Column Tooltip Identifiers

Stateflow gives you row and column header tooltips to aid truth table navigation when you are scrolling to other columns or rows when you are editing a large truth table. When you place your mouse cursor over row or column headers, the following tooltips appear:

Table	Row or Column	Tooltip
Condition	Condition row	Condition entered for this row
Condition	Decision column (**D1**, **D2**,...)	Row or label entered for this decision in the **Actions** row
Condition	**Actions** row	Actions: specify a row from the Action Table
Action	Any row	Description entered for this action

13

Using Embedded MATLAB Functions

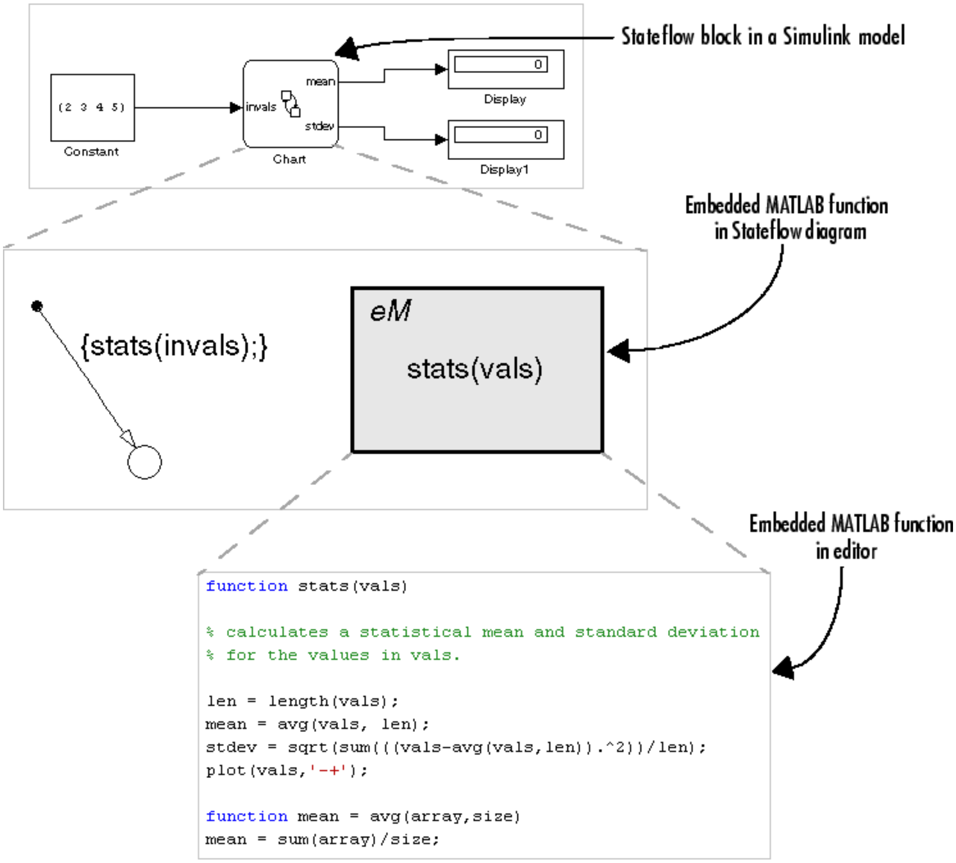
You can add Embedded MATLAB functions to Stateflow charts. Embedded MATLAB functions use a rich subset of the MATLAB language that generates efficient C code and also meets the strict memory and data type requirements of embedded target environments. In this way, Embedded MATLAB functions bring the power of MATLAB into Stateflow diagrams.

To learn how to use Embedded MATLAB functions in Stateflow charts, see the following sections:

Introduction to Embedded MATLAB Functions

Embedded MATLAB functions allow you to add MATLAB functions to a Stateflow chart. This capability is useful for coding algorithms that are better expressed in the textual language of MATLAB than in the graphical language of Stateflow. Embedded MATLAB functions work with a subset of the MATLAB language called the Embedded MATLAB subset, which provides optimizations for generating efficient, production-quality C code for embedded applications. For more information, see "Working with Embedded MATLAB".

Here is an example of a Simulink model with a Stateflow chart that contains an Embedded MATLAB function:



Stateflow block in a Simulink model

Embedded MATLAB function in Stateflow diagram

Embedded MATLAB function in editor

```
function stats(vals)

% calculates a statistical mean and standard deviation
% for the values in vals.

len = length(vals);
mean = avg(vals, len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

You will build this model in “Building a Simulink Model with a Stateflow Embedded MATLAB Function” on page 13-5.

Note in this example that the Embedded MATLAB function can call any of the following types of functions:

- Subfunctions

  Subfunctions are defined in the body of the Embedded MATLAB function. In the preceding example, `avg` is a subfunction. See “Calling Subfunctions” in the Embedded MATLAB documentation.

- Embedded MATLAB run-time library functions

  Embedded MATLAB run-time library functions are a subset of the functions that you can call in MATLAB. They generate C code for building targets that conform to the memory and data type requirements of embedded environments. In the preceding example, `length`, `sqrt`, and `sum` are examples of Embedded MATLAB run-time library functions. See “Calling Embedded MATLAB Run-Time Library Functions” in the Embedded MATLAB documentation.

- Stateflow functions

  Graphical, truth table, and other Embedded MATLAB functions can be called from an Embedded MATLAB function in a Stateflow chart.

- Some MATLAB functions

  Functions that cannot be resolved as subfunctions, Embedded MATLAB run-time library functions, or Stateflow functions are resolved in the MATLAB workspace. These functions do not generate code; they execute only in the MATLAB workspace during simulation of the model. See “Calling MATLAB Functions” in the Embedded MATLAB documentation.

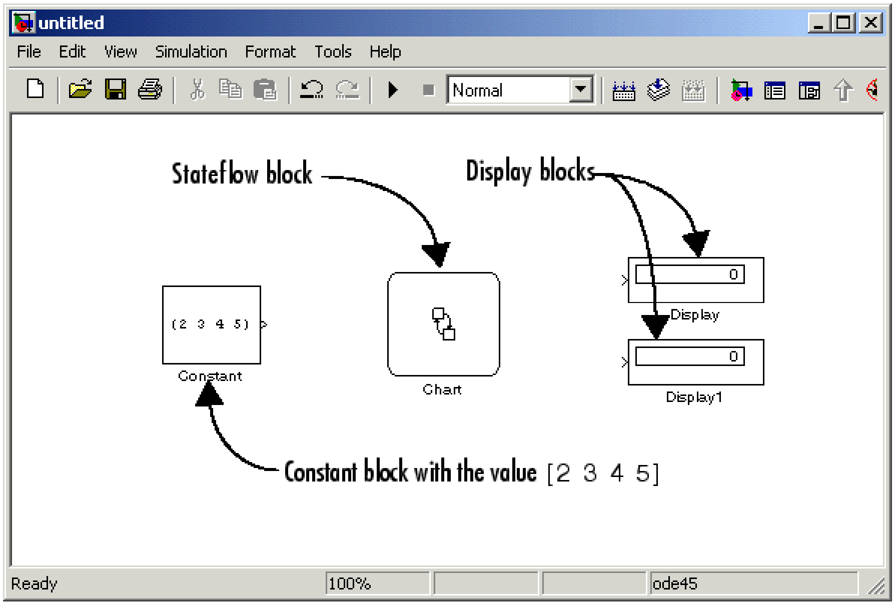
- Fixed-Point Toolbox run-time library functions

  For more information on fixed-point support in Embedded MATLAB, refer to “Working with the Fixed-Point Embedded MATLAB Subset” in the Fixed-Point Toolbox documentation.

Building a Simulink Model with a Stateflow Embedded MATLAB Function

Embedded MATLAB functions are special Stateflow functions that use the Embedded MATLAB Language, a rich subset of the MATLAB programming language. This section takes you through the steps of creating a Simulink model with a Stateflow block that calls two Embedded MATLAB functions, `meanstats` and `stdevstats`. `meanstats` calculates a mean and `stdevstats` calculates a standard deviation for the values in `vals` and outputs them to the Stateflow data `mean` and `stdev`, respectively. Use the following steps to create the model and learn how to use embedded MATLAB functions in Stateflow.

1 Create a new Simulink model with the following blocks:



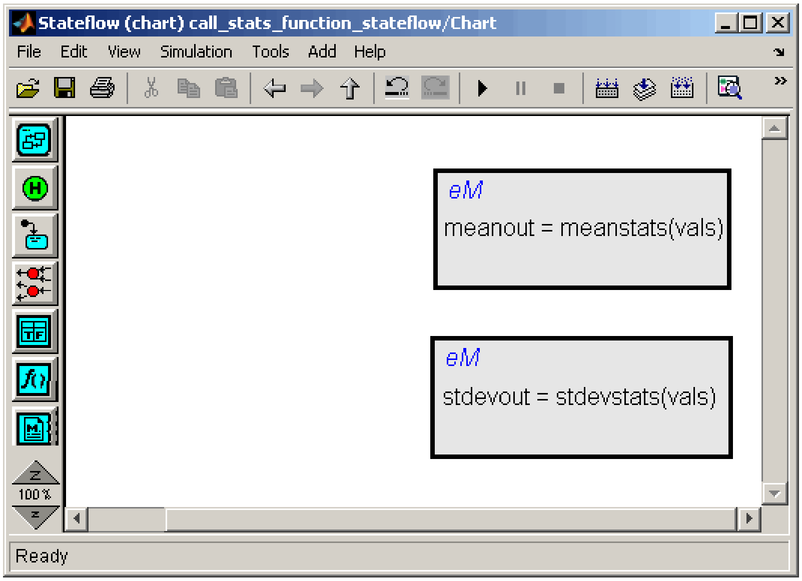
2 Save the model as `call_stats_function_stateflow`.

3 In the Simulink model, double-click the Stateflow block to open the Stateflow Editor.

4 In the Stateflow Editor, drag two Embedded MATLAB functions into the empty Stateflow chart using this icon from the tool palette:

A text field with a flashing cursor appears in the middle of each Embedded MATLAB function.

5 Label each function as shown:



meanout = meanstats(vals)

stdevout = stdevstats(vals)

As with other Stateflow functions, you should label an Embedded MATLAB function with its signature, using the following syntax:

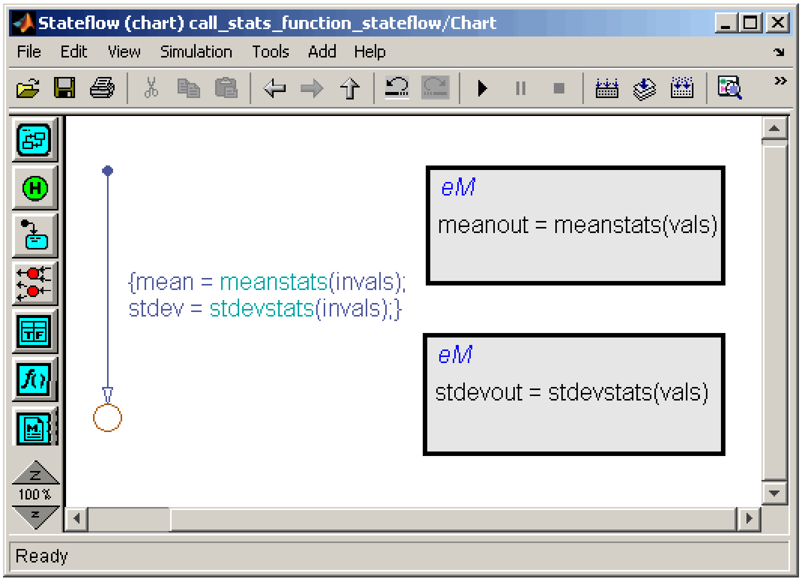
```
return_value = function_name (argument1, argument2,...)
```

Each argument and the return value can be a scalar, vector, or matrix of values. A matrix is a two-dimensional array of values. A vector is a matrix with a row or column dimension of 1. Multiple return values are not allowed.

6 In the Stateflow chart, draw a default transition into a terminating junction with the following condition action:

```
{mean = meanstats(invals);
stdev = stdevstats(invals);}
```

The Stateflow chart should look like this:


Stateflow (chart) call_stats_function_stateflow/Chart
File Edit View Simulation Tools Add Help
100%
Ready

```
{mean = meanstats(invals);
stdev = stdevstats(invals);}
```

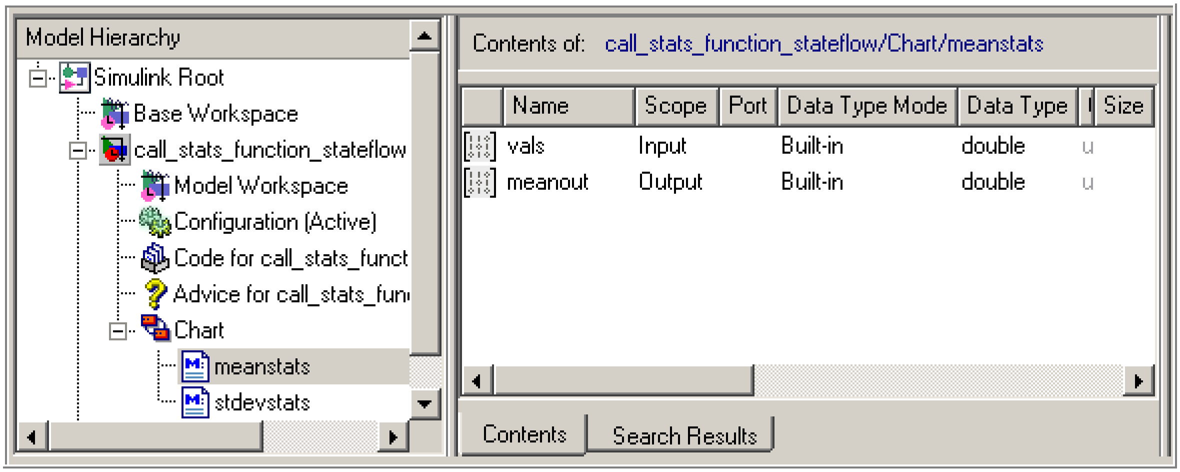
eM
meanout = meanstats(vals)

eM
stdevout = stdevstats(vals)

7 In the Stateflow chart, double-click the function `meanstats` to edit its function body in the Embedded MATLAB Editor.

8 In the Embedded MATLAB Editor, select **Tools > Model Explorer**.

The Model Explorer window appears:



Contents of: call_stats_function_stateflow/Chart/meanstats

Name	Scope	Port	Data Type Mode	Data Type	I	Size
vals	Input		Built-in	double	u	
meanout	Output		Built-in	double	u	

The function `meanstats` is highlighted in the Model Hierarchy pane (left). The Contents pane (right) displays the input argument `vals` and output argument `meanout`. Both are scalars of type `double` by default.

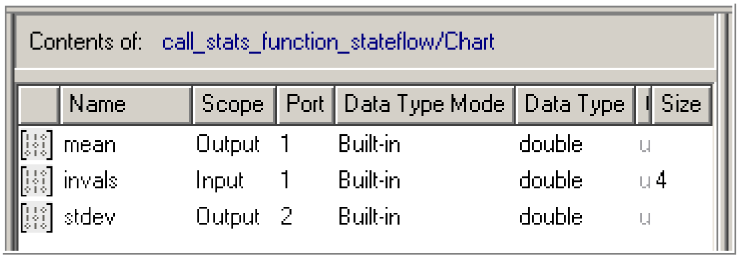
9 Double-click the `vals` row under the **Size** column to set the size of `vals` to `4`.

10 Back in the Stateflow chart, double-click the function `stdevstats` and repeat steps 8 and 9.

11 Back in the Model Hierarchy pane of the Model Explorer, select **Chart** and add the following data:

Name	Scope	Size
`invals`	**Input** from Simulink	4
`mean`	**Output** to Simulink	Scalar (no change)
`stdev`	**Output** to Simulink	Scalar (no change)

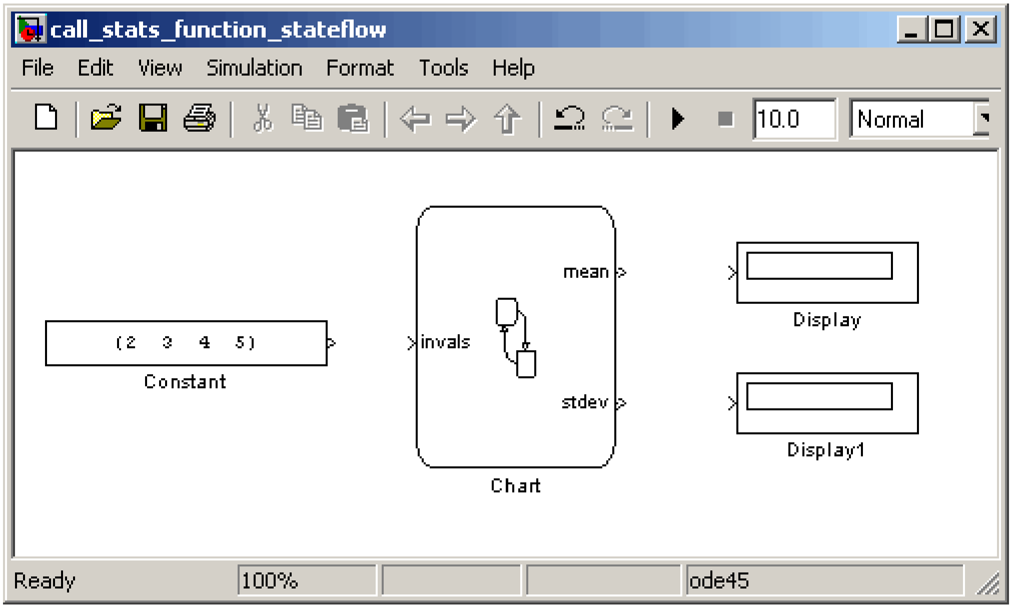
You should now see the following data in the **Model Explorer**:



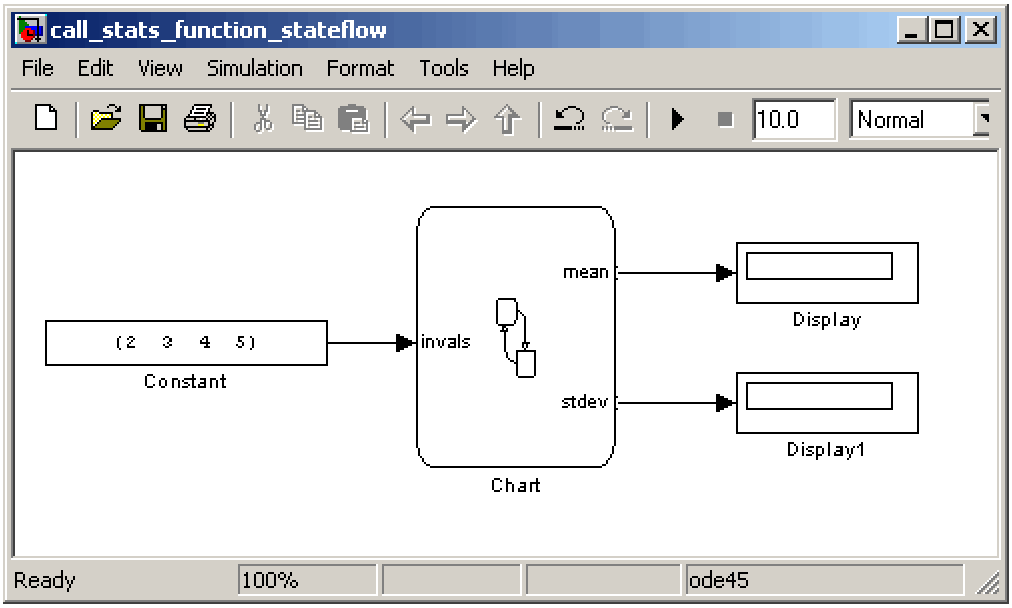
Contents of: call_stats_function_stateflow/Chart

Name	Scope	Port	Data Type Mode	Data Type	I	Size
mean	Output	1	Built-in	double	u	
invals	Input	1	Built-in	double	u	4
stdev	Output	2	Built-in	double	u	

After you add the data invals, mean, and stdev to the Stateflow chart, the corresponding input and output ports appear on the Stateflow block in Simulink.



12 Connect the Constant block and the Display block to the ports of the Stateflow block and save the model.



The section “Debugging a Stateflow Embedded MATLAB Function” on page 13-15 shows you how to program the functions `meanstats` and `stdevstats`.

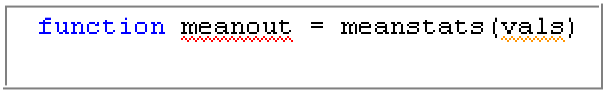
Programming a Stateflow Embedded MATLAB Function

You program an Embedded MATLAB function with the Embedded MATLAB language, a rich subset of MATLAB, as described in “Working with Embedded MATLAB” in the Embedded MATLAB documentation. To program the functions `meanstats` and `stdevstats` that you created in “Building a Simulink Model with a Stateflow Embedded MATLAB Function” on page 13-5, follow these steps:

1 Open the Stateflow chart in the model`call_stats_function_stateflow`.

2 In the Stateflow chart, open the Embedded MATLAB function `meanstats`.

The Embedded MATLAB Editor appears with the function header as shown.



```
function meanout = meanstats(vals)
```

This function header is taken from the label that you added to the function in the Stateflow chart. You can edit it directly in the Embedded MATLAB Editor and your changes will be reflected in the Stateflow diagram editor when you close the window or select the Update Diagram tool in the editor toolbar:

3 After the function header, enter a line space and the following comment lines:

```
% Calculates a statistical mean for vals
```

4 Now enter the following statement:

```
eml.extrinsic('plot');
```

The function `plot` is a MATLAB function that is not supported by the Embedded MATLAB subset. To call unsupported MATLAB functions, you must first declare them to be extrinsic, as described in “Calling MATLAB Functions” in the Embedded MATLAB documentation.

5 Add the line:

```
len = length(vals);
```

The function `length` is an example of a built-in MATLAB function that is supported by the Embedded MATLAB subset. 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. MATLAB functions supported by Embedded MATLAB appear in “Embedded MATLAB Run-Time Function Library” in the Embedded MATLAB documentation.

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`. You can change the size and type of `len` as described in “Creating Local Variables Implicitly” in the Embedded MATLAB documentation.

Embedded MATLAB treats implicitly declared local data as temporary data. It comes into existence only when the function is called and disappears when the function exits. You can declare local data for an Embedded MATLAB function to be persistent by using the `persistent` construct (see “Declaring Persistent Variables” in the Embedded MATLAB documentation).

6 Enter the following line to calculate the value of `mean`:

```
meanout = avg(vals,len);
```

`meanstats` stores the mean of `vals` in the Stateflow data `meanout` . Since these data are defined for the parent Stateflow chart, you can use them directly in the Embedded MATLAB function.

Two-dimensional arrays with a single row or column of elements are treated as vectors or matrices in Embedded 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 Embedded MATLAB function uses the functions `avg` and `sum` to compute the value of `mean`. `sum` is an Embedded MATLAB run-time library functions. avg is a subfunction that you define later. When resolving function names, Embedded MATLAB functions look for subfunctions first, followed by Embedded MATLAB run-time library functions.

Note If you call a function that Embedded MATLAB cannot resolve as a subfunction or Embedded MATLAB runtime library function, you must declare the function to be extrinsic so it can be resolved as a MATLAB function, as described in "Calling MATLAB Functions" in the Embedded MATLAB documentation.

---

7 Enter the following 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 in the Embedded MATLAB runtime library. When Embedded MATLAB encounters an extrinsic function, it sends the call to MATLAB for execution during simulation.

8 Now, define the subfunction 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 subfunction avg calculates the average of the elements in array by dividing their sum by the value of argument size.

For more information on creating subfunctions, see "Subfunctions" in MATLAB online documentation.

The complete code for the Embedded MATLAB function meanstats looks like this:

```
function meanout = meanstats(vals)

% Calculates a statistical mean for vals
```

```
eml.extrinsic('plot');
len = length(vals);
meanout = avg(vals,len);

plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

9 Save the model (`call_stats_function_stateflow`).

10 Back in the Stateflow chart, open the second Embedded MATLAB 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)

%Calculate 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;
```

Debugging a Stateflow Embedded MATLAB Function

The following topics explain how to debug the Embedded MATLAB function `meanstats` in its Stateflow diagram.

- "Checking Embedded MATLAB Functions for Syntax Errors" on page 13-15 — Describes the way that Stateflow checks Embedded MATLAB functions for syntactical errors.
- "Run-Time Debugging for Embedded MATLAB Functions" on page 13-17 — Executes the model and tests the Embedded MATLAB unction with different input data values.

Checking Embedded MATLAB Functions for Syntax Errors

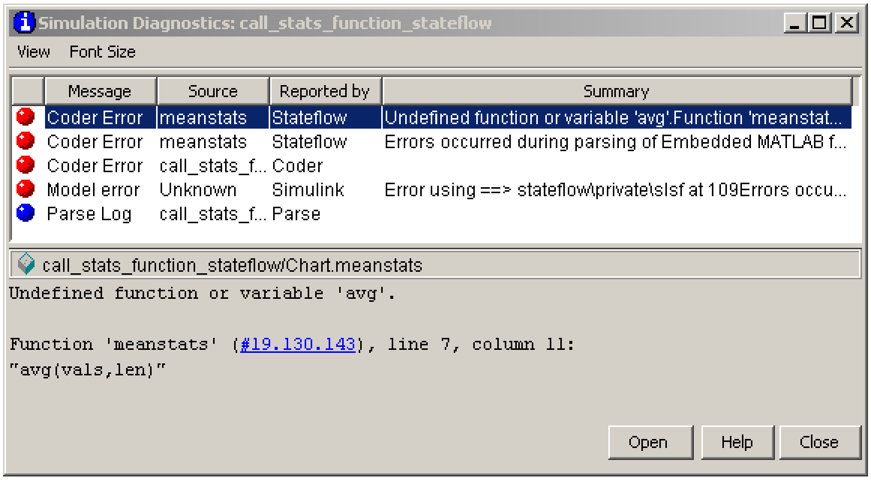
Before you can build a simulation application for a model, you need to fix syntax errors. Use the following steps to check the Embedded MATLAB function `meanstats` for syntax violations:

1. Open the the Embedded MATLAB function `meanstats` inside the Stateflow chart in the `call_stats_function_stateflow` model that you updated in "Programming a Stateflow Embedded MATLAB Function" on page 13-11.

   The Embedded MATLAB Editor uses the MATLAB M-Lint Code Analyzer to automatically check your function code for errors and recommend corrections (see "Using M-Lint with Embedded MATLAB" in Embedded MATLAB documentation).

2. In the Embedded MATLAB Editor, select the Build tool to build a simulation application for the example Simulink model.

   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 subfunction `avg` to a nonexistent subfunction `aug` in `meanstats`, the Builder reports the following errors:



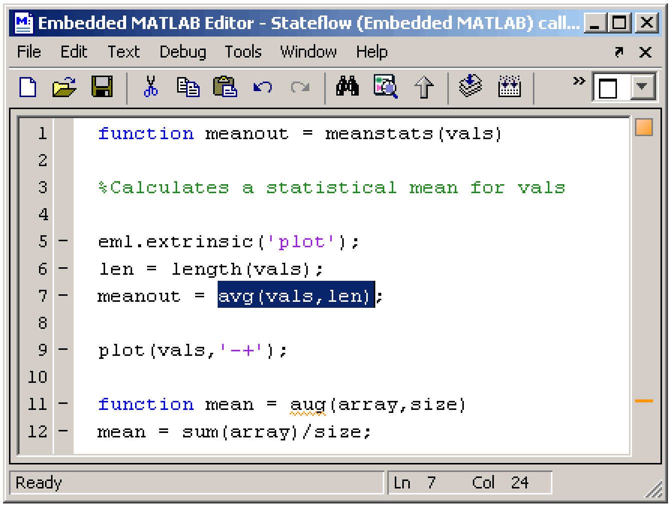
Message	Source	Reported by	Summary
Coder Error	meanstats	Stateflow	Undefined function or variable 'avg'.Function 'meanstat...
Coder Error	meanstats	Stateflow	Errors occurred during parsing of Embedded MATLAB f...
Coder Error	call_stats_f...	Coder	
Model error	Unknown	Simulink	Error using ==> stateflow\private\slsf at 109Errors occu...
Parse Log	call_stats_f...	Parse	

call_stats_function_stateflow/Chart.meanstats

```
Undefined function or variable 'avg'.

Function 'meanstats' (#19.130.143), line 7, column 11:
"avg(vals,len)"
```

Each error message appears with a red button. The selected error message displays diagnostic information in the bottom pane.

3 Click the link in the diagnostic message to display the offending line of code, as shown.


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call...
File
Edit
Text
Debug
Tools
Window
Help
Ready
Ln 7
Col 24

```
 1  function meanout = meanstats(vals)
 2
 3  %Calculates a statistical mean for vals
 4
 5  eml.extrinsic('plot');
 6  len = length(vals);
 7  meanout = avg(vals,len);
 8
 9  plot(vals,'-+');
10
11  function mean = aug(array,size)
12  mean = sum(array)/size;
```

4

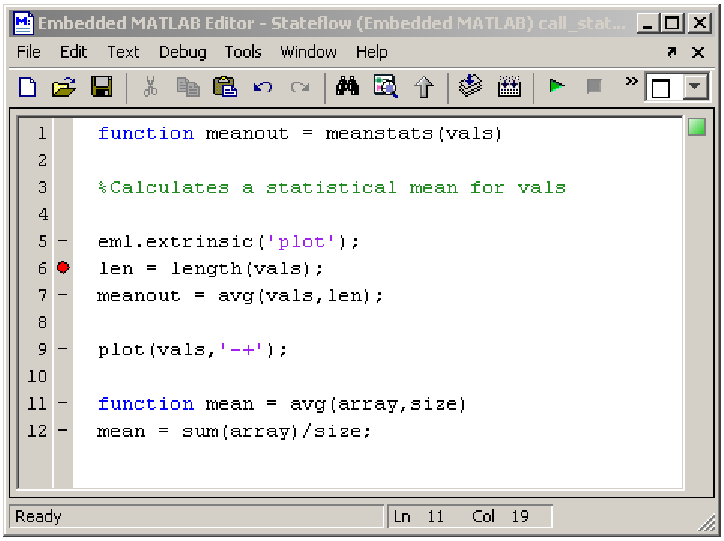
Run-Time Debugging for Embedded MATLAB Functions

You use simulation to test your Embedded MATLAB functions for run-time errors that are not detectable by Stateflow diagnostics. When simulate your model, Simulink tests of your Embedded MATLAB functions for missing or undefined information and possible logical conflicts as described in "Checking Embedded MATLAB Functions for Syntax Errors" on page 13-15. If no errors are found, Stateflow begins the simulation of your model.

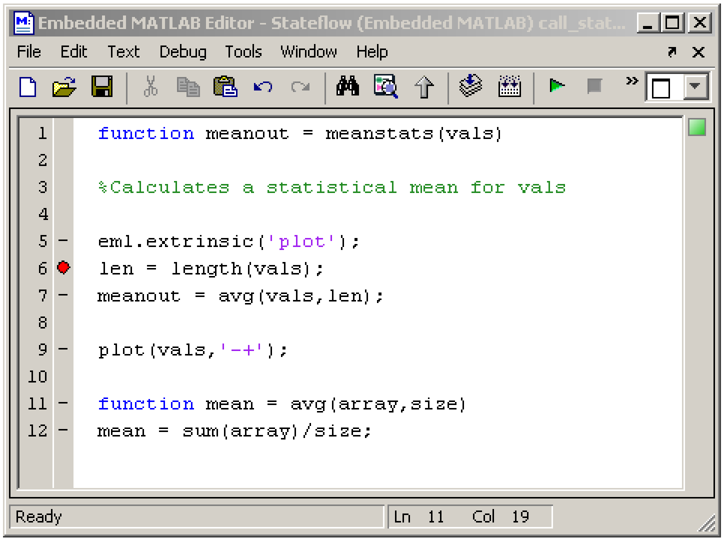
Use the following procedure to simulate and debug the `meanstats` Embedded MATLAB function during run-time conditions:

1 In the Embedded MATLAB Editor, click the dash (-) character in the left margin of line 6.

A small red ball appears next to line 6, indicating that you set a breakpoint.


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call_stat...
File
Edit
Text
Debug
Tools
Window
Help
Ready
Ln 11
Col 19

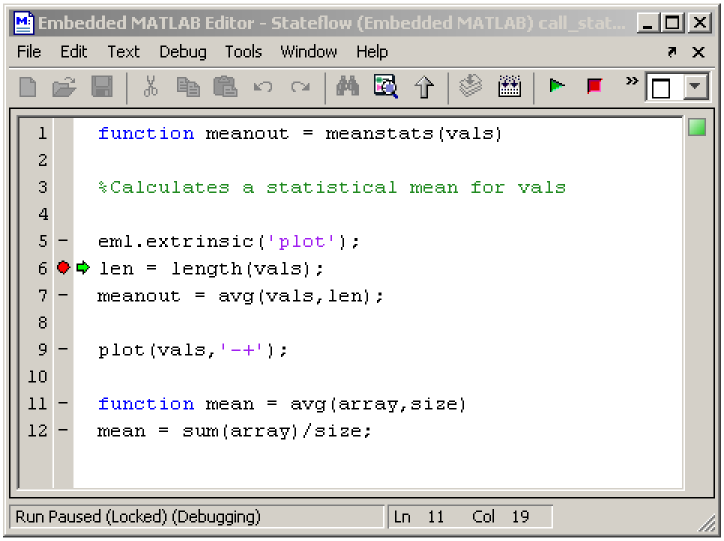
```
 1    function meanout = meanstats(vals)
 2
 3    %Calculates a statistical mean for vals
 4
 5 -  eml.extrinsic('plot');
 6 ●  len = length(vals);
 7 -  meanout = avg(vals,len);
 8
 9 -  plot(vals,'-+');
10
11 -  function mean = avg(array,size)
12 -  mean = sum(array)/size;
```


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call_stat...
File Edit Text Debug Tools Window Help
Ready
Ln 11 Col 19

```
function meanout = meanstats(vals)

%Calculates a statistical mean for vals

eml.extrinsic('plot');
len = length(vals);
meanout = avg(vals,len);

plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

2 Click the Start Simulation tool ▶ to begin simulating 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. This is indicated by a small green arrow in the left margin as shown.


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call_stat...
File Edit Text Debug Tools Window Help

```
 1      function meanout = meanstats(vals)
 2
 3      %Calculates a statistical mean for vals
 4
 5 -    eml.extrinsic('plot');
 6 ● ⇨  len = length(vals);
 7 -    meanout = avg(vals,len);
 8
 9 -    plot(vals,'-+');
10
11 -    function mean = avg(array,size)
12 -    mean = sum(array)/size;
```

Run Paused (Locked) (Debugging) | Ln 11 | Col 19

3 Click the Step tool to advance execution one line to line 7.

Notice that line 7 calls the subfunction avg. If you click Step here, execution advances to line 9, past the execution of the subfunction avg. In order to track execution of the lines in the subfunction avg, you need to click the Step In tool.

4 Click the Step In tool to advance execution to the first line of the called subfunction avg.

Once you are in the subfunction, you can advance through the subfunction one line at a time with the Step tool. If the subfunction calls another subfunction, use the Step In tool to step into it. If you want to continue through the remaining lines of the subfunction and go back to the line after the subfunction call, click the Step Out tool .

5 Click the Step tool to execute the only line in the subfunction avg.

When the subfunction avg finishes its execution, you see a green arrow pointing down under its last line.

6 Click the Step tool to return to the function `meanstats`.

Execution advances to the line after to the call to the subfunction `avg`, line 9.

7 To display the value of the variable `len`, place the mouse cursor over the text `len` in line 6 for at least a second.

The value of `len` appears adjacent to the cursor.

You can display the value for any data in the Embedded MATLAB block 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 the cursor over it as an argument to the function `length` in line 6, or as an argument in the function header.

You can also report the values for Embedded MATLAB block function data in the MATLAB window during simulation. When you reach a breakpoint, the `debug>>` command prompt appears in the MATLAB window (you might have to press **Enter** to see it). At this prompt you can inspect data defined for the Embedded MATLAB block by entering the name of the data as shown in the following example:

```
debug>> len
len =
     4
debug>>
```

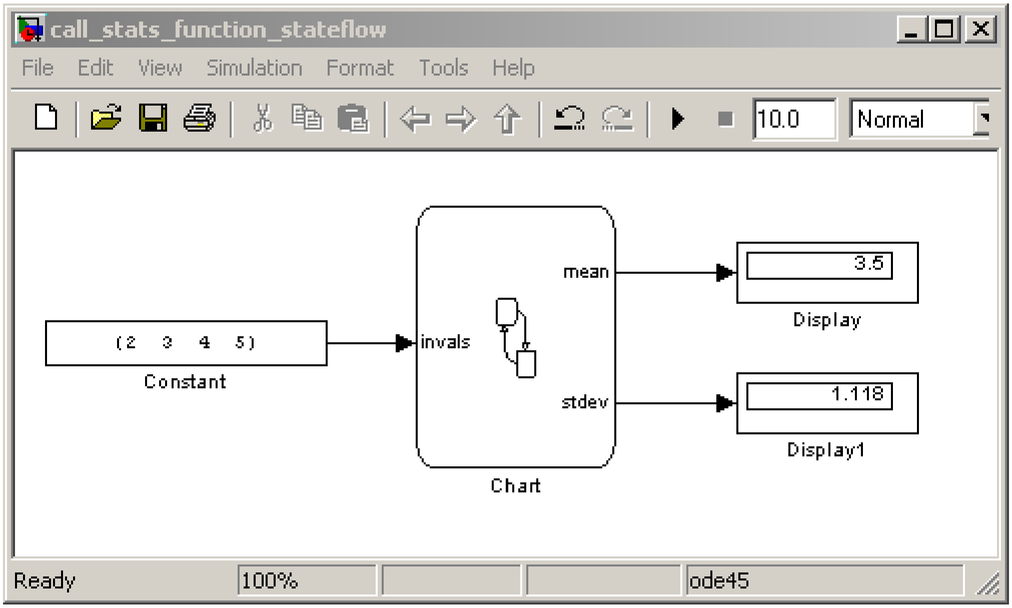
As another debugging alternative, you can display the execution result of an Embedded MATLAB function line by omitting the terminating semicolon. If you do, execution results for the line are echoed to the MATLAB window during simulation.

8 Click the Continue tool to leave the function until it is called again and the breakpoint on line 6 is reached.

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, clicking the Step tool accomplishes the same thing.

9 Click the breakpoint at line 6 to remove it and click the green arrow to complete the simulation.

In the Simulink window, the computed values of `mean` and `stdev` now appear in the Display blocks.



Model Coverage for an Embedded MATLAB Function

The **Model Coverage** tool in Simulink reports model coverages for the decisions and conditions of Embedded MATLAB functions in Stateflow. For example, the Embedded MATLAB function `if` statement

```
if (x > 0 || y > 0)
 reset = 1;
```

contains a decision with two conditions (`x > 0` and `y > 0`). You use the **Model Coverage** tool for Embedded MATLAB functions to make sure that all decisions and conditions are taken during simulation of the model.

See the following topics for a description of model coverage for an example Embedded MATLAB function:

- "Types of Model Coverage in Embedded MATLAB Functions" on page 13-23 — Lists the types of elements in an Embedded MATLAB function that receive model coverage during simulation.
- "Creating a Model with Embedded MATLAB Function Decisions" on page 13-23 — Shows you an example model that you use to examine model coverage for Embedded MATLAB functions.
- "Understanding Embedded MATLAB Function Model Coverage" on page 13-28 — Describes the individual coverages for the Model Coverage report of the example Embedded MATLAB function.

For a description of model coverage for other Stateflow objects, see "Understanding Model Coverage for Stateflow Charts" on page 15-44.

Note The Model Coverage tool requires a Simulink Verification and Validation license.

Types of Model Coverage in Embedded MATLAB Functions

During simulation, the following Embedded MATLAB block function statements are tested for Decision Coverage:

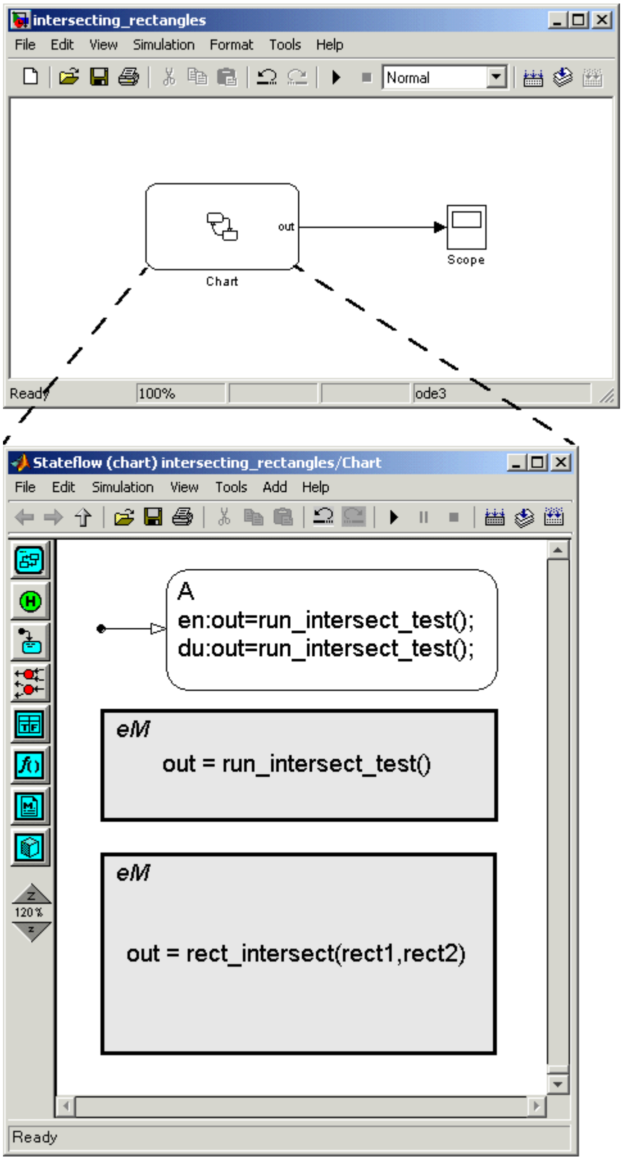
- function header — Decision coverage is 100% if the function or subfunction is executed.
- `if`— Decision coverage is 100% if the `if` expression evaluates to true at least once and false at least once.
- `switch`— Decision coverage is 100% if every `switch` case is taken, including the fall-through case.
- `for`— Decision coverage is 100% if the equivalent loop condition evaluates to true at least once, and false at least once.
- `while` — Decision coverage is 100% if the equivalent loop condition evaluates to true at least once, and false at least once.

During simulation, the following logical conditions are tested for Condition Coverage and MCDC in the Embedded MATLAB block function:

- `if` statement conditions
- `while` statement conditions, if present

Creating a Model with Embedded MATLAB Function Decisions

In this topic you examine an example model you can use to generate a model coverage report for two Embedded MATLAB functions in Stateflow. The following model is named `intersecting_rectangles`. It contains a single Stateflow block with output data sent to a Scope block as shown.


intersecting_rectangles
File Edit View Simulation Format Tools Help
Normal
out
Chart
Scope
Ready
100%
ode3
Stateflow (chart) intersecting_rectangles/Chart
File Edit Simulation View Tools Add Help
120%
Ready

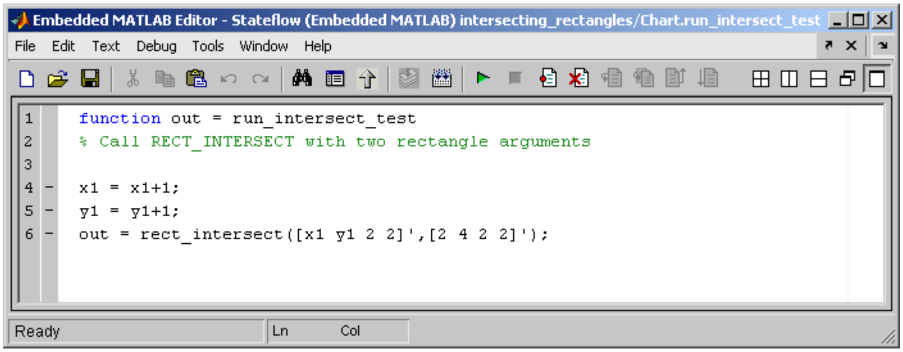
```
A
en:out=run_intersect_test();
du:out=run_intersect_test();
```

```
eM
    out = run_intersect_test()
```

```
eM
  out = rect_intersect(rect1,rect2)
```

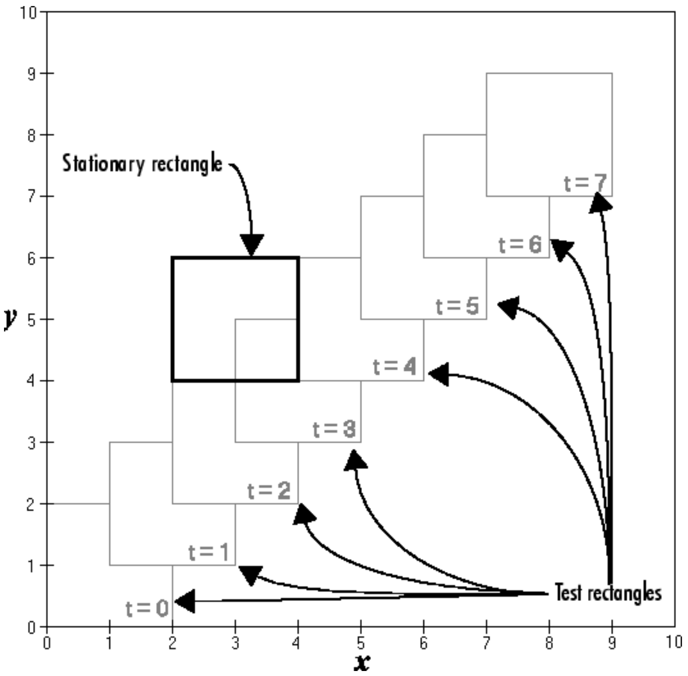
The preceding Stateflow diagram has a state with a default transition and entry and during actions. The state executes its entry action the first time that it is entered for the first time sample. Each succeeding time sample calls the during action of the active state.

The entry and during actions of state `A` call the Embedded MATLAB function `run_intersect_test`, which appears as follows in the **Embedded MATLAB Editor** window:


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) intersecting_rectangles/Chart.run_intersect_test
File
Edit
Text
Debug
Tools
Window
Help
Ready
Ln
Col

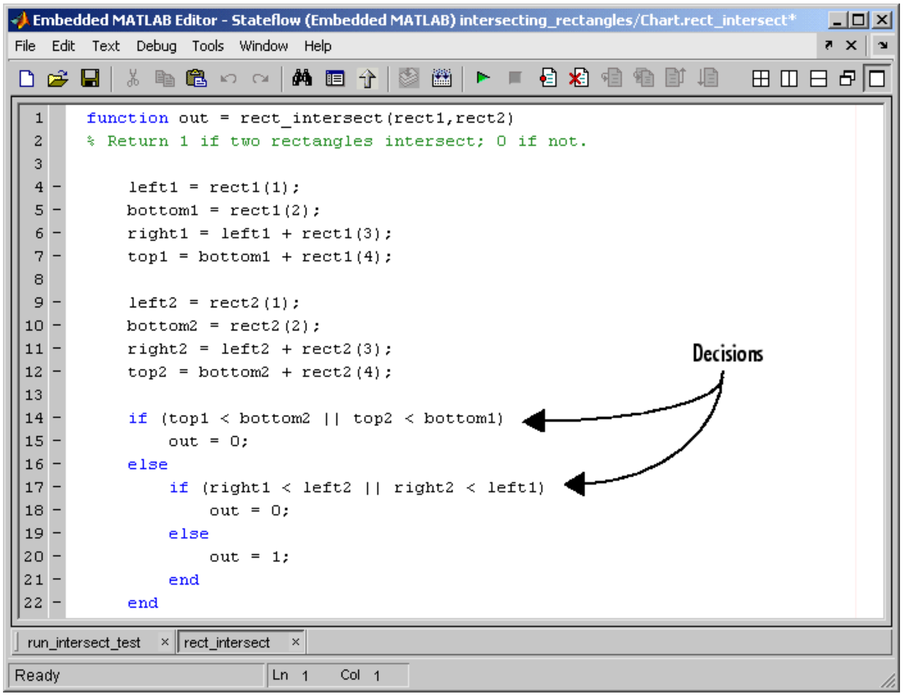
```
function out = run_intersect_test
% Call RECT_INTERSECT with two rectangle arguments

x1 = x1+1;
y1 = y1+1;
out = rect_intersect([x1 y1 2 2]',[2 4 2 2]');
```

`run_intersect_test` calls the function `rect_intersect` with two rectangle arguments that each consist of coordinates for the lower left corner of the rectangle (origin), and its width and height. The first rectangle is a test rectangle, and the second is a stationary rectangle. The coordinates for the origin of the test rectangle are represented by the Stateflow data `x1` and `y1`, which are both initialized to -1. This means that `x1` and `y1` are 0 for the first sample. The progression of rectangle arguments during simulation is as follows:



In the preceding display, the stationary rectangle is shown in bold with a lower left origin of `(2,4)` and a width and height of 2. At time `t = 0`, the first test rectangle has an origin of `(0,0)` and a width and height of 2. For each succeeding sample, the origin of the test rectangle is incremented by `(1,1)`. The rectangles at sample times `t = 2`, `3`, and `4` intersect with the test rectangle.

The function `rect_intersect`, as shown, checks to see if two rectangles intersect.

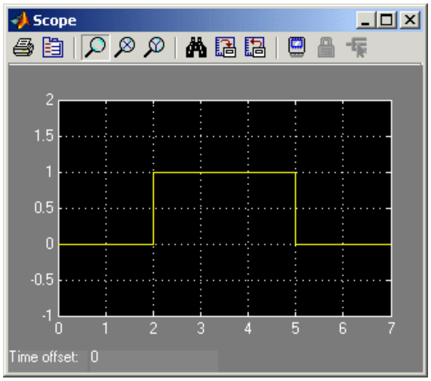


Embedded MATLAB Editor - Stateflow (Embedded MATLAB) intersecting_rectangles/Chart.rect_intersect*
File Edit Text Debug Tools Window Help
Decisions
run_intersect_test
rect_intersect
Ready
Ln 1 Col 1

```
function out = rect_intersect(rect1,rect2)
% Return 1 if two rectangles intersect; 0 if not.

    left1 = rect1(1);
    bottom1 = rect1(2);
    right1 = left1 + rect1(3);
    top1 = bottom1 + rect1(4);

    left2 = rect2(1);
    bottom2 = rect2(2);
    right2 = left2 + rect2(3);
    top2 = bottom2 + rect2(4);

    if (top1 < bottom2 || top2 < bottom1)
        out = 0;
    else
        if (right1 < left2 || right2 < left1)
            out = 0;
        else
            out = 1;
        end
    end
```

`rect_intersect` receives the two rectangle arguments from `run_intersect_test`. It first calculates horizontal (`x`) coordinates for the left and right sides, and vertical (`y`) values for the top and bottom sides for each rectangle and compares them in the nested `if-else` decisions shown. The function returns a logical value of 1 if the rectangles intersect and 0 if they do not.

Scope output during simulation, which plots the return value against the sample time, confirms the intersecting rectangles for sample `2`, `3`, and `4`.



Understanding Embedded MATLAB Function Model Coverage

Model coverage reports are generated during simulation if you specify them (see “Making Model Coverage Reports” on page 15-45). When simulation is finished, the model coverage report appears in a browser window. After the summary for the model, the Details section reports on each of the parts of the model. Model coverage for the parts of the example model in “Creating a Model with Embedded MATLAB Function Decisions” on page 13-23 appears in the following order:

- Model "intersecting_rectangles"
- Subsystem "Chart"
- Chart "Chart"
  - Function rect_intersect

    #1: function out = rect_intersect(rect1,rect2)

    #14: if (top1 < bottom2 || top2 < bottom1)

    #17: if (right1 < left2 || right2 < left1
  - Function "run_intersect_test"

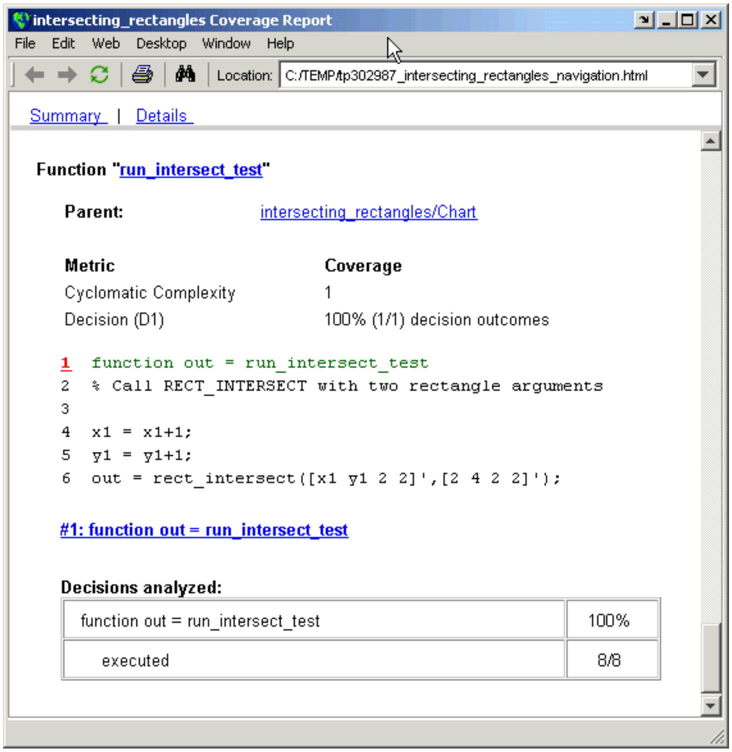
    #1: function out = run_intersect_test

The reports for the Embedded MATLAB functions `rect_intersect` and `run_intersect_test` appear in alphabetical order as part of the report on their parent, the Stateflow block Chart. The reports on individual decisions for each function appear in numerical line order. Line numbers are indicated by the # character.

The following subtopics examine the model coverage report for the example model in reverse order of the report. Reversing the order helps you make sense of the summary information that appears at the top of each section.

Model Coverage for Embedded MATLAB Function run_intersect_test

Model coverage for the Embedded MATLAB function `run_intersect_test`, which sends test rectangles to the function `rect_intersect`, appears in the model coverage report as shown.


intersecting_rectangles Coverage Report
File Edit Web Desktop Window Help
Location: C:/TEMP/tp302987_intersecting_rectangles_navigation.html
Summary | Details

Function "run_intersect_test"

Parent: intersecting_rectangles/Chart

Metric	Coverage
Cyclomatic Complexity	1
Decision (D1)	100% (1/1) decision outcomes

```
1 function out = run_intersect_test
2 % Call RECT_INTERSECT with two rectangle arguments
3
4 x1 = x1+1;
5 y1 = y1+1;
6 out = rect_intersect([x1 y1 2 2]',[2 4 2 2]');
```

#1: function out = run_intersect_test

Decisions analyzed:

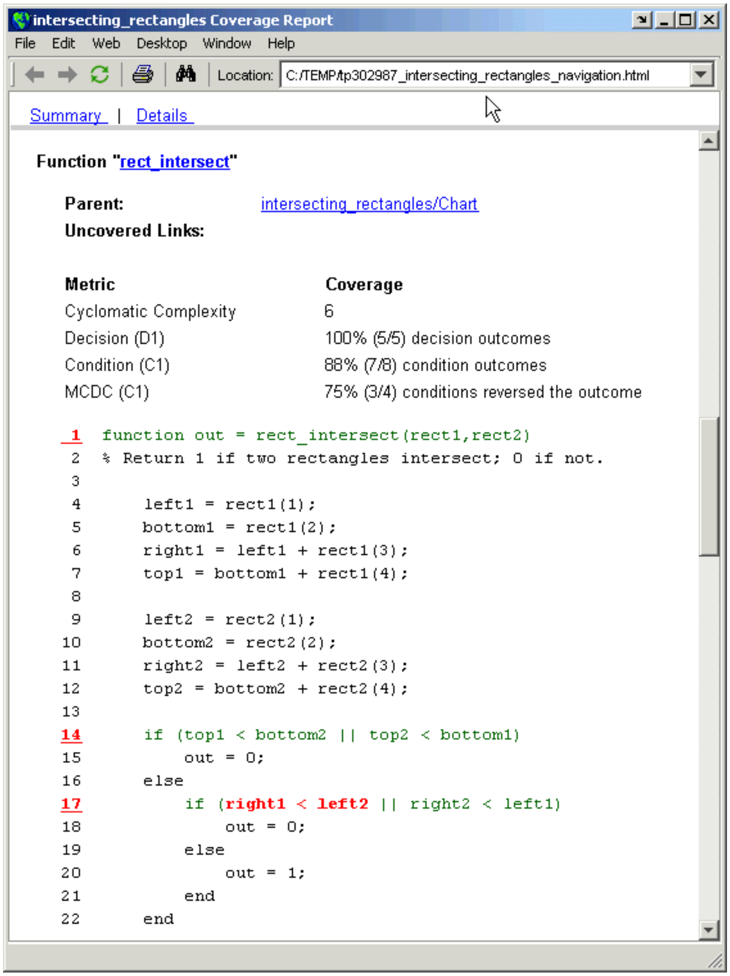
function out = run_intersect_test	100%
executed	8/8

The report on run_intersect_test begins with the function name run_intersect_test, which links to an **Embedded MATLAB Editor** for the function. Following the name is a link to the model coverage report for the parent of run_intersect_test, the Stateflow chart Chart. Coverage continues with a summary of the coverage metrics for the function followed by a code listing. The line number for the first line of the listing is highlighted in bold red, which is actually a link to an analysis for that decision below.

The first line of every function receives coverage analysis indicative of the decision to run the function. Its coverage here indicates that the function run_intersect_test executed 8 out of 8 times for the samples taken at 0 through 7 seconds. Because this is the only decision in the function run_intersect_test, coverage for it in the metrics table above indicates the occurrence of 1 out of 1 possible outcomes. In this case, the only possible outcome is function execution. In other words, the function was executed during simulation.

Coverage for Embedded MATLAB Function rect_intersect

Model coverage for the Embedded MATLAB function rect_intersect, which tests rectangles for intersection, appears first in the model coverage report as shown.


intersecting_rectangles Coverage Report
File Edit Web Desktop Window Help
Location: C:/TEMP/tp302987_intersecting_rectangles_navigation.html
Summary | Details

Function "rect_intersect"

Parent: intersecting_rectangles/Chart

Uncovered Links:

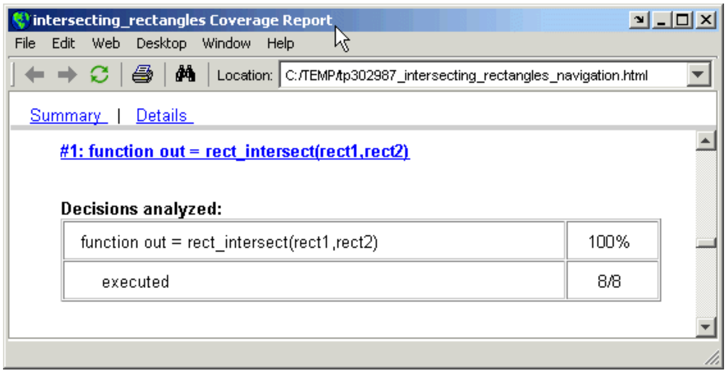
Metric	Coverage
Cyclomatic Complexity	6
Decision (D1)	100% (5/5) decision outcomes
Condition (C1)	88% (7/8) condition outcomes
MCDC (C1)	75% (3/4) conditions reversed the outcome

```
 1  function out = rect_intersect(rect1,rect2)
 2  % Return 1 if two rectangles intersect; 0 if not.
 3
 4      left1 = rect1(1);
 5      bottom1 = rect1(2);
 6      right1 = left1 + rect1(3);
 7      top1 = bottom1 + rect1(4);
 8
 9      left2 = rect2(1);
10      bottom2 = rect2(2);
11      right2 = left2 + rect2(3);
12      top2 = bottom2 + rect2(4);
13
14      if (top1 < bottom2 || top2 < bottom1)
15          out = 0;
16      else
17          if (right1 < left2 || right2 < left1)
18              out = 0;
19          else
20              out = 1;
21          end
22      end
```

The coverage metrics for `rect_intersect` include Decision, Condition, and MCDC coverage. These are best understood after you examine the coverage for the decisions in `rect_intersect` highlighted in the listing below.

The listing for `rect_intersect` includes three highlighted line numbers. The first line is highlighted as the decision on whether or not to execute the function. Highlighted line numbers 14 and 17 indicate decisions in a nested `if-else` statement. Notice that the condition `right1 < left2` in line 17 is highlighted in red. This means that this condition did not test both the true and false possible outcomes for this decision during simulation. Exactly which of the outcomes was not tested is answered by the metrics for the decision in line 17. The metrics for line 17 and the remaining decisions appear below listed in numerical line order, and are easily accessed through the line number links in the listing.

Coverage for Line 1. Coverage metrics for line 1 appear directly below the listing for `rect_intersect` as shown.


intersecting_rectangles Coverage Report
File Edit Web Desktop Window Help
Location: C:/TEMP/tp302987_intersecting_rectangles_navigation.html
Summary | Details

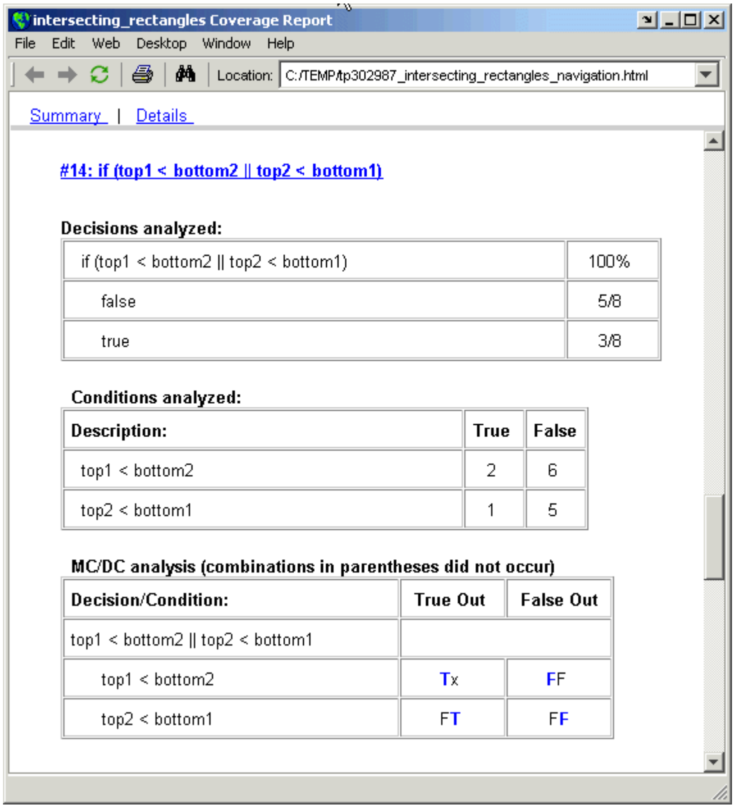
#1: function out = rect_intersect(rect1,rect2)

Decisions analyzed:

function out = rect_intersect(rect1,rect2)	100%
executed	8/8

The first line of every function receives coverage analysis indicative of the decision to run the function in response to a call. The preceding table indicates that `rect_intersect` executed. Coverage for this decision, which is equivalent to decision D1 in the metrics table for `rect_intersect`, is therefore 100%.

Coverage for Line 14. Coverage metrics for line 14 appear directly below the coverage metrics for line 1 as shown.



Location: C:/TEMP/tp302987_intersecting_rectangles_navigation.html

#14: if (top1 < bottom2 || top2 < bottom1)

Decisions analyzed:

if (top1 < bottom2 || top2 < bottom1)	100%
false	5/8
true	3/8

Conditions analyzed:

Description:	True	False
top1 < bottom2	2	6
top2 < bottom1	1	5

MC/DC analysis (combinations in parentheses did not occur)

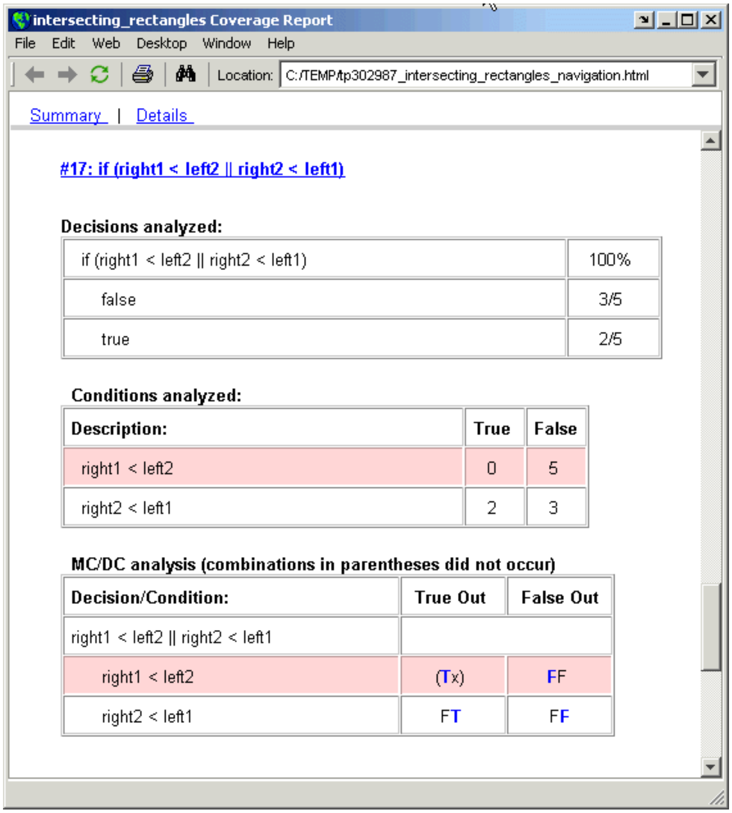
Decision/Condition:	True Out	False Out
top1 < bottom2 || top2 < bottom1		
top1 < bottom2	Tx	FF
top2 < bottom1	FT	FF

The **Decisions analyzed** table indicates that there are two possible outcomes for the decision in line 14: false and true. 5 of 8 times the decision evaluated false, and the remaining times (3) it evaluated true. Because both the true and false outcome occurred during simulation, Decision Coverage is 100%.

The following **Conditions analyzed** table sheds some light on the decision in line 14. Because this decision consists of two conditions linked by a logical or (`||`) operation, only one condition must evaluate true for the decision to be true. Also, if the first condition evaluates to true, there is no need to evaluate the second condition. The first condition, `top1 < bottom2`, was evaluated 8 times, and was true twice. This means that it was necessary to evaluate the second condition only 6 times. In only one case was it true, which brings the total of the true occurrence for the decision to 3 as reported in the **Decisions analyzed** table.

MCDC coverage looks for decision reversals that occur because one condition outcome changes from T to F or from F to T. The table identifies all possible combinations of outcomes for the conditions that lead to a reversal in the decision. The character x is used to indicate a condition outcome that is irrelevant to the decision reversal. Reversing condition outcomes that are not achieved during simulation are marked with a set of parentheses. There are no parentheses, so all decision reversing outcomes occurred, and MCDC Coverage is complete for this decision.

Coverage for rect_intersect Line 17. Coverage metrics for line 17 appear directly below the coverage metrics for line 14, as shown.



Location: C:/TEMP/tp302987_intersecting_rectangles_navigation.html

#17: if (right1 < left2 || right2 < left1)

Decisions analyzed:

if (right1 < left2 || right2 < left1)	100%
false	3/5
true	2/5

Conditions analyzed:

Description:	True	False
right1 < left2	0	5
right2 < left1	2	3

MC/DC analysis (combinations in parentheses did not occur)

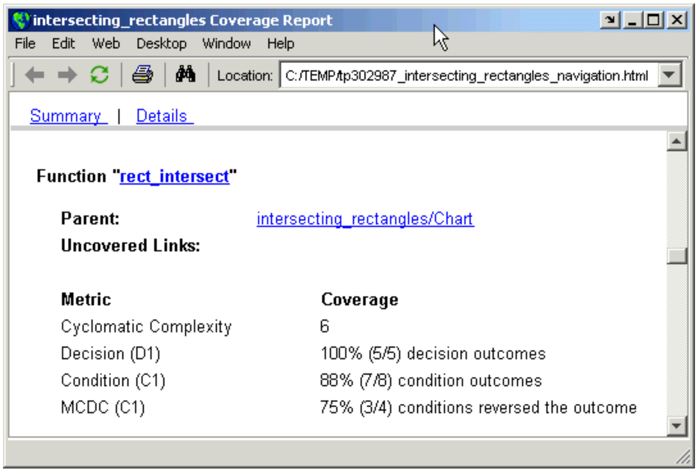
Decision/Condition:	True Out	False Out
right1 < left2 || right2 < left1		
right1 < left2	(Tx)	FF
right2 < left1	FT	FF

The line 17 decision `if (right1 < left2 || right2 < left1)` is nested in the `if` statement of the line 14 decision and is evaluated only if the line 14 decision is false. Because the line 14 decision evaluated false 5 times, line 17 is evaluated 5 times, 3 of which were false. Because both the true and false outcomes were achieved, Decision Coverage for line 17 is 100%.

Because line 17, like line 14, has two conditions related by a logical OR operator (`||`), condition 2 is tested only if condition 1 is false. Because condition 1 tests false 5 times, condition 2 is tested 5 times. Of these, condition 2 tests true 2 times and false 3 times, which accounts for the two occurrences of the true outcome for this decision.

Because the first condition of the line 17 decision does not test true, both outcomes did not occur for that condition, and the Condition Coverage for the first condition is highlighted with a rose color. Because the first condition of the line 17 decision does not test true, MCDC coverage is also highlighted in the same way for a decision reversal based on the true outcome for that condition.

Coverage for All rect_intersect Lines. Reviewing the coverage report for each line of `rect_intersect` in the previous topics makes sense of the coverage metrics reported at the beginning of the model coverage report for `rect_intersect`, which is as shown.


intersecting_rectangles Coverage Report
File
Edit
Web
Desktop
Window
Help
Location:
C:/TEMP/tp302987_intersecting_rectangles_navigation.html
Summary
Details

Function "rect_intersect"

Parent: intersecting_rectangles/Chart

Uncovered Links:

Metric	Coverage
Cyclomatic Complexity	6
Decision (D1)	100% (5/5) decision outcomes
Condition (C1)	88% (7/8) condition outcomes
MCDC (C1)	75% (3/4) conditions reversed the outcome

Reflecting on the model coverage reports for each line of `rect_intersect`, you can draw the following conclusions:

- There are five decision outcomes reported for `rect_intersect` in the line reports: one for line 1 (execute), two for line 14 (true and false), and two for line 17 (true and false). The decision coverage for each line shows 100% coverage. This means that decision coverage for `rect_intersect` is 5 of 5 or 100%.
- There are four conditions reported for `rect_intersect` in the line reports. Lines 14 and 17 each have two conditions, and each condition has two condition outcomes (true and false), for a total of eight condition outcomes in `rect_intersect`. All conditions tested for both the true and false outcome, except for the first condition of line 17 (`right1 < left2`). This means that condition coverage for `rect_intersect` is 7 of 8 or 88%.
- The MCDC tables for each line list two cases of decision reversal for each condition. Only the decision reversal from changing the condition 1 outcome from true to false did not occur during simulation. This means that 3 of 4 or 75% of the possible reversal cases were tested for during simulation. Therefore, only three of a possible four reversals were observed and coverage is 75%.

Working with Structures and Bus Signals in Stateflow Embedded MATLAB Functions

This section explains how to define structures in Stateflow Embedded MATLAB functions that you can interface to Simulink bus signals, or define as local or persistent variables.

- "About Structures in Stateflow Embedded MATLAB Functions" on page 13-37
- "Defining Structures in Stateflow Embedded MATLAB Functions" on page 13-37

About Structures in Stateflow Embedded MATLAB Functions

Embedded MATLAB supports MATLAB structures. You can create structures in top-level Embedded MATLAB functions in Stateflow charts to interface with Simulink bus signals at input and output ports. Simulink buses appear inside the Embedded MATLAB function as structures; structure outputs from the Embedded MATLAB function appear as buses.

You can also create structures as local and persistent variables in top-level functions and subfunctions of Embedded MATLAB functions in Stateflow.

Defining Structures in Stateflow Embedded MATLAB Functions

This section describes how to define structures in Stateflow Embedded MATLAB functions.

- "Rules for Defining Structures in Stateflow Embedded MATLAB Functions" on page 13-38
- "Defining Structure Inputs and Outputs to Interface with Bus Signals" on page 13-38
- "Defining Local and Persistent Structure Variables" on page 13-40

Rules for Defining Structures in Stateflow Embedded MATLAB Functions

Follow these rules when defining structures in Stateflow Embedded MATLAB functions:

- For each structure input or output in an Embedded MATLAB function in Stateflow, you must define a `Simulink.Bus` object in the base workspace to specify its type to Simulink.
- Embedded MATLAB structures cannot inherit their type from Simulink.
- Embedded MATLAB Function blocks support nonvirtual buses only (see "Virtual and Nonvirtual Buses" in the Simulink User's Guide documentation).
- Structures cannot have scopes defined as **Parameter** or **Constant**.

Defining Structure Inputs and Outputs to Interface with Bus Signals

When you create structure inputs in Stateflow Embedded MATLAB functions, Embedded MATLAB determines the type, size, and complexity of the structure from the Simulink input signal. When you create structure outputs, you must define their type, size, and complexity in the Embedded MATLAB function.

You can connect Embedded MATLAB structure inputs and outputs to any Simulink bus signal, including:

- Simulink blocks that output bus signals— such as Bus Creator blocks
- Simulink blocks that accept bus signals as input — such as Bus Selector and Gain blocks
- S-Function blocks
- Other Embedded MATLAB functions

To define structure inputs and outputs in Stateflow Embedded MATLAB functions, follow these steps:

1. Create a Simulink bus object in the base workspace to specify the properties of the structure you will create in the Stateflow Embedded MATLAB function.

For information about how to create Simulink bus objects, see `Simulink.Bus` in the Simulink Reference.

2 From the Embedded MATLAB Editor menu bar, open the Model Explorer by selecting **Tools > Model Explorer**.

3 In the Model Explorer, follow these steps:

   a In the Model Hierarchy pane, select the Embedded MATLAB function in your Stateflow chart.

   b Add a data object, as described in "Adding Data Using the Model Explorer" on page 7-27.

   The Model Explorer adds a data object and opens a Properties dialog box in its right-hand Dialog pane.

   c In the Properties dialog box, enter the following information in the General tab fields:

Field	What to Specify
Name	Enter a name for referencing the structure in the Embedded MATLAB function. This name does not have to match the name of the bus object in the base workspace.
Scope	Select **Input** or **Output**.
Data type mode	Select **Bus Object**.
Bus object	Enter the name of the `Simulink.Bus` object in the base workspace that defines the structure.

   d To add or modify `Simulink.Bus` objects, click the **Edit** button to bring up the Simulink Bus Types Editor (see "Using Bus Objects" in the Simulink User's Guide).

   e Click **Apply**.

4 If your structure is an output (has scope of **Output**), define the output implicitly in the Embedded MATLAB function to have the same type, size, and complexity as its `Simulink.Bus` object, as described in "About Embedded MATLAB Structures" in Embedded MATLAB documentation.

Defining Local and Persistent Structure Variables

You can define structures as local or persistent variables inside Embedded MATLAB functions (see “Types of Embedded MATLAB Structures” in the Simulink Reference documentation).

Building Targets

Stateflow generates code that lets you execute Stateflow diagrams on target computers. Stateflow builds a special simulation target (sfun) that lets you simulate your Stateflow application in Simulink. Stateflow also works with Simulink to let you build a Real-Time Workshop (RTW) target application for running Stateflow and Simulink applications on other computers. Finally, Stateflow lets you build custom targets from Stateflow applications only.

Overview of Stateflow Targets

This section gives you an overview understanding of what targets are in Stateflow and how you use them in the following topics:

- "What Is a Simulink RTW Target?" on page 14-3 — Describes the type of targets you can build from a model in Simulink.
- "What Is a Stateflow Target?" on page 14-3 — Describes the type of targets you can use to configure Stateflow contributions to a target you build for a library model in Simulink.

What Is a Simulink RTW Target?

A Simulink RTW target is a container for specifying the generated code, custom code, and build type used in building an application or producing generated code for a Simulink model. The model represented by an RTW target can include non-Stateflow as well as Stateflow blocks. An RTW target can also run on computers that do not have a floating-point instruction set. Building an RTW target requires the Real-Time Workshop and Stateflow Coder.

What Is a Stateflow Target?

A Stateflow target is a container in Stateflow for specifying the generated code, custom code, and build type used in building an application or producing generated code from the Stateflow blocks in a Simulink model. There are three types of Stateflow targets:

- Simulation target (`sfun`)

  The Stateflow simulation target (named `sfun`) is a container in Stateflow for specifying the generated code, custom code, and build type used for simulating Stateflow blocks in a Simulink model. When you build a simulation target for a Simulink model, the information from a Stateflow simulation target is combined with the information for the rest of the model. When you add a Stateflow block to a Simulink model, a Stateflow simulation target named `sfun` is added to the model by default.

- Real-Time Workshop (`rtw`) target

The Stateflow RTW target is *used for library models only* to specify custom code options that apply to the library model, but not the main model. Stateflow blocks in nonlibrary models use the RTW configuration settings of the parent Simulink model (see "Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop" on page 14-13). The Stateflow RTW target is a container in Stateflow for specifying the generated code, custom code, and build type used for generating code for Stateflow blocks in Simulink library models. When you build an RTW target for a Simulink model, the information from a Stateflow RTW target is combined with the information for the rest of the model. Inputs to and outputs from Stateflow blocks in a library model can only be resolved when a Stateflow target is combined with the Simulink target during the build process. Stateflow RTW targets let you specify target information for the Stateflow blocks in a library model before the model is used in building an application (see "Configuring Stateflow Blocks in Library Models for Real-Time Workshop" on page 14-16).

- Custom targets — A Stateflow custom target (named anything but `sfun` or `rtw`) is a convenience for collecting the generated code for the Stateflow charts used in a model. After you collect the code, you can use this code at your own discretion in building your own applications.

How Do You Build a Target?

This section gives an overview to the entire process of building a target for models with Stateflow blocks. Use the following steps to find the right procedure for building a target for your model:

1 Add a Stateflow target, if necessary.

You need to add a Stateflow target to the model for any of the following cases:

- You are configuring the Simulink RTW target for a *library* model with Stateflow blocks.

  In this case, you need to add an RTW target (named `rtw`) in Stateflow or the **Model Explorer**.

  Note You *cannot* add targets named `rtw` for Stateflow charts in *nonlibrary* models. In this scenario, the Stateflow charts use the RTW configuration settings of the parent Simulink model (see "Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop" on page 14-13).

- You want to generate code from the Stateflow blocks in a model with a custom target.

  In this case, you need to add a custom target (named anything but `sfun` or `rtw`) to the model in the **Model Explorer**.

See "Adding Stateflow Targets" on page 14-8 for instructions on adding a Stateflow target to the model.

2 Configure the target.

See one of the following sections for the target you build:

- "Configuring a Simulation Target for Stateflow" on page 14-10
- "Configuring Real-Time Workshop for Stateflow" on page 14-13
- "Configuring a Custom Target in Stateflow" on page 14-22

3 Include your own custom code in the target.

This is actually a part of step 2 that requires special attention. You can include your own custom C code in the target when you configure it. See “Integrating Custom Code with Stateflow Targets” on page 14-27 for details.

4 Configure the target for the rest of the Simulink model.

The preceding steps configure a target only for the contribution from the Stateflow blocks in a model. You configure the rest of the model in the Simulink **Configuration Parameters** dialog. See the “Configuration Parameters Dialog Box” in Simulink documentation.

5 Start the build process.

Stateflow automatically builds or rebuilds simulation targets when you initiate simulation of the Stateflow machine. You must explicitly initiate the build process for other types of targets. See “Starting the Build” on page 14-34 for more information.

How Does Stateflow Build into Targets?

This topic give you information on how Stateflow blocks contribute to the building of targets in the following steps:

1. Stateflow parses the charts in the model to ensure that their logic is valid.

2. If any errors are found, Stateflow displays the errors in the Build window and halts. See “Parsing Stateflow Diagrams” on page 14-36 for more details.

3. If the charts parse without error, Stateflow Coder generates C code from the charts.

   The code generator accepts various options that control the code generation process. You specify these options when you configure Stateflow for targets.

4. Stateflow Coder generates a makefile to build the generated source code into an executable program.

   The generated makefile can optionally build custom code that you specify into the target. See “Integrating Custom Code with Stateflow Targets” on page 14-27 for details.

5. The specified C compiler for MATLAB and a make utility build the code into an application for the target.

   Building Simulink targets requires a C compiler that is supported by MATLAB. The Microsoft Windows version of Stateflow comes with a C compiler (`lcc.exe`) and a make utility (`lccmake`). Both tools are installed in the directory `matlabroot\sys\lcc`. If you do not configure MATLAB to use any other compiler, Stateflow uses `lcc` to build targets. For details on setting up your own C compiler, see “Setting Up Your Own Target Compiler”

Adding Stateflow Targets

This section describes how to add targets from the Stateflow Editor. You can also create Stateflow targets in the **Model Explorer** (see “Adding a Target in the Model Explorer” on page 16-6 for details).

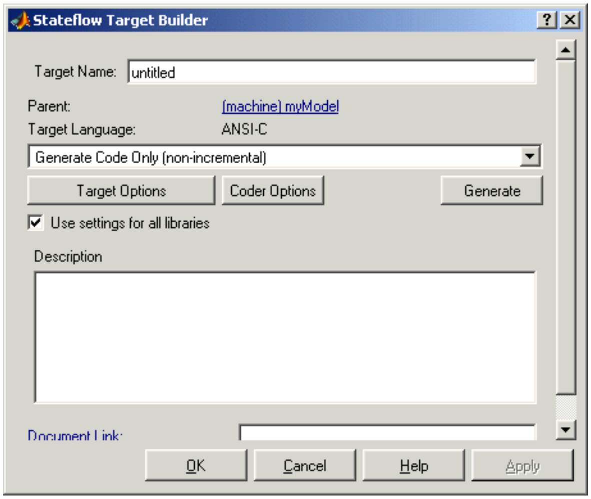
- “Adding Stateflow Custom Targets” on page 14-8
- “Adding Custom Code to Stateflow in Library Models” on page 14-9

Adding Stateflow Custom Targets

You add custom targets in Stateflow when you want to collect the generated code for Stateflow blocks in a model for building your own applications. To add custom targets, follow these steps:

1 In the Stateflow Editor, select **Target** from the **Add** menu.

The **Stateflow Target Builder** dialog appears, as shown.



Stateflow Target Builder

Target Name: untitled

Parent: (machine) myModel

Target Language: ANSI-C

Generate Code Only (non-incremental)

☑ Use settings for all libraries

Description

Document Link:

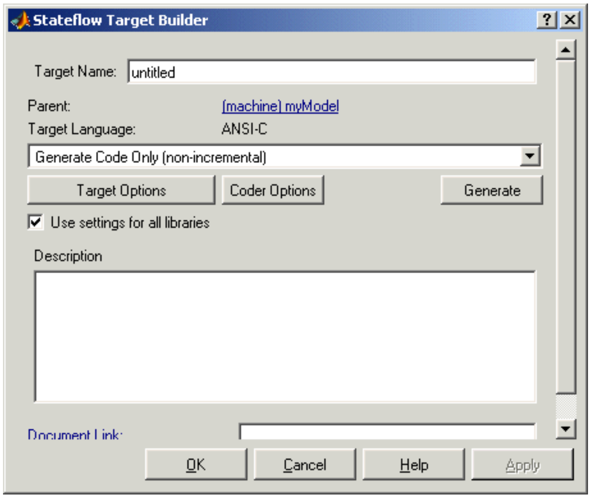
2 In the **Target: Name** field, enter any name except the reserved names `sfun` and `rtw`, and click **OK**.

Adding Custom Code to Stateflow in Library Models

Stateflow charts use the RTW configuration settings of the parent Simulink model for code generation. However, if you wish to specify custom code options for Stateflow in a library model, you can add a Stateflow RTW target, as follows:

1 In the Stateflow Editor, select **Target** from the **Add** menu.

The **Stateflow Target Builder** dialog appears, as shown.



Stateflow Target Builder

Target Name: untitled

Parent: (machine) myModel

Target Language: ANSI-C

Generate Code Only (non-incremental)

☑ Use settings for all libraries

Description

Document Link:

2 In the **Target: Name** field, enter`rtw` as the name of the target and click **OK**.

Note You cannot create a Stateflow `rtw` target for nonlibrary models. Stateflow blocks in nonlibrary models always use the RTW configuration settings of the parent Simulink model (see “Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop” on page 14-13).

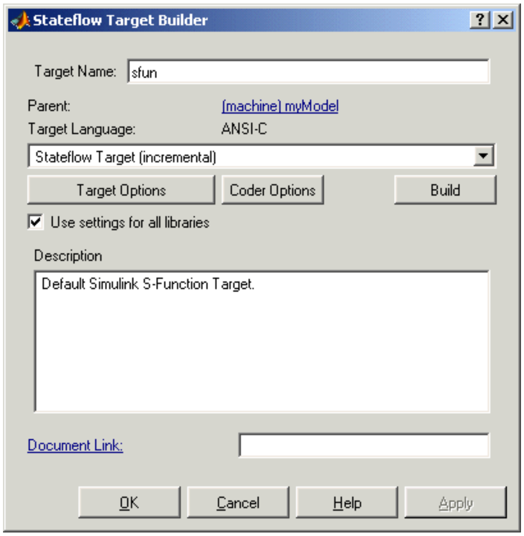
Configuring a Simulation Target for Stateflow

You can configure your model to simulate the Stateflow blocks in your model by configuring the Stateflow simulation target (`sfun`). Any model that contains one or more Stateflow blocks has a Stateflow simulation target. When you configure this target and build the model for simulation, this target configuration is carried into the simulation configuration for the entire model.

To configure the Stateflow simulation target, do the following:

1 From the Stateflow diagram editor **Tools** menu, select **Open Simulation Target**.

The **Stateflow Target Builder** dialog appears.



Stateflow Target Builder

Target Name: sfun

Parent: (machine) myModel

Target Language: ANSI-C

Stateflow Target (incremental)

☑ Use settings for all libraries

Description

Default Simulink S-Function Target.

Document Link:

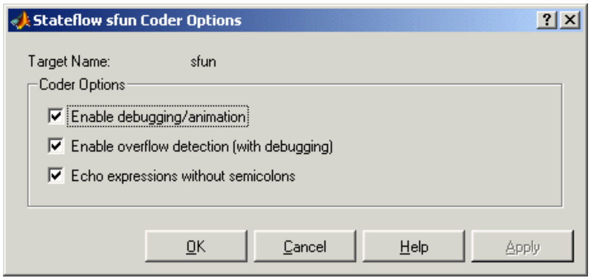
2 Select one of the following build options:

- **Stateflow Target (incremental)**) to rebuild only those portions of the target corresponding to charts that have changed logically since the last build.
- **Rebuild All (including libraries)** to rebuild the target, including chart libraries, from scratch.

- **Make without generating code** to invoke the make process without generating code. This is useful when you have custom source files that need to be recompiled within a Stateflow incremental build mechanism that does not detect changes in custom software files.

3 To specify code generation options for a simulation target, select **Coder Options**.

The **Simulation Coder Options** dialog box appears.



Stateflow sfun Coder Options

Target Name: sfun

Coder Options

☑ Enable debugging/animation

☑ Enable overflow detection (with debugging)

☑ Echo expressions without semicolons

4 Select **OK** or **Apply** for any or all of the following options:

- **Enable debugging/animation** -- Enables chart animation and debugging. Stateflow enables debugging code generation when you use the debugger to start a model simulation. You can enable or disable chart animation separately in the debugger. (The Stateflow debugger does not work with stand-alone and RTW targets. Therefore, Stateflow and Real-Time Workshop do not generate debugging/animation code for these targets, even if this option is enabled.)

- **Enable overflow detection (with debugging)** -- Overflow occurs for data when a value is assigned to it that exceeds the numeric capacity of its type. If this check box is selected, Stateflow generates code for overflow detection of Stateflow data. If cleared, no code is generated for overflow detection.

  The **Enable overflow detection (with debugging)** option is particularly important for fixed-point data. See "Overflow Detection for Fixed-Point Types" on page 9-11.

Note To actually detect overflow in data during simulation, you must also select the **Data Range** check box in the Debugger window. See "Debugging Data Range Violations" on page 15-20 for more details.

- **Echo expressions without semicolons** — Display run-time output in the MATLAB Command Window, specifically actions that are not terminated by a semicolon.

5 Select (check) the **Use settings for all libraries** option if you want the settings that you specify for this target to apply to all the Stateflow charts contributed by library models as well.

6 To specify custom code options for the simulation target, select **Target Options**.

See "Integrating Custom Code with Stateflow Targets" on page 14-27 for details on using the simulation target to integrate custom code with generated code for the Stateflow diagrams in the model.

7 To finish configuring the simulation target, do one of the following:

- Click **Apply** to apply the selected options
- Click **OK** to apply the options and close the dialog
- Click **Build** to build the simulation target.

Note Use the **Chart Properties** dialog to tell the simulation target builder to recognize C bitwise operators (~, &, |, ^, >>, and so on) in action language statements and encode them as C bitwise operations.

Configuring Real-Time Workshop for Stateflow

If you have a Real-Time Workshop (RTW) license, you can configure the Stateflow blocks in your model to generate code for an RTW target. The RTW configuration you use depends on whether your model is a normal nonlibrary model or a library model.

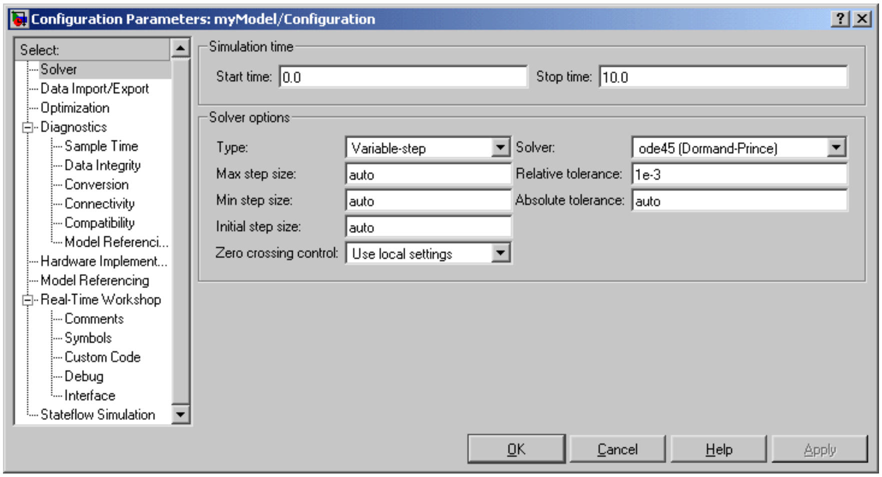
- "Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop" on page 14-13 — For a nonlibrary model, specify the RTW configuration for Stateflow in the Simulink **Configuration Parameters** dialog.
- "Configuring Stateflow Blocks in Library Models for Real-Time Workshop" on page 14-16 — For a library model, specify the RTW configuration for Stateflow by configuring an RTW target in Stateflow.

Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop

Stateflow blocks in nonlibrary models use the RTW configuration settings of the parent Simulink model. However, you can specify how to optimize RTW code generation for Stateflow blocks in nonlibrary models, as follows:

1. In a Simulink window or a Stateflow diagram editor, from the Simulation menu, select Configuration Parameters.

   The Configuration Parameters dialog appears, as shown.



Configuration Parameters: myModel/Configuration

Simulation time

Start time: 0.0 Stop time: 10.0

Solver options

Type: Variable-step Solver: ode45 (Dormand-Prince)

Max step size: auto Relative tolerance: 1e-3

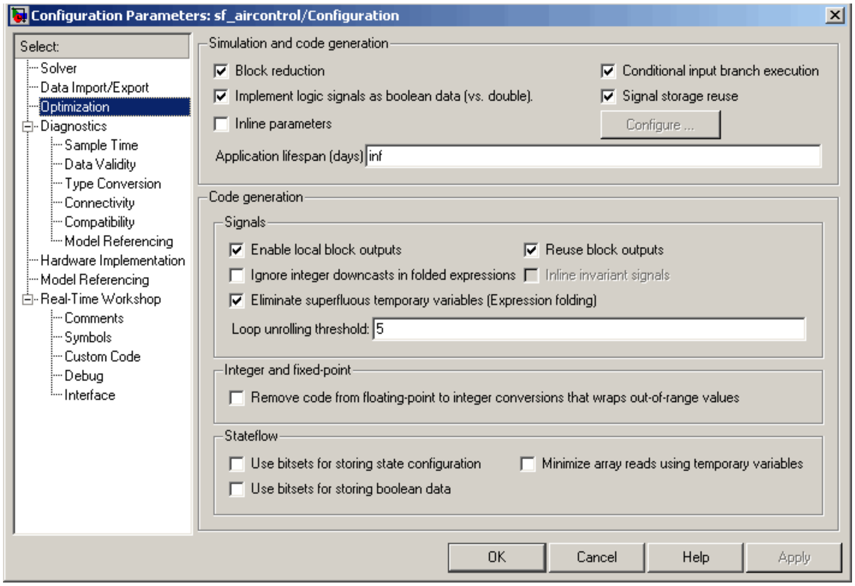
Min step size: auto Absolute tolerance: auto

Initial step size: auto

Zero crossing control: Use local settings

2 Select the Optimization node, as shown.

The Optimization configuration settings appear in the right pane, as shown.



Configuration Parameters: sf_aircontrol/Configuration

Simulation and code generation

☑ Block reduction ☑ Conditional input branch execution

☑ Implement logic signals as boolean data (vs. double). ☑ Signal storage reuse

☐ Inline parameters

Application lifespan (days) inf

Code generation

Signals

☑ Enable local block outputs ☑ Reuse block outputs

☐ Ignore integer downcasts in folded expressions ☐ Inline invariant signals

☑ Eliminate superfluous temporary variables (Expression folding)

Loop unrolling threshold: 5

Integer and fixed-point

☐ Remove code from floating-point to integer conversions that wraps out-of-range values

Stateflow

☐ Use bitsets for storing state configuration ☐ Minimize array reads using temporary variables

☐ Use bitsets for storing boolean data

3 In the right pane, in the **Stateflow** section, select from the following options:

- **Use bitsets for storing state configuration** — Enabling this option specifies that bitsets be used for storing state configuration variables. This can significantly reduce the amount of memory required to store the variables. However, it can increase the amount of memory required to store target code if the target processor does not include instructions for manipulating bitsets.
- **Use bitsets for storing boolean data** — Enabling this option specifies that bitsets be used for storing Boolean data. This can significantly reduce the amount of memory required to store Boolean variables. However, it can increase the amount of memory required to store target code if the target processor does not include instructions for manipulating bitsets.
- **Minimize array reads using temporary variables** — In certain microprocessors, global array read operations are more expensive than accessing a temporary variable on stack. Using this option minimizes array reads by using temporary variables when possible.

  For example, the generated code

  ```
  a[i] = foo();
  if(a[i]<10 && a[i]>1) {
      y = a[i]+5;
  }else{
  z = a[i];
  }
  ```

  now becomes

  ```
  a[i] = foo();
  temp = a[i];
  if(temp<10 && temp>1) {
      y = temp+5;
  }else{
      z = temp;
  }
  ```

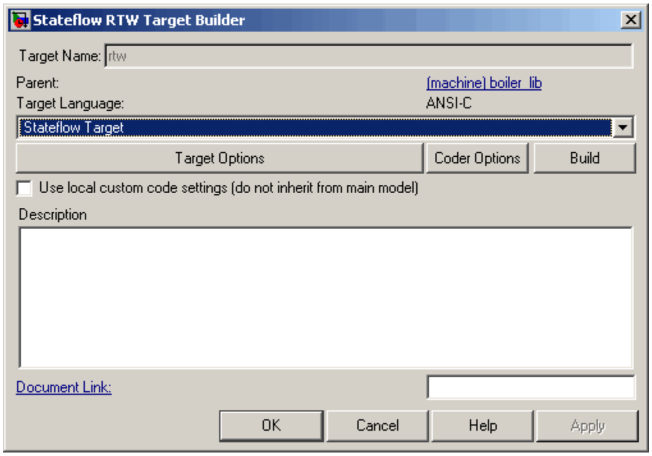
Configuring Stateflow Blocks in Library Models for Real-Time Workshop

For library models you configure the Stateflow blocks in your model for Real-Time Workshop by adding an RTW target. When the model is built, the configuration for this target is carried into the Simulink RTW configuration and resolved under actual Simulink conditions.

To configure an existing Stateflow RTW target for a library model, do the following:

1 From the Stateflow diagram editor **Tools** menu, select **Open RTW Target**.

The Stateflow RTW Target Builder dialog box appears:



Stateflow RTW Target Builder

Target Name: rtw

Parent: [machine] boiler_lib

Target Language: ANSI-C

Stateflow Target

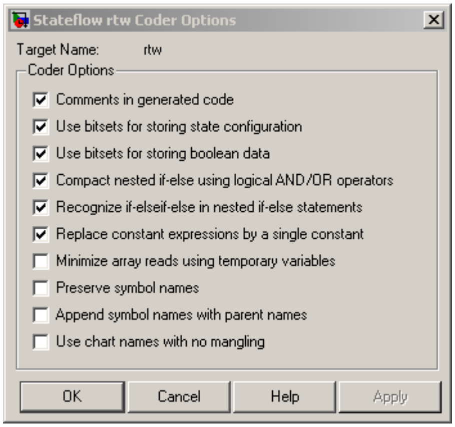
□ Use local custom code settings (do not inherit from main model)

Description

Note The option **Stateflow Target** builds Stateflow code in the RTW target.

2 Select **Coder Options** to specify Stateflow code generation options for the RTW target.

The **RTW Coder Options** dialog box appears, as shown.



Stateflow rtw Coder Options

Target Name: rtw

Coder Options

☑ Comments in generated code
☑ Use bitsets for storing state configuration
☑ Use bitsets for storing boolean data
☑ Compact nested if-else using logical AND/OR operators
☑ Recognize if-elseif-else in nested if-else statements
☑ Replace constant expressions by a single constant
☐ Minimize array reads using temporary variables
☐ Preserve symbol names
☐ Append symbol names with parent names
☐ Use chart names with no mangling

3 Select any combination of the following coder options:

- **Comments in generated code** — Include comments in the generated code.

- **Use bitsets for storing state configuration** — Use bitsets for storing state configuration variables. This can significantly reduce the amount of memory required to store the variables. However, it can increase the amount of memory required to store target code if the target processor does not include instructions for manipulating bitsets.

- **Use bitsets for storing boolean data** — Use bitsets for storing Boolean data. This can significantly reduce the amount of memory required to store Boolean variables. However, it can increase the amount of memory required to store target code if the target processor does not include instructions for manipulating bitsets.

- **Compact nested if-else using logical AND/OR operators --** Improves readability of generated code by compacting nested if-else statements using logical AND (&&) and OR (||) operators.

  For example, the generated code

  ```
  if(c1) {
      if(c1) {
          a1();
      }
  }
  ```

now becomes

```
if(c1 && c2) {
    a1();
}
```

and the generated code

```
if(c1) {
    /* fall through to do a1() */
}else if(c2) {
    /* fall through to do a1() */
}else{
    /* skip doing a1() */
    goto label1;
}
a1();
label1:
    a2();
```

becomes

```
if(c1 || c2) {
    a1();
}
a2();
```

- **Recognize if-elseif-else in nested if-else statements** -- Improves readability of generated code by recognizing and emitting an `if-elseif-else` construct in place of deeply nested `if-else` statements.

  For example, the generated code

  ```
  if(c1) {
      a1();
  }else{
      if(c2) {
          a2();
      }else{
          if(c3) {
  ```

```
            a3();
        }
    }
}
```

becomes

```
if(c1) {
    a1();
}else if(c2) {
    a2();
}else if(c3) {
    a3();
}
```

- **Replace constant expressions by a single constant** -- Improves readability by preevaluating constant expressions and emitting a single constant. This optimization also opens up opportunities for eliminating dead code.

  For example, the generated code

  ```
  if(2+3<2) {
      a1();
  }else {
      a2(4+5);
  }
  ```

  becomes

  ```
  if(0) {
      a1();
  }else {
      a2(9);
  }
  ```

  in the first phase of this optimization. The second phase eliminates the `if` statement, resulting in simply

  ```
  a2(9);
  ```

- **Minimize array reads using temporary variables** — In certain microprocessors, global array read operations are more expensive than accessing a temporary variable on stack. Using this option minimizes array reads by using temporary variables when possible.

  For example, the generated code

  ```
  a[i] = foo();
  if(a[i]<10 && a[i]>1) {
      y = a[i]+5;
  }else{
      z = a[i];
  }
  ```

  becomes

  ```
  a[i] = foo();
  temp = a[i];
  if(temp<10 && temp>1) {
      y = temp+5;
  }else{
      z = temp;
  }
  ```

- **Preserve symbol names** — (See note below before using.) Preserve symbol names (names of states and data) in generated code. This option is useful when the target contains custom code that accesses Stateflow data.

  This option can generate duplicate C symbols if the source chart contains duplicate symbols, for example, two substates with identical names. Enable the next option to avoid duplicate substate names.

- **Append symbol names with parent names** — (See note below before using.) Generate a state or data name by appending the name of the item's parent to the item's name.

- **Use chart names with no mangling** — (See note below before using.) Preserve the names of chart entry functions so that they can be invoked by user-written C code.

Note When you use the options **Preserve symbol names**, **Append symbol names with parent names**, or **Use chart names with no mangling**, the names of symbols in generated code are not mangled to make them unique. Because these options do not check for symbol conflicts in generated code, use them only when your symbol names are unique within the model. Conflicts in generated names cause variable aliasing and compilation errors.

4 Select (check) the **Use local custom code settings (do not inherit from the main model)** option if you want the library model to use its own custom code settings rather than inheriting the main model's custom code settings.

5 To integrate custom code with Stateflow generated code for the RTW target, select **Target Options**.

   See "Integrating Custom Code with Stateflow Targets" on page 14-27 for details on using the RTW target to integrate custom code with generated code for the Stateflow diagrams in the model.

6 To finish configuring the RTW target, do one of the following:

   - Click **Apply** to apply the selected options.
   - Click **OK** to apply the options and close the dialog.
   - Click **Build** to build the RTW target.

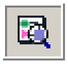
Note To configure Stateflow to recognize C bitwise operators (~, &, |, ^, >>, and so on) in action language statements and encode them as C bitwise operations, select the **Enable C-bit operations** property in the **Chart Properties** dialog.

Custom code options are selected through the **Target Options** button. To specify custom code options for your RTW target, see "Integrating Custom Code with Stateflow Targets" on page 14-27.

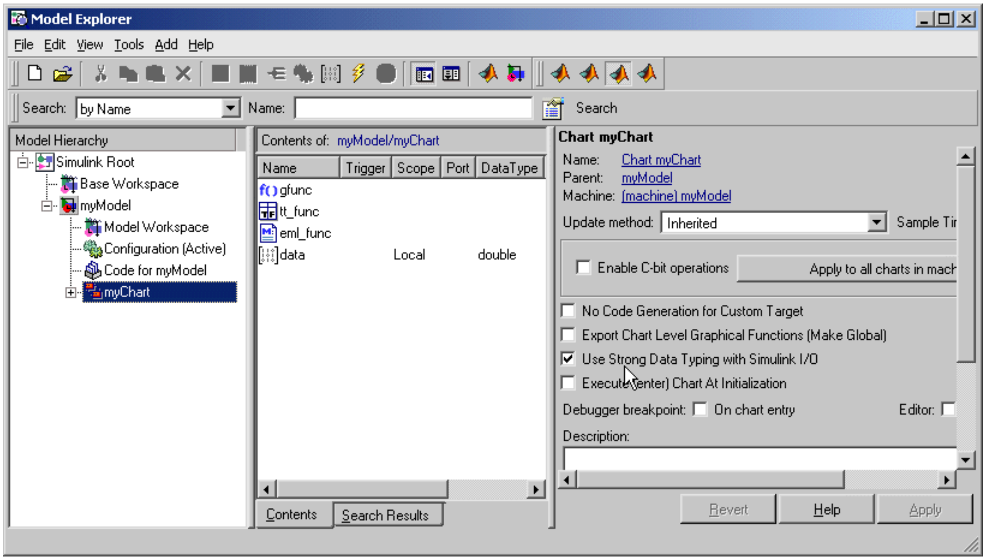
Configuring a Custom Target in Stateflow

A Stateflow custom target (named anything but `sfun` or `rtw`) is a convenience for collecting the generated code for the Stateflow charts in a model. After you collect the code, you can use this code at your own discretion in building your own applications. You configure a custom target in the **Model Explorer** with the following procedure:

1 From the Stateflow diagram editor toolbar, select Explore icon:



2 The **Model Explorer** appears with the Stateflow chart highlighted in the **Model Hierarchy** pane.



Contents of: myModel/myChart

Name	Trigger	Scope	Port	DataType
gfunc				
tt_func				
eml_func				
data		Local		double

Chart myChart

Name: Chart myChart

Parent: myModel

Machine: (machine) myModel

Update method: Inherited Sample Ti

□ Enable C-bit operations Apply to all charts in mach

□ No Code Generation for Custom Target

□ Export Chart Level Graphical Functions (Make Global)

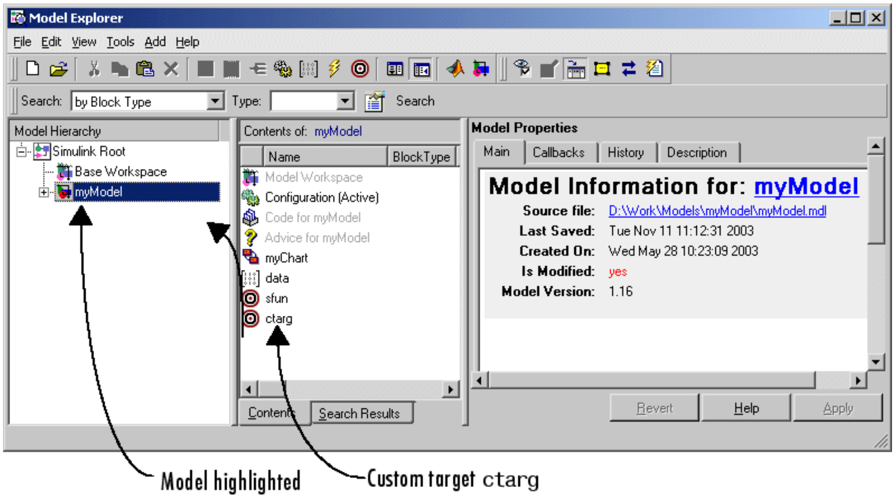
☑ Use Strong Data Typing with Simulink I/O

□ Execute (enter) Chart At Initialization

Debugger breakpoint: □ On chart entry Editor: □

Description:

3 In the **Model Explorer**, in the left **Model Hierarchy** pane, select the Simulink model with the custom target.



Model Information for: myModel

Source file: D:\Work\Models\myModel\myModel.mdl
Last Saved: Tue Nov 11 11:12:31 2003
Created On: Wed May 28 10:23:09 2003
Is Modified: yes
Model Version: 1.16

Model highlighted

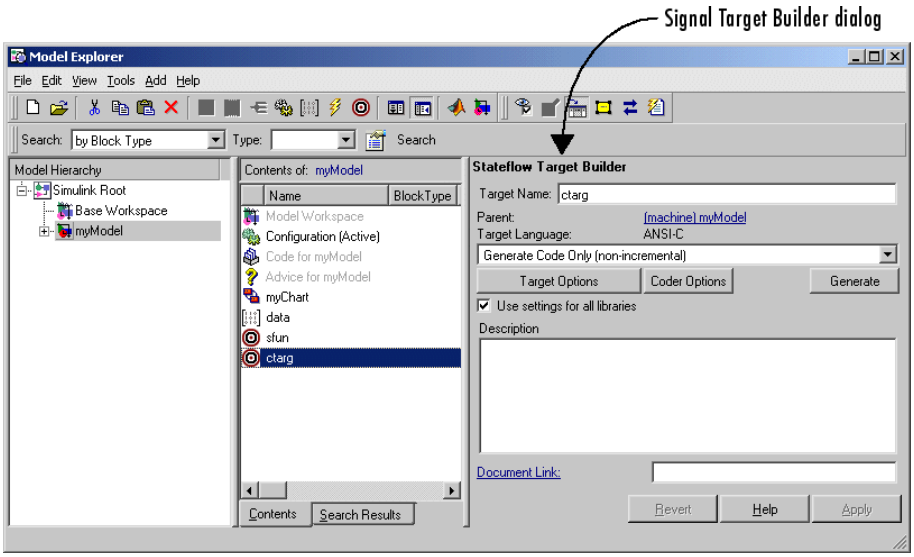
Custom target ctarg

The custom target (in this example, `ctarg`) appears as a child of the Simulink model. Custom targets have names other than `sfun` or `rtw`.

If you need to create a custom target in the **Model Explorer**, see “Adding a Target in the Model Explorer” on page 16-6.

4 In the **Contents** pane, click the row for the custom target `ctarg`.

The **Stateflow Target Builder** dialog appears in the dynamic dialog on the right, as shown.



Signal Target Builder dialog

Stateflow Target Builder

Target Name: ctarg

Parent: (machine) myModel

Target Language: ANSI-C

Generate Code Only (non-incremental)

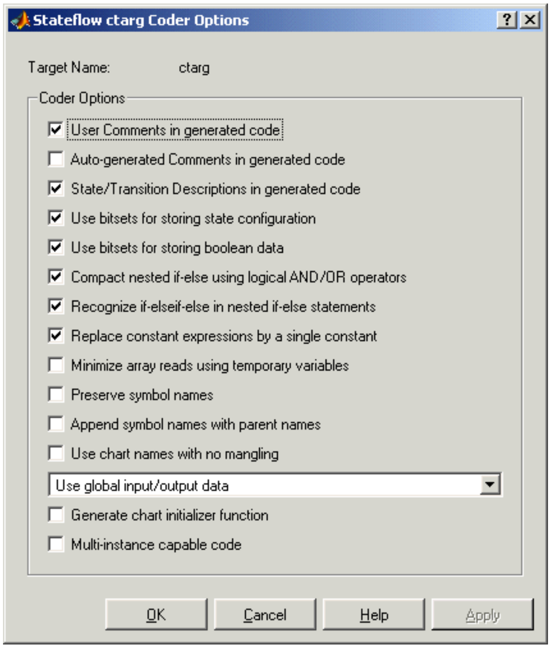
☑ Use settings for all libraries

5 In the **Stateflow Target Builder** dynamic dialog, in the long field below the **Target Language** descriptor, select one of the following build options:

- **Generate code only (non-incremental)** to regenerate code for all charts in the model.
- **Rebuild All (including libraries)** to rebuild the target, including chart libraries, from scratch.
- **Make without generating code** to invoke the Make process without generating code. This is useful when you have custom source files that need to be recompiled within a Stateflow incremental build mechanism that does not detect changes in custom software files.

6 To specify code generation options for a custom target, select the **Coder Options**.

The **Coder Options** dialog box for the custom target appears as follows:



Stateflow ctarg Coder Options

Target Name: ctarg

Coder Options

- ☑ User Comments in generated code
- ☐ Auto-generated Comments in generated code
- ☑ State/Transition Descriptions in generated code
- ☑ Use bitsets for storing state configuration
- ☑ Use bitsets for storing boolean data
- ☑ Compact nested if-else using logical AND/OR operators
- ☑ Recognize if-elseif-else in nested if-else statements
- ☑ Replace constant expressions by a single constant
- ☐ Minimize array reads using temporary variables
- ☐ Preserve symbol names
- ☐ Append symbol names with parent names
- ☐ Use chart names with no mangling

Use global input/output data

- ☐ Generate chart initializer function
- ☐ Multi-instance capable code

7 Select any or all of the following options:

The following options are unique to custom targets:

- **I/O Format Options** — Can be any one of the following:

  Select **Use global input/output data** to generate chart input and output data as global variables.

  Select **Pack input/output data into structures** to generate structures for chart input data and chart output data.

  The **Separate argument for input/output data** generates input and output data as separate arguments to a function.

- **Generate chart initializer function** — Generates a function initializer of data.
- **Multi-instance capable code** — Generates multiply instantiable chart objects instead of a static definition.

The following options are also available for RTW targets. See “Configuring Real-Time Workshop for Stateflow” on page 14-13 for a description.

- **Comments in generated code**
- **Use bitsets for storing state configuration**
- **Use bitsets for storing boolean data**
- **Compact nested if-else using logical AND/OR operators**
- **Recognize if-elseif-else in nested if-else statements**
- **Replace constant expressions by a single constant**
- **Minimize array reads using temporary variables**
- **Preserve symbol names**
- **Append symbol names with parent names**
- **Use chart names with no mangling**

Custom code options are selected through the **Target Options** button. To specify custom code options for your rtw target, see “Integrating Custom Code with Stateflow Targets” on page 14-27.

1 Select (check) the **Use settings for all libraries** option if you want the settings that you specify for this target to apply to all the Stateflow charts contributed by library models as well.

2 To specify custom code options for the simulation target, select **Target Options**.

   See “Integrating Custom Code with Stateflow Targets” on page 14-27 for details on using the custom target to integrate custom code with generated code for the Stateflow diagrams in the model.

3 To finish configuring the custom target, do one of the following:

   - Click **Apply** to apply the selected options.
   - Click **OK** to apply the options and close the dialog.
   - Click **Build** to build the RTW target.

Integrating Custom Code with Stateflow Targets

For all Stateflow targets (simulation, RTW, and custom) you can configure custom code options that let you incorporate custom C or C++ code into the target you build for a model. This lets you take advantage of legacy code that augments model capabilities and lets you define and include custom global variables that can be shared by both Stateflow generated code and your custom code.

Integrate custom code with Stateflow targets as described in the following topics:

- "Specifying Custom Code Options for Stateflow Targets" on page 14-27 — Describes the target options you need to set and specify in order to build custom code into your target.
- "Specifying Relative Paths for Custom Code" on page 14-30— Shows you where Stateflow searches for the custom code files you specify with a relative path.
- "Including Custom C++ Code" on page 14-31 — Shows you how to specify and include C++ custom code with your library model.

Specifying Custom Code Options for Stateflow Targets

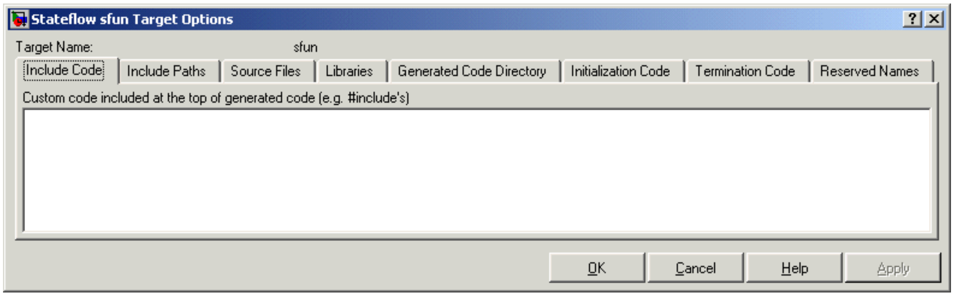
You include custom code in Stateflow simulation, RTW, and custom targets in the tabbed option pages of the Stateflow **Target Options** dialog. Use the following procedure to specify configuration options to build custom code into a Stateflow target:

1. Open the **Target Builder** dialog for the Stateflow simulation, RTW, or custom target as described in the following sections:
   - "Configuring a Simulation Target for Stateflow" on page 14-10
   - "Configuring Stateflow Blocks in Library Models for Real-Time Workshop" on page 14-16
   - "Configuring a Custom Target in Stateflow" on page 14-22

You also access the **Target Builder** dialog for an RTW or custom target when you first create it. See “Adding Stateflow Targets” on page 14-8 for instructions.

2 In the **Target Builder** dialog, select the **Target Options** button.

The **Target Options** dialog appears, as shown:



Stateflow sfun Target Options

Target Name: sfun

Custom code included at the top of generated code (e.g. #include's)

3 Specify your custom code in the edit boxes of the following tabbed pages of the **Target Options** dialog:

- **Include Code** — Enter code lines (for example, `#include test.h`) to include at the top of a generated header file that declares custom functions and data used by the generated code. These code lines are included at the top of all generated source code files and are visible to all generated code.

  Since the code specified in this option is included in multiple source files that are linked into a single binary, there are some limitations on what you can and cannot include. For example, you should 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 symbols are defined 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);`.

- **Include Paths** — Enter a space-separated list of the directory paths that contain custom header files to be included either directly (see Include Code option) or indirectly in the compiled target. See “Specifying Relative Paths for Custom Code” on page 14-30 for instructions on entering directory path names.
- **Source Files** — Enter a list of source files to be compiled and linked into the target. You can separate source files with either a comma, a space, or a new line. See “Specifying Relative Paths for Custom Code” on page 14-30 for instructions on entering directory path names.
- **Libraries** — Enter a space-separated list of static libraries containing custom object code to be linked into the target. See “Specifying Relative Paths for Custom Code” on page 14-30 for instructions on entering directory path names.
- **Generated Code Directory** — For custom targets you can specify an optional directory to receive the generated code.
- **Initialization Code** — Code statements that are executed once at the start of simulation. You can use this initialization code to invoke functions that allocate memory or perform other initializations of your custom code. This option does not apply to custom targets.
- **Termination Code** — Enter code statements that are executed at the end of simulation. You can use this code to invoke functions that free memory allocated by the custom code or perform other cleanup tasks. This option does not apply to custom targets.
- **Reserved Names** — Sometimes the names of variables and functions in Stateflow generated code matches the names of variables or functions specified in custom code. When this occurs, the compiler reports a “redeclaration” or “redefinition” of the variable or function name. When you encounter an error like this, enter the name that causes this conflict. Stateflow changes the name in its generated code.

4. Click **Apply** to apply the specification to the target or **OK** to apply the specifications and close the dialog.

   If you make a change in one of your custom code options, to force the target rebuild to incorporate your changes you must either change one of the charts slightly (this forces a rebuild when you simulate again) or go to the **Simulation Target Builder** dialog box and select the **Rebuild All** option.

References

For additional information on specifying custom code for your target, see the following online articles:

- "Integrating Custom C Code Using Stateflow 2.0" by V. Raghavan
- "Automatic Code Generation from Stateflow for Palm OS Handhelds: a Tutorial" by D. Maclay

Specifying Relative Paths for Custom Code

You specify custom code options for Stateflow targets in "Specifying Custom Code Options for Stateflow Targets" on page 14-27. If you specify paths and files with absolute paths and later move them, you have to change these paths to point to new locations. Because of this, it is recommended that you use relative paths for custom code options that specify paths or files.

How Stateflow Searches Relative Paths

Stateflow searches paths relative to the following directories:

- The current directory
- The model directory (if different from the current directory)
- The list of directories specified for the **Include Path** option
- All the directories on MATLAB's search path, excluding the toolbox directories

Path Syntax Rules

When constructing 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 parses these strings and returns the path names with the correct platform-specific file separators.
- Paths can contain tokens that are evaluated in the MATLAB workspace, as long as you enclose them with dollar signs ($...$). For example, consider this path:

```
$mydir1$\dir1
```

In this example, mydir1 is a string variable defined in the MATLAB workspace as 'd:\work\source\module1'. Stateflow generates this custom include path 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 (-).

Including Custom C++ Code

You specify custom C code for Stateflow targets as described in “Specifying Custom Code Options for Stateflow Targets” on page 14-27. Use the following procedure to include custom C++ code with a target:

1. Add a C function wrapper to your existing custom code. This wrapper function executes the C++ code that you are including.

   The C function wrapper should have the following 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 the following form:

   ```
   int my_c_function_wrapper();
   ```

The value `_cplusplus` is defined if your compiler supports C++ code. The `extern "C"` wrapper specifies C linkage with no name mangling.

3 Configure the Stateflow simulation target. You can access this dialog as follows:

   a From the Stateflow chart, select **Tools -> Open Simulation Target** and click the **Target Options** button.

   b Add the header file to the **Include Code** tab. Click **Apply**.

   c Add the custom C++ files to the **Include Paths** or **Source Files** tabs. Click **Apply**.

   d If you need to make additional configurations in this dialog, do so now. Click **OK** when you are done.

4 Select `C++` in the **Language** option of the Real-Time Workshop configuration dialog. You can access this dialog as follows:

   a From the model, select **Simulation -> Configuration Parameters**.

   b Select the **Real-Time Workshop** pane.

   The general Real-Time Workshop pane is displayed.

   c Select `C++` from the **Language** pull-down menu. Click **Apply**.

   d If you need to make additional configurations in this dialog, do so now. Click **OK** when you are done.

The preceding procedure describes how to include custom C++ code with a target for a simulation. If you also want to generate code with Real-Time Workshop, use the following procedure to duplicate the Stateflow chart header file and C++ file entries for Real-Time Workshop:

1 Be sure that you have performed the preceding procedure.

2 Configure the Real-Time Workshop configuration set. You can access this dialog as follows:

   a From the model, select **Simulation -> Configuration Parameters**.

   b Select the **Custom Code** subpane under the **Real-Time Workshop** pane.

c Add the header file to the **Header File** option. Click **Apply**.

d Add the custom C++ files to the **Include directories** or **Source files** option. Click **Apply**.

e If you need to make additional configurations in this dialog, do so now. Click **OK** when you are done.

You can now generate code for the model.

Starting the Build

Once you have completely configured a Stateflow simulation or RTW target, you want to start the build process to generate code from your model and compile it. This section describes how to start a build for a simulation target or Real-Time Workshop target in Stateflow with the following topics:

- "Starting a Simulation Target Build" on page 14-34 — Tells you how to start a build for the simulation target (`sfun`).
- "Starting an RTW Target Build" on page 14-35 — Tells you how to start a build for the RTW target (`rtw`).

Starting a Simulation Target Build

You can start a target build for a Stateflow simulation target (`sfun`) in one of the following ways:

- Select **Start** from the Stateflow or Simulink editor's **Simulation** menu

  Automatically builds and runs a simulation target.
- Select **Debug** from the Stateflow editor's **Tools** menu

  Automatically builds and runs a simulation target. This is equivalent to the previous method.
- Select the **Build** button on the **Simulation Target Builder** dialog box for the target

  Use this option if you want to build a simulation target without running it. You would typically want to do this to ensure that Stateflow can build a target containing custom code.

  Using the target builder to launch the build allows you to choose between an incremental build, a full build, and a build without code generation. See "Configuring a Simulation Target for Stateflow" on page 14-10 for more information.

Starting an RTW Target Build

You can start a target build for a Stateflow Real-Time Workshop (`rtw`) target in one of the following ways:

- By selecting the **Build RTW** button on the **RTW Target Builder** dialog box for the target

  You must use this option to build stand-alone targets. Using the target builder to launch the build allows you to choose between full build or rebuild and a build of Stateflow code only. See “Configuring Real-Time Workshop for Stateflow” on page 14-13 for more information.

- By selecting the **Build** button on the **Real-time Workshop** panel of the **Simulation Parameters** dialog box in Simulink.

  Select **Real-Time Workshop** options on the **RTW Target Builder** dialog box to access the **Simulation Parameters** dialog box of Simulink. See “Configuring Real-Time Workshop for Stateflow” on page 14-13 for more information.

Parsing Stateflow Diagrams

When you begin a build for a target as described in “Starting the Build” on page 14-34, the parser evaluates the graphical and nongraphical objects in each Stateflow machine against the supported Stateflow notation and the action language syntax. This section describes the Stateflow parser and how its messages appear with the following topics:

- “Calling the Stateflow Parser” on page 14-36 — Shows you how to call the Stateflow Parser to parse your current diagram at any time.
- “Parser Error Checking” on page 14-37 — Lists the types of errors that Stateflow parses the diagram for.
- “Parsing Diagram Example” on page 14-37 — Gives you an example of parsing an example Stateflow diagram with a parsing error.

Calling the Stateflow Parser

Apart from building a target, you can call the Stateflow parser to check the syntax of your Stateflow diagrams in one of the following ways:

- Parse an individual Stateflow diagram in the Stateflow diagram editor by selecting **Parse Diagram** from the **Tools** menu.
- Parse a Stateflow machine, that is, all the Stateflow charts in a model, by selecting **Parse** from the **Tools** menu in the Stateflow diagram editor.
- When you simulate a model, build a target, or generate code, the Stateflow machine is automatically parsed.

In all cases, the **Stateflow Builder** window displays when parsing is complete. If parsing is unsuccessful (that is, an error is detected), the Stateflow diagram editor automatically appears with the highlighted object causing the first parse error. In the **Stateflow Builder** window, each error is displayed with a leading red button icon. You can double-click any error in this window to bring its source Stateflow diagram to the front with the source object highlighted. See “Parsing Diagram Example” on page 14-37 for example displays of parsing results in the Stateflow Builder window.

Note Parsing informational messages are also displayed in the MATLAB Command Window.

Parser Error Checking

The parser evaluates the graphical and nongraphical objects in each Stateflow machine against the supported Stateflow notation and the action language syntax. Errors are displayed in informational pop-up windows. See “Parsing Stateflow Diagrams” on page 14-36 for more information.

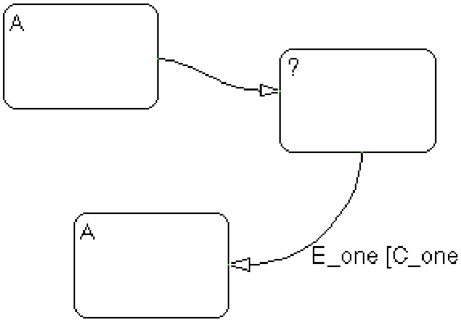
Some aspects of the notation are verified at run-time. Others are verified during application run-time. Using the Debugger, you can detect the following run-time errors during simulation:

- State Inconsistency — Most commonly caused by the omission of a default transition to a substate in superstates with XOR decomposition. See “Debugging State Inconsistencies” on page 15-16.
- Transition Conflict — Occurs when there are two equally valid transition paths from the same source. See “Debugging Conflicting Transitions” on page 15-18.
- Data Range Violation — Occurs when minimum and maximum values specified for a data in its properties dialog are exceeded or when fixed-point data overflows its base word size. See “Debugging Data Range Violations” on page 15-20.
- Cyclical Behavior — Occurs when a step or sequence of steps repeats itself indefinitely. See “Debugging Cyclic Behavior” on page 15-22.

You can modify the notation to resolve run-time errors. See Chapter 15, “Debugging and Testing” for more information on debugging run-time errors.

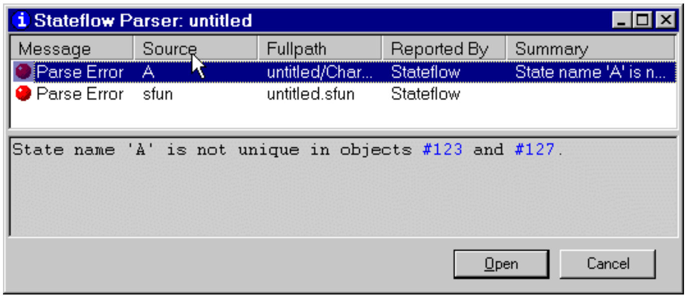
Parsing Diagram Example

For the following Stateflow diagram, the steps that follow describe the parsing process and its reported results.



1 Parse the Stateflow diagram.

Choose **Parse Diagram** from the graphics editor **Tools** menu to parse the Stateflow diagram. State A in the upper left corner is selected and this message is displayed in the pop-up window and the MATLAB Command Window.


Stateflow Parser: untitled

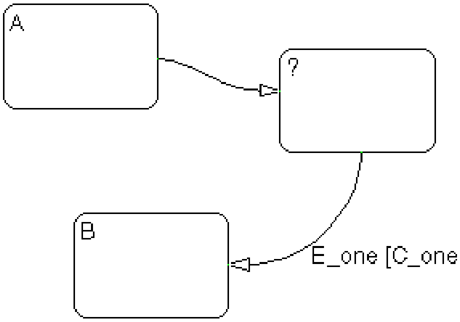
Message	Source	Fullpath	Reported By	Summary
Parse Error	A	untitled/Char...	Stateflow	State name 'A' is n...
Parse Error	sfun	untitled.sfun	Stateflow	

```
State name 'A' is not unique in objects #123 and #127.
```

2 Fix the parse error.

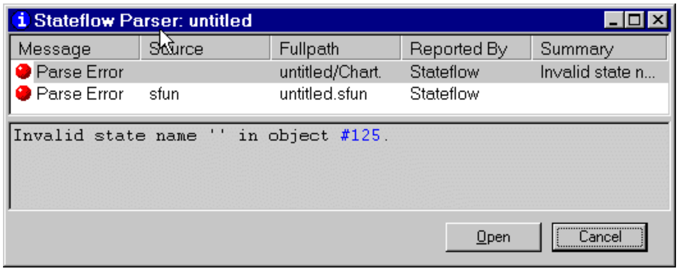
In this example, there are two states with the name A. Edit the Stateflow diagram and label the duplicate state with the text B.

The Stateflow diagram should look similar to this.



3 Reparse.

Choose **Parse Diagram** from the graphics editor **Tools** menu. This message displays in the pop-up menu and the MATLAB Command Window.

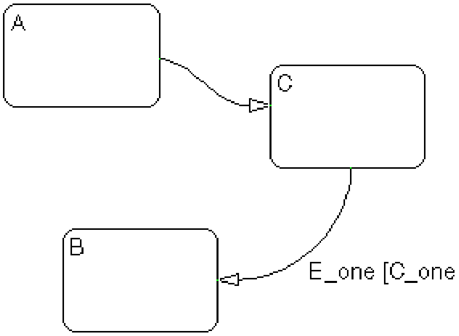

Stateflow Parser: untitled

Message	Source	Fullpath	Reported By	Summary
Parse Error		untitled/Chart.	Stateflow	Invalid state n...
Parse Error	sfun	untitled.sfun	Stateflow	

```
Invalid state name '' in object #125.
```

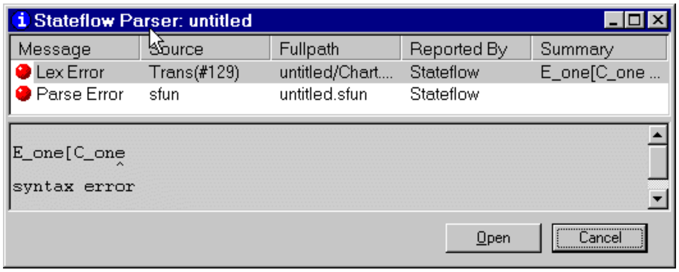
4 Fix the parse error.

In this example, the state with the question mark needs to be labeled with at least a state name. Edit the Stateflow diagram and label the state with the text `C`. The Stateflow diagram should look similar to this.



5 Reparse.

Choose **Parse Diagram** from the graphics editor **Tools** menu. This message is displayed in the pop-up window and the MATLAB Command Window.



Message	Source	Fullpath	Reported By	Summary
● Lex Error	Trans(#129)	untitled/Chart....	Stateflow	E_one[C_one ...
● Parse Error	sfun	untitled.sfun	Stateflow	

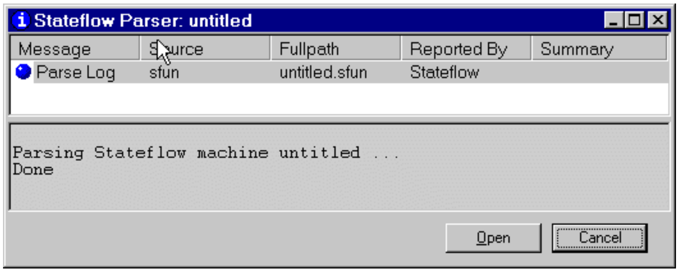
```
E_one[C_one
          ^
syntax error
```

6 Fix the parse error.

In this example, the transition label contains a syntax error. The closing bracket of the condition is missing. Edit the Stateflow diagram and add the closing bracket so that the label is `E_one [C_one]`.

7 Reparse.

Choose **Parse Diagram** from the graphics editor **Tools** menu. This message is displayed in the pop-up window and the MATLAB Command Window.



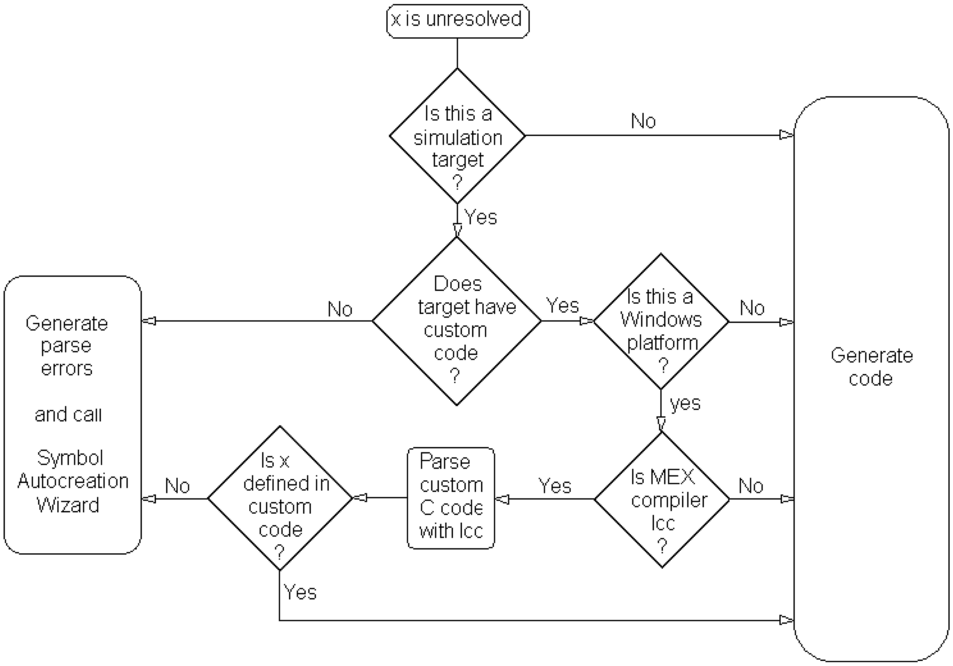
Message	Source	Fullpath	Reported By	Summary
● Parse Log	sfun	untitled.sfun	Stateflow	

```
Parsing Stateflow machine untitled ...
Done
```

The Stateflow diagram now has no parse errors.

Resolving Event, Data, and Function Symbols

When you simulate a model, build a target, or generate code for a target, the Stateflow machine is automatically parsed (see “Parsing Stateflow Diagrams” on page 14-36). During that time, if Stateflow finds that your diagram does not resolve some of its symbols, it uses the following process to determine whether to report parse errors for the unresolved symbols or continue generating code:

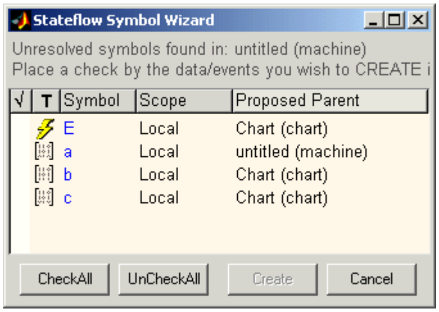

x is unresolved
Is this a simulation target ?
No
Yes
Does target have custom code ?
No
Yes
Is this a Windows platform ?
No
yes
Generate code
Generate parse errors

and call

Symbol Autocreation Wizard
Is MEX compiler lcc ?
Yes
No
Parse custom C code with lcc
Is x defined in custom code ?
No
Yes

Symbol Autocreation Wizard

The Symbol Autocreation Wizard helps you to add missing data and events to your Stateflow charts. When you parse or simulate a diagram, the Wizard detects references to data and events that are not already defined in the Stateflow Explorer and opens with a list of the recommended data or events that you need to define.



Unresolved symbols found in: untitled (machine)
Place a check by the data/events you wish to CREATE i

√	T	Symbol	Scope	Proposed Parent
	⚡	E	Local	Chart (chart)
	▦	a	Local	untitled (machine)
	▦	b	Local	Chart (chart)
	▦	c	Local	Chart (chart)

To accept, reject, or change a recommended item, do the following:

- To accept an item, select the space in front of the item under the check mark column.

  To accept all items, select the **CheckAll** button.

- To reject an item, leave it unchecked.

- To change an item, select the value under the **T** (type), **Scope**, or **Proposed Parent** column for that item.

  Each time you select the value, the Wizard replaces the entry with a different value. Keep selecting until the desired value appears.

When you are satisfied with the proposed symbol definitions, click the Wizard's **Create** button to add the symbols to Stateflow's data dictionary.

Error Messages

When building a target or parsing a diagram, you might see error messages from any of the following sources: the parser, the code generator, or external build tools (make utility, C compiler, linker). Stateflow displays errors in a dialog box and in the MATLAB Command Window. Double-clicking a message in the error dialog zooms the source Stateflow diagram to the object that caused the error.

This section contains the following topics:

- "Parser Error Messages" on page 14-44 — Lists some of the messages you can receive during parsing of your Stateflow diagram.
- "Code Generation Error Messages" on page 14-45 — Lists some of the messages you can receive during code generation for your Stateflow diagram.
- "Compilation Error Messages" on page 14-46 — Explains the difference between compilation error messages that you receive during parsing and code generation messages.

Parser Error Messages

The Stateflow parser flags syntax errors in a state chart. For example, using a backward slash (\) instead of a forward slash (/) to separate the transition action from the condition action generates a general parse error message.

Typical parse error messages include the following:

- `"Invalid state name xxx"` or `"Invalid event name yyy"` or `"Invalid data name zzz"`

  A state, data, or event name contains a nonalphanumeric character other than underscore.
- `"State name xxx is not unique in objects #yyy and #zzz"`

  Two or more states at the same hierarchy level have the same name.
- `"Invalid transition out of AND state xxx (#yy)"`

  A transition originates from an AND (parallel) state.

- `"Invalid intersection between states xxx and yyy"`

  Neighboring state borders intersect. If the intersection is not apparent, consider the state to be a cornered rectangle instead of a rounded rectangle.

- `"Junction #x is sourcing more than one unconditional transition"`

  More than one unconditional transition originates from a connective junction.

- `"Multiple history junctions in the same state #xxx"`

  A state contains more than one history junction.

Code Generation Error Messages

Typical code generation error messages include the following:

- `"Failed to create file:  modelName_sfun.c"`

  The code generator does not have permission to generate files in the current directory.

- `"Another unconditional transition of higher priority shadows transition # xx"`

  More than one unconditional inner, default, or outer transition originates from the same source.

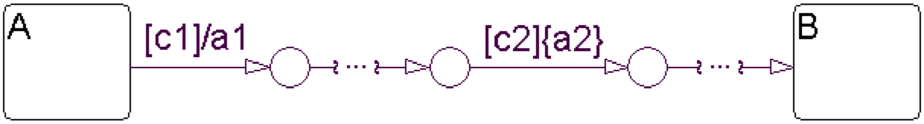
- `"Default transition cannot end on a state that is not a substate of the originating state."`

  A transition path starting from a default transition segment in one state completes at a destination state that is not a substate of the original state.

- `"Input data xxx on left hand side of an expression in yyy"`

  A Stateflow expression assigns a value to an **Input from Simulink** data object. By definition, Stateflow cannot change the value of a Simulink input.

- `"Transition <number> has a condition action which is preceded by a transition <number> containing a transition action.  This is not allowed as it results in out-of-order execution, i.e., the condition action of <number> gets executed before the transition action of <number>."`



The preceding Stateflow diagram flags this error. Assuming that there are no other actions than those indicated for the labeled transition segments between state A and state B, the sequence of execution that takes place when state A is active is expressed by the following pseudocode:

```
If (c1) {
 if(c2) {
  a2;
  exit A;
  a1;
  enter B;
 }
}
```

Because condition actions are evaluated when their guarding condition is true and transition actions are evaluated when the transition is actually taken, condition action a2 is executed prior to transition action a1. This violates the apparent graphical sequence of executing a1 then a2. In this case, the preceding diagram is flagged for an error during build time. As a remedy, the user can change a1 and a2 to be both condition or transition actions.

Compilation Error Messages

If compilation errors indicate the existence of undeclared identifiers, verify that variable expressions in state, condition, and transition actions are defined.

Consider, for example, an action language expression such as a=b+c. In addition to entering this expression in the Stateflow diagram, you must create data objects for a, b, and c using the Explorer. If the data objects are not defined, the parser assumes that these unknown variables are defined in the **Custom code** portion of the target (which is included at the beginning of the generated code). This is why the error messages are encountered at compile time and not at code generation time.

Generated Files

All generated files are placed in a subdirectory of the `sfprj` subdirectory of the MATLAB current directory. You set the MATLAB current directory in the **Start in** field for the properties of the MATLAB program icon that you used to start MATLAB. You can change it in MATLAB with a `cd` command as you would in DOS or UNIX.

Note Do not confuse the `sfprj` directory created in the MATLAB current directory for generated files with the `sfprj` directory in the directory containing the model file. The latter `sfprj` directory is used for storing information on the model, while the former stores generated files. However, if the MATLAB current directory is the model directory, the same `sfprj` directory (under the model directory) is used to store both model information and generated files.

This section contains the following topics:

- "S-Function MEX-Files" on page 14-47 — Explains the origin of `MEX` files that Stateflow generates as part of building a simulation target.
- "Code Files" on page 14-48 — Describes the code files that you build for your target as part of code generation.
- "Makefiles" on page 14-49 — Describes the makefiles that result when you build your target into an executable.

S-Function MEX-Files

If you have a Simulink model named `mymodel.mdl`, which contains two Stateflow blocks named `chart1` and `chart2`, this means that you have a machine named `mymodel` that parents two charts named `chart1` and `chart2`.

When you simulate the Stateflow chart for `mymodel.mdl`, Stateflow generates code for `mymodel.mdl` that is compiled into an S-function MEX-file known as a simulation target. MEX-file extensions are platform-specific, as described in "Using MEX-Files" in the MATLAB External Interfaces documentation. For example, on 32-bit Windows PC platforms, Stateflow generates a MEX-file for mymodel called mymodel_sfun.mexw32 On Linux x86-64 platforms, Stateflow generates mymodel_sfun.mexa64.

Code Files

Code files for the Simulation target (sfun) are generated for each model and placed in the subdirectory sfprj/build/<model>/sfun/src of the current directory, where <model> represents the name of the model.

Note Do not keep any of your custom source files in the sfprj subdirectory of your model directory.

The code generated for the simulation target sfun is organized into the following files:

- <model>_sfun.h is the machine header file. It contains the following:
  - All the defined global variables needed for the generated code
  - Type definition of the Stateflow machine-specific data structure that holds machine-parented local data
  - External declarations of any Stateflow machine-specific global variables and functions
  - Custom code strings specified via the **Target Options** dialog box
- <model>_sfun.c is the machine source file. It includes the machine header file and all the chart header files (described below) and contains the following:
  - All the machine-parented event broadcast functions
  - Simulink interface code
- <model>_sfun_registry.c is a machine registry file that contains Simulink interface code.
- <model>_sfun_cn.h is the chart header file for the chart chartn, where n = 1, 2, 3, and so on, depending on how many charts your model has (see the following note). This file contains type definitions of the chart-specific data structures that hold chart-parented local data and states.

- <model>_sfun_cn.c is the chart source file for chartn, where n = 1, 2, 3, and so on, depending on how many charts your model has (see the following note). This chart source file includes the machine header file and the corresponding chart header file. It contains the following:
  - Chart-parented data initialization code
  - Chart execution code (state entry, during, and exit actions, and so on)
  - Chart-specific Simulink interface code

Note Every chart is assigned a unique number at creation time by Stateflow. This number is used as a suffix for the chart source and chart header file names for every chart (where n = 1, 2, 3, and so on, depending on how many charts your model has).

Makefiles

Makefiles generated for your model are platform and compiler specific. On UNIX platforms, Stateflow generates a gmake-compatible makefile named mymodel_sfun.mku that is used to compile all the generated code into an executable. On PC platforms, an ANSI C compiler-specific makefile is generated based on your C-MEX setup as follows:

- If your installed compiler is Microsoft Visual C++ 4.2, 5.0, or 6.0, the following files are generated:
  - MSVC-compatible makefile named mymodel_sfun.mak
  - Symbol definition file named mymodel_sfun.def (required for building S-function MEX-files)
- If your installed compiler is Watcom 10.6 or 11.0, the following file is generated:
  - Watcom-compatible makefile named mymodel_sfun.wmk
- If your installed compiler is Borland 5.0, the following files are generated:
  - Borland-compatible makefile named mymodel_sfun.bmk
  - Symbol definition file named mymodel_sfun.def (required for building S-function MEX-files)

- If you choose lcc-win32, a bundled ANSI-C compiler shipped with Stateflow, the following file is generated:
  - An lcc compatible makefile named mymodel_sfun.lmk

Stateflow Coder also generates another support file needed for the make process, named <model>_sfun.mol.

15

Debugging and Testing

To ensure that your Stateflow diagrams are behaving as you expect them to, use the **Stateflow Debugging** window to evaluate code coverage and perform dynamic checking during simulation.

Watching Data Values with Debuggers (p. 15-26)	Shows you a variety of ways that you can keep track of the values for Stateflow data and state activity during simulation.
Monitoring Stateflow Test Points (p. 15-32)	Shows you how to specify local data or states as test points that you can plot with a floating scope or log to MATLAB workspace during simulation.
Understanding Model Coverage for Stateflow Charts (p. 15-44)	Describes how the Model Coverage tool determines the extent to which a model test case exercises simulation control flow paths through a model.

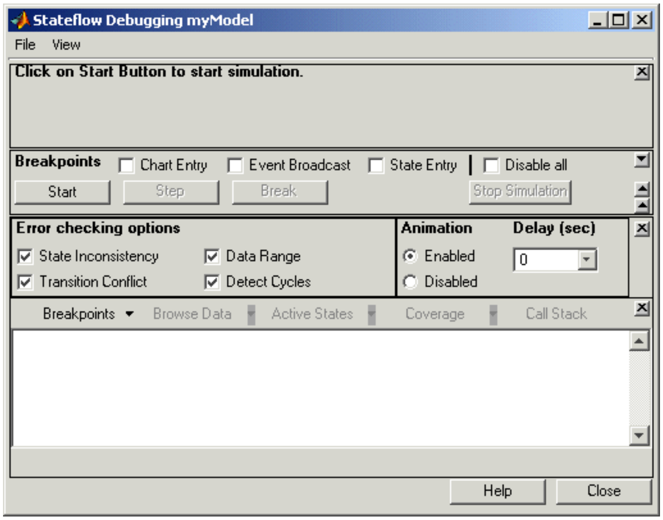
Debugging with the Debugging Window

You use the Stateflow Debugging window to control simulation to make sure that your Stateflow diagrams are behaving exactly as you expect them to.

To open the Stateflow Debugging window,

1 From the **Tools** menu, select Debug.

   The Stateflow Debugging window opens as shown:



Click on Start Button to start simulation.

□ Chart Entry □ Event Broadcast □ State Entry □ Disable all

☑ State Inconsistency ☑ Data Range
☑ Transition Conflict ☑ Detect Cycles

● Enabled ○ Disabled

Delay (sec) 0

This section shows you how to use the Stateflow Debugging window to debug your Stateflow diagrams during simulation in the following topics:

- "Setting Breakpoints for Debugging" on page 15-4 — Shows you how to specify execution points in your target where execution stops for debugging purposes.
- "Setting Error Checking in the Debugging Window" on page 15-6 — Describes the optional error checking available in the Debugging window.
- "Controlling Animation in the Debugging Window" on page 15-8 — Shows you how to activate, deactivate, and control the speed of animation of Stateflow diagrams during simulation.

- "Starting Simulation in the Debugging Window" on page 15-7 — Shows you how to start simulation in the Debugging window and describes the items displayed in the Status Display Area of the **Stateflow Debugging** window when a breakpoint is encountered during simulation.
- "Controlling the Execution Rate in the Debugging Window" on page 15-9 — Describes the control buttons that you can use to control execution during simulation before and after breakpoints are encountered.
- "Setting the Output Display Pane" on page 15-10 — Describes the buttons you use during simulation to display information you use to debug your application.

Setting Breakpoints for Debugging

A breakpoint indicates a point at which the Stateflow Debugging window halts execution of a simulating Stateflow diagram. At this time you can inspect Stateflow and MATLAB workspace data and examine the status of a simulating Stateflow diagram.

The Stateflow Debugging window supports global and local breakpoints. Global breakpoints halt execution on any occurrence of the specific type of breakpoint. Local breakpoints halt execution on a specific object.

Setting Global Breakpoints

Use the **Breakpoint** controls in the Stateflow Debugging window to specify global breakpoints. When a global breakpoint is encountered during simulation, execution stops and the Debugger takes control. Select any or all of the following global breakpoints:

- **Chart Entry** — Simulation halts on chart entry.
- **Event Broadcast** — Simulation halts when an event is broadcast.
- **State Entry** — Simulation halts when a state is entered.

These breakpoints can be changed during run-time and are immediately enforced. When you save a Stateflow diagram, the breakpoint settings are saved with it.

Global breakpoints can be changed during run-time and are immediately enforced. When you save the Stateflow diagram, all the **Stateflow**

Debugging window settings (including breakpoints) are saved, so that the next time you open the model, the breakpoints are as you left them.

Setting Local Breakpoints

You can set breakpoints for specific state actions, transitions, function calls, and event broadcasts in a Stateflow chart.

1 Open the properties dialog of the object for which you want to set a breakpoint, as follows:

  a Right-click the object from one of these sources:

Object	Right-Click In:	
	Stateflow Chart	Model Explorer
State	✓	✓
Transition	✓	
Function	✓	✓
Event		✓

  b From the resulting pop-up menu, select **Properties**.

  A dialog box appears for setting the properties of the object.

2 In the properties dialog box, select from the following breakpoints options:

For:	Select:
States	**State During** — Stop execution before performing the state during actions. **State Entry** — Stop execution before performing the state entry actions. **State Exit** — Stop execution before performing the state exit actions.
Transitions	**When Tested** — Stop execution before testing the transition to see if it is a valid path. **When Valid** — Stop execution after the transition tests valid, but before taking the transition.
Functions	**Function Call** — Stop execution before calling the function.
Events	**Start of Broadcast** — Stop execution before broadcasting the event. **End of Broadcast** — Stop execution after a Stateflow object reads the event.

Setting Error Checking in the Debugging Window

The options in the **Error checking options** section of the **Stateflow Debugging** window insert generated code in the simulation target to provide breakpoints to catch different types of errors that might occur during simulation. Select any or all of the following error checking options:

- **State inconsistency** — Check for state inconsistency errors that are most commonly caused by the omission of a default transition to a substate in superstates with XOR decomposition. See "Debugging State Inconsistencies" on page 15-16 for a complete description and example.
- **Transition Conflict** — Check whether there are two equally valid transition paths from the same source at any step in the simulation. See "Debugging Conflicting Transitions" on page 15-18 for a complete description and example.
- **Data Range** — Check whether the minimum and maximum values you specified for a data in its properties dialog are exceeded. Also check

whether fixed-point data overflows its base word size. See “Debugging Data Range Violations” on page 15-20 for a complete description and example.

- **Detect Cycles** — Check whether a step or sequence of steps indefinitely repeats itself. See “Debugging Cyclic Behavior” on page 15-22 for a complete description and example.

To include the supporting code designated for these debugging options in the simulation application, select the **Enable debugging/animation** check box in the **Coder Options** dialog for the simulation target. This is described in “Configuring a Simulation Target for Stateflow” on page 14-10.

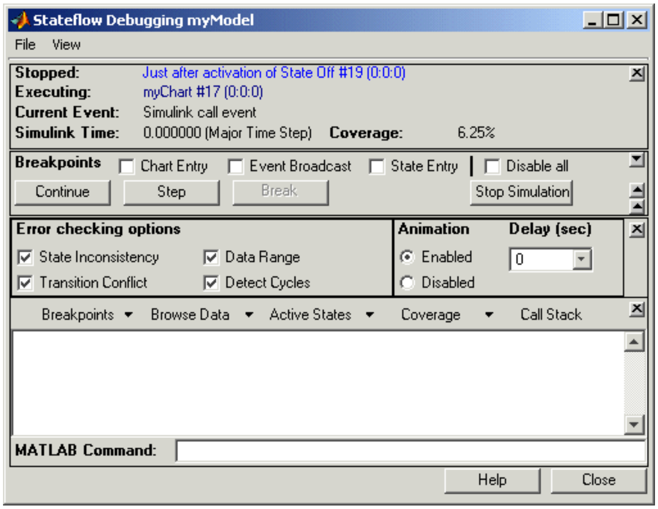
Note You must rebuild the target for any changes to any of the settings referred to above to take effect.

Starting Simulation in the Debugging Window

To debug the Stateflow diagrams in a model, you start simulation in the Debugging window with the following steps:

1. Select the **Start** button.

   A debugging simulation session starts. When a breakpoint that you set is encountered, the Stateflow Debugging window takes on the following appearance:



Stateflow Debugging myModel

Stopped: Just after activation of State Off #19 (0:0:0)
Executing: myChart #17 (0:0:0)
Current Event: Simulink call event
Simulink Time: 0.000000 (Major Time Step) Coverage: 6.25%

Breakpoints □ Chart Entry □ Event Broadcast □ State Entry □ Disable all

Error checking options
☑ State Inconsistency ☑ Data Range
☑ Transition Conflict ☑ Detect Cycles

Animation ● Enabled ○ Disabled Delay (sec) 0

MATLAB Command:

At the breakpoint, the following status items are displayed in the upper portion of the Debugger window:

- **Stopped** — Displays the step executed just prior to breaking execution.
- **Executing** — Displays the currently executing Stateflow chart.
- **Current Event** — Displays the event being processed by the Stateflow chart.
- **Simulink Time** — Displays the current simulation time.
- **Code Coverage** — Displays the percentage of code covered in this simulation.

During simulation the Stateflow diagram is marked read-only. The appearance of the Stateflow diagram editor toolbar and menus changes so that object creation is not possible. When the diagram editor is in this read-only mode, its condition is referred to as *iced*.

Controlling Animation in the Debugging Window

During simulation of a Simulink model, you can animate the Stateflow diagrams. Animation highlights objects in Stateflow diagrams as they execute during simulation. You activate or deactivate animation for Stateflow diagrams during simulation in the **Debugging** window as follows:

- To activate animation for simulation, in the Animation section of the Debugging window, select **Enabled** to activate animation before the start of simulation.
- To deactivate animation for simulation, stop simulation and select **Disabled**.

Before, during, and after simulation, you control the speed of animation by selecting a value for the **Delay** field as follows:

- For the fastest animation, select a value of 0 seconds.
- For the slowest animation, select a value 1 seconds.

Controlling the Execution Rate in the Debugging Window

Once you start simulation as described in “Starting Simulation in the Debugging Window” on page 15-7, and a breakpoint is reached, you can control the rate of execution of Stateflow diagrams to execute step-by-step or continuously until another breakpoint is reached. Use the following buttons in the Stateflow Debugging window to control the rate of execution:

- **Continue** — After simulation has been started, and a breakpoint has been encountered, the **Start** button is marked **Continue**. Press **Continue** to continue simulation.
- **Step** — Execute the next execution step, and suspend the simulation.
- **Break** — Suspend the simulation and transfer control to the **Debugging** window.
- **Stop Simulation** — Stop simulation altogether and relinquish debugging control. When simulation stops, the Stateflow diagram editor toolbar and menus return to their normal appearance and operation so that object creation is again possible.

Setting the Output Display Pane

During simulation, the Debugging window monitors a variety of execution indicators in its output display in the bottom pane of the Debugging window. You select the contents of this display with the following pull-downs located just above the display, which are enabled only after a breakpoint is reached during simulation.

- **Breakpoints** — Display a list of the set breakpoints. You can set breakpoints in the Debugger and in the properties dialogs of individual objects such as states, transitions, and functions. See "Setting Breakpoints for Debugging" on page 15-4 for details. This option lists breakpoints for the currently executing chart or for all charts in the model.
- **Browse Data** — Display the current values of defined data objects. This pull-down list lets you filter displayed data between all data and watched data. Watched data has the **Data** property **Watch in Debugger** enabled for it. Each of these categories is further filtered by data for the currently executing chart, or all charts in the model. For more details see "Watching Data in the Stateflow Debugger" on page 15-26.
- **Active States** — Display a list of active states in the display area. Double-clicking any state causes the graphics editor to display that state. This pull-down lets you display active states in the current chart, or active states for all charts in the model.
- **Call Stack** — Display a sequential list of the **Stopped** and **Current Event** status items that occur with each single-step through the simulation.

Once you make a selection, the pull-down menu corresponding to the current display is highlighted. Once you select an output display button, that type of output is displayed until you choose a different display type. You can clear the display by selecting **Clear Display** from the **File** menu of the **Stateflow Debugging** window.

Debugging Run-Time Errors Example

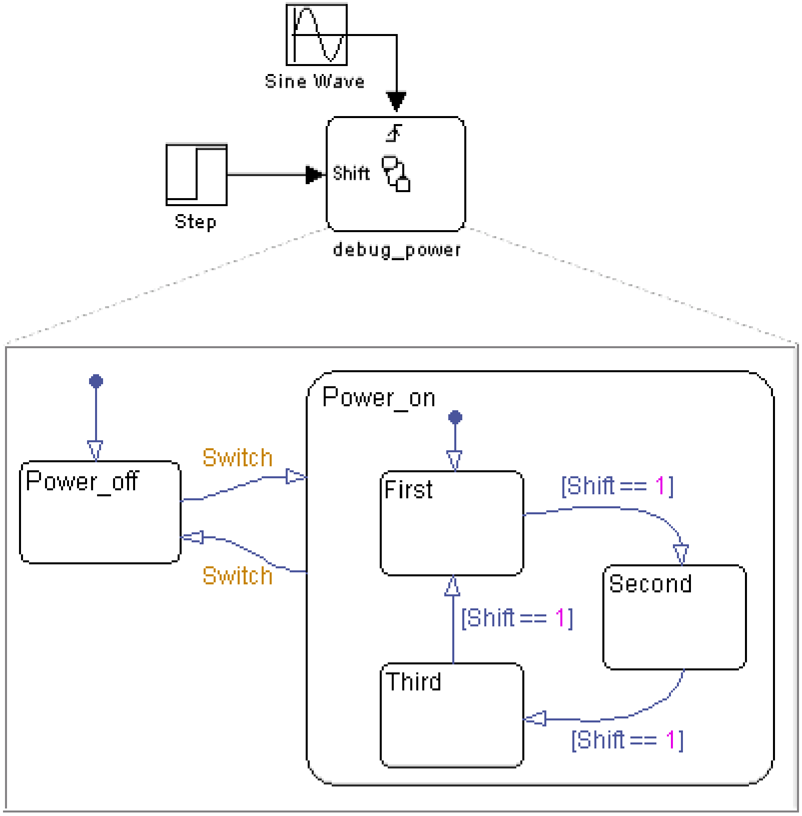
The following topics describe the steps used in a typical debugging scenario to resolve run-time errors in an example model:

1. "Create the Model and Stateflow Diagram" on page 15-11 — Create a Simulink model with a Stateflow diagram to debug.
2. "Debugging the Stateflow Diagram" on page 15-13 — Describes the individual steps that you take to inspect the behavior the Stateflow diagram during simulation.
3. "Correcting the Run-Time Error" on page 15-14 — Shows you how to deal with the run-time error you encounter.

Create the Model and Stateflow Diagram

In this topic you create an example model that you use as a debugging example. Use the following steps to create the example model:

1. Create the following Simulink model and Stateflow diagram:



2 From the Stateflow diagram editor, add an event `Switch` with a scope of **Input from Simulink**. and a **Rising Edge** trigger.

3 Also add a data `Shift` with a scope of **Input from Simulink**.

The Stateflow diagram 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 Simulink model, there is an event input and a data input. A Sine wave block is used to generate a repeating input event that corresponds with the Stateflow event `Switch`. The Step block is used to generate a repeating pattern of 1 and 0 that corresponds with the Stateflow data object `Shift`. Ideally, the `Switch` event occurs in a frequency that allows at least one cycle through `First`, `Second`, and `Third`.

Debugging the Stateflow Diagram

You create an example model with a Stateflow diagram that needs debugging in “Create the Model and Stateflow Diagram” on page 15-11. Use the steps that follow to debug the Stateflow diagram in this model.

1. In the Stateflow diagram editor, from the Tools menu, select **Open Simulation Target**.

   The Target Options dialog appears.

2. In the **Target Options** dialog, select **Coder Options**.

   The **Coder Options** dialog appears.

3. Make sure that **Enable Debugging/Animation** is selected.

4. Select **Close** in both the **Coder Options** and **Target Options** dialogs to close them and apply the changes.

5. In the Stateflow diagram editor, from the **Tools** menu, select **Debug**.

   The Stateflow Debugging window opens.

6. Select the **Chart entry** option under the **Break Controls** border.

7. Under **Animation**, select **Enabled** to enable animation of Stateflow diagrams during simulation.

8. In the **Stateflow Debugging** window, select the **Start** button to start the simulation.

   Informational messages are displayed in the MATLAB Command Window. The graphics editor toolbar and menus change appearance to indicate a read-only interface. The Stateflow diagram is parsed, the code is generated, and the target is built.

Because you specified a breakpoint on chart entry, the execution stops at that point and the Debugger display status indicates the following:

```
Stopped: Just after entering during function
   of Chart debug__power
Executing: sf_debug_ex_debug_power
Current Event: Input event Switch
```

9 Select the **Step** button.

The **Step** button executes the next execution step and stops.

10 Continue selecting the **Step** button and watching the animating Stateflow diagram.

After each step, watch the Stateflow diagram animation and the Debugger status area to see the sequence of execution.

Single-stepping shows that the Stateflow diagram does not exhibit the desired behavior. The transitions from the First to the Second to the Third state 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.

Correcting the Run-Time Error

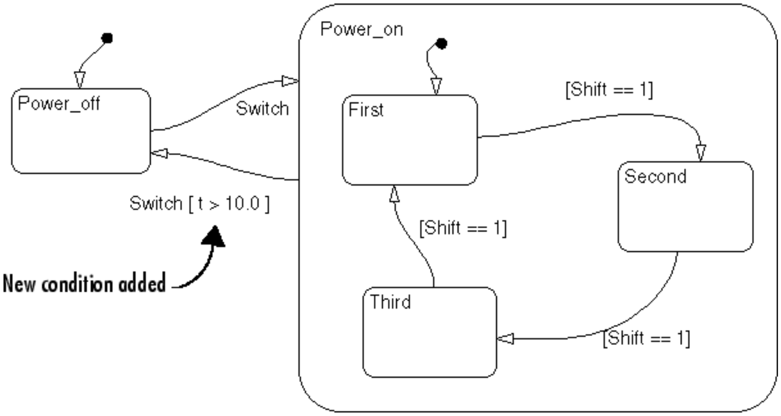
In "Debugging the Stateflow Diagram" on page 15-13, you step through a simulation of an example Stateflow diagram and find an error: the generation of the event Switch is driving the simulation and the simulation time is passing too quickly for the input data object Shift to have an effect.

Correct this error in the following steps:

1 Choose **Stop** from the **Simulation** menu of the graphics editor.

The Stateflow diagram editor is now writable. The model might need to be completely rethought.

2 Add the condition `[t > 10.0]` to the transition from `Power_on` to `Power_off` as shown.



Now the transition from `Power_on` to `Power_off` is not taken until simulation time is greater than 10.0.

3 In the **Stateflow Debugging** window, select **Start** to begin simulation again.

4 Select **Step** repeatedly to observe the new behavior.

Debugging State Inconsistencies

Stateflow notations specify that states are consistent if

- An active state (consisting of at least one substate) with XOR decomposition has exactly one active substate.
- All substates of an active state with AND decomposition are active.
- All substates of an inactive state with either XOR or AND decomposition are inactive.

A state inconsistency error has occurred if, after a Stateflow diagram completes an update, the diagram violates any of the preceding notation rules.

- "Causes of State Inconsistency" on page 15-16
- "Detecting State Inconsistency" on page 15-16
- "State Inconsistency Example" on page 15-16

Causes of State Inconsistency

State inconsistency errors are most commonly caused by the omission of a default transition to a substate in superstates with XOR decomposition.

Design errors in complex Stateflow diagrams can also result in state inconsistency errors. These errors are only detectable using the Debugger at run-time.

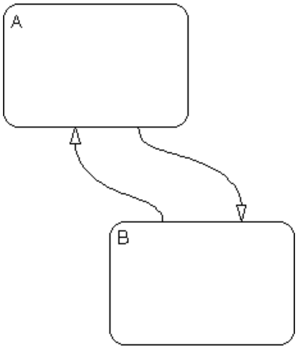
Detecting State Inconsistency

To detect the state inconsistency during a simulation,

1. Build the target with debugging enabled.
2. Invoke the Debugger and enable **State Inconsistency** checking.
3. Start the simulation.

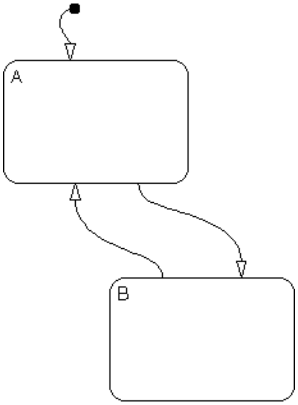
State Inconsistency Example

This Stateflow diagram has a state inconsistency.



In the absence of a default transition indicating which substate is to become active, the simulation encounters a run-time state inconsistency error.

Adding a default transition to one of the substates resolves the state inconsistency.



Debugging Conflicting Transitions

A transition conflict exists if, at any step in the simulation, there are two equally valid transition paths from the same source. In the case of a conflict, equivalent transitions (based on their labels) are evaluated based on the geometry of the outgoing transitions. See "Transition Testing Order" on page 3-11 for more information.

- "Detecting Conflicting Transitions" on page 15-18
- "Conflicting Transition Example" on page 15-18

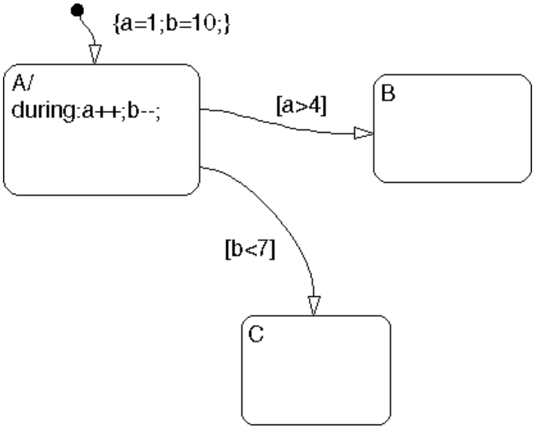
Detecting Conflicting Transitions

To detect conflicting transitions during a simulation, do the following:

1. Build the target with debugging enabled.
2. Invoke the Debugger and enable **Transition Conflict** checking.
3. Start the simulation.

Conflicting Transition Example

This Stateflow diagram has a conflicting transition.



The default transition to state A assigns data a equal to 1 and data b equal to 10. State A's during action increments a and decrements b. 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. As the simulation proceeds, there is a point where state A is active and both conditions are true. This is a transition conflict.

Multiple outgoing transitions from states that are of equivalent label priority are evaluated in a clockwise progression starting from the twelve o'clock position on the state. In this example, the transition from state A to state B is taken.

Although the geometry is used to continue after the transition conflict, it is not recommended that you design your Stateflow diagram based on an expected execution order.

Debugging Data Range Violations

Types of Data Range Violations

Stateflow detects the following data range violations during simulation:

- If a data object equals a value outside the range of the values set in the **Initial**, **Minimum**, and **Maximum** fields specified in the data properties dialog

  See “Setting Data Properties in the Data Dialog” on page 7-31 for a description of the **Initial**, **Minimum**, and **Maximum** fields in the data properties dialog.

- If the fixed-point result of a fixed-point operation overflows its bit size

  See “Overflow Detection for Fixed-Point Types” on page 9-11 for a description of the overflow condition in fixed-point numbers.

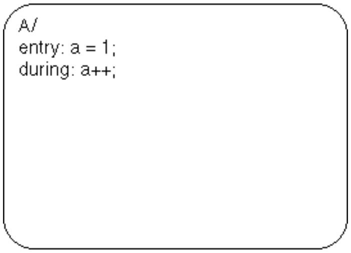
Detecting Data Range Violations

To detect data range violations during a simulation,

1. Build the target with debugging enabled.
2. Open the Debugger window.
3. In the **Error checking options** of the Debugger, select **Data Range**.
4. Start the simulation.

Data Range Violation Example

This Stateflow diagram has a data range violation.



```
A/
entry: a = 1;
during: a++;
```

The data a is defined to have an **Initial** and **Minimal** value of 0 and a **Maximum** value of 2. Each time an event awakens this Stateflow diagram and state A is active, a is incremented. The value of a quickly becomes a data range violation.

Debugging Cyclic Behavior

When a step or sequence of steps is indefinitely repeated (recursive), this is called cyclic behavior. The Debugger cycle detection algorithms detect a class of infinite recursions caused by event broadcasts.

To detect cyclic behavior during a simulation, do the following:

1. Build the target with debugging enabled.

2. Invoke the Debugger and enable **Detect Cycles**.

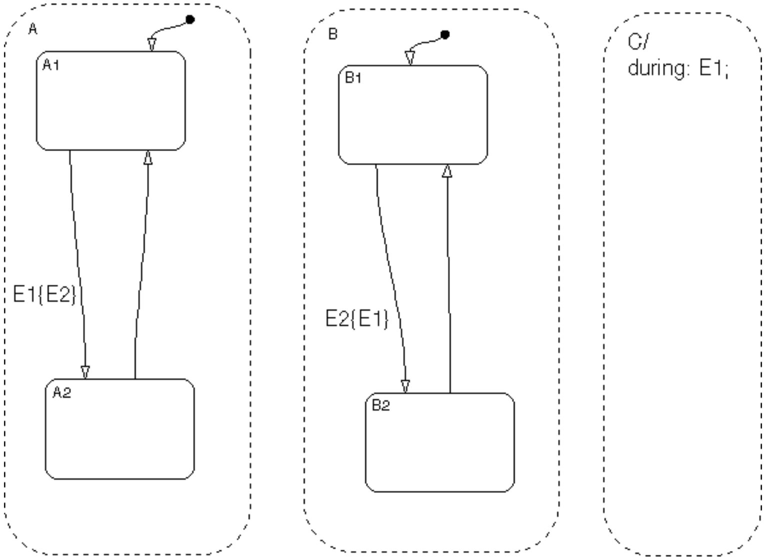
3. Start the simulation.

See the following sections for examples of cyclic behavior:

- “Cyclic Behavior Example” on page 15-22 — Shows a typical example of a cycle created by infinite recursions caused by an event broadcast.
- “Flow Cyclic Behavior Not Detected Example” on page 15-23 — Shows an example of cyclic behavior in a flow diagram that is not detected by the Debugger.
- “Noncyclic Behavior Flagged as a Cyclic Example” on page 15-24 — Shows an example of noncyclic behavior that the Debugger flags as being cyclic.

Cyclic Behavior Example

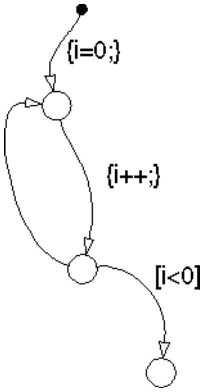
This Stateflow diagram shows a typical example of a cycle created by infinite recursions caused by an event broadcast.



When the state C during action executes, event E1 is broadcast. The transition from state A.A1 to state A.A2 becomes valid when event E1 is broadcast. Event E2 is broadcast as a condition action of that transition. The transition from state B.B1 to state B.B2 becomes valid when event E2 is broadcast. Event E1 is broadcast as a condition action of the transition from state B.B1 to state B.B2. Because these event broadcasts of E1 and E2 are in condition actions, a recursive event broadcast situation occurs. Neither transition can complete.

Flow Cyclic Behavior Not Detected Example

This Stateflow diagram shows an example of cyclic behavior in a flow diagram that is not detected by the Debugger.

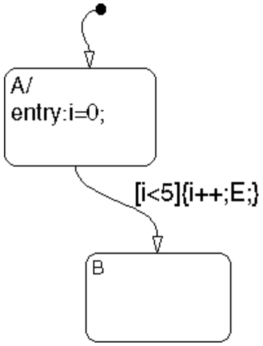


The data object `i` is set to 0 in the condition action of the default transition. `i` is incremented in the next transition segment condition action. The transition to the third connective junction is valid only when the condition `[i < 0]` is true. This condition will never be true in this flow diagram and there is a cycle.

This cycle is not detected by the Debugger because it does not involve event broadcast recursion. Detecting cycles that depend on data values is not currently supported.

Noncyclic Behavior Flagged as a Cyclic Example

This Stateflow diagram shows an example of noncyclic behavior that the Debugger flags as being cyclic.



State A becomes active and i is initialized to 0. When the transition is tested, the condition [i < 5] is true. The condition actions that increment i and broadcast the event E are executed. The broadcast of E when state A is active causes a repetitive testing (and incrementing of i) until the condition is no longer true. The Debugger flags this as a cycle when in reality the apparent cycle is broken when i becomes greater than 5.

Watching Data Values with Debuggers

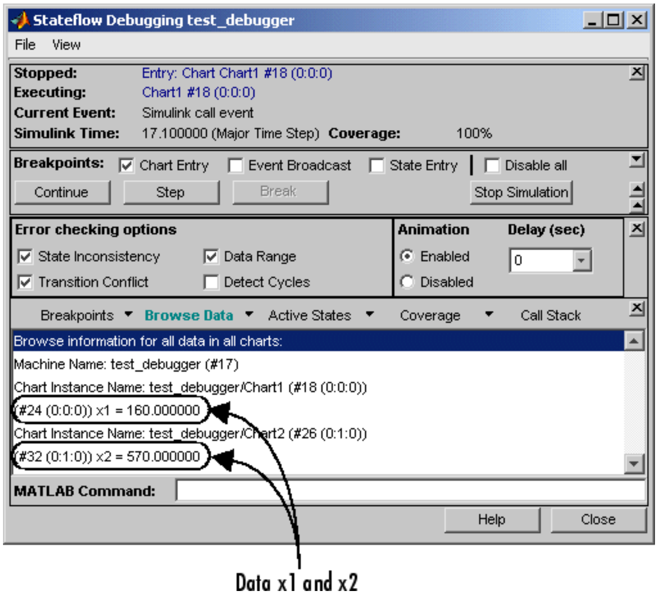
An important part of debugging is to observe the value of individual data during simulation. Use the following topics to display the value of Stateflow data while you are simulating a model:

- "Watching Data in the Stateflow Debugger" on page 15-26 — Display Stateflow data values in the Stateflow Debugger after a breakpoint is reached.
- "Watching Stateflow Data in MATLAB Command Window" on page 15-27 — Use the Command Line Debugger to report data values for the currently executing Stateflow block at the MATLAB prompt when a breakpoint is reached.

Watching Data in the Stateflow Debugger

The **Browse Data** pull-down menu in the Stateflow **Debugger** lets you display selected data in the bottom output display pane of the Stateflow Debugger during simulation, after a breakpoint is reached. Its selections filter the displayed data items between watched data and all data. Watched data has the property **Watch in Debugger** enabled for it. Watched data is further filtered between data for the currently executing chart, or data for all charts in the model.

The following example is set to display **All Data (All Charts)** for two executing charts, `Chart1` and `Chart2`, for the simulating model `test_debugger.mdl`. Each chart has its own data value: `x1` and `x2`, respectively.



Stateflow Debugging test_debugger

File View

Stopped: Entry: Chart Chart1 #18 (0:0:0)
Executing: Chart1 #18 (0:0:0)
Current Event: Simulink call event
Simulink Time: 17.100000 (Major Time Step) Coverage: 100%

Breakpoints: ☑ Chart Entry □ Event Broadcast □ State Entry | □ Disable all

Continue | Step | Break | Stop Simulation

Error checking options
☑ State Inconsistency ☑ Data Range
☑ Transition Conflict □ Detect Cycles

Animation: ● Enabled ○ Disabled
Delay (sec): 0

Breakpoints | Browse Data | Active States | Coverage | Call Stack

```
Browse information for all data in all charts:
Machine Name: test_debugger (#17)
Chart Instance Name: test_debugger/Chart1 (#18 (0:0:0))
(#24 (0:0:0)) x1 = 160.000000
Chart Instance Name: test_debugger/Chart2 (#26 (0:1:0))
(#32 (0:1:0)) x2 = 570.000000
```

MATLAB Command:

Help | Close

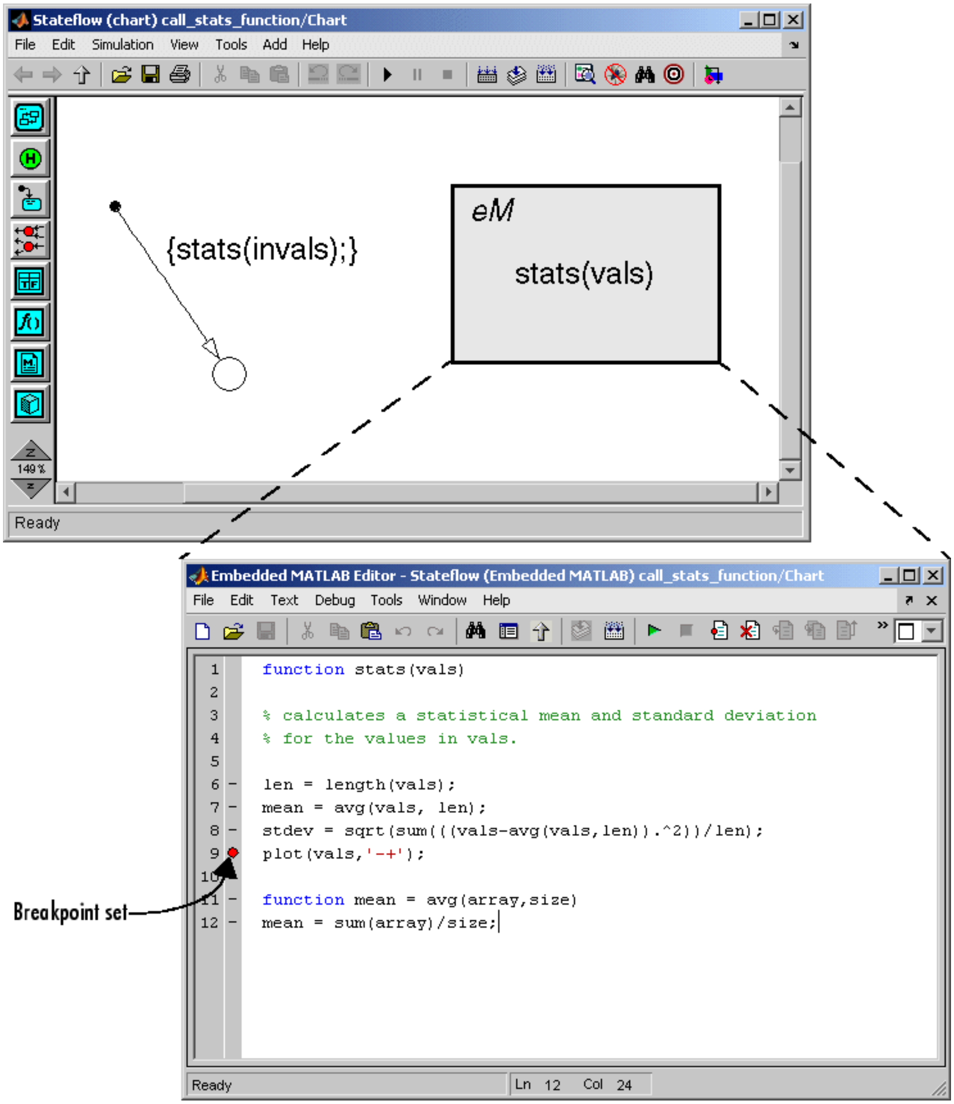
Data x1 and x2

The data for each chart is headed by its owning object. Each displayed object (chart, state, data, and so on) is accompanied by a unique identifier in the form (#id(xx:yy:zz)), which is used in linking the listed object to its appearance in the Stateflow diagram.

Note Fixed-point data is displayed with two values: the quantized integer value (stored integer) and the scaled real-world (actual) value. See “Using Fixed-Point Data in Stateflow” on page 9-5.

Watching Stateflow Data in MATLAB Command Window

When simulation reaches a breakpoint, you can view the values of Stateflow data in the MATLAB Command Window. In the following example, a default transition calls an Embedded MATLAB function with a breakpoint set at the last executable line of the function:


Stateflow (chart) call_stats_function/Chart
File Edit Simulation View Tools Add Help
{stats(invals);}
eM
stats(vals)
149%
Ready
Embedded MATLAB Editor - Stateflow (Embedded MATLAB) call_stats_function/Chart
File Edit Text Debug Tools Window Help
Ready
Ln 12 Col 24

```
function stats(vals)

% calculates a statistical mean and standard deviation
% for the values in vals.

len = length(vals);
mean = avg(vals, len);
stdev = sqrt(sum(((vals-avg(vals,len)).^2))/len);
plot(vals,'-+');

function mean = avg(array,size)
mean = sum(array)/size;
```

Breakpoint set

When simulation reaches the breakpoint, you can display Stateflow data in the MATLAB Command Window. Assuming you want to watch the data variable `vals` from the previous example, follow these steps:

1 At the MATLAB Command Window command prompt, press **Enter**.

A debug>> prompt appears.

2 Enter the MATLAB command whos to view the data that is visible at the current scope.

```
debug>> whos
  Name        Size                   Bytes  Class

  vals        4x1                       32  double array
  len         1x1                        8  double array
  stdev       1x1                        8  double array
  mean        1x1                        8  double array
  invals      4x1                       32  double array

Grand total is 5 data in scope

debug>>
```

3 Enter the name of data array vals at the prompt to display its value.

```
debug>> vals

 vals =

     2
     3
     4
     5

debug>>
```

4 Enter vals(2:3) to view the values of a submatrix of the array.

```
debug>> vals (2:3)

ans =

     3
     4
```

```
debug>>
```

The Command Line Debugger provides the following commands during simulation:

Command	Description
`dbstep`	Advance to next executable line of code.
`dbstep [in/out]`	When debugging Embedded MATLAB functions: • `dbstep [in]` advances to the next executable line of code. If that line contains a call to another function, execution continues to the first executable line of the function. • `dbstep [out]` executes the rest of the function and stops just after leaving the function.
`dbcont`	Continue execution to next breakpoint.
`dbquit` `(ctrl-c)`	Stop simulation of the model. Press **Enter** after this command to return to the MATLAB prompt.
`help`	Display help for command-line debugging.
`print` *var* ...or... *var*	Display the value of the variable *var*.
var (*i*)	Display the value of the *i*th element of the vector or matrix *var*.
var (*i:j*)	Display the value of a submatrix of the vector or matrix *var*.
`save`	Saves all variables to the specified file. Follows the syntax of the MATLAB `save` command. To retrieve variables to the MATLAB base workspace, use `load` command after simulation has been ended.
`whos`	Display the size and class (type) of all variables in the scope of the halted Embedded MATLAB Function block.

You can issue any other MATLAB command at the `debug>>` prompt but the results are executed in the Stateflow workspace. For example, you can issue the MATLAB command plot (*var*) to plot the values of the variable *var*.

To issue a command in the MATLAB base workspace at the `debug>>` prompt, use the `evalin` command with the first argument `'base'` followed by the second argument command string, for example, `evalin('base','whos')`.

Note To return to the MATLAB base workspace, use the `dbquit` command.

Monitoring Stateflow Test Points

A Stateflow test point is a signal that Stateflow guarantees to be observable, for example, by a Floating Scope block, during a simulation. Stateflow allows you to designate a data or a state in a Stateflow diagram as a test point. While all Stateflow states can be test points, only Stateflow data of local scope qualify. They can be scalar, one-dimensional, or two-dimensional in size, and of any data type except type `ml`. Like states, test point data must also be a descendant of a Stateflow chart.

You implicitly declare all Stateflow data of local scope and all states as test points if the **Enable debugging/animation** code option is selected for the Stateflow simulation target. If this option is not set, you can specify individual local data or states as test points by setting their **TestPoint** property in the Stateflow API or through the Model Explorer (see "Setting Test Points for Stateflow States and Local Data with Model Explorer" on page 15-32).

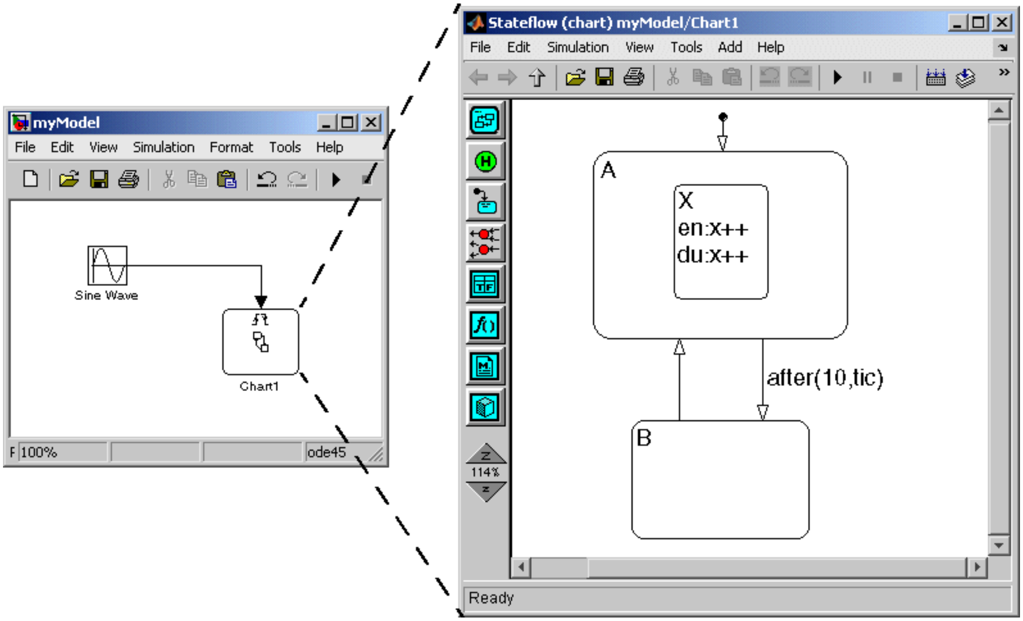
You can monitor individual Stateflow test points with a floating scope during model simulation. You can also log test point values into MATLAB workspace objects. Use the following topics to learn how to set test points and display the values of Stateflow test points while you are simulating a model.

- "Setting Test Points for Stateflow States and Local Data with Model Explorer" on page 15-32 — Through Model Explorer, set test points for states and local data for logging and monitoring.
- "Logging Data Values and State Activity" on page 15-35 — During simulation, log data values and state activity values into MATLAB objects for reporting and plotting.
- "Using a Floating Scope to Monitor Data Values and State Activity" on page 15-40 — Use a Floating Scope block to monitor Stateflow data values continuously during simulation.

Setting Test Points for Stateflow States and Local Data with Model Explorer

You can explicitly set individual states or local data as test points through the Model Explorer. Use the example you create in the following procedure to learn how to set individual test points for Stateflow states and data.

1 Create the following model:


myModel
File Edit View Simulation Format Tools Help
Sine Wave
Chart1
100%
ode45
Stateflow (chart) myModel/Chart1
File Edit Simulation View Tools Add Help
A
X
en:x++
du:x++
after(10,tic)
B
114%
Ready

The model consists of a single Stateflow block named Chart1, which is triggered by a signal from a Sine Wave block through the input trigger event `tic`. In the Stateflow diagram, the state A and its substate X are entered for the first `tic` event. State A and substate X stay active until 10 `tic` events have taken place and then state B is entered. On the following event, state A and substate X are entered and the cycle continues.

The data `x` is added to the state X. The entry and during actions for substate X increment `x` while X is active for 10 `tic` events. When state B is entered, `x` is reinitialized to zero, and the cycle repeats.

2 At the MATLAB Command Window prompt, type

```
myModel
```

3 Start the Model Explorer. In the Simulink model, select **View -> Model Explorer**.

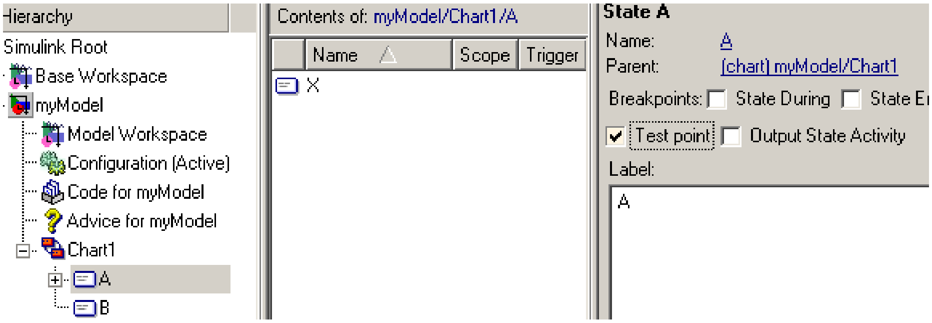
The Model Explorer is displayed.

4 In the Model Explorer, expand `myModel`.

5 Expand `Chart1`, then select `A`.

6 In the rightmost pane, **State A**, select the **Test point** check box. Click **Apply**.

This creates a test point for the `A` state.



Contents of: myModel/Chart1/A

X

State A

Name: A

Parent: (chart) myModel/Chart1

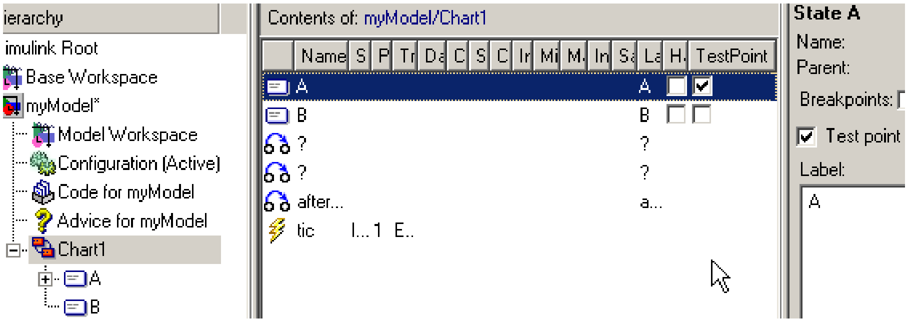
Breakpoints: ☐ State During ☐ State En

☑ Test point ☐ Output State Activity

Label:

A

Alternatively, you can access a test point through the middle pane. By default, the Model Explorer displays event and data child objects in the **Contents** pane for the selected object in the **Model Hierarchy** pane. You can set the test point for the A state through this pane by selecting the parent of `A`. If the states are not listed in the middle pane, select the **States/Functions/Boxes/Etc.** check box in the **View -> List View Options** for **All Stateflow Objects**.



Contents of: myModel/Chart1

Name	S	P	Tr	Da	C	S	C	Ir	Mi	M.	In	Sa	La	H.	TestPoint
A													A	☐	☑
B													B	☐	☐
?													?		
?													?		
after...													a...		
tic			I...1	E..											

State A

Name:

Parent:

Breakpoints: ☐

☑ Test point

Label:

A

7 Repeat step 6 for state `X`. Click **Apply**.

8 Select `X` again. Select the local data `x` in the **Contents** pane.

9 In the rightmost pane for that data, select the **Value Attributes** tab, then select the **Test point** check box. Click **Apply**.

10 Repeat step 6 for state B. Click **Apply** and save the model.

You can now log these test points. See "Logging Data Values and State Activity" on page 15-35.

Logging Data Values and State Activity

During simulation, you can log values for data and state activity into Simulink objects. After simulation, you can access these objects in the MATLAB workspace and use them to report and plot the values.

You can use the following procedure to learn how to access logged Stateflow data and state activity. This procedure uses the model, `myModel`, from the preceding topic, "Setting Test Points for Stateflow States and Local Data with Model Explorer" on page 15-32.

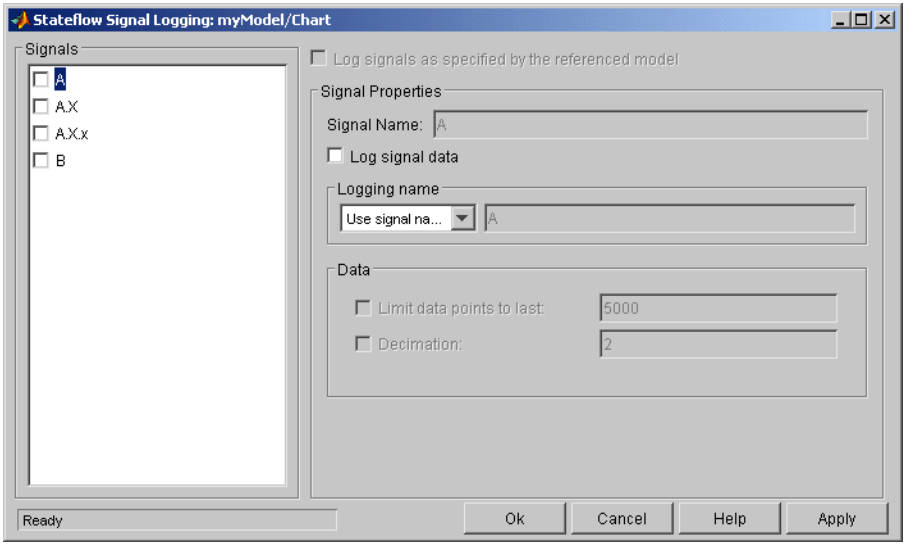
1 If `myModel` is not already open, in the MATLAB Command Window prompt, type

```
myModel
```

The model is displayed.

2 In the Simulink window, right-click the Stateflow block and select **Log Chart Signals**.

The **Signal Logging** dialog appears, as shown.



Stateflow Signal Logging: myModel/Chart

Signals

□ A
□ A.X
□ A.X.x
□ B

□ Log signals as specified by the referenced model

Signal Properties

Signal Name: A

□ Log signal data

Logging name

Use signal na... ▼ A

Data

□ Limit data points to last: 5000

□ Decimation: 2

Ready

3 Select the check box next to A.

This is the state activity signal for state A. When A is active, its value is 1. When A is inactive, its value is 0.

After checking A, notice the following properties in the right pane of the **Signal Logging** dialog:

Signal Properties	Description
Signal Name	Name of the highlighted state or data.
Log signal data	Checking this selects the highlighted signal in the **Signals** pane.
Logging name	Name of the signal logged. By default, this is set to the name of the selected/highlighted state or data. You can select `Custom` for this property to rename the selected/highlighted signal in the adjacent field to the right.

Signal Properties	Description
Limit data points to last	Select this property to enter the number of most recent sample values to log in the adjacent field to the right for the selected/highlighted signal.
Decimation	Select this property to enter the level of decimation for the signal values logged for the selected/highlighted signal.

4 Select all the signals in the **Signal** pane and click **OK** to close the **Signal Logging** dialog.

5 Simulate the model.

During simulation, the Simulink model data log object `logsOut` is generated in the MATLAB workspace.

6 After simulation, enter the following at the MATLAB prompt:

```
>> logsOut
```

You see the following result:

```
logsOut =

Simulink.ModelDataLogs (myModel):
Name                   Elements  Simulink Class

Chart1                    4      StateflowDataLogs
```

The display identifies `logsOut` as a Simulink object of type `ModelDataLogs`. This is the highest level logging object. The object `Chart1` appears as the only contents of `logsOut`. It represents logged data for the Stateflow block Chart1 and is identified as a Simulink object of type `StateflowDataLogs`.

7 At the MATLAB prompt, enter the following:

```
>> logsOut.Chart1
```

You see the following result:

```
ans =

Simulink.StateflowDataLogs (Chart1):
  Name                    Elements  Simulink Class

  ('A.X.x')                  1      Timeseries
  A                          1      Timeseries
  ('A.X')                    1      Timeseries
  B                          1      Timeseries
```

The signals that you selected in the **Signal Logging** dialog appear as Simulink objects of type `Timeseries`. Notice that the signals for the activity of state X and the value of data `x` appear as `('A.X')` and `('A.X.x')`, respectively. Because of the way that logged signals are stored for Stateflow, you need to use this notation to access logged data for Stateflow objects below chart level in the Stateflow diagram.

8 At the MATLAB prompt, enter the following:

```
>> logsOut.Chart1.('A.X.x')
```

You see the following result:

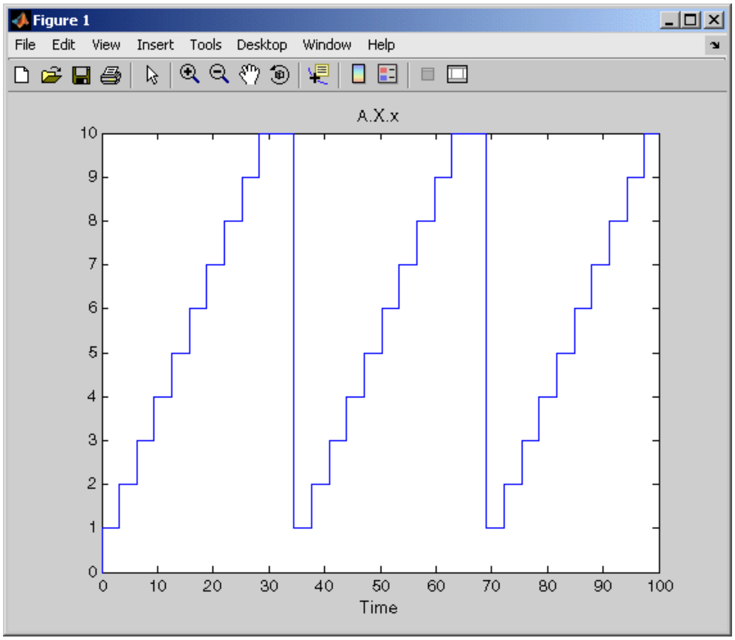
```
ans =

          Name: 'A.X.x'
     BlockName: 'StateflowChart/A.X.x'
     PortIndex: 1
    SignalName: 'A.X.x'
    ParentName: 'A.X.x'
      TimeInfo: [1x1 Simulink.TimeInfo]
          Time: [114x1 double]
          Data: [114x1 double]
```

The logging object for the data `x`, `('A.X.x')`, is actually a structure of logged data pertinent to `x`. The actual logged signal values for `x` are contained in the `Data` object, a vector of 114 values. For example, if you were to enter the MATLAB command logsOut.Chart1.('A.X.x').Data, a long stream of data would appear. A better way to see the logged values of `x` is to use the `plot` method shown in the next step.

9 At the MATLAB prompt, plot the values of x with the following command:

```
>> logsOut.Chart1.('A.X.x').plot
```

You see the following result:

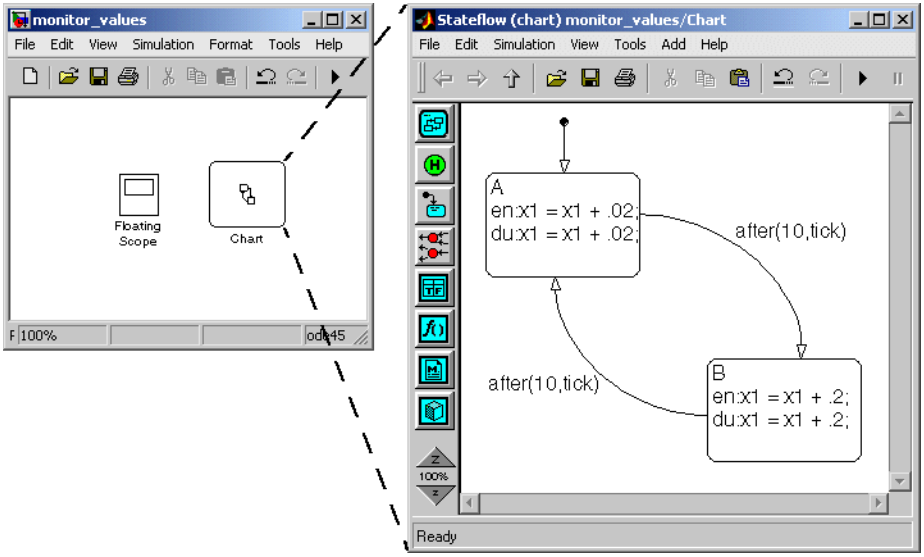


The preceding plot exhibits the expected results for the value of x. It is incremented for 10 time steps before resetting to 0 when states X and A are exited and state B is entered in the Stateflow diagram.

The preceding example is a demonstration of some of the capabilities you have for reporting logged Stateflow data. Stateflow data conforms to the general rules for handling logging signals in Simulink. For more information on how you can use and manipulate logged data with commands and scripts in MATLAB, see “Logging Signals” in the Simulink documentation.

Using a Floating Scope to Monitor Data Values and State Activity

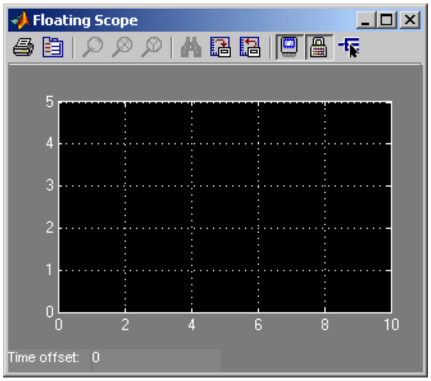
In the steps of this topic, you configure a Floating Scope block to monitor a data value and the activity of a state in the following example model:



The model consists of a Floating Scope block and a Stateflow block. The Stateflow diagram for the Stateflow block starts by adding an increment of `.02` for 10 samples to the data `x1`. For the next 10 samples, an increment of .2 is added, and the cycle repeats.

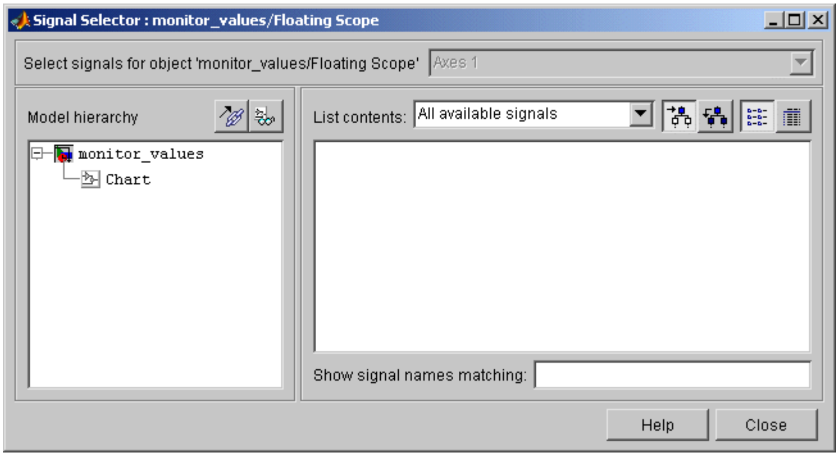
1 Double-click the Floating Scope block.

   A **Floating Scope** window appears, already scaled for this example.



2 In the **Floating Scope** window, select the Signal Selection tool .

The **Signal Selector** dialog appears with a hierarchy of Simulink blocks for the model.



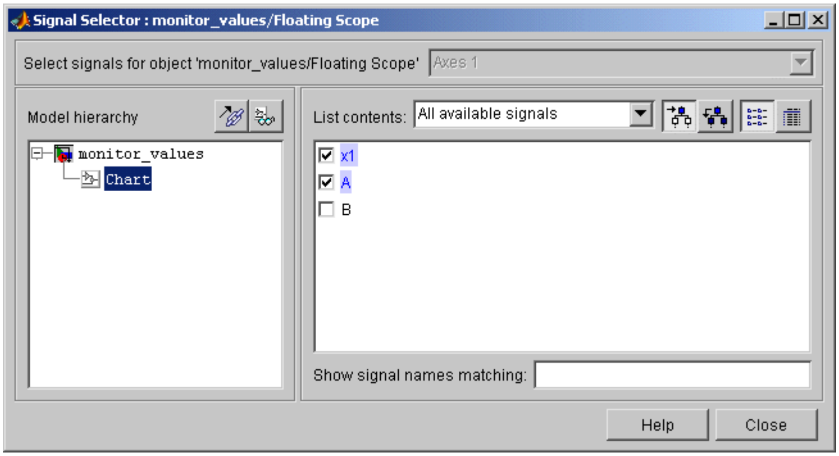
Select signals for object 'monitor_values/Floating Scope' Axes 1

```
monitor_values
  Chart
```

List contents: All available signals

Show signal names matching:

3 In the **Model hierarchy** pane, select the Stateflow block whose signals you want to monitor and, in the **List contents** pane, select the data you want to monitor.



Signal Selector : monitor_values/Floating Scope

Select signals for object 'monitor_values/Floating Scope' Axes 1

Model hierarchy

- monitor_values
  - Chart

List contents: All available signals

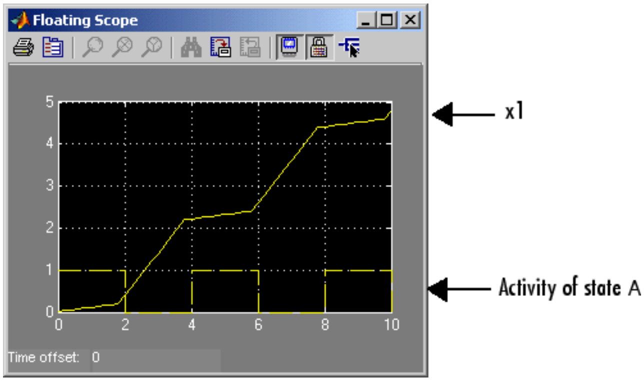
☑ x1
☑ A
□ B

Show signal names matching:

In the preceding example, the block named Chart is selected in the **Model hierarchy** pane, and the data x1 and the activity of state A are selected in the **Contents** pane.

4 Simulate the model.

When the example model is simulated, you receive a signal trace for x1 and for the activity of state A, as shown.



Notice that when state A is active, its activity signal value is 1, and when it is inactive, its signal value is 0. Because this value is very low or very high compared to some data, you might want to put it in a second Floating Scope block to compare it with other data.

Understanding Model Coverage for Stateflow Charts

Model coverage is a measure of how thoroughly a model is tested. The Model Coverage tool helps you to validate your model tests by measuring model coverage for your tests. It determines the extent to which a model test case exercises simulation control flow paths through a model. The percentage of paths that a test case exercises is called its *model coverage*.

Note The Model Coverage tool requires a Simulink Verification and Validation license.

For an understanding of how to generate and interpret model coverage reports for your Stateflow charts, see the following topics:

- “Making Model Coverage Reports” on page 15-45 — Gives you an overview of how model coverage reports are generated and how they are interpreted.
- “Specifying Coverage Report Settings” on page 15-45 — Gives you the settings you need to specify for each available model coverage report option.
- “Cyclomatic Complexity” on page 15-46 — Explains the cyclomatic complexity results you see on model coverage reports.
- “Decision Coverage” on page 15-46 — Explains the decision coverage results you see on model coverage reports if you select it for the report.
- “Condition Coverage” on page 15-51 — Explains the condition coverage results you see on model coverage reports if you select it for the report.
- “MCDC Coverage” on page 15-51 — Explains the MCDC (modified condition decision coverage) results you see on model coverage reports if you select it for the report.
- “Coverage Reports for Stateflow Charts” on page 15-51 — Describes different parts of a model coverage report for Stateflow charts.
- “Colored Stateflow Diagram Coverage Display” on page 15-61 — Describes an option for displaying model coverage information directly in Stateflow diagrams with context-sensitive access.

Stateflow provides model coverage for other Stateflow objects that incorporate logical decisions in the following sections:

- “Model Coverage for Truth Tables” on page 12-58
- “Model Coverage for an Embedded MATLAB Function” on page 13-22

Making Model Coverage Reports

Model Coverage reports are generated during simulation if you specify them (see “Specifying Coverage Report Settings” on page 15-45). For Stateflow charts, the Model Coverage tool records the execution of the chart itself and the execution of its states, transition decisions, and the individual conditions that compose each decision. When simulation is finished, the Model Coverage report tells you how thoroughly a model has been tested, in terms of how many times each exclusive substate is entered, executed, and exited based on the history of the superstate, how many times each transition decision has been evaluated as true or false, and how many times each condition (predicate) has been evaluated as true or false.

Note You must have the Simulink Verification and Validation installed on your system to use the Model Coverage tool.

Specifying Coverage Report Settings

Coverage report settings appear in the **Coverage Settings** dialog. Access this dialog by selecting **Coverage settings** from the **Tools** menu in a Simulink model window.

Selecting the **Generate HTML Report** option on the **Coverage Settings** dialog causes Simulink to create an HTML report containing the coverage data generated during simulation of the model. Simulink displays the report in the MATLAB Help browser at the end of simulation.

Selecting the **Generate HTML Report** option also enables the selection of different coverages that you can specify for your reports. The following sections address only those coverage metrics that have direct bearing on reports for the Stateflow charts. These include decision coverage, condition coverage, and MCDC coverage. For a complete discussion of all dialog fields and entries, consult the “Specifying Model Coverage Reporting Options” section in the Simulink Verification and Validation documentation.

Cyclomatic Complexity

Cyclomatic complexity is a measure of the complexity of a software module based on its edges, nodes, and components within a control-flow graph. It provides an indication of how many times you need to test the module.

The calculation of cyclomatic complexity is as follows:

```
CC = E - N + p
```

where CC is the cyclomatic complexity, E is the number of edges, N is the number of nodes, and p is the number of components.

Within the Model Coverage tool, each decision is exactly equivalent to a single control flow node, and each decision outcome is equivalent to a control flow edge. Any additional structure in the control-flow graph is ignored since it contributes the same number of nodes as edges and therefore has no effect on the complexity calculation. This allows cyclomatic complexity to be reexpressed as follows:

```
CC = OUTCOMES - DECISIONS + p
```

For analysis purposes, each chart is considered to be a single component.

Decision Coverage

Decision coverage interprets a model execution in terms of underlying decisions where behavior or execution must take one outcome from a set of mutually exclusive outcomes.

Note Full coverage for an object of decision means that every decision has had at least one occurrence of each of its possible outcomes.

Decisions belong to an object making the decision based on its contents or properties. The following table lists the decisions recorded for model coverage for the Stateflow objects owning them. The sections that follow the table describe these decisions and their possible outcomes.

Object	Possible Decisions
Chart	If a chart is a triggered Simulink block, it must decide whether or not to execute its block. See "Chart as a Triggered Simulink Block Decision" on page 15-47. If a chart contains exclusive (OR) substates, it must decide which of its states to execute. See "Chart Containing Exclusive OR Substates Decision" on page 15-47.
State	If a state is a superstate containing exclusive (OR) substates, it must decide which substate to execute. See "Superstate Containing Exclusive OR Substates Decision" on page 15-48. If a state has `on` *`event name`* actions (which might include temporal logic operators), the state must decide whether or not to execute the actions. See "State with On Event_Name Action Statement Decision" on page 15-50.
Transition	If a transition is a conditional transition, it must decide whether or not to exit its active source state or junction and enter another state or junction. See "Conditional Transition Decision" on page 15-50.

Chart as a Triggered Simulink Block Decision

If the chart is a triggered block in Simulink, the decision to execute the block is tested. If the block is not triggered, there is no decision to execute the block, and the measurement of decision coverage is not applicable (NA).

See "Chart as Subsystem Details Report Section" on page 15-53.

Chart Containing Exclusive OR Substates Decision

If the chart contains exclusive (OR) substates, the decision on which substate to execute is tested. If the chart contains only parallel AND substates, this coverage measurement is not applicable (NA).

See "Chart as Superstate Details Report Section" on page 15-54.

Superstate Containing Exclusive OR Substates Decision

Since a diagram is hierarchically processed from the top down, procedures such as exclusive (OR) substate entry, exit, and execution are sometimes decided by the parenting superstate.

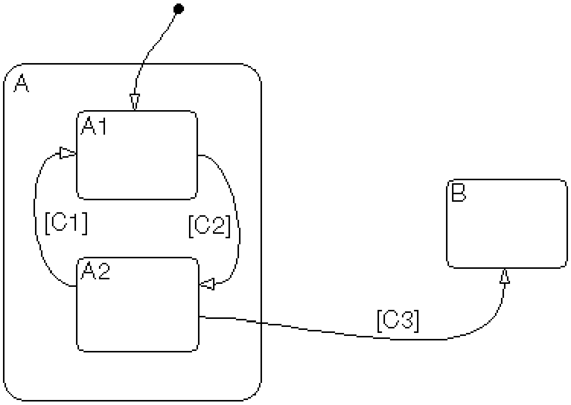
Note Decision coverage for superstates applies to exclusive (OR) substates only. A superstate makes no decisions for its parallel (AND) substates.

Since a superstate must decide which of its exclusive (OR) substates to process, the number of decision outcomes for the superstate is equal to the number of exclusive (OR) substates that it contains. In the examples following, the choice of which substate to process is made in one of three possible contexts.

Note Implicit transitions are shown as dashed lines in the following examples.

1 Active Call

In the following example, states A and A1 are active.



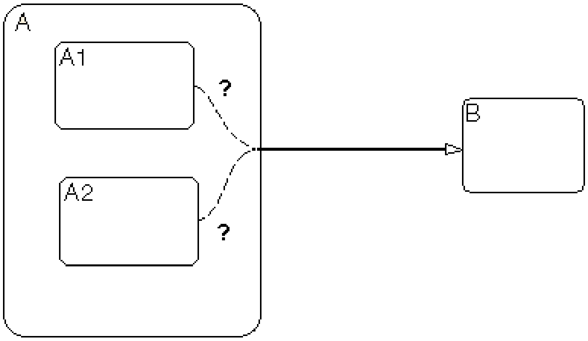
This gives rise to the following superstate/substate decisions:

- The parent of states A and B must decide which of these states to process. This decision belongs to the parent. Since A is active, it is processed.
- State A, the parent of states A1 and A2, must decide which of these states to process. This decision belongs to state A. Since A1 is active, it is processed.

  During processing of state A1, all its outgoing transitions are tested. This decision belongs to the transition and not to its parent state A. In this case, the transition marked by condition C2 is tested and a decision is made whether to take the transition to A2 or not. See “Conditional Transition Decision” on page 15-50.

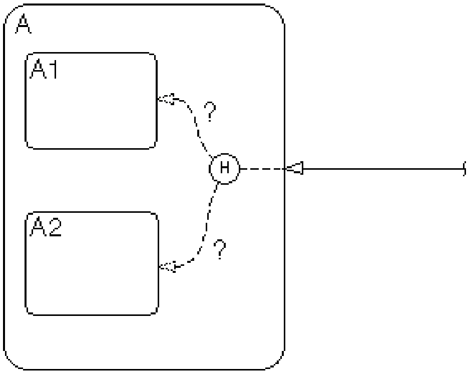
1 Implicit Substate Exit Context

   In the following example, a transition takes place whose source is superstate A and whose destination is state B. If the superstate has two exclusive (OR) substates, it is the decision of superstate A as to which of these substates will perform the implicit transition from substate to superstate.



2 Substate Entry with a History Junction

   A history junction, similar to the one shown in the example following, provides a superstate with the means of recording which of its substates was last active before the superstate was exited. If that superstate now becomes the destination of one or more transitions, the history junction provides it the means of deciding which previously active substate to enter.



See “State Details Report Section” on page 15-55.

State with On Event_Name Action Statement Decision

A state that has an `on` *`event_name`* action statement must decide whether to execute that statement based on the reception of a specified event or on an accumulation of the specified event when using temporal logic operators.

See “State Labels” on page 2-9 and “Using Temporal Logic in Actions” on page 8-51.

Conditional Transition Decision

A conditional transition is a transition with a triggering event and/or a guarding condition (see “Transition Label Notation” on page 2-15). In a conditional transition from one state to another, the decision to exit one state and enter another is credited to the transition itself.

See “Transition Details Report Section” on page 15-57.

Note Only conditional transitions receive decision coverage. Transitions without decisions are not applicable to decision coverage.

Condition Coverage

Condition coverage reports on the extent to which all possible outcomes are achieved for individual subconditions composing a transition decision.

Note Full condition coverage means that all possible outcomes occurred for each subcondition in the test of a decision.

For example, for the decision [A & B & C] on a transition, condition coverage reports on the true and false occurrences of each of the subconditions A, B, and C. This results in six possible outcomes: true and false for each of three subconditions.

See “Transition Details Report Section” on page 15-57.

MCDC Coverage

The Modified Condition Decision Coverage (MCDC) option reports a test’s coverage of occurrences in which changing an individual subcondition within a transition results in changing the entire transition trigger expression from true to false or false to true.

Note If matching true and false outcomes occur for each subcondition, coverage is 100%.

For example, if a transition executes on the condition [C1 & C2 & C3 | C4 & C5], the MCDC report for that transition shows actual occurrences for each of the five subconditions (C1, C2, C3, C4, C5) in which changing its result from true to false is able to change the result of the entire condition from true to false.

See “Transition Details Report Section” on page 15-57.

Coverage Reports for Stateflow Charts

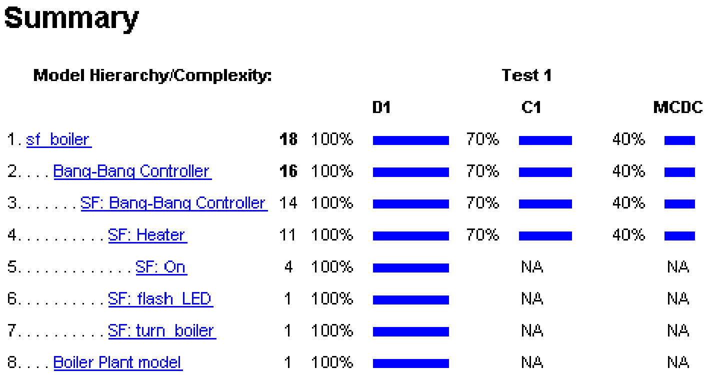
The following sections of a Model Coverage report were generated by simulating the Bang-Bang Boiler demonstration model, which includes the Stateflow Chart block Bang-Bang Controller. The coverage metrics for **Decision Coverage**, **Condition Coverage**, and **MCDC Coverage** are enabled for this report; the **Look-up Table Coverage** metric is Simulink dependent and not relevant to the coverage of Stateflow charts.

This topic contains the following subtopics:

- "Summary Report Section" on page 15-52
- "Chart as Subsystem Details Report Section" on page 15-53
- "Chart as Superstate Details Report Section" on page 15-54
- "State Details Report Section" on page 15-55
- "Transition Details Report Section" on page 15-57

For information on the model coverage of truth tables, see "Model Coverage for Truth Tables" on page 12-58.

Summary Report Section



Summary

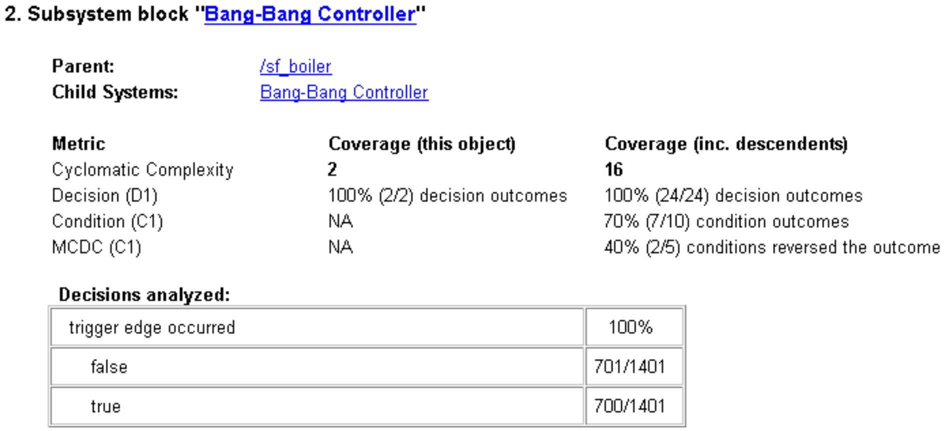
Model Hierarchy/Complexity:		Test 1		
		D1	C1	MCDC
1. sf_boiler	**18**	100%	70%	40%
2. . . . Bang-Bang Controller	**16**	100%	70%	40%
3. . . . . . . SF: Bang-Bang Controller	14	100%	70%	40%
4. . . . . SF: Heater	11	100%	70%	40%
5. . . . . SF: On	4	100%	NA	NA
6. . . . . SF: flash_LED	1	100%	NA	NA
7. . . . . SF: turn_boiler	1	100%	NA	NA
8. . . . Boiler Plant model	1	100%	NA	NA

The Summary section shows coverage results for the entire test. It appears at the beginning of the Model Coverage report after the listing of the Start and End execution times for the test (simulation).

Each line in the hierarchy summarizes the coverage results at its level and the levels below it. It includes a hyperlink to a later section in the report with the same assigned hierarchical order number that details that coverage and the coverage of its children.

The top level, sf_boiler, is the model itself. The second level, Bang-Bang Controller, is the Simulink Stateflow chart block. The next levels are superstates within the Stateflow chart control logic in order of hierarchical containment. Each of these superstates uses an SF: prefix. The bottom level, Boiler Plant model, is an additional subsystem in the model.

Chart as Subsystem Details Report Section



2. Subsystem block "Bang-Bang Controller"

Parent: /sf_boiler
Child Systems: Bang-Bang Controller

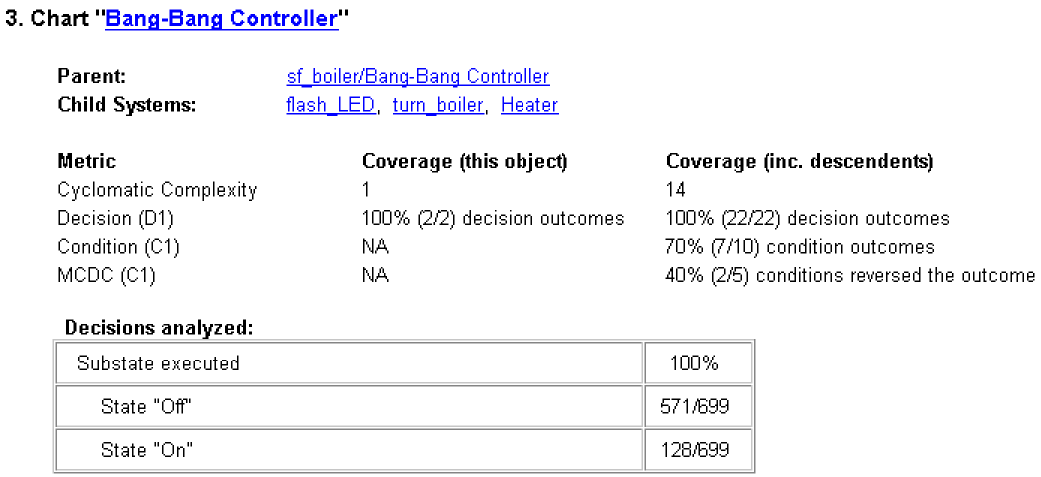
Metric	Coverage (this object)	Coverage (inc. descendents)
Cyclomatic Complexity	**2**	**16**
Decision (D1)	100% (2/2) decision outcomes	100% (24/24) decision outcomes
Condition (C1)	NA	70% (7/10) condition outcomes
MCDC (C1)	NA	40% (2/5) conditions reversed the outcome

Decisions analyzed:

trigger edge occurred	100%
false	701/1401
true	700/1401

The Subsystem report sees the chart as a block in a Simulink model, instead of a chart with states and transitions. You can confirm this by taking the hyperlink of the subsystem name in the title; it takes you to a highlighted Bang-Bang Controller Stateflow block sitting in its resident Simulink block diagram.

Chart as Superstate Details Report Section



3. Chart "Bang-Bang Controller"

Parent:	sf_boiler/Bang-Bang Controller
Child Systems:	flash_LED, turn_boiler, Heater

Metric	Coverage (this object)	Coverage (inc. descendents)
Cyclomatic Complexity	1	14
Decision (D1)	100% (2/2) decision outcomes	100% (22/22) decision outcomes
Condition (C1)	NA	70% (7/10) condition outcomes
MCDC (C1)	NA	40% (2/5) conditions reversed the outcome

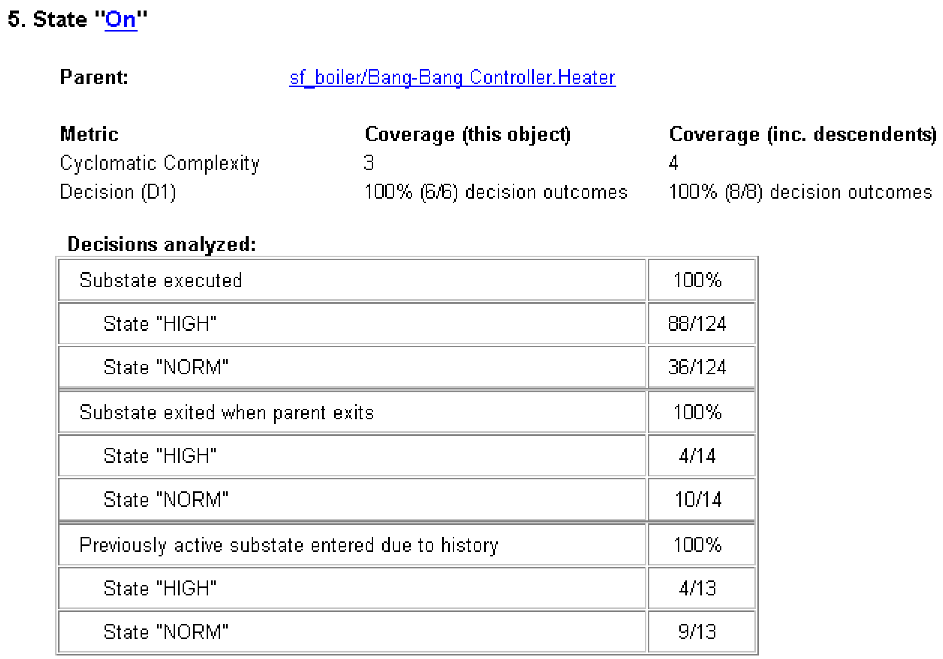
Decisions analyzed:

Substate executed	100%
State "Off"	571/699
State "On"	128/699

The Chart report sees a Stateflow chart as the superstate container of all of its states and transitions. You can confirm this through the hyperlinked chart name, which takes you to a display of the control logic chart in the Stateflow diagram editor.

Cyclomatic complexity and decision coverage are also displayed for the chart and for the chart including its descendants. Condition coverage and MCDC are both not applicable (NA) coverages for a chart, but apply to descendants.

State Details Report Section



5. State "On"

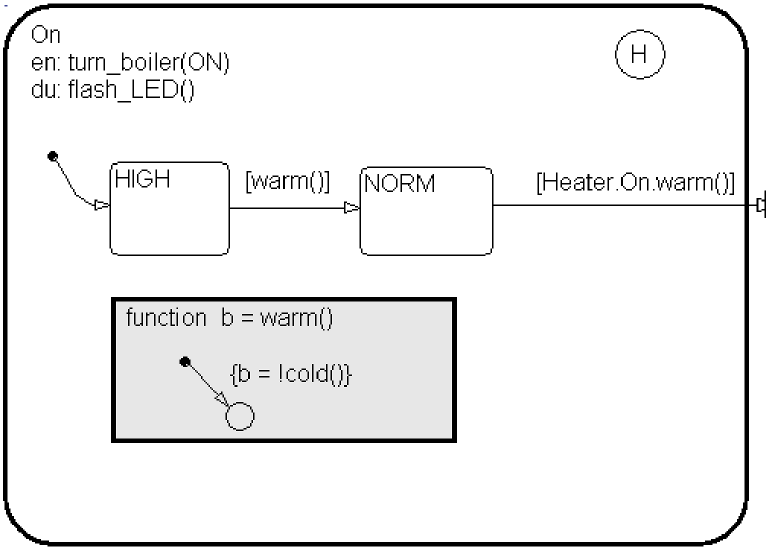
Parent: sf_boiler/Bang-Bang Controller.Heater

Metric	**Coverage (this object)**	**Coverage (inc. descendents)**
Cyclomatic Complexity	3	4
Decision (D1)	100% (6/6) decision outcomes	100% (8/8) decision outcomes

Decisions analyzed:

Substate executed	100%
State "HIGH"	88/124
State "NORM"	36/124
Substate exited when parent exits	100%
State "HIGH"	4/14
State "NORM"	10/14
Previously active substate entered due to history	100%
State "HIGH"	4/13
State "NORM"	9/13

The example state section contains a report on the state On. The Stateflow diagram for On is as follows:



On resides in the box Heater, which has its own details report (not shown) because it contains other Stateflow objects. However, because `On` is a superstate containing the two states `HIGH` and `NORM` along with a history junction and the function `warm`, it has its own numbered report in the Details section.

The decision coverage for the On state tests the decision of which of its states to execute. The results indicate that six of a possible six outcomes were tested during simulation. Each decision is described as follows:

1 The choice of which substate to execute when On is executed

2 The choice of which state to exit when On is exited

3 The choice of which substate to enter when On is entered and the History junction has a record of the previously active substate

Because each of the above decisions can result in processing either HIGH or NORM, the total possible outcomes are 3 x 2 = 6.

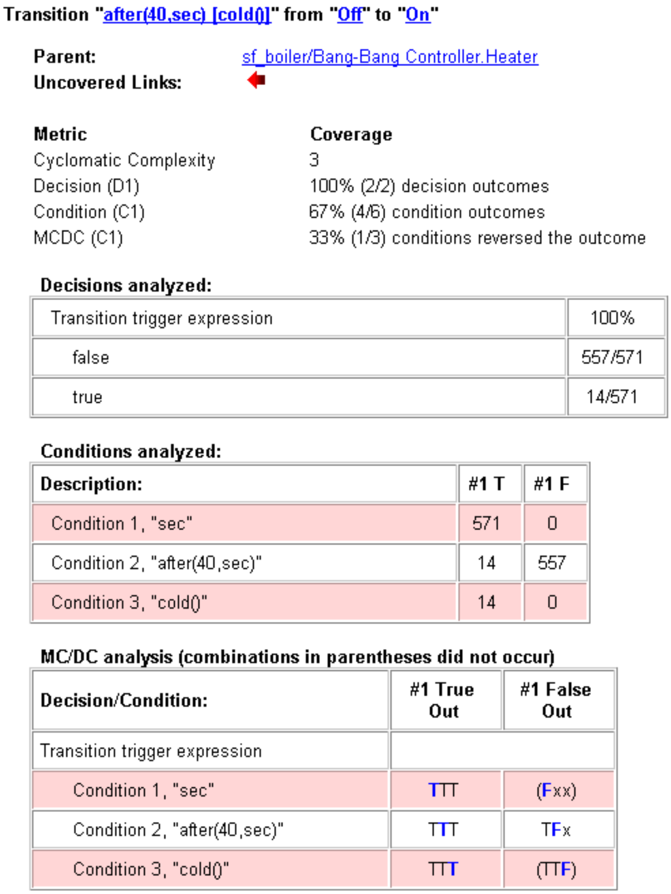
The decision coverage tables also display the number of occurrences for each decision and the number of times each state was chosen. For example, the first decision was made 124 times. Of these, the HIGH state was executed 88 times and the NORM state was executed 36 times.

Cyclomatic complexity and decision coverage are also displayed for the On state including its descendants. This includes the coverage discussed above plus the decision required by the condition `[warm()]` for the transition from HIGH to NORM for a total of eight outcomes. Condition coverage and MCDC are both not applicable (NA) coverages for a state.

Note Nodes and edges that make up the cyclomatic complexity calculation have no direct relationship with model objects (states, transitions, and so on). Instead, this calculation requires a graph representation of the equivalent control flow.

Transition Details Report Section

Reports for transitions appear under the report sections of their owning states. They do not appear in the model hierarchy of the Summary section, since that is based entirely on superstates owning other Stateflow objects.



Transition "after(40,sec) [cold()]" from "Off" to "On"

Parent:	sf_boiler/Bang-Bang Controller.Heater
Uncovered Links:	⬅

Metric	**Coverage**
Cyclomatic Complexity	3
Decision (D1)	100% (2/2) decision outcomes
Condition (C1)	67% (4/6) condition outcomes
MCDC (C1)	33% (1/3) conditions reversed the outcome

Decisions analyzed:

Transition trigger expression	100%
false	557/571
true	14/571

Conditions analyzed:

Description:	**#1 T**	**#1 F**
Condition 1, "sec"	571	0
Condition 2, "after(40,sec)"	14	557
Condition 3, "cold()"	14	0

MC/DC analysis (combinations in parentheses did not occur)

Decision/Condition:	**#1 True Out**	**#1 False Out**
Transition trigger expression		
Condition 1, "sec"	TTT	(Fxx)
Condition 2, "after(40,sec)"	TTT	TFx
Condition 3, "cold()"	TTT	(TTF)

The decision for this transition is based on the broadcast of 40 `sec` events and the condition `[cold()]`. If, after the reception of 40 `sec` events (equivalent to a 40 second delay) the environment is cold (`cold() = 1`), the decision to execute this transition and turn the Heater on is made. For other time intervals or environment conditions, the decision is made not to execute.

For decision coverage, both the true and false evaluations for the decision occurred. Because two of two decision outcomes occurred, coverage was full (that is, 100%).

Condition coverage shows that only 4 of 6 condition outcomes were tested. The temporal condition `after(40,sec)` is a short form expression for `sec[after(40,sec]` which is actually two conditions: the event `sec` and the accumulation condition `after(40,sec)`. Consequently, there are actually three conditions on the transition: `sec`, `after(40,sec)`, and `cold()`. Since each of these decisions can be true or false, there are now six possible outcomes.

A look at the **Decisions analyzed** table shows each of these conditions as a row with the recorded number of occurrences for each outcome for that decision (true or false). Decision rows in which a possible outcome did not occur are shaded. For example, the first and the third decision rows did not record an occurrence of a false outcome and are therefore shaded.

In the MC/DC report, all sets of occurrences of the transition conditions are scanned for a particular pair of decisions for each condition in which the following are true:

- The condition varies from true to false.
- All other conditions contributing to the decision outcome remain constant.
- The outcome of the decision varies from true to false, or the reverse.

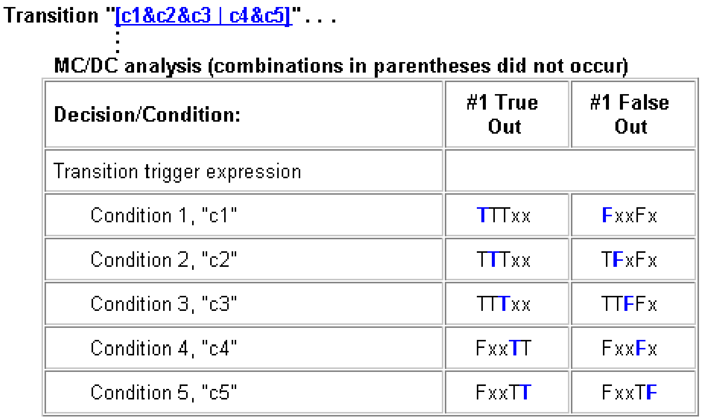
For three conditions related by an implied AND operator, these criteria can be satisfied by the occurrence of the following conditions.

Condition Tested	True Outcome	False Outcome
1	**T**TT	**F**xx
2	T**T**T	T**F**x
3	TT**T**	TT**F**

Notice that in each line, the condition tested changes from true to false while the other condition remains constant. Irrelevant contributors are coded with an "x" (discussed below). If both outcomes occur during testing, coverage is complete (100%) for the condition tested.

The preceding report example shows coverage only for condition 2. The false outcomes required for conditions 1 and 3 did not occur, and are indicated by parentheses for both conditions. Therefore the table lines for conditions (rows) 1 and 3 are shaded in red. Thus, while condition 2 has been tested, conditions 1 and 3 have not and MCDC is 33%.

For some decisions, the values of some conditions are irrelevant under certain circumstances. For example, in the decision [C1 & C2 & C3 | C4 & C5] the left side of the "|" is false if any one of the conditions C1, C2, or C3 is false. The same applies to the right side result if either C4 or C5 is false. When searching for matching pairs that change the outcome of the decision by changing one condition, holding some of the remaining conditions constant is irrelevant. In these cases, the MC/DC report marks these conditions with an "x" to indicate their irrelevance as a contributor to the result. This is shown in the following example.



Transition "[c1&c2&c3 | c4&c5]" . . .

MC/DC analysis (combinations in parentheses did not occur)

Decision/Condition:	#1 True Out	#1 False Out
Transition trigger expression		
Condition 1, "c1"	TTTxx	FxxFx
Condition 2, "c2"	TTTxx	TFxFx
Condition 3, "c3"	TTTxx	TTFFx
Condition 4, "c4"	FxxTT	FxxFx
Condition 5, "c5"	FxxTT	FxxTF

Consider the very first matched pair. Since condition 1 is true in the **True** outcome column, it must be false in the matching **False** outcome column. This makes the conditions C2 and C3 irrelevant for the false outcome since C1 & C2 & C3 is always false if C1 is false. Also, since the false outcome is required to evaluate to false, the evaluation of C4 & C5 must also be false. In this case, a match was found with C4 = F, making condition C5 irrelevant.

Colored Stateflow Diagram Coverage Display

The Model Coverage tool displays model coverage results for individual blocks directly in Simulink diagrams. If you enable this feature, the Model Coverage tool does the following:

- Highlights (colors) Stateflow objects that have received model coverage during simulation
- Provides a context-sensitive display of summary model coverage information for each object

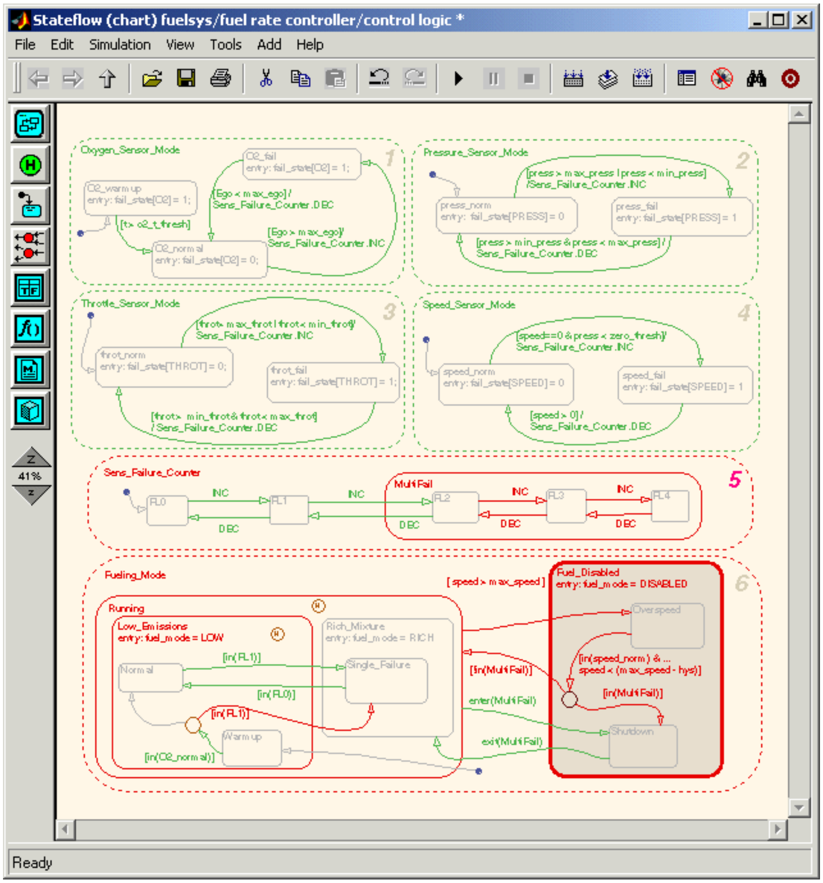
---

Caution The coverage tool only changes colors for open Stateflow at the time coverage information is reported. When you interact with the Stateflow diagram, such as selecting a transition or a state, colors revert to their default values.

For details on enabling and selecting this feature in Simulink, see “Enabling the Colored Diagram Display” in the Simulink Verification and Validation documentation.

Displaying Model Coverage with Model Coloring

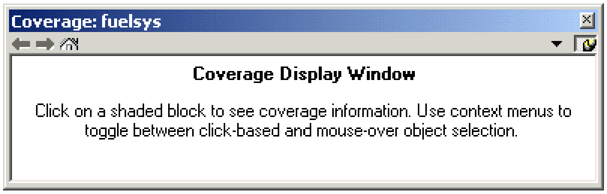
Once you enable display coverage with model coloring, anytime that the model generates a model coverage report, individual Stateflow objects receiving coverage are highlighted with light green or light red as shown in the following example:



Objects highlighted in light green received full coverage during testing. Objects highlighted in light red received incomplete coverage. Objects with no color highlighting receive no coverage at all.

Note To revert the Stateflow diagram to show original colors, select and unselect its objects.

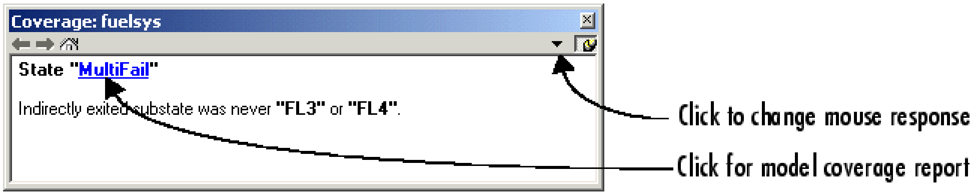
Along with the highlighted Stateflow diagram, a **Coverage Display Window** appears, as shown.



Coverage Display Window

Click on a shaded block to see coverage information. Use context menus to toggle between click-based and mouse-over object selection.

If you click a highlighted Stateflow object, its summarized coverage appears in the **Coverage Display Window**. In the preceding example, the following summary report appears when you click the MultiFail state:



Coverage: fuelsys
Click to change mouse response
Click for model coverage report

State "MultiFail"

Indirectly exited substate was never "FL3" or "FL4".

Summary coverage information appears in the **Coverage Display Window** for the Stateflow object, whose hyperlinked name appears at the top of the window. Click the hyperlink to access the appropriate section of the coverage report for this object.

You can set the **Coverage Display Window** to appear for a block in response to a hovering mouse cursor instead of a mouse click in one of two ways:

- Select the downward arrow on right side of the **Coverage Display Window**, and, from the resulting menu, select **Focus**.
- Right-click a colored block and select **Coverage display on mouse-over** from the resulting context menu.

16

Exploring and Modifying Charts

Stateflow provides you with tools for searching for objects and replacing them with others. Learn how to search and replace objects in Stateflow in the following sections:

Using the Model Explorer with Stateflow Objects

The **Model Explorer** displays any object in the Stateflow hierarchy. You can also use the **Model Explorer** as a platform for creating, modifying, and deleting Stateflow objects. You can also display, create, modify, and delete target objects for generating code and building the simulation application in the **Model Explorer**.

You can create data, events, and targets in the Stateflow diagram editor and in the **Model Explorer**. However, the **Model Explorer** is the only location where you can modify and delete existing data, events, and targets.

The following topics describe the use of the **Model Explorer** for creating, modifying, and deleting Stateflow objects:

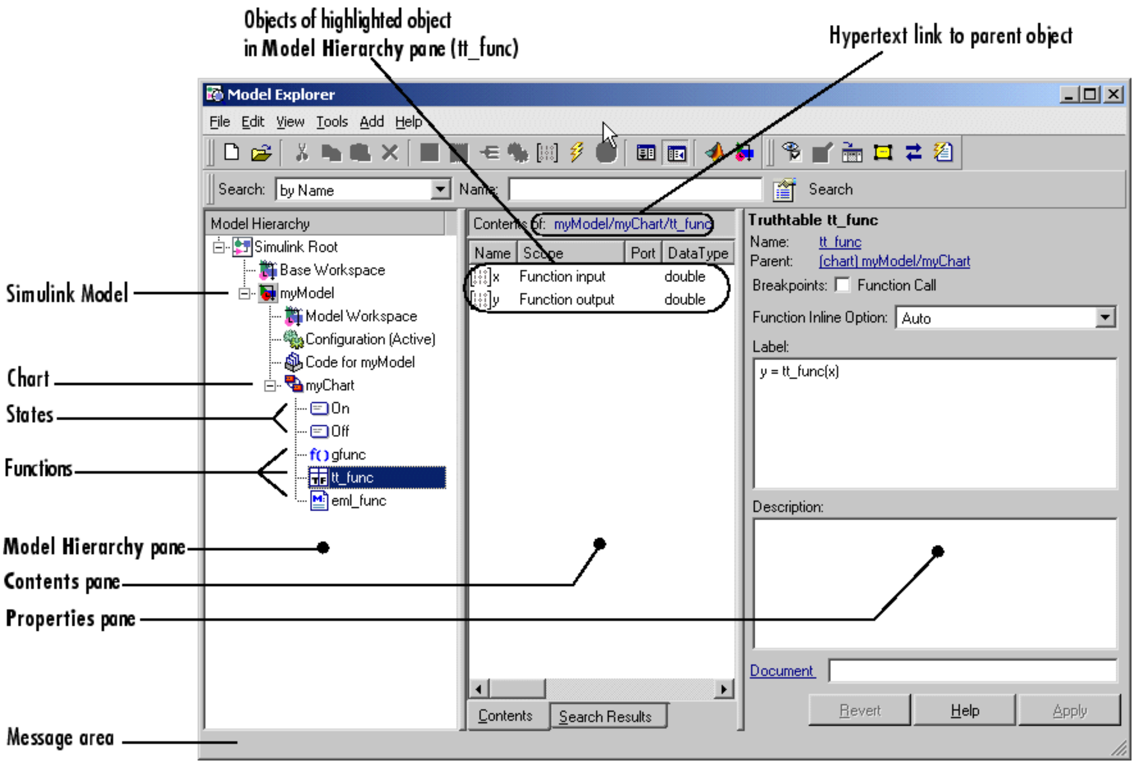
- "Viewing Stateflow Objects in the Model Explorer" on page 16-3 — Tells you how to open the Stateflow Explorer in the Stateflow diagram editor.
- "Editing States or Charts in the Model Explorer" on page 16-5 — Shows you how to edit states and charts from the Stateflow Explorer.
- "Adding Data and Events in the Model Explorer" on page 16-6 — Shows you how to create data in the **Model Explorer** and objects and which of their properties are displayed in the Stateflow Explorer.
- "Adding a Target in the Model Explorer" on page 16-6 — Describes target objects as they appear in the Stateflow Explorer.
- "Setting Properties for Stateflow Objects in the Model Explorer" on page 16-8 — Shows you how to set the properties of data, events, and targets from the Stateflow Explorer.
- "Moving and Copying Data, Events, and Targets in the Model Explorer" on page 16-9 — Shows you how to move and copy events, data, and targets to different owning objects in Stateflow Explorer.
- "Changing the Port Order of Input and Output Data and Events" on page 16-10 — Shows you how to change the order of input and output data and event ports as they appear on the Stateflow block in the Simulink model.
- "Deleting Data, Events, and Targets in the Model Explorer" on page 16-11 — Shows you how to delete events, data, and targets in the Explorer.

Viewing Stateflow Objects in the Model Explorer

Depending on what you are editing in Stateflow, you can use one of the following methods for opening **Model Explorer**:

- From the toolbar menu of the Stateflow diagram editor, truth table editor, or Embedded MATLAB Editor, select Explore .
- From the **Tools** menu of the Stateflow diagram editor or truth table editor, select **Explore**.
- Right-click an empty area in the Stateflow diagram. From the resulting pop-up menu, select **Explore**.

The **Model Explorer** window appears similar to the following:



Objects of highlighted object in Model Hierarchy pane (tt_func)

Hypertext link to parent object

Simulink Model

Chart

States

Functions

Model Hierarchy pane

Contents pane

Properties pane

Message area

Name	Scope	Port	DataType
x	Function input		double
y	Function output		double

Truthtable tt_func

Name: tt_func

Parent: (chart) myModel/myChart

Breakpoints: □ Function Call

Function Inline Option: Auto

Label:

y = tt_func(x)

Description:

The Explorer 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 object you are editing in Stateflow (chart, truth table, or Embedded MATLAB function) is highlighted in the **Model Hierarchy** pane and its objects are displayed in the **Contents** pane. In the preceding example, the **Model Explorer** was opened from the truth table editor for the truth table `tt_func` in the Stateflow chart `myChart`.

The **Model Hierarchy** pane displays the elements of all loaded Simulink models, which includes Stateflow charts, and their states, boxes, and functions. 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. For convenience, a hypertext link to the currently selected object in the **Model Hierarchy** pane is included following 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, selecting the link

```
(Stateflow.TruthTable) myModel/myChart/myChart/tt_func
```

displays the truth table `tt_func` in the truth table editor.

By default, the **Model Explorer** displays event and data child objects in the **Contents** pane for the selected object in the **Model Hierarchy** pane. To display additional or different child Stateflow objects in the **Contents** pane, do the following:

1 From the **Model Explorer View** menu, select **List View Options**.

2 In the resulting submenu, select any or all of the following individual options: **States**, **Transitions**, **Junctions**, **Events**, or **Data**.

   To display all of the preceding Stateflow child objects, select **All Stateflow Objects**.

Each type of object, whether in the **Object Hierarchy** or **Contents** pane, is displayed with an adjacent icon. Objects that are subcharted (states, boxes, and graphical functions) have their appearance altered by shading.

Object	Icon	Icon for Subcharted Object
Chart	⧉	Not applicable
State	▭	▤
Box	⬢	⬡
Graphical Function	f()	f(●)
Truth Table Function	TF	Not applicable
Embedded MATLAB Function	M	Not applicable
Data	[ ]	Not applicable
Event	⚡	Not applicable
Target	◎	Not applicable

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 for an object from the **Model Explorer**. See “Setting Properties for Stateflow Objects in the Model Explorer” on page 16-8 for more details.

Editing States or Charts in the Model Explorer

To edit a state or chart displayed in the Explorer’s **Object Hierarchy** pane, do the following:

1. Right-click the object.

2. Select **Edit** from the resulting menu.

   Stateflow displays the selected object highlighted in the Stateflow editor in the context of its parent.

Adding Data and Events in the Model Explorer

State, box, and function Stateflow objects can parent data and events. You can also add data and events to the Simulink model to make them globally available to all Stateflow objects in the model.

To add a data or an event to a Stateflow object or to the Simulink model, do the following:

1 In the **Model Hierarchy** pane of the **Model Explorer**, select a Simulink model or a Stateflow object.

2 From the **Add** menu, select **Data** or **Event**.

   A data or event is added to the **Model Explorer Contents** pane with the default name `data` or `event`. If you continue adding more data, each new data or event is named with an integer suffix (`data1`, `event1`, `data2`, `event2`, and so on).

   You can change the displayed properties for a data or event directly in the **Model Explorer**. You can also access the complete list of properties for a data or event from the **Model Explorer**. See “Setting Properties for Stateflow Objects in the Model Explorer” on page 16-8.

For more detailed examples of creating data and events in the **Model Explorer**, see “Adding Events Using the Model Explorer” on page 7-5 and “Adding Data Using the Model Explorer” on page 7-27.

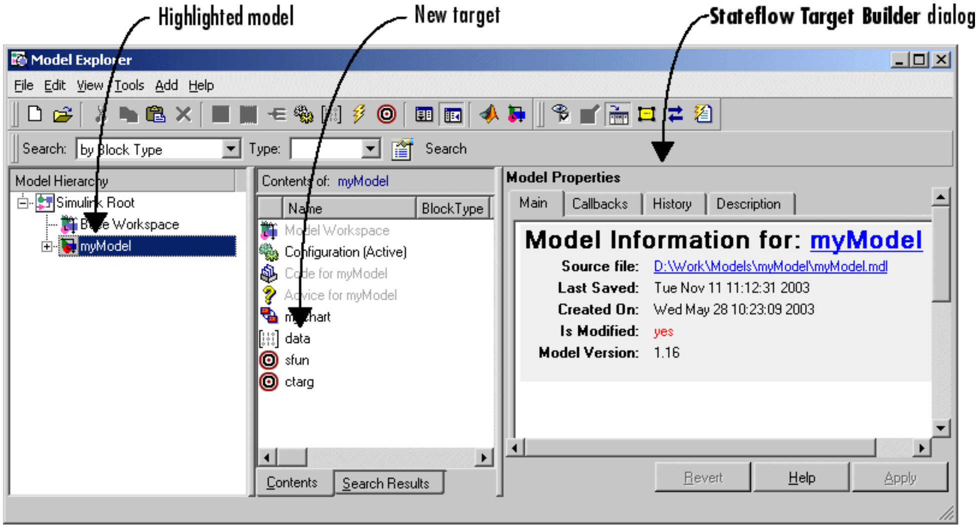
Adding a Target in the Model Explorer

Targets are parented exclusively by a Simulink model. A permanent simulation target (`sfun`) is automatically created when you add a Stateflow block to a Simulink model. You can also add an RTW target to a library model or multiple custom targets to a model in the **Model Explorer** as follows:

1 In the **Model Explorer**, in the left **Model Hierarchy** pane, select the Simulink model to receive the target.

2 From the Explorer’s **Add** menu, select **Stateflow Target**.

The **Contents** pane of the **Model Explorer** displays the existing default simulation target `sfun` and the new custom target with the default name `untitled`.



Model Information for: myModel

Source file: D:\Work\Models\myModel\myModel.mdl

Last Saved: Tue Nov 11 11:12:31 2003

Created On: Wed May 28 10:23:09 2003

Is Modified: yes

Model Version: 1.16

3 In the **Stateflow Target Builder** dialog pane on the right, enter the name of the target and other properties. Click **Apply** when finished.

The simulation target for the model has the name `sfun`. The RTW target for a model has the name `rtw`. Custom targets have names other than `sfun` and `rtw`.

The properties you enter for the target depend on the kind of target you create. See "How Do You Build a Target?" on page 14-5 for a guide.

Note You create RTW targets for Stateflow blocks in *library* models only. Stateflow blocks in nonlibrary models use the RTW configuration settings of the parent Simulink model (see "Configuring Stateflow Blocks in Nonlibrary Models for Real-Time Workshop" on page 14-13).

Renaming Objects in the Model Explorer

Use the following steps to rename a state, box, function, data, event, or target objects in the **Model Explorer**:

1 Right-click the object row in the **Contents** pane of the Explorer.

A pop-up menu appears.

2 From the resulting pop-up menu, select **Rename**.

The Explorer redisplays the name of the selected object in a text edit box that overlays the Name property for the object row.

3 Change the target's name in the edit box and click outside the edit box.

You can also change the name of an object in the **Model Explorer** by changing the value of its Name property. See "Setting Properties for Stateflow Objects in the Model Explorer" on page 16-8 for details.

Setting Properties for Stateflow Objects in the Model Explorer

To change one of the displayed properties of a displayed object in the **Contents** pane of the **Model Explorer**, do the following:

1 In the **Contents** pane, click anywhere in the row of the displayed object.

This highlights the row.

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 **Return** 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) check or uncheck the check 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**, do the following:

1. Right-click the object.

2. Select **Properties** from the resulting menu.

   The properties dialog for the object appears.

3. Edit the appropriate properties and select **Apply** or **OK** to apply the changes.

To display the property dialog dynamically for the selected object in the **Model Hierarchy** or **Contents** panes of the **Model Explorer**, do the following:

1. From the **View** menu, select **Show Dialog View**.

   The property dialog for the selected object appears in the far right pane of the **Model Explorer**.

Moving and Copying Data, Events, and Targets 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** is automatically changed to **Local**.

You can move data, event, or target objects to another parent by doing the following:

1. Select the data, event, or target to move in the **Contents** pane of the 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.

You can accomplish the same outcome by cutting or copying the selected events, data, and targets as follows:

1 Select the event, data, and targets to move in the **Contents** pane of the Explorer.

2 From the **Edit** menu of the Explorer, select **Edit** -> **Cut** or **Copy**.

   If you select **Cut**, the selected items are deleted and are 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 resulting menu. Explorer also uses the keyboard equivalents of **Ctrl+X** (Cut) and **Ctrl+C** (Copy).

3 Select a new parent machine, chart, or state in the **Model Hierarchy** pane of the **Model Explorer**.

4 From the **Edit** menu of the Explorer, select **Edit** -> **Paste**. The cut items appear in the **Contents** pane of the Explorer.

   You can also paste the cut items by right-clicking an empty part of the **Contents** pane of the Explorer and selecting **Paste** from the resulting menu. Explorer also uses the keyboard equivalents of **Ctrl+V** (Paste).

Changing 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 to Simulink** or **Output to Simulink** 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.

Deleting Data, Events, and Targets in the Model Explorer

Delete event, data, and target objects in the **Contents** pane of the **Model Explorer** as follows:

1 Select the object.

2 Press the **Delete** key.

You can also select **Cut** from the **Edit** menu or **Ctrl+X** from the keyboard to delete an object.

Using the Stateflow Search & Replace Tool

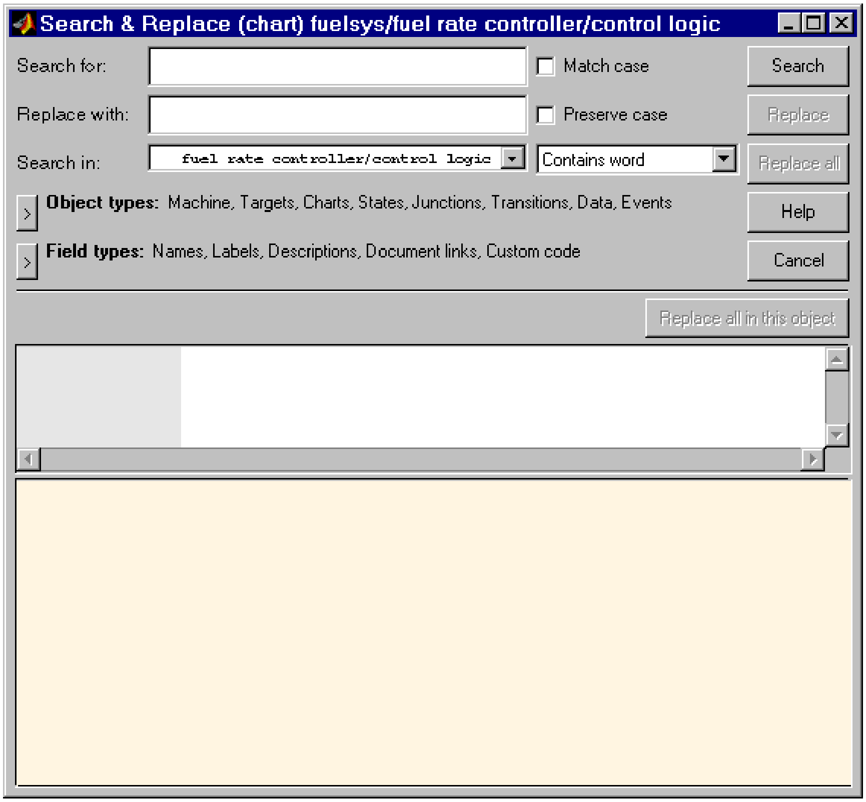
Based on textual criteria that you specify, the Stateflow Search & Replace tool searches for and replaces text belonging to objects in Stateflow charts. The following topics describe the Stateflow Search & Replace tool:

- "Opening the Search & Replace Tool" on page 16-12 — Tells you how to open the Search & Replace tool and describes the parts of the resulting dialog.
- "Using Different Search Types" on page 16-15 — Describes the different types of text searches available in the Search & Replace tool.
- "Specify the Search Scope" on page 16-17 — Tells you how to specify the parts of the model that you want to search.
- "Using the Search Button and View Area" on page 16-19 — Tells you how to use the Search button and how to interpret the display of found objects.
- "Specifying the Replacement Text" on page 16-22 — Tells you what you can specify for replacement text for the objects found by text.
- "Using the Replace Buttons" on page 16-24 — Interprets the replace buttons available and describes their use in text replacement.
- "Search and Replace Messages" on page 16-25 — Describes the text and defining icon for the informational and warning messages that appear in the Full Path Name Containing Object field.

Opening the Search & Replace Tool

To display the **Search & Replace** dialog box, do the following:

1. Open a Stateflow chart in the Stateflow chart editor.
2. Select **Search & Replace** from the Stateflow Editor's **Tools** menu.



Search & Replace (chart) fuelsys/fuel rate controller/control logic

Search for:

Replace with:

Search in: fuel rate controller/control logic

Contains word

Object types: Machine, Targets, Charts, States, Junctions, Transitions, Data, Events

Field types: Names, Labels, Descriptions, Document links, Custom code

The window name for the **Search & Replace** dialog box contains a full path expression for the current Stateflow chart or machine in the following form.

```
(object) Machine/Subsystem/Chart
```

The **Search & Replace** dialog box contains the following fields:

- **Search for**

  Enter search pattern text in the **Search for** text box. Interpretation of the search pattern is selected with the **Match case** check box and the **Match Options** field.

- **Match case**

  If this check box is selected, the search is case sensitive and the Search & Replace tool finds only text matching the search pattern exactly. See “Match case (Case Sensitive)” on page 16-15.

- **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 “Using the Replace Buttons” on page 16-24.

- **Preserve case**

  This option modifies replacement text. For an understanding of this option, see “Replacing with Case Preservation” on page 16-23.

- **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 chart 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 “Using Different Search Types” on page 16-15.

- **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. By default, these boxes are hidden; only current selections are displayed next to their titles.

  Select the right-facing arrow button > in front of the title to expand a selection box and make changes.

  Select the same button (this time with a left-facing arrow) < to compress the selection box to display the settings only, or, if you want, just leave the box expanded.

- **Search** and **Replace** buttons

  These are described in “Using the Search Button and View Area” on page 16-19 and “Using the Replace Buttons” on page 16-24.

- **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 16-20.

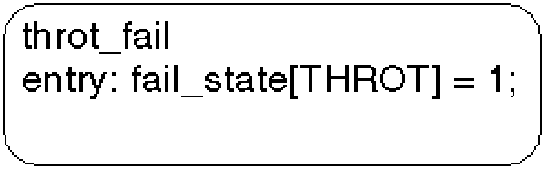
Using Different Search Types

Enter search pattern text in the **Search for** text box. You can use one of the following settings in the **Match options** field (unlabeled and just to the right of the **Search in** field) to further refine the meaning of the text entered.

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.

The following example is taken from the Sensor Failure Detection demo model.



```
throt_fail
entry: fail_state[THROT] = 1;
```

Searching for the string `fail` with the **Contains word** option set finds both occurrences of the string `fail`.

Match case (Case Sensitive)

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 strings with the same sequence of base characters in lower- or uppercase. For example, the search string `"AnDrEw"` finds the matching text `"andrew"` or `"Andrew"` or `"ANDREW"`.

Match whole word

Select this option to specify that the search pattern text 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 preceding example from the Sensor Failure Detection demo model, if **Match whole word** is selected, searching for the string `fail` finds no text within the above state. However, searching for the string `"fail_state"` does find the text `"fail_state"` as part of the second line since it is delimited as a word by a space on the front and a left square bracket (`[`) on the back.

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 a string composed of letters, numbers, and special symbols that defines one or more string 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 backslash (`\`) character precedes it.

If the **Match options** field is set to **Regular expression** in the preceding example from the Sensor Failure Detection demo model, searching for the string `"fail_"` matches the `"fail_"` string that is part of the second line, character for character. Searching with the regular expression `"\w*_"` also finds the string `"fail_"`. This search string uses the regular expression shorthand `"\w"` that represents any part-of-word character, an asterisk (`*`), which represents any number of any characters, and an underscore (_), which represents itself.

For a list of regular expression meta characters, see the topic “Regular Expressions” in MATLAB documentation.

Searching with Regular Expression Tokens

Within a regular expression, you use parentheses to group characters or expressions. For example, the regular expression `"and(y|rew)"` matches the text `"andy"` or `"andrew"`. Parentheses also have the side effect of remembering what they match so that you can recall and reuse the found text with a special variable in the **Search for** field. These are referred to as *tokens*.

For an understanding of how to use tokens to enhance searching in the Search & Replace tool, see the topic "Tokens" in MATLAB documentation.

You can also use tokens in the **Replace with** field. See "Replacing with Tokens" on page 16-23 in for a description of using regular expression tokens for replacing.

Preserve case

This option actually modifies replacement text and not search text. For an understanding of this option, see "Replacing with Case Preservation" on page 16-23.

Specify the Search Scope

You specify the search scope for your search by selecting from the field regions discussed in the following topics:

- "Search in" on page 16-17 — Select a whole machine or individual Stateflow chart for searching.
- "Object Types" on page 16-18 — Limit your search to text matches in the selected object types.
- "Field Types" on page 16-18 — Limit your search to text matches for the specified fields

Search in

You can select a whole machine or individual Stateflow chart for searching in the **Search in** field. By default, the current Stateflow chart in which you entered the Search & Replace tool is selected.

To select a machine, do the following:

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 underlying Stateflow charts.

2 Select a machine.

To select a Stateflow chart for searching, do the following:

1 Select the down arrow of the **Search in** field again.

This time the displayed 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 to text matches in the selected object types only when you do the following:

1 Expand the **Object types** field.

2 Select one or more object types.

Field Types

Limit your search to text matches for the specified fields only by doing the following:

1 Expand the **Field types** field.

2 Select one or more of the available 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 remainder of the label is subject to succeeding 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 Simulink 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.

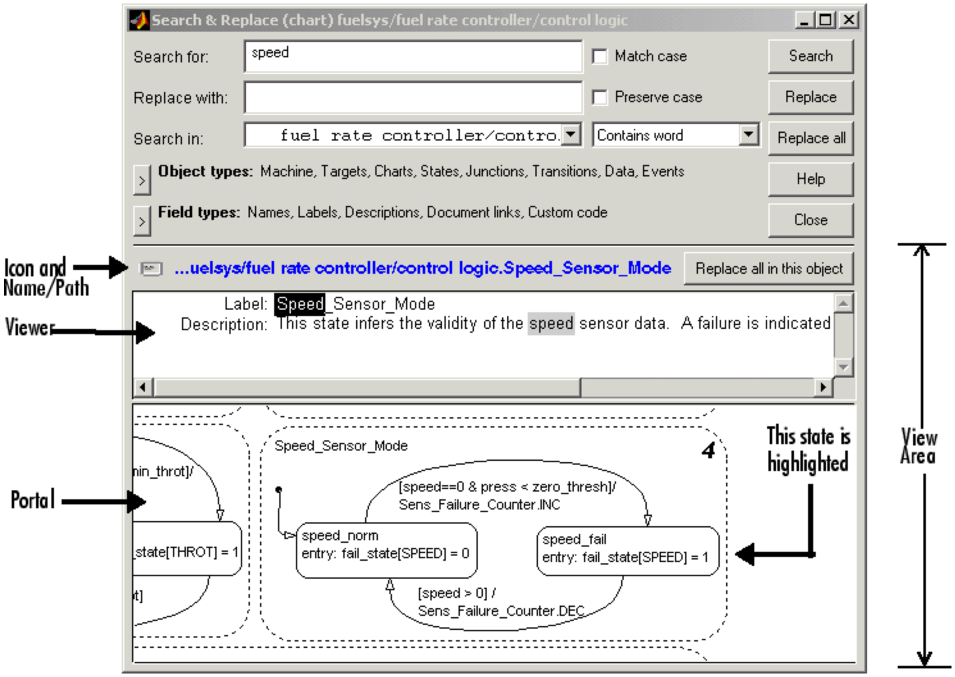
Custom code. Only target objects contain custom code.

Using the Search Button and View Area

This topic contains the following subtopics:

- "A Breakdown of the View Area" on page 16-20
- "The Search Order" on page 16-21
- "Additional Display Options" on page 16-22

Click **Search** to initiate a single-search operation. If an object match is made, its text fields are displayed in the **Viewer** pane in the middle of the **Search & Replace** dialog. If the object is graphical (state, transition, junction, chart), the matched object is displayed in a **Portal** pane below the **Viewer** pane.



Search & Replace (chart) fuelsys/fuel rate controller/control logic

Search for: speed

Replace with:

Search in: fuel rate controller/contro. ▾ Contains word ▾

□ Match case

□ Preserve case

Object types: Machine, Targets, Charts, States, Junctions, Transitions, Data, Events

Field types: Names, Labels, Descriptions, Document links, Custom code

...uelsys/fuel rate controller/control logic.Speed_Sensor_Mode

Label: Speed_Sensor_Mode

Description: This state infers the validity of the speed sensor data. A failure is indicated

A Breakdown of the View Area

The view area of the **Search & Replace** dialog box displays found text and its containing object, if viewable. In the preceding example, taken from the Sensor Fuel Detection demo model, a search for the word `"speed"` finds the **Description** field for the state `Speed_Sensor_Mode`. The resulting view area display consists of the following parts:

Icon. Displays an icon appropriate to the object containing the found text. These icons are identical to the icons used in the **Model Explorer** to represent Stateflow objects displayed in “Viewing Stateflow Objects in the Model Explorer” on page 16-3.

Full Path Name of Containing Object. This area displays the full path name for the object containing the found text in the following format:

```
(<type>) <machine name>/<subsystem>/<chart
name>.[p1]...[pn].<object name> (<id>)
```

where p_1 through p_n denote the object's parent states.

To display the object, click the mouse once on the full path name of the object. If the object is a graphical member of a Stateflow chart, it is displayed in the Stateflow chart editor. Otherwise, it is displayed as a member of its Stateflow chart in the Stateflow Explorer.

Viewer. This area displays the found 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 view area.

Portal. This area contains a graphic display of the object containing the matching text. The object containing the found text is highlighted in blue (default).

To display the highlighted object in the Stateflow chart editor window, double-click anywhere in the portal.

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 displayed in the Stateflow chart 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's objects have been searched.

The search order taken in searching an individual chart for matching text is equivalent to a depth-first search of the Stateflow Explorer. Starting at the highest level of the chart, the 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 is repeated.

Additional Display Options

Right-click anywhere in the **Search & Replace** dialog to display a menu with the following selections.

Selection	Result
Show Portal	A toggle switch that hides or displays the portal.
Edit	Displays the object with the matching text in the Stateflow chart editor. Applies to states, junctions, transitions, and charts.
Explore	Displays the object with the matching text in the Stateflow Explorer. Applies to states, data, events, machines, charts, and targets.
Properties	Displays the **Properties** dialog box for the object with the matching text.

Note The **Edit**, **Explore**, and **Properties** selections are enabled only after a successful search.

If the portal is not visible, you can select the **Show Portal** option to display it. You can also simply click and drag the border between the viewer and the portal (the cursor turns to a vertical double arrow), which resides just above the bottom boundary of the **Search & Replace** dialog. Moving this border allows you to exchange area between the portal and the viewer. If you click and drag the border with the left mouse button, the graphic display resizes after you reposition the border. If you click and drag the border with the right mouse button, the graphic display continuously resizes as you move the border.

Specifying the Replacement Text

The Search & Replace tool replaces found text with the exact (case-sensitive) text you entered in the **Replace With** field unless you choose one of the dynamic replacement options described below.

Replacing with Case Preservation

If you choose the **Case Preservation** option, matched text is replaced based on one of the following conditions discovered in the found text:

- Whisper

  In this case, the found text has no uppercase characters, only lowercase. Found text is replaced entirely with the lowercase equivalent of all replacement characters. For example, if the replacement text is `"ANDREW"`, the found text `"bill"` is replaced by `"andrew"`.

- Shout

  In this case, the found text contains only uppercase characters. Found text is replaced entirely with the uppercase equivalent of all replacement characters. For example, if the replacement text is `"Andrew"`, the found text `"BILL"` is replaced by `"ANDREW"`.

- Proper

  In this case, the found text contains uppercase characters in the first character position of each word. Found text is replaced entirely with the case equivalent of all replacement characters. For example, if the replacement text is `"andrew johnson"`, the found text `"Bill Monroe"` is replaced by `"Andrew Johnson"`.

- Sentence

  In this case, the found text contains an uppercase character in the first character position of a sentence with all remaining sentence characters in lowercase. Found text is replaced in like manner, with the first character of the sentence given an uppercase equivalent and all remaining sentence characters set to lowercase. For example, if the replacement text is `"andrew is tall."`, the found text `"Bill is tall."` is replaced by `"Andrew is tall."`.

Replacing with Tokens

Within a regular expression, you use parentheses to group characters or expressions. For example, the regular expression `"and(y|rew)"` matches the text `"andy"` or `"andrew"`. Parentheses also have the side effect of remembering what they matched so that you can recall and reuse the found text with a special variable in the **Replace with** field. These are referred to as *tokens*.

Tokens outside the search pattern have the form `$1,$2,...,$n (n<17)` and are assigned left to right from parenthetical expressions in the search string.

For example, the search pattern `"(\w*)_(\w*)"` finds all word expressions with a single underscore separating the left and right sides of the word. If you specify an accompanying replacement string of `"$2_$1"`, you can replace all these expressions by their reverse expression with a single **Replace all**. For example, the expression `"Bill_Jones"` is replaced by `"Jones_Bill" and the` expression `"fuel_system"` is replaced by `"system_fuel".`

For a clearer understanding of how tokens are used in regular expression search patterns, see "Regular Expressions" in MATLAB documentation.

Using the 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 string in the **Search for** field is replaced by the text string entered in the **Replace with** field. The Search & Replace tool then automatically searches for the next occurrence of the **Search for** text string.

Replace All

When you select the **Replace All** button, all instances of text matching the **Search for** field are replaced by the text string entered in the **Replace with** field. Replacement starts at the point of invocation to the end of the current Stateflow chart. This means that if you initially skip through some search matches with the **Search** button, they are also skipped when you select the **Replace All** button.

If the search scope is set to **Search Whole Machine**, then after finishing the current Stateflow chart, replacement continues to the completion of all remaining charts in your Simulink model.

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 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.

ℹ – Informational Messages

⚠ – Warnings

The following messages are informational only:

Please specify a search string

A search was attempted without a search string specified.

No Matches Found

There are no matches within the selected search scope.

Search Completed

There are no more matches within the selected search scope.

The following messages are warnings that refer to invalid conditions for searching or replacing:

Invalid option set

The object types and field types that you have selected are incompatible. For example, a search on **Custom Code** fields without selecting target objects is invalid.

Match object not currently editable

The found object is not editable by replacement because of one of the following.

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 messages are warnings that, when the Search & Replace tool performs a search or replacement immediately after finding an object, it must first refind the object and its matching text field. If that original found 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 results if you continue to search.

Match object not found

If you search for text, find it, and then delete the containing object, this warning results 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 results if you perform a replacement.

Search string changed

If you search for text, find it, and then change the **Search For** field, this warning results if you perform a replacement.

Using the Stateflow Finder Tool

There are two varieties of tools that search only for Stateflow, depending on your platform. These are as follows:

- On most platforms, when you select **Find** from the Stateflow Editor's **Tools** menu, the Simulink **Find** dialog appears. This tool allows you to search Stateflow models for Simulink and Stateflow objects, such as states and transitions, that meet criteria you specify. Simulink displays any objects that satisfy the search criteria in the dialog box's search results pane.
- On platforms that do not support the Simulink Find tool, the original Stateflow Finder appears when you select **Find** from the Stateflow Editor's **Tools** menu. The following topics explain how to use the original Stateflow Finder to search for objects.
  - "Opening Stateflow Finder" on page 16-27 — Tells you how to open the Stateflow Finder tool.
  - "Using Stateflow Finder" on page 16-28 — Describes the fields and selections available for describing the objects you want to find.
  - "Finder Display Area" on page 16-31 — Describes the display columns for found items in the display area.

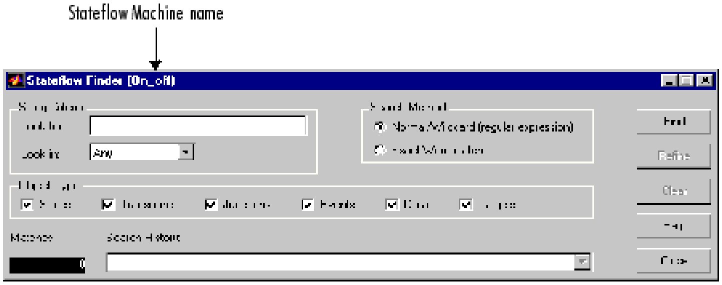
Note See the Simulink Release Notes in the online documentation for a list of platforms on which the Simulink Find tool is not available.

Opening Stateflow Finder

On platforms that do not support the Simulink Find tool (see preceding note), display the Stateflow **Finder** dialog box with one of the following:

- Select **Find** from the Stateflow Editor's **Tools** menu.
- Select **Find** from the Simulink model window's **Edit** menu.

The Finder operates on the machine whose name appears in the window title area of the **Finder** dialog as shown:



Stateflow Machine name

Stateflow Finder (On_off)
Look in:
Any
Normal/Wildcard (regular expression)
Find
Refine
Clear
Matches
Search History
0

Using Stateflow Finder

The following topics in this section describe the parts of the Stateflow Finder:

- "String Criteria" on page 16-28
- "Search Method" on page 16-29
- "Object Type" on page 16-30
- "Find Button" on page 16-30
- "Matches" on page 16-30
- "Refine Button" on page 16-30
- "Search History" on page 16-31
- "Clear Button" on page 16-31
- "Close Button" on page 16-31
- "Help Button" on page 16-31

String Criteria

You specify the string by entering the text to search for in the **Look for** text box. The search is case sensitive. All text fields are included in the search by default. Alternatively, you can search in specific text fields by using the **Look in** list box to choose one of these options:

Any. Search the state and transition labels, object names, and descriptions of the specified object types for the string specified in the **Look for** field.

Label. Search the state and transition labels of the specified object types for the string specified in the **Look for** field.

Name. Search the **Name** fields of the specified object types for the string specified in the **Look for** field.

Description. Search the **Description** fields of the specified object types for the string specified in the **Look for** field.

Document Link. Search the **Document** link fields of the specified object types for the string specified in the **Look for** field.

Custom Code. Search custom code for the string specified in the **Look for** field.

Search Method

By default the **Search Method** is **Normal/Wildcard** (regular expression). Alternatively, you can click the **Exact Word match** option if you are searching for a particular sequence of one or more words.

A regular expression is a string composed of letters, numbers, and special symbols that define one or more strings. 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 \ precedes it.

These are the special characters supported by Stateflow Finder.

Character	Description
^	Start of string
$	End of string
.	Any character
\	Quote the next character
*	Match zero or more

Character	Description
+	Match one or more
[ ]	Set of characters

Object Type

Specify the object types to search by toggling the check boxes. A check mark indicates that the object is included in the search criteria. By default, all object types are included in the search criteria. **Object Types** include the following:

- States
- Transitions
- Junctions
- Events
- Data
- Targets

Find Button

Click the **Find** button to initiate the search operation. The data dictionary is queried and the results are listed in the display area.

Matches

The **Matches** field displays the number of objects that match the specified search criteria.

Refine Button

After the results of a search are displayed, enter additional search criteria and click **Refine** to narrow the previously entered search criteria. An ampersand (&) is prefixed to the search criteria in the **Search History** field to indicate a logical AND with any previously specified search criteria.

Search History

The **Search History** text box displays the current search criteria. Click the pull-down list to display search refinements. An ampersand is prefixed to the search criteria to indicate a logical AND with any previously specified search criteria. You can undo a previously specified search refinement by selecting a previous entry in the search history. By changing the **Search History** selection you force the Finder to use the specified criteria as the current, most refined, search output.

Clear Button

Click **Clear** to clear any previously specified search criteria. Results are removed and the search criteria are reset to the default settings.

Close Button

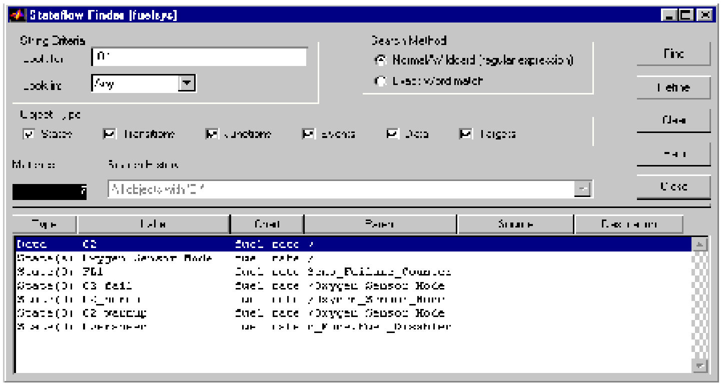
Click **Close** to close the Finder.

Help Button

Click **Help** to display the Stateflow documentation in an HTML browser window.

Finder Display Area

The Finder display area has an appearance similar to the following.



Look for: O2

Look in: Any

● Normal/Wildcard (regular expression)

○ Exact Word match

☑ States ☑ Transitions ☑ Junctions ☑ Events ☑ Data ☑ Targets

Matches: 7

Search History: All objects with 'O2'

```
Data      O2                   fuel_rate /
State(OR) Oxygen_Sensor_Mode   fuel_rate /
State(OR) FAIL                 fuel_rate Sens_Failure_Counter
State(OR) O2_fail              fuel_rate /Oxygen_Sensor_Mode
State(OR) O2_normal            fuel_rate /Oxygen_Sensor_Mode
State(OR) O2_warmup            fuel_rate /Oxygen_Sensor_Mode
State(OR) Overspeed            fuel_rate [illegible]_Disabled
```

The display area displays found entries with the following columns:

Field	Description
Type	The object type is listed in this field. States with exclusive (OR) decomposition are followed by an (O). States with parallel (AND) decomposition are followed by (A).
Label	The string label of the object is listed in this field.
Chart	The title of the Stateflow diagram (Stateflow block) is listed in this field.
Parent	This object's parent in the hierarchy.
Source	Source object of a transition.
Destination	Destination object of a transition.

All fields are truncated to maintain column widths. The **Parent**, **Source**, and **Destination** fields are truncated from the left so that the name at the end of the hierarchy is readable. The entire field contents, including the truncated portion, are used for resorting.

Each field label is also a button. Click the button to have the list sorted based on that field. If the same button is pressed twice in a row, the sort ordering is reversed.

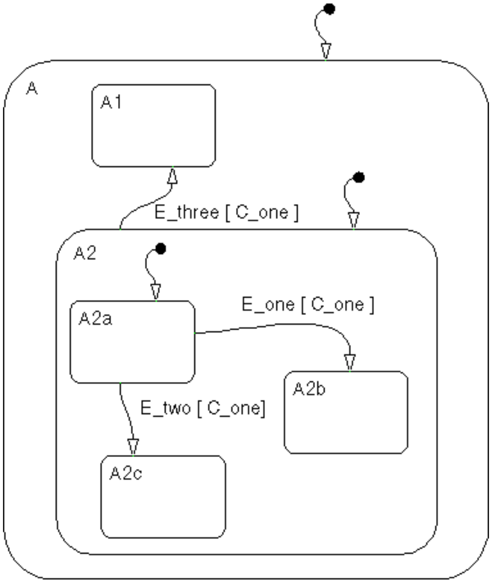
You can resize the Finder vertically to display more output rows, but you cannot expand it horizontally.

Click a graphical entry to highlight that object in the graphical editor window. Double-click an entry to invoke the **Properties** dialog box for that object. Right-click the entry to display a menu that allows you to explore, edit, or display the properties of that entry.

Representing Hierarchy

The Finder displays **Parent**, **Source**, and **Destination** fields to represent the hierarchy. The Stateflow diagram is the root of the hierarchy and is represented by the / character. Each level in the hierarchy is delimited by a period (.) character. The **Source** and **Destination** fields use the combination of the tilde (~) and the period (.) characters to denote that the state listed is relative to the **Parent** hierarchy.

Using the following Stateflow diagram as an example, what are the values for the **Parent**, **Source**, and **Destination** fields for the transition from A2a to A2b?



The A2a to A2b transition is within state A2. State A2's parent is state A and state A's parent is the Stateflow diagram itself. The notation for state A2a's parent is /A.A2. State A2a is the transition source and state A2b is the destination. These states are at the same level in the hierarchy. The relative hierarchy notation for the source of the transition is ~.A2a. The full path is /A.A2.A2a. The relative hierarchy notation for the destination of the transition is ~.A2b. The full path is /A.A2.A2b.

Semantic Rules Summary

Stateflow semantics describe how the notation in Stateflow charts is interpreted and implemented into a behavior. Knowledge of Stateflow semantics is important to make sound Stateflow diagram design decisions for code generation. Different notations result in different behavior during simulation and generated code execution. This appendix contains a short summary of the rules that Stateflow abides by in executing a Stateflow diagram.

Entering a Chart

The set of default flow paths is executed (see “Executing a Set of Flow Graphs” on page A-3). If this does not cause a state entry and the chart has parallel decomposition, then each parallel state is entered (see “Entering a State” on page A-2).

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

Executing an Active Chart

If the chart has no states, each execution is equivalent to initializing a chart. Otherwise, the active children are executed. Parallel states are executed in the same order that they are entered.

Entering a State

1. If the parent of the state is not active, perform steps 1-4 for the parent.
2. If this is a parallel state, check that all siblings with a higher (i.e., earlier) entry order are active. If not, perform all entry steps for these states first.
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 parallel decomposition, i.e., has children that are parallel states, perform entry steps 1-5 for each state according to its entry order.

6 If this is a parallel state, perform all entry actions 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.

Executing an Active State

1 The set of outer flow graphs is executed (see "Executing a Set of Flow Graphs" on page A-3). If this causes a state transition, execution stops. (Note that this step is never required for parallel states.)

2 During actions and valid on-event actions are performed.

3 The set of inner flow graphs is executed. If this does not cause a state transition, the active children are executed, starting at step 1. Parallel states are executed in the same order that they are entered.

Exiting an Active State

1 If this is a parallel state, make sure that all sibling states that were entered after this state have already been exited. 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 they were entered.

3 Perform any exit actions.

4 Mark the state as inactive.

Executing a Set of Flow Graphs

Flow graphs are executed by starting at step 1 below with a set of starting transitions. The starting transitions for inner flow graphs are all transition segments that originate on the respective state and reside entirely within that state. The starting transitions for outer flow graphs are all transition segments that originate on the respective state but reside at least partially outside that state. The starting transitions for default flow graphs are all default transition segments that have starting points with the same parent:

1 A set of transition segments is ordered.

2 While there are remaining segments to test, a segment is tested for validity. If the segment is invalid, move to the next segment in order. If the segment is valid, execution depends on the destination:

   States

   a No more transition segments are tested and a transition path is formed 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 are exited (see “Exiting an Active State” on page A-3).

   c The transition action from the final transition segment is executed.

   d The destination state is entered (see “Entering a State” on page A-2).

   Junctions with no outgoing transition segments

   Testing stops without any states being exited or entered.

   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, back up the incoming transition segment that brought you to the junction and continue at step 2, starting with the next transition segment after the back up segment. The set of flow graphs is done executing when all starting transitions have been tested.

Executing 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 is executed (see “Executing an Active Chart” on page A-2 and “Executing an Active State” on page A-3). (The event *receiver* is the parent of the event unless the event was explicitly directed to a *receiver* 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 are not performed.
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 are not performed.
State During	If the state is no longer active at the end of the event broadcast, any remaining steps in executing an active state are not performed.
Condition	If the origin state of the inner or outer flow graph or parent state of the default flow graph is no longer active at the end of the event broadcast, the remaining steps in the execution of the set of flow graphs are not performed.
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 are not performed.

B

The Stateflow Block

Stateflow

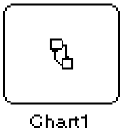
Purpose

A version of a finite state machine for controlling a physical plant

Library

Stateflow

Description

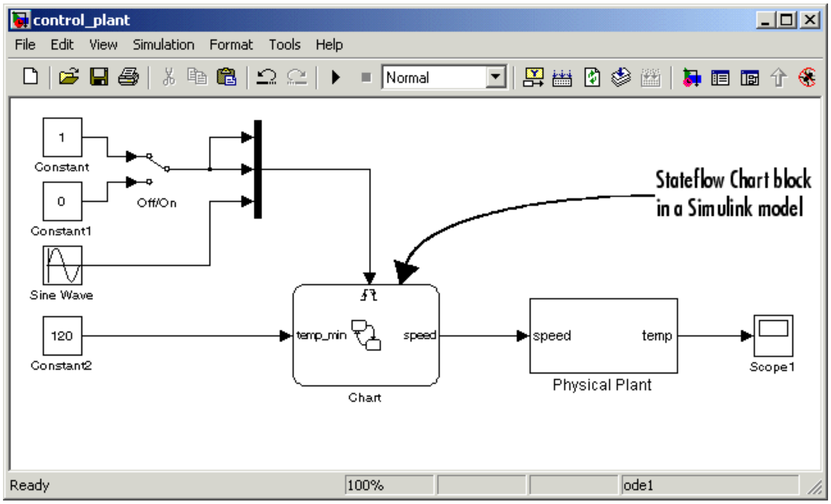


A *finite state machine* is a representation of an event-driven (reactive) system. In an event-driven system, the system responds by making a transition from one state (mode) to another prescribed state in response to an event, provided that the condition defining the change is true.

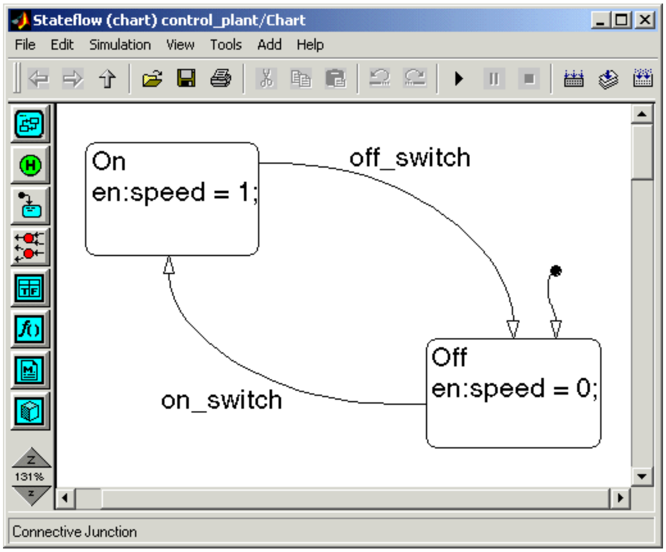
A Stateflow diagram is a graphical representation of a finite state machine, where *states* and *transitions* form the basic building blocks of the system. You can also represent flow (stateless) diagrams using Stateflow. Stateflow provides a block that you include in a Simulink model.

Stateflow charts are usually used to control a physical plant in response to events such as a temperature or pressure sensor, or clock or user-driven events. For example, you can use a state machine to represent a car's automatic transmission. The transmission has a number of 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.

The following diagram shows a simple Simulink model that has a Stateflow block named Chart (default) that responds to input from a manual switch:



If you double-click the Stateflow block in Simulink, the Stateflow diagram that programs the Stateflow block appears in the Stateflow diagram editor window.


Stateflow (chart) control_plant/Chart
File Edit Simulation View Tools Add Help
On
en:speed = 1;
off_switch
Off
en:speed = 0;
on_switch
131%
Connective Junction

During simulation of the Simulink model, you can interactively debug Stateflow diagrams with animated diagrams. Stateflow diagrams generate efficient C code for simulation, and also for Real-Time Workshop, and custom targets, that is suitable for embedded environments.

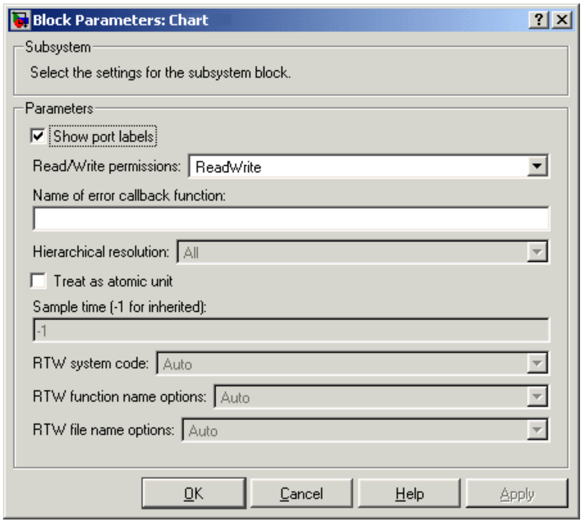
For an introduction to using Stateflow in Simulink models, see *Getting Started with Stateflow*, the Stateflow getting started guide.

Data Type Support

The Stateflow block accepts inputs of any type including two-dimensional matrices and fixed-point data. Floating-point inputs are passed through the block unchanged. `Boolean` inputs are treated as `uint8` signals.

For a discussion on the variable types supported by Embedded MATLAB functions in Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

You can declare local data of any type or size.



Block Parameters: Chart

Subsystem

Select the settings for the subsystem block.

Parameters

☑ Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Hierarchical resolution: All

□ Treat as atomic unit

Sample time (-1 for inherited): -1

RTW system code: Auto

RTW function name options: Auto

RTW file name options: Auto

Parameters and Dialog Box

Note It is highly recommended that the default settings for the block parameters of an Embedded MATLAB Function block not be changed.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample time** parameter
Scalar Expansion	N/A
Dimensionalized	Yes
Zero Crossing	No

C

The Truth Table Block

Truth Table

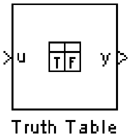
Purpose

Represents logical decision-making behavior with conditions, decisions, and actions.

Library

Stateflow

Description



The Truth Table block is an Embedded MATLAB truth table function that you can add to a Simulink model directly. The Truth Table block requires a Stateflow license.

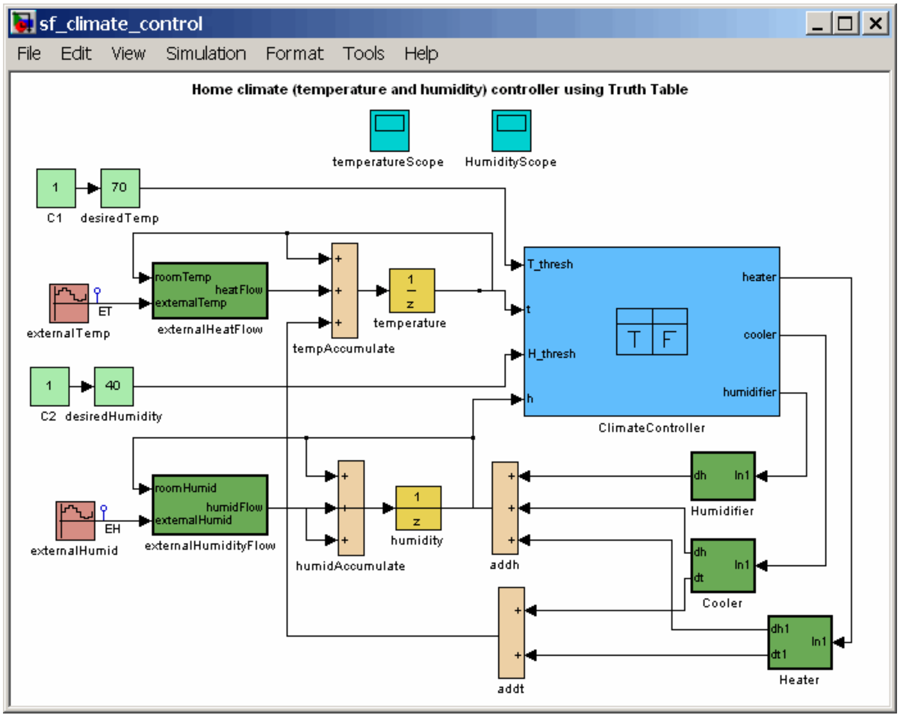
There are several advantages to adding a Truth Table block directly to a Simulink model instead of calling truth table functions from a Stateflow chart:

- It is a more direct approach, especially if your model requires only a single truth table.
- You can define truth table inputs and outputs to have inherited types and sizes.

The Truth Table block supports the Embedded MATLAB language for programming conditions and actions, and generates content as Embedded MATLAB code. As a result, you can take advantage of Embedded MATLAB tools to debug your Truth Table block during simulation. For more information, see "Debugging a Stateflow Embedded MATLAB Function" on page 13-15.

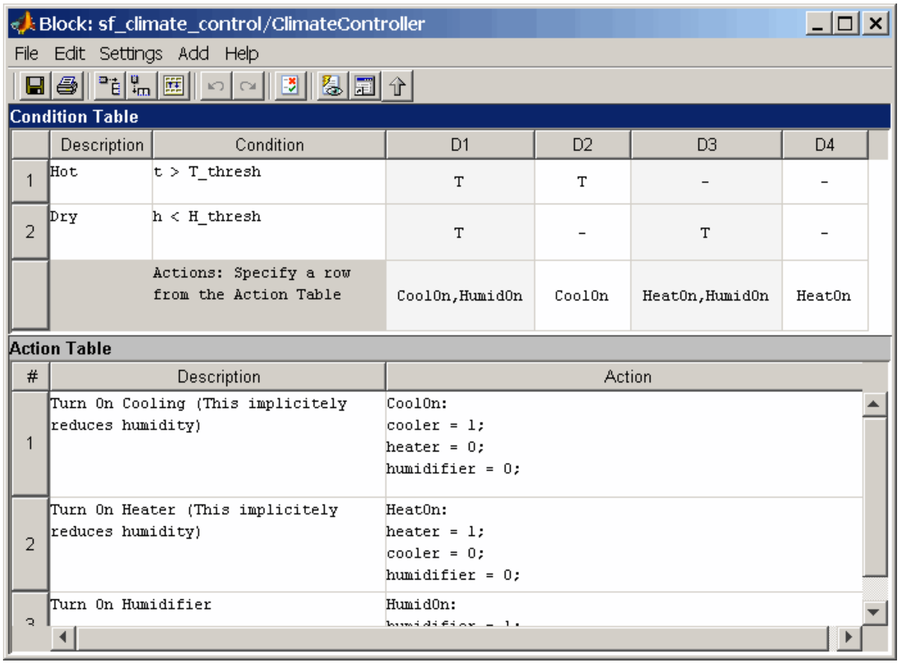
For purely logical behavior, truth tables are easier to program and maintain than graphical functions. Truth tables also provide diagnostics that indicate whether you have too few (under specified) or too many (over specified) decisions for the conditions you specify. For an introduction to truth tables, see Chapter 12, "Truth Table Functions".

The following diagram shows a Simulink model (`sf_climate_control.mdl`) of a home environment controller that attempts to maintain a selected temperature and humidity. The model has a Truth Table block (`ClimateController`) that responds to changes in room temperature (input `t`) and humidity (input `h`).



Truth Table Editor

If you double-click the Truth Table block in the Simulink model, the Truth Table Editor opens to display its conditions, actions, and decisions. Here is the display for the Truth Table block named `ClimateController`.


Block: sf_climate_control/ClimateController
File Edit Settings Add Help

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

Action Table

#	Description	Action

1	Turn On Cooling (This implicitely reduces humidity)	CoolOn:
		cooler = 1;
		heater = 0;
		humidifier = 0;

2	Turn On Heater (This implicitely reduces humidity)	HeatOn:
		heater = 1;
		cooler = 0;
		humidifier = 0;

3	Turn On Humidifier	HumidOn: humidifier = 1;

Note how the inputs `t` and `h` are used to define the conditions, and the outputs `heater`, `cooler`, and `humidifier` are used to define the actions for this Truth Table block. For more details, refer to the demo for this model.

The Truth Table Editor lets you perform the following functions:

- Enter and edit conditions, actions, and decisions.
- Add or modify Stateflow data and ports using the Ports and Data Manager.
- Run diagnostics to detect parser errors.
- View generated content after simulation.

For more information about the Truth Table Editor, see “Truth Table Editor Operations” on page 12-72.

Ports and Data Manager

If you want to add or edit data in a Truth Table block, open the Ports and Data Manager by clicking the **Edit Data/Ports** button in the Truth Table Editor toolbar:

The Ports and Data Manager lets you add the following elements to a Truth Table block:

Element	Tool	Description
Data		You can add the following types of data: • Local • Constant • Parameter • Data store memory

Element	Tool	Description
Input trigger	↑	An *input trigger* causes a Truth Table block to execute when a Simulink control signal changes or through a Simulink block that outputs function-call events. You can add the following types of input triggers: • Rising edge • Falling edge • Either rising or falling edge • Function call For more information, see “Defining Input Events” on page 7-13.
Function call output	f()	A *function call output* triggers a function call to a subsystem. For more information, see “Function-Call Subsystems” in the Simulink User’s Guide documentation

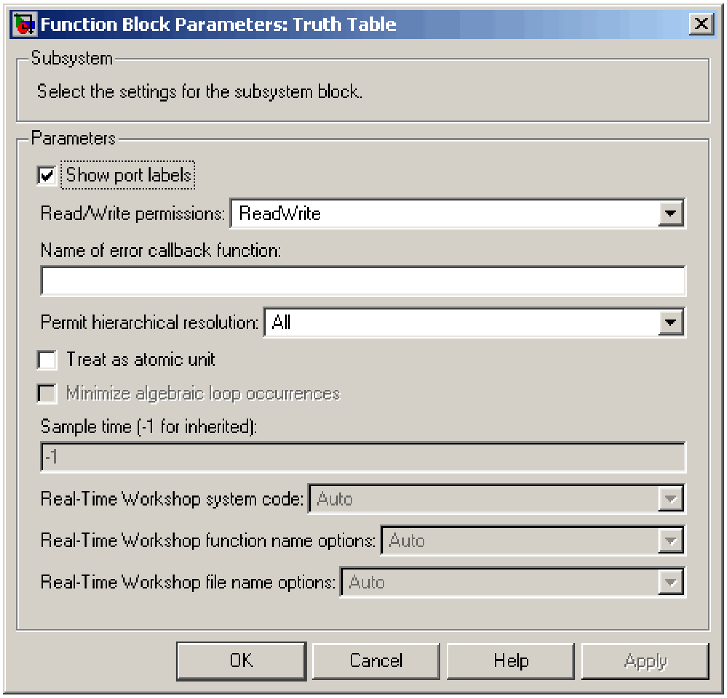
Data Type Support

The Truth Table block accepts signals of any data type supported by Simulink, including fixed-point data types and frame-based signals. Truth Table blocks work with frame-based signals in the same way as Embedded MATLAB Function blocks (see “Working with Frame-Based Signals” in the Using Simulink documentation).

For a discussion of data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

Parameters and Dialog Box

Right-click over a Truth Table block, and from the submenu, select **Subsystem Parameters**.



Function Block Parameters: Truth Table

Subsystem

Select the settings for the subsystem block.

Parameters

☑ Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

☐ Treat as atomic unit

☐ Minimize algebraic loop occurrences

Sample time (-1 for inherited):

-1

Real-Time Workshop system code: Auto

Real-Time Workshop function name options: Auto

Real-Time Workshop file name options: Auto

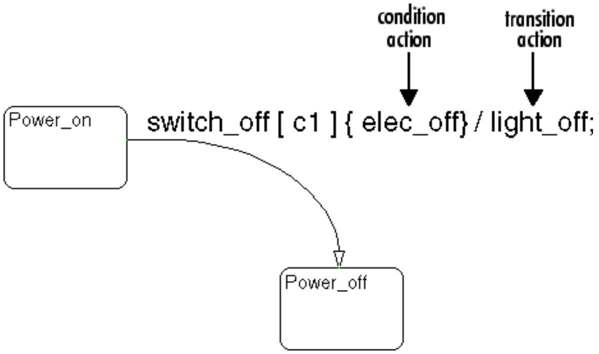
Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample time** parameter
Scalar Expansion	N/A
Dimensionalized	Yes
Zero Crossing	No

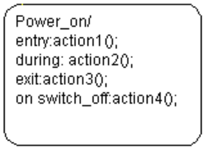
Glossary

actions

Actions take place as a part of Stateflow diagram execution. The action can be executed as part of a transition from one state to another, or depending on the activity status of a state. Transitions can have condition actions and transition actions. For example,



Action language defines the categories of actions you can specify and their associated notations. For example, states can have `entry`, `during`, `exit`, and `on` *`event_name`* actions as shown by the following:



An action can be a function call, a broadcast event, a variable assignment, and so on. For more information on actions and action language, see Chapter 8, “Using Actions in Stateflow”.

API (application programming interface)

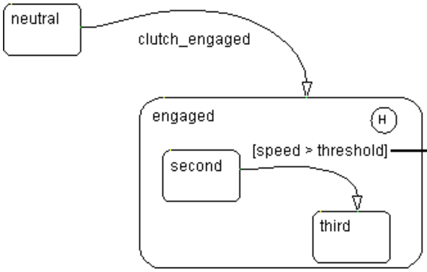
Format provided to access and communicate with an application program from a programming or script environment.

chart instance

Link from a Stateflow model to a chart stored in a Simulink library. A chart in a library can have many chart instances. Updating the chart in the library automatically updates all the instances of that chart.

condition

Boolean expression to specify that a transition occurs if the specified expression is true. For example,



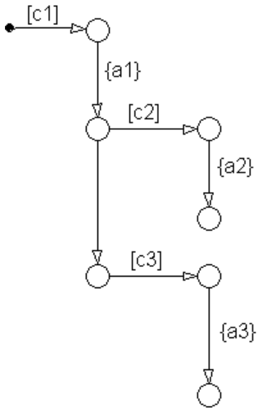
[speed>threshold] is a condition.

In the preceding example, assume that the state `second` is active. If an event occurs and the value for the data `speed` is greater than the value of the data `threshold`, the transition between states `second` and `third` is taken, and the state `third` becomes active.

connective junction

Decision points in the system. A connective junction is a graphical object that simplifies Stateflow diagram representations and facilitates generation of efficient code. Connective junctions provide alternative ways to represent desired system behavior.

This example shows how connective junctions (displayed as small circles) are used to represent the decision flow of an `if` code structure.



```
if [c1]{
     a1
     if [c2]{
        a2
     }else if [c3]{
       a3
     }
}
```

Name	Button Icon	Description
Connective junction		One use of a connective junction is to handle situations where transitions out of one state into two or more states are taken based on the same event but guarded by different conditions.

See “Connective Junctions” on page 2-31 for more information.

data

Data objects store numerical values for reference in the Stateflow diagram.

See “Adding Data” on page 7-27 for more information on representing data objects.

data dictionary

Database where Stateflow diagram information is stored. When you create Stateflow diagram objects, the information about those objects is stored in the data dictionary once you save the Stateflow diagram.

Debugger

See **Stateflow Debugger** on page Glossary-10.

decomposition

A state has a *decomposition* when it consists of one or more substates. A Stateflow diagram that contains at least one state also has decomposition. Representing hierarchy necessitates some rules around how states can be grouped in the hierarchy. A superstate has either parallel (AND) or exclusive (OR) decomposition. All substates at a particular level in the hierarchy must be of the same decomposition.

Parallel (AND) State Decomposition

Parallel (AND) state decomposition is indicated when states have dashed borders. This representation is appropriate if all states at that same level in the hierarchy are active at the same time. The activity within parallel states is essentially independent.

Exclusive (OR) State Decomposition

Exclusive (OR) state decomposition is represented by states with solid borders. Exclusive (OR) decomposition is used to describe system modes that are mutually exclusive. Only one state at the same level in the hierarchy can be active at a time.

default transition

Primarily used to specify which exclusive (OR) state is to be entered when there is ambiguity among two or more neighboring exclusive (OR) states. For example, default transitions specify which substate of a superstate with exclusive (OR) decomposition the system enters by default in the absence of any other information. Default transitions are also used to specify that a junction should be entered by default. A default transition is represented by selecting the default transition object from the toolbar and then dropping it to attach to a destination object. The default transition object is a transition with a destination but no source object.

Name	Button Icon	Description
Default transition		Use a default transition to indicate, when entering this level in the hierarchy, which state becomes active by default.

See “Default Transitions” on page 2-26 for more information.

events

Events drive the Stateflow diagram execution. All events that affect the Stateflow diagram must be defined. The occurrence of an event causes the status of the states in the Stateflow diagram to be evaluated. The broadcast of an event can trigger a transition to occur and/or can trigger an action to be executed. Events are broadcast in a top-down manner starting from the event’s parent in the hierarchy.

Events are added, removed, and edited through the Stateflow Explorer. See “Adding Events” on page 7-4 for more information.

Explorer

A tool for displaying, modifying, and creating data and event objects for any parent object in Stateflow. The Explorer also displays, modifies, and creates targets for the Stateflow machine. See **Stateflow Explorer** on page Glossary-11.

Finder

A tool to search for objects in Stateflow diagrams on platforms that do not support the Simulink Find tool. See **Stateflow Finder** on page Glossary-11.

finite state machine (FSM)

Representation of an event-driven system. FSMs are also used to describe reactive systems. In an event-driven or reactive system, the system transitions from one mode or state to another prescribed mode or state, provided that the condition defining the change is true.

flow graph

Set of decision flow paths that start from a transition segment that, in turn, starts from a state or a default transition segment.

flow path

Ordered sequence of transition segments and junctions where each succeeding segment starts on the junction that terminated the previous segment.

flow subgraph

Set of decision flow paths that start on the same transition segment.

graphical function

Function whose logic is defined by a flow graph. See “Using Functions to Extend Actions” on page 6-29.

hierarchy

Hierarchy enables you to organize complex systems by placing states within other higher-level states. A hierarchical design usually reduces the number of transitions and produces neat, more manageable diagrams. See “Stateflow Hierarchy of Objects” on page 1-21 for more information.

history junction

Provides the means to specify the destination substate of a transition based on historical information. If a superstate has a history junction, the transition to the destination substate is defined to be the substate that was most recently visited. The history junction applies to the level of the hierarchy in which it appears.

Name	Button Icon	Description
History junction	H	Use a history junction to indicate, when entering this level in the hierarchy, that the last state that was active becomes the next state to be active.

See these sections for more information:

- “History Junctions” on page 2-38
- “Default Transition and a History Junction Example” on page 3-58
- “Labeled Default Transitions Example” on page 3-59
- “Inner Transition to a History Junction Example” on page 3-68

inner transitions

Transition that does not exit the source state. Inner transitions are most powerful when defined for superstates with XOR decomposition. Use of inner transitions can greatly simplify a Stateflow diagram.

See “Inner Transitions” on page 2-22 and “Inner Transition to a History Junction Example” on page 3-68 for more information.

library link

Link to a chart that is stored in a library model in a Simulink block library.

library model

Stateflow model that is stored in a Simulink library. You can include charts from a library in your model by copying them. When you copy a chart from a library into your model, Stateflow does not physically include the chart in your model. Instead, it creates a link to the library chart. You can create multiple links to a single chart. Each link is called a *chart instance*. When you include a chart from a library in your model, you also include its Stateflow machine. Thus, a Stateflow model that includes links to library charts has multiple Stateflow machines. When

Stateflow simulates a model that includes charts from a library model, it includes all charts from the library model even if there are links to only some of its models. However, when Stateflow generates a stand-alone or RTW target, it includes only those charts for which there are links. A model that includes links to a library model can be simulated only if all charts in the library model are free of parse and compile errors.

machine

Collection of all Stateflow blocks defined by a Simulink model. This excludes chart instances from library links. If a model includes any library links, it also includes the Stateflow machines defined by the models from which the links originate.

notation

Defines a set of objects and the rules that govern the relationships between those objects. Stateflow notation provides a common language to communicate the design information conveyed by a Stateflow diagram.

Stateflow notation consists of

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

parallelism

A system with *parallelism* can have two or more states that can be active at the same time. The activity of parallel states is essentially independent. Parallelism is represented with a parallel (AND) state decomposition.

See “State Decomposition” on page 2-8 for more information.

Real-Time Workshop

Automatic C language code generator for Simulink. It produces C code directly from Simulink block diagram models and automatically builds programs that can be run in real time in a variety of environments. See the Real-Time Workshop documentation for more information.

rtw target

Executable built from code generated by Real-Time Workshop. See Chapter 14, “Building Targets” for more information.

S-function

When using Simulink together with Stateflow for simulation, Stateflow generates an *S-function* (MEX-file) for each Stateflow machine to support model simulation. This generated code is a simulation target and is called the `sfun` target within Stateflow.

For more information, see the Using Simulink documentation.

semantics

Semantics describe how the notation is interpreted and implemented behind the scenes. A completed Stateflow diagram communicates how the system will behave. A Stateflow diagram contains actions associated with transitions and states. The semantics describe in what sequence these actions take place during Stateflow diagram execution.

Simulink

Software package for modeling, simulating, and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates.

It allows you to represent systems as block diagrams that you build using your mouse to connect blocks and your keyboard to edit block parameters. Stateflow is part of this environment. The Stateflow block is a masked Simulink model. Stateflow builds an S-function that corresponds to each Stateflow machine. This S-function is the agent Simulink interacts with for simulation and analysis.

The control behavior that Stateflow models complements the algorithmic behavior modeled in Simulink block diagrams. By incorporating Stateflow diagrams into Simulink models, you can add event-driven behavior to Simulink simulations. You create models that represent both data and decision flow by combining Stateflow blocks with the standard Simulink blocksets. These combined models are simulated using Simulink.

The Using Simulink documentation describes how to work with Simulink. It explains how to manipulate Simulink blocks, access block parameters, and connect blocks to build models. It also provides reference descriptions of each block in the standard Simulink libraries.

state

A *state* describes a mode of a reactive system. A reactive system has many possible states. States in a Stateflow diagram represent these modes. The activity or inactivity of the states dynamically changes based on transitions among events and conditions.

Every state has hierarchy. In a Stateflow diagram consisting of a single state, that state's parent is the Stateflow diagram itself. A state also has history that applies to its level of hierarchy in the Stateflow diagram. States can have actions that are executed in a sequence based upon action type. The action types are `entry`, `during`, `exit`, or `on event_name` actions.

Name	Button Icon	Description
State	▣	Use a state to depict a mode of the system.

Stateflow block

Masked Simulink model that is equivalent to an empty, untitled Stateflow diagram. Use the Stateflow block to include a Stateflow diagram in a Simulink model.

The control behavior that Stateflow models complements the algorithmic behavior modeled in Simulink block diagrams. By incorporating Stateflow blocks into Simulink models, you can add complex event-driven behavior to Simulink simulations. You create models that represent both data and decision flow by combining Stateflow blocks with the standard Simulink and toolbox block libraries. These combined models are simulated using Simulink.

Stateflow Debugger

Use to debug and animate your Stateflow diagrams. Each state in the Stateflow diagram simulation is evaluated for overall code coverage. This coverage analysis is done automatically when the target is compiled and built with the debug options. The Debugger can also be used to perform dynamic checking. The Debugger operates on the Stateflow machine.

Stateflow diagram

Using Stateflow, you create Stateflow diagrams. A *Stateflow diagram* is also a graphical representation of a finite state machine where *states* and *transitions* form the basic building blocks of the system. See "Stateflow and Simulink" on page 1-6 for more information on Stateflow diagrams.

Stateflow Explorer

Use to add, remove, and modify data, event, and target objects. See "Using the Model Explorer with Stateflow Objects" on page 16-2 for more information.

Stateflow Finder

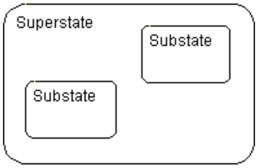
Use to display a list of objects based on search criteria you specify. You can directly access the properties dialog box of any object in the search output display by clicking that object. See "Using the Stateflow Finder Tool" on page 16-27 for more information.

subchart

Chart contained by another chart. See "Using Subcharts to Extend Charts" on page 6-6.

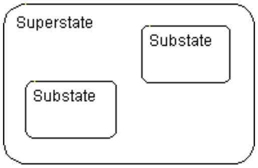
substate

A state is a *substate* if it is contained by a superstate.



superstate

A state is a *superstate* if it contains other states, called substates.



supertransition

Transition between objects residing in different subcharts. See "Using Supertransitions to Extend Transitions" on page 6-12 for more information.

target

A container object for the generated code from the Stateflow diagrams in a model. Stateflow represents the collection of all Stateflow diagrams for a model as a Stateflow machine. This means that target objects belong to the Stateflow machine.

Stateflow generates code for all target types, which include Simulation, Real-Time Workshop, and Custom targets. See Chapter 14, "Building Targets" for more information.

topdown processing

The way in which Stateflow processes states and events. In particular, Stateflow processes superstates before states. Stateflow processes a state only if its superstate is activated first.

transition

The circumstances under which the system moves from one state to another. Either end of a transition can be attached to a source and a destination object. The *source* is where the transition begins and the *destination* is where the transition ends. It is often the occurrence of some event that causes a transition to take place.

transition path

Flow path that starts and ends on a state.

transition segment

A state-to-junction, junction-to-junction, or junction-to-state part of a complete state-to-state transition. Transition segments are sometimes loosely referred to as transitions.

virtual scrollbar

Enables you to set a value by scrolling through a list of choices. When you move the mouse over a menu item with a virtual scrollbar, the cursor changes to a line with a double arrowhead. Virtual scrollbars are either vertical or horizontal. The direction is indicated by the positioning of the arrowheads. Drag the mouse either horizontally or vertically to change the value.

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