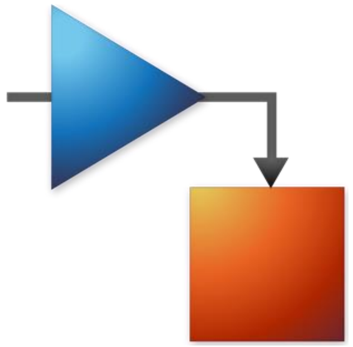
Lecture 12: Simulink & Stateflow

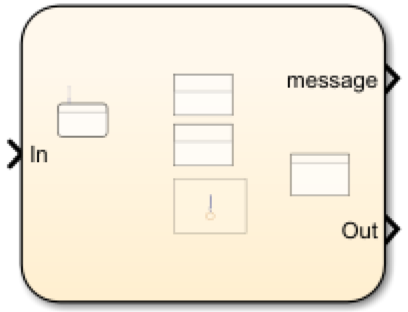


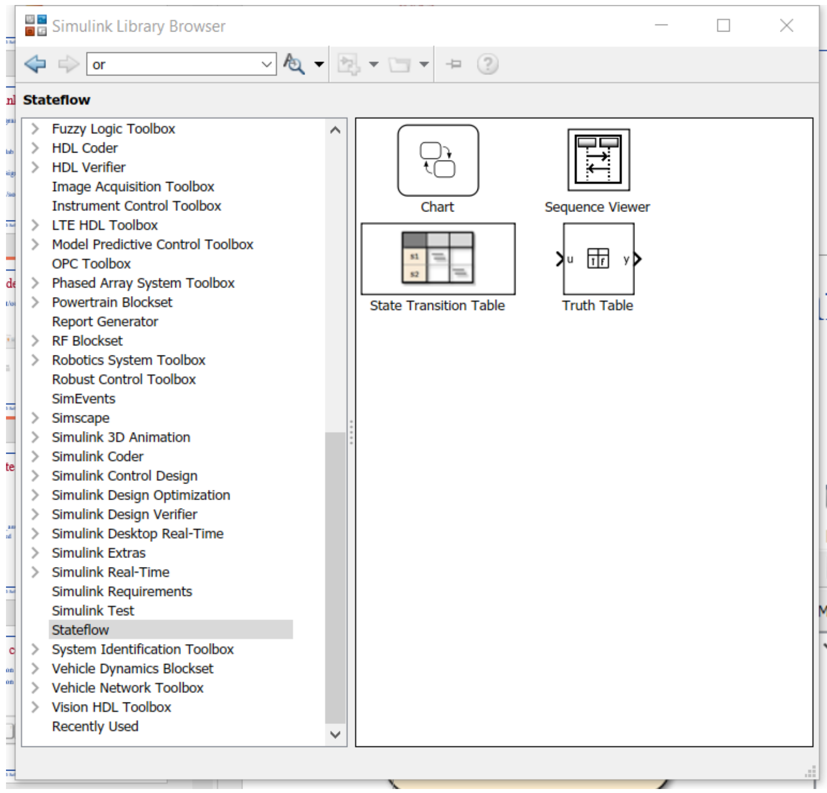
Simulink & Stateflow

- A graphical modeling/programming language
- Developed by Mathworks
  - Highly integrated with Matlab
- Has a full model-based design toolchain
- Widely adapted by system/software developers
- Rich expressiveness

Model Explorer

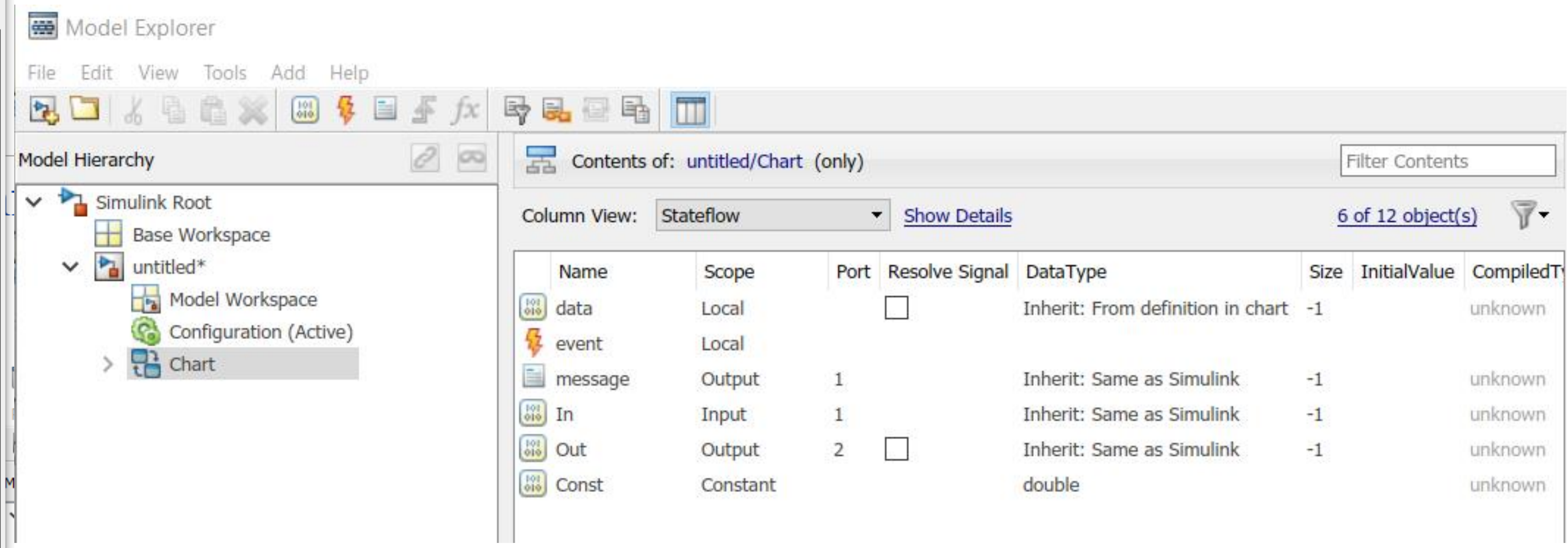
- Define and configure input/output, event/message, variables.





Stateflow

- Fuzzy Logic Toolbox
- HDL Coder
- HDL Verifier
- Image Acquisition Toolbox
- Instrument Control Toolbox
- LTE HDL Toolbox
- Model Predictive Control Toolbox
- OPC Toolbox
- Phased Array System Toolbox
- Powertrain Blockset
- Report Generator
- RF Blockset
- Robotics System Toolbox
- Robust Control Toolbox
- SimEvents
- Simscape
- Simulink 3D Animation
- Simulink Coder
- Simulink Control Design
- Simulink Design Optimization
- Simulink Design Verifier
- Simulink Desktop Real-Time
- Simulink Extras
- Simulink Real-Time
- Simulink Requirements
- Simulink Test
- Stateflow
- System Identification Toolbox
- Vehicle Dynamics Blockset
- Vehicle Network Toolbox
- Vision HDL Toolbox
- Recently Used



Model Hierarchy

- Simulink Root
  - Base Workspace
  - untitled*
    - Model Workspace
    - Configuration (Active)
    - Chart

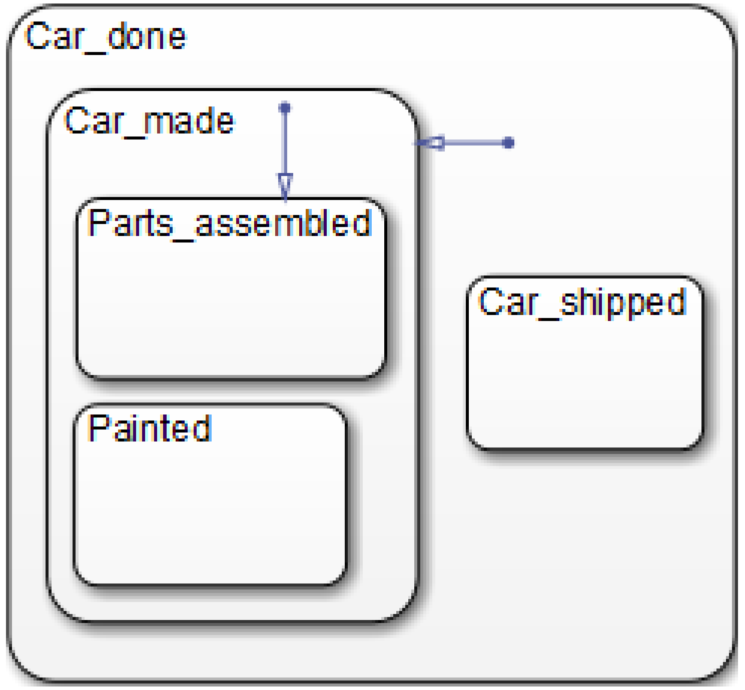
Contents of: untitled/Chart (only)

Column View: Stateflow — 6 of 12 object(s)

Name	Scope	Port	Resolve Signal	DataType	Size	InitialValue	CompiledT
data	Local		☐	Inherit: From definition in chart	-1		unknown
event	Local						
message	Output	1		Inherit: Same as Simulink	-1		unknown
In	Input	1		Inherit: Same as Simulink	-1		unknown
Out	Output	2	☐	Inherit: Same as Simulink	-1		unknown
Const	Constant			double			unknown

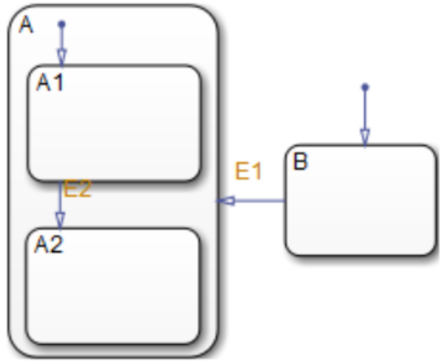
State Hierarchy

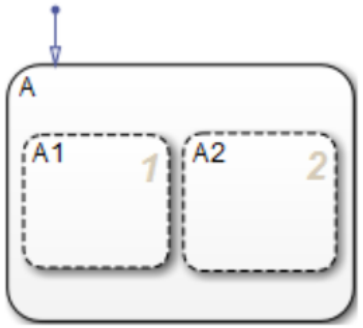
- Object oriented modeling
  - /Car_done
  - /Car_done.Car_made
  - /Car_done.Car_shipped
  - /Car_done.Car_made.Parts_assembled
  - /Car_done.Car_made.Painted

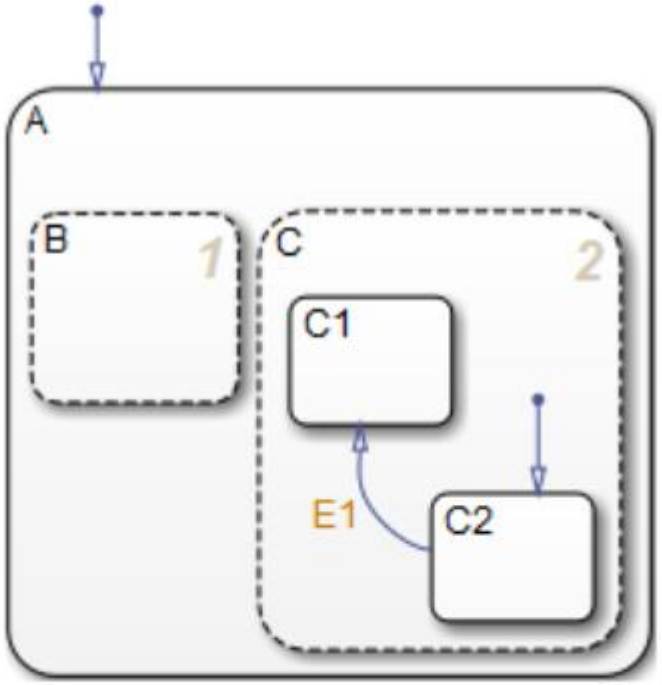


State compositions

- “OR”/exclusive composition
- “AND”/parallel composition

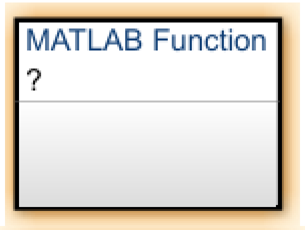


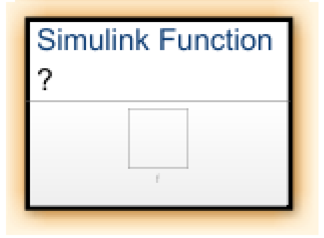


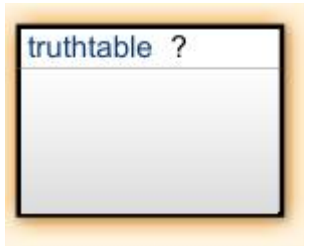


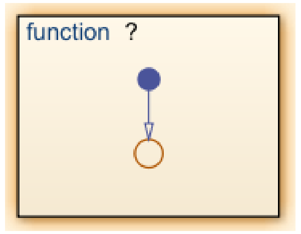
Embedded Functions

- Matlab function
- Simulink function
- Truthtable
- Graphical function



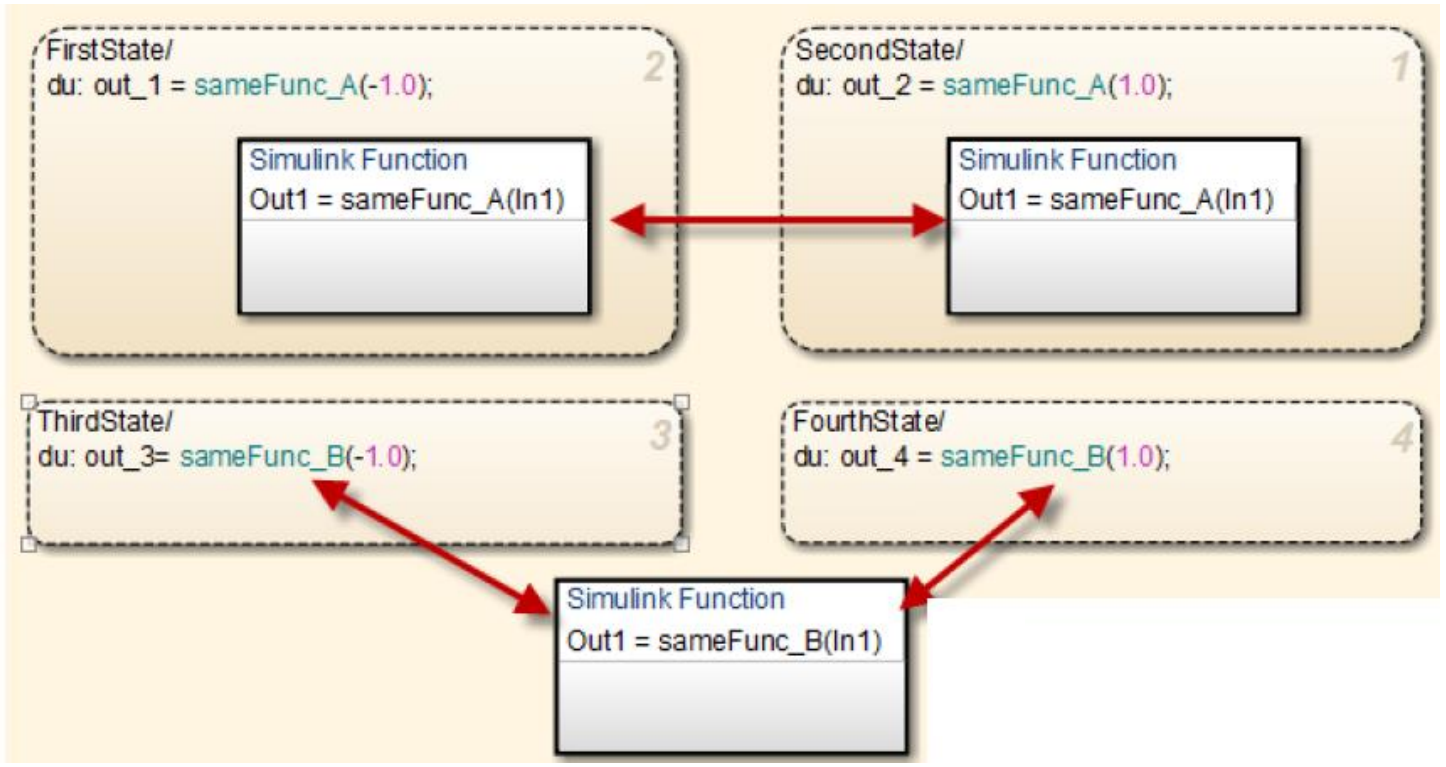






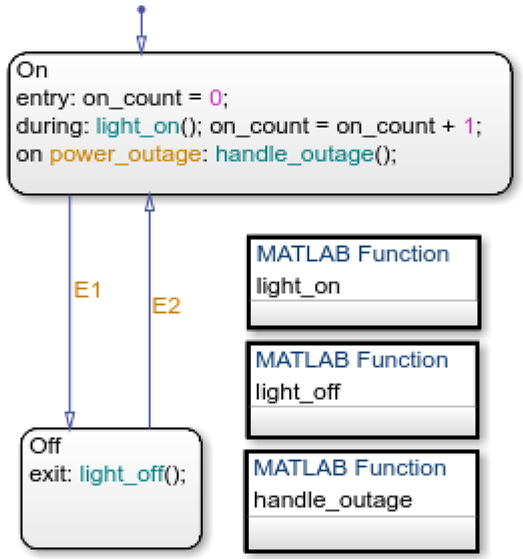
Function availability

- Only available to states at the same level



State Actions

- entry: (en:) entry actions
  - Action occurs on a time step when the state becomes active.
- during: (du:) during actions
  - Action occurs on a time step when the state is already active and the chart does not transition out of the state.
- exit: (ex:) exit actions
  - Action occurs on a time step when the chart transitions out of the state.
- on event_name: on event_name actions
- on message_name: on message_name actions



```
On
entry: on_count = 0;
during: light_on(); on_count = on_count + 1;
on power_outage: handle_outage();
```

```
Off
exit: light_off();
```

Reduce redundancy

```
en:
  fcn1();
  fcn2();
du: fcn1();
ex: fcn1();
```

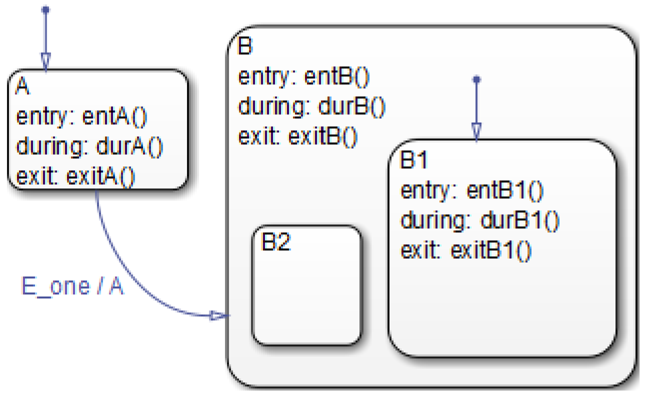
```
en, du, ex: fcn1();
en: fcn2();
```

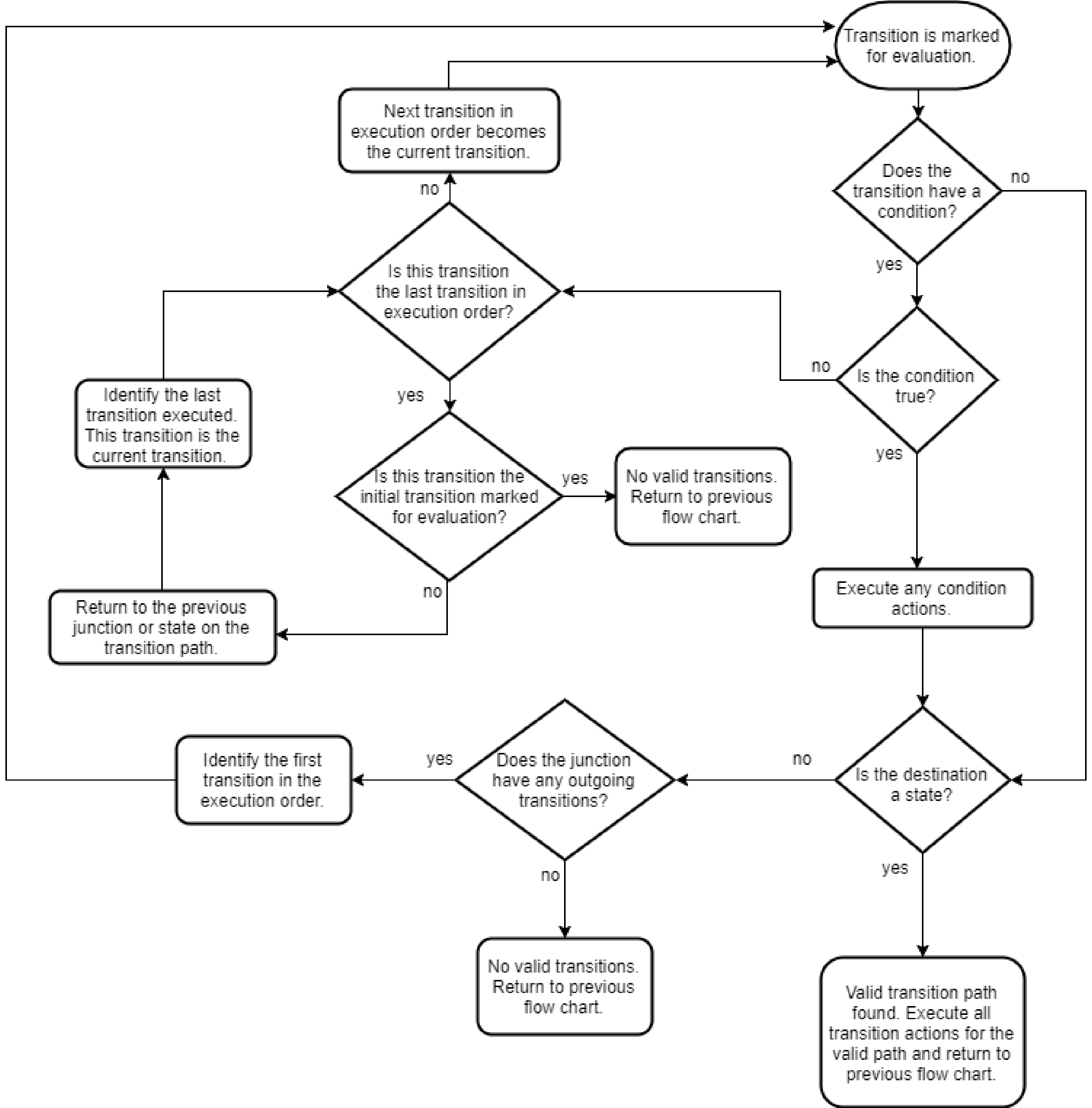
Transition

- event_or_message[condition]{condition_action}/transition_action
- Condition
  - Boolean expression that specifies that a transition path is valid if the expression is true; part of a transition label
- Condition actions
  - Executes after the condition for the transition is evaluated as true, but before the transition to the destination is determined to be valid
- Transition actions
  - Executes after the transition to the destination is determined to be valid

Default transitions

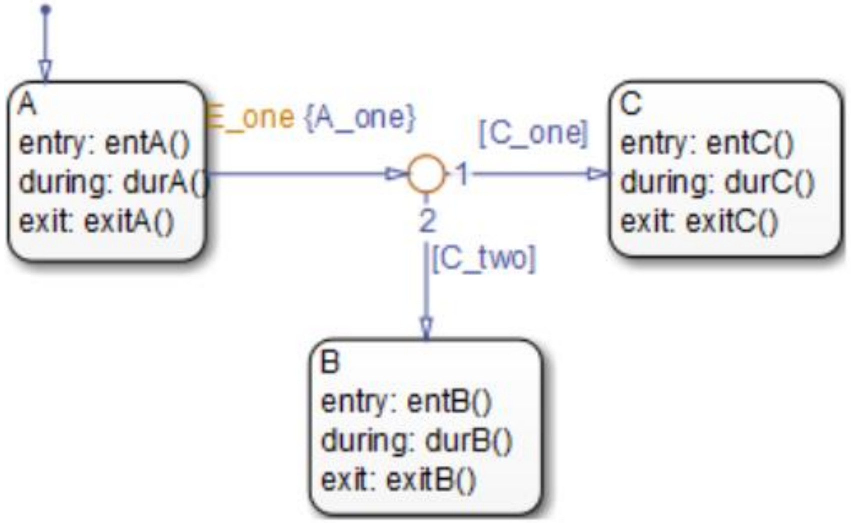
- State A is active. Event E_one occurs and awakens the chart
- State A exit actions (exitA()) execute and complete.
- State A is marked inactive.
- The transition action, A, is executed and completed.
- State B is marked active.
- State B entry actions (entB()) execute and complete.
- State B detects a valid default transition to state B.B1.
- State B.B1 is marked active.
- State B.B1 entry actions (entB1()) execute and complete.
- The chart goes back to sleep.




Transition is marked for evaluation.
Does the transition have a condition?
no
yes
Is the condition true?
no
yes
Execute any condition actions.
Is the destination a state?
no
yes
Valid transition path found. Execute all transition actions for the valid path and return to previous flow chart.
Does the junction have any outgoing transitions?
yes
no
No valid transitions. Return to previous flow chart.
Identify the first transition in the execution order.
Is this transition the last transition in execution order?
no
yes
Next transition in execution order becomes the current transition.
Is this transition the initial transition marked for evaluation?
yes
no
No valid transitions. Return to previous flow chart.
Return to the previous junction or state on the transition path.
Identify the last transition executed. This transition is the current transition.

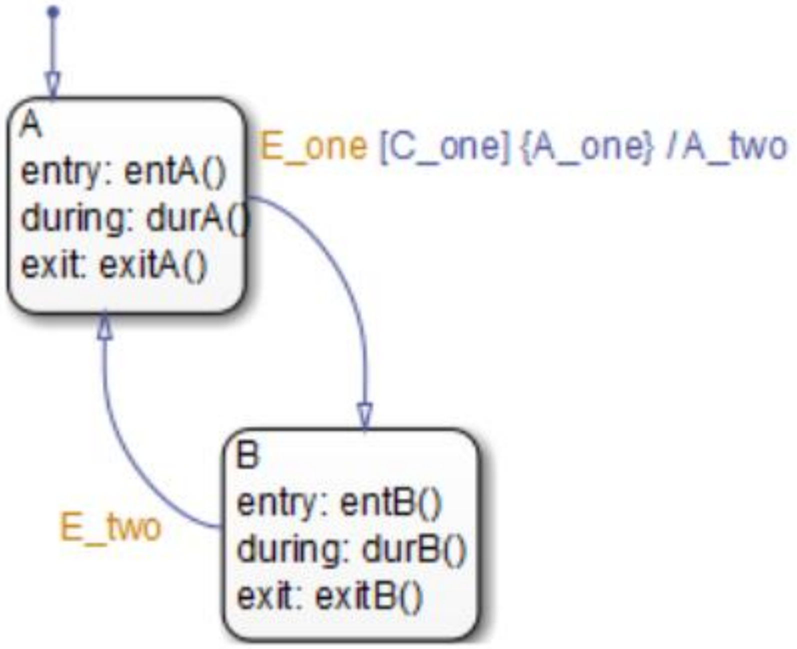
Condition Action Behavior

- E_one happened when state A is active. C_one and C_two are false
- A valid transition segment from state A to a connective junction is detected.
- The condition action A_one is immediately executed and completed. State A is still active.
- No complete transitions is valid.
- State A during actions (durA()) execute and complete.
- State A remains active.
- The chart goes back to sleep.



Condition and Transition Action Behavior

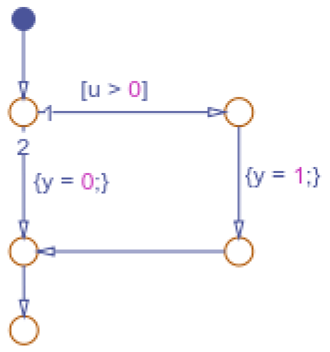
- E_one happened and awaked the chart.
- The condition C_one is true. The condition action A_one is immediately executed.
- State A is still active.
- State A exit actions (ExitA()) execute and complete.
- State A is marked inactive.
- The transition action A_two is executed.
- State B is marked active.
- State B entry actions (entB()) execute.
- The chart goes back to sleep.



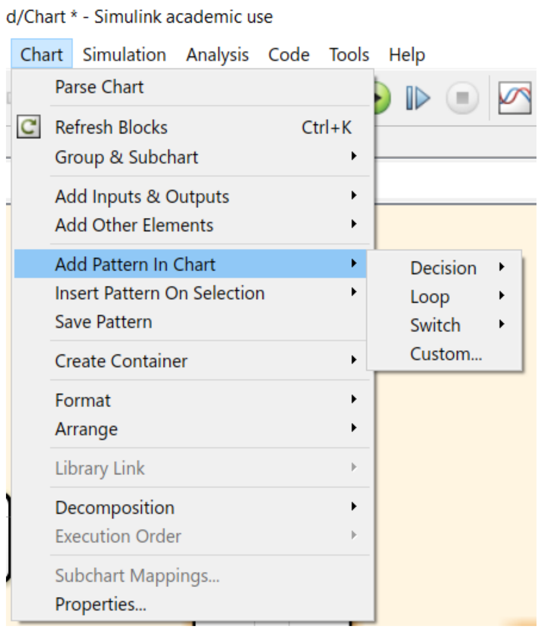
Flow chart

- No time consumption during execution
- Can be used for graphical function definition

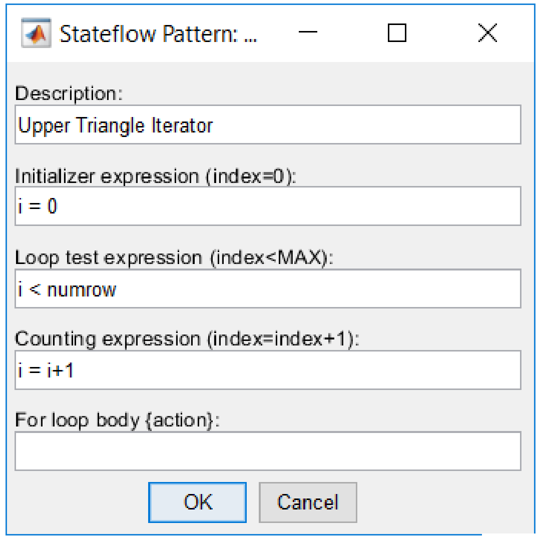
```
if u > 0
   y = 1;
else
   y = 0;
end
```



Add pattern in chart

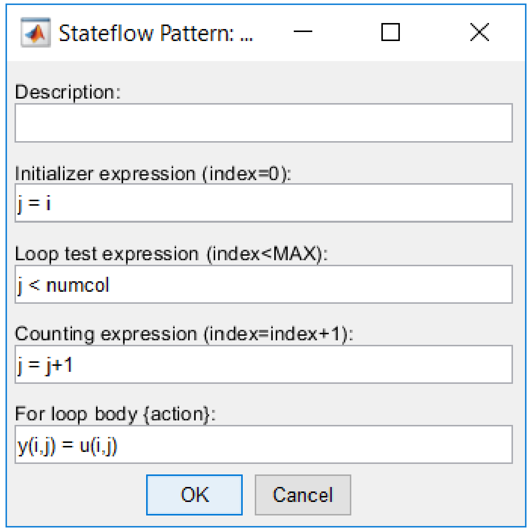


+

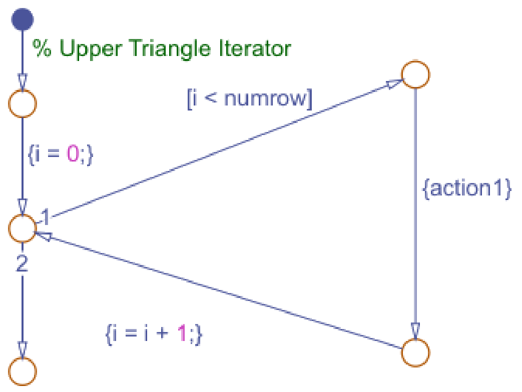


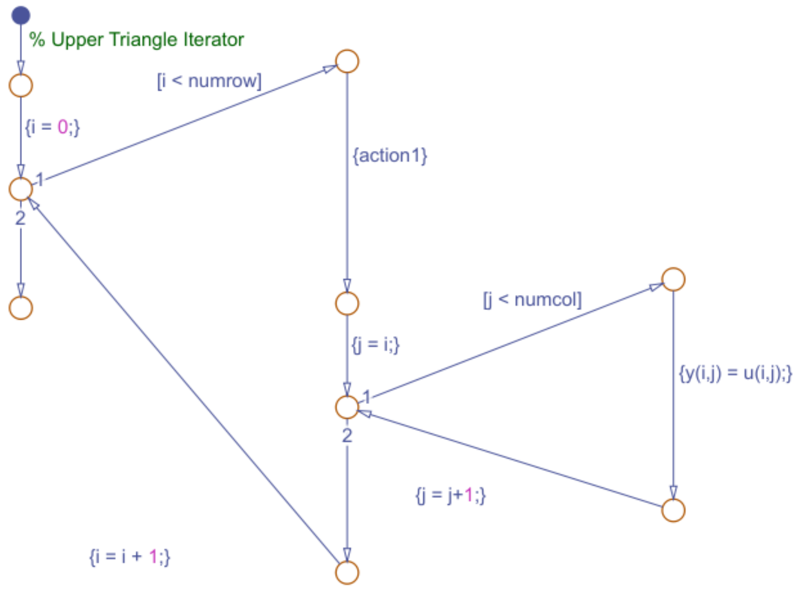
Description: Upper Triangle Iterator
Initializer expression (index=0): i = 0
Loop test expression (index<MAX): i < numrow
Counting expression (index=index+1): i = i+1
For loop body {action}:

+



Description:
Initializer expression (index=0): j = i
Loop test expression (index<MAX): j < numcol
Counting expression (index=index+1): j = j+1
For loop body {action}: y(i,j) = u(i,j)

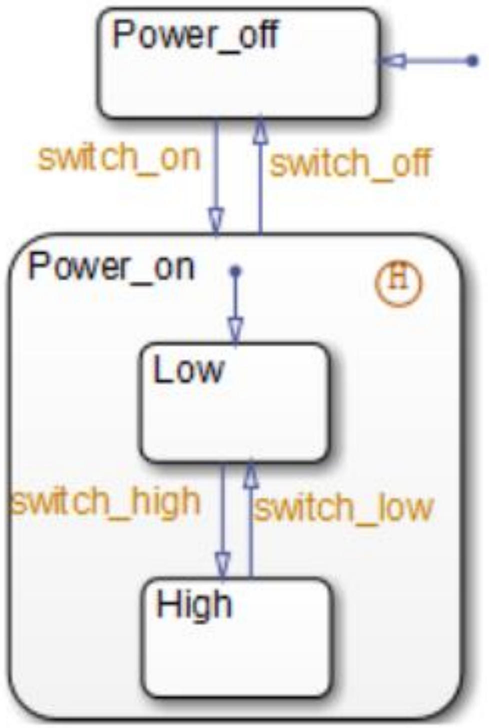




History Junction

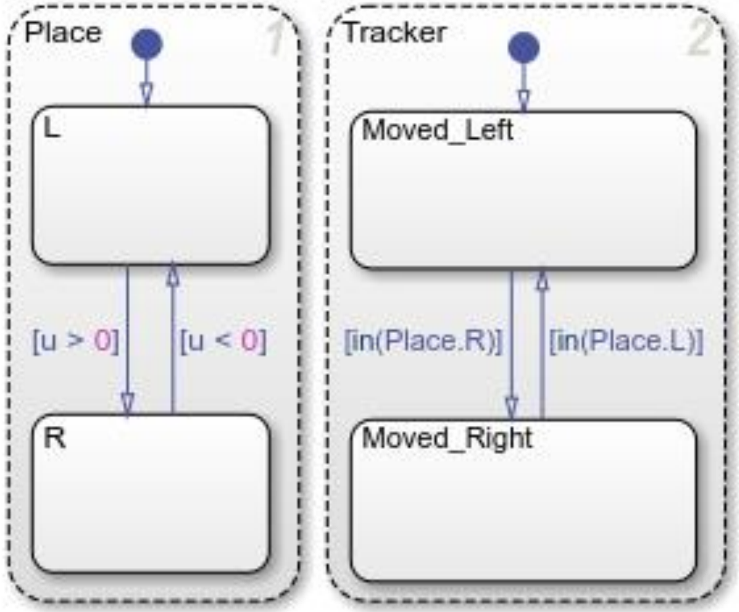
- Restores the state that is on the same level of the composite state as the history state itself

- If the system was switched off when the system was at the “High” state, when the system is switched back on, it will start from the “High” state



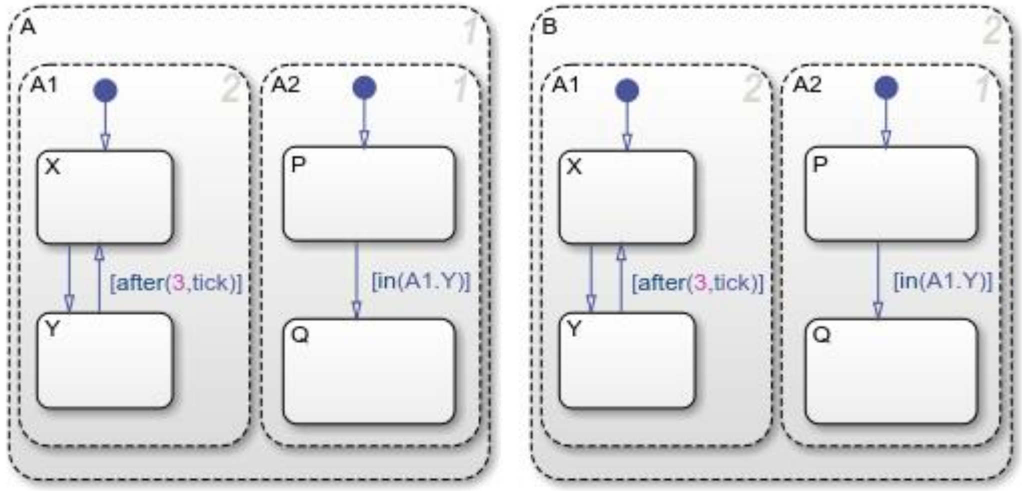
Check State Activity by Using in() Operator

- We can use in() operator to reference status of other parallel states
  - Return 1 if the referenced state is also active
- Starting point
  - If in state action, start from the containing state
  - If on transition, start from the parent state
- Search up the state hierarchy until the chart level is reached



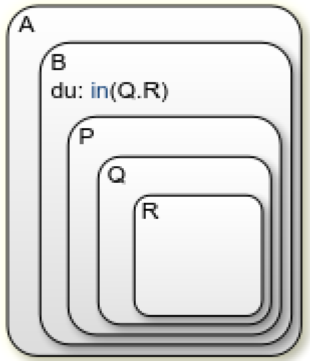
In() operator example

- In(A1.Y) in both A and B only find local copies of A1.Y
- Because at the chart level, there is no A1.Y



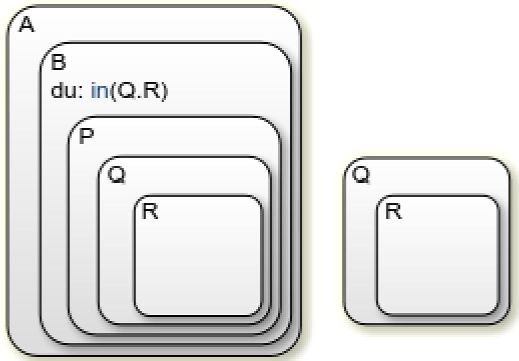
In() operator example (cont.)

No match



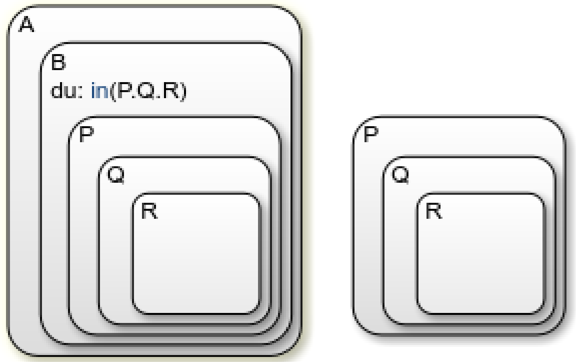
In(P.Q.R) will do

Wrong match

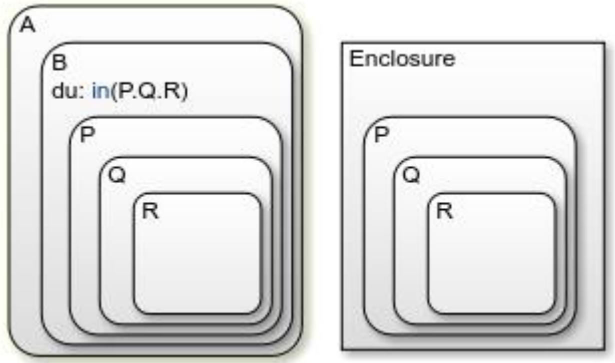


In(B.P.Q.R) will do

Multiple match

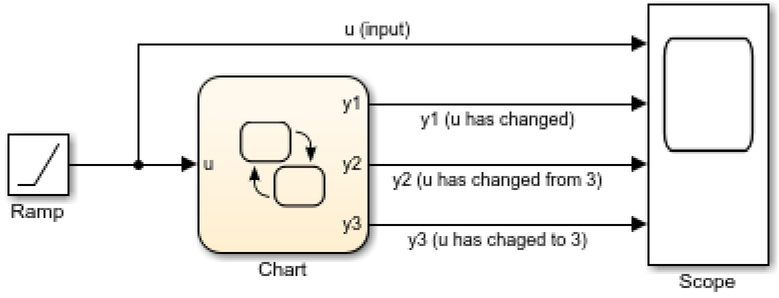


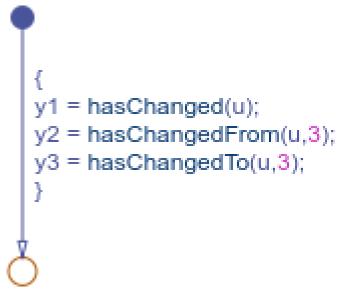
Use enclosure to ensure local match



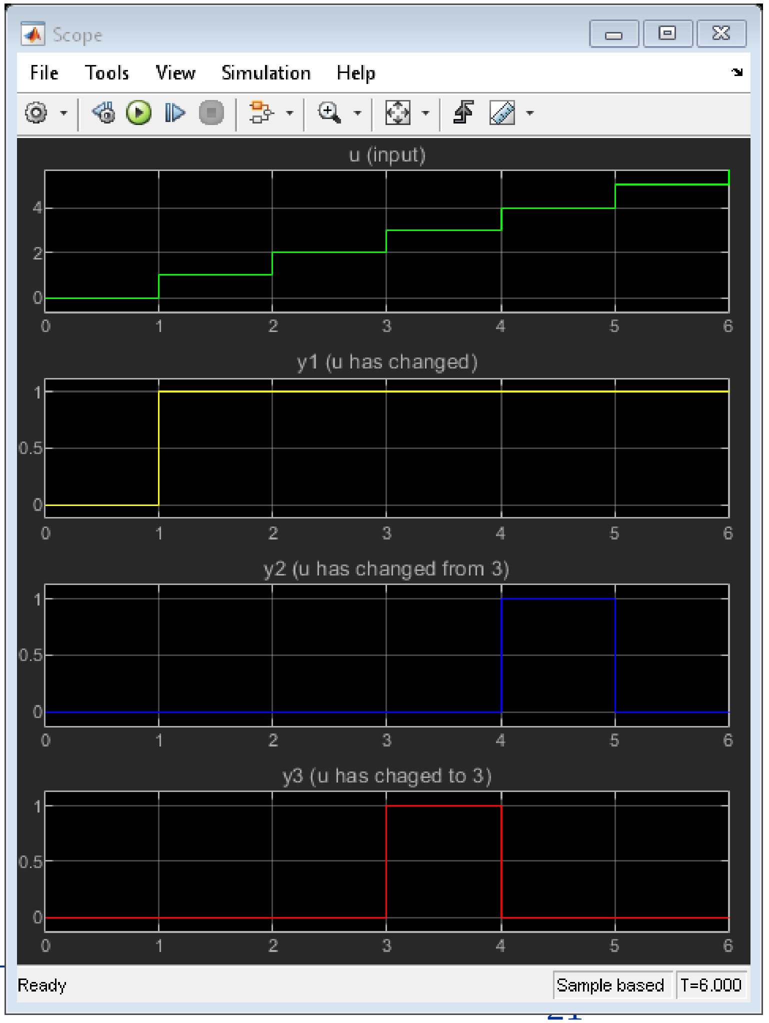
Detect data change

- hasChanged(u)
  - Detects changes in data value from the beginning of the last time step to the beginning of the current time step.
- hasChangedFrom(u,v)
  - Detects changes in data value from a specified value at the beginning of the last time step to a different value at the beginning of the current time step.
- hasChangedTo(u,v)
  - Detects changes in data value to a specified value at the beginning of the current time step from a different value at the beginning of the last time step.



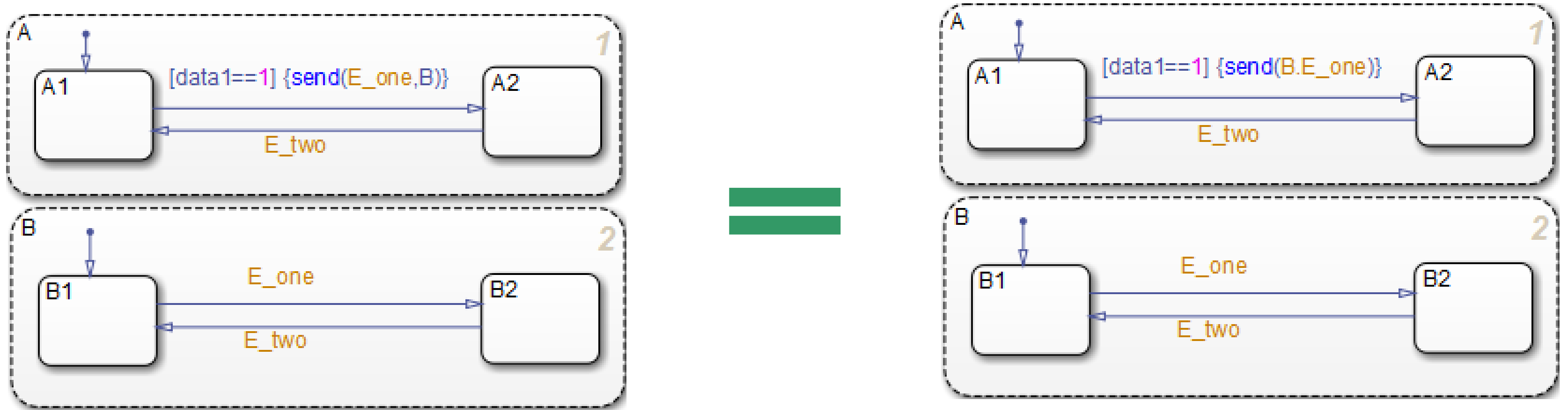


```
{
y1 = hasChanged(u);
y2 = hasChangedFrom(u,3);
y3 = hasChangedTo(u,3);
}
```



Broadcast Local Events to Synchronize Parallel States

- send(event_name,state_name)
- event_name is broadcast to its owning state (state_name) and any offspring of that state in the hierarchy.
- The receiving state must be active during the event broadcast.
- An action in one chart cannot broadcast events to states in another chart.

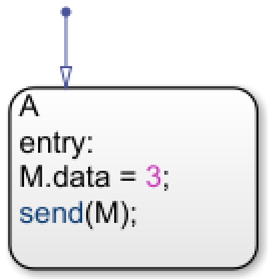


Implicit Events

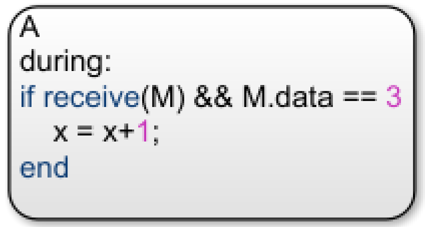
- change(data_name) or chg(data_name)
  - generates a local event when writing a value to the variable data_name
  - Data_name has to be at chart level or lower
- enter(state_name) or en(state_name)
  - generates a local event when the specified state_name is entered
- exit(state_name) or ex(state_name)
  - generates a local event when the specified state_name is exited
- Tick/wakeup
  - generates a local event when the chart of the action being evaluated awakens

Message

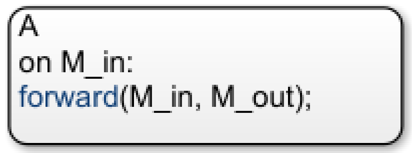
- Contains data: Message_name.data
- Receiver has a queue for each input message
- send(message_name)
- receive(message_name)
- discard(message_name)
- forward(input_message_name, output_message_name)
- isvalid(message_name)
  - if the chart has removed it from the queue and has not forwarded or discarde



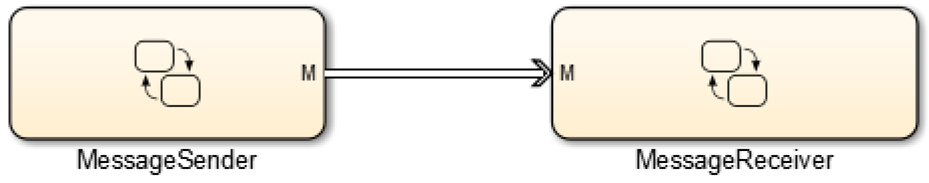
```
A
entry:
M.data = 3;
send(M);
```



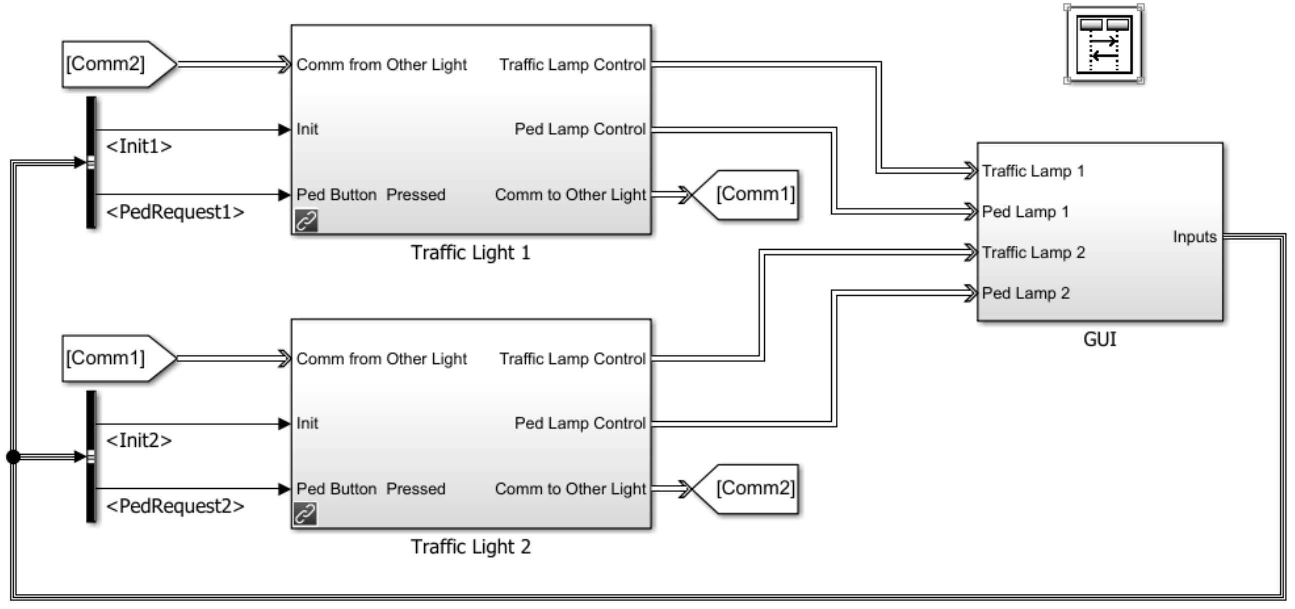
```
A
during:
if receive(M) && M.data == 3
   x = x+1;
end
```



```
A
on M_in:
forward(M_in, M_out);
```



Visualizing messages/events



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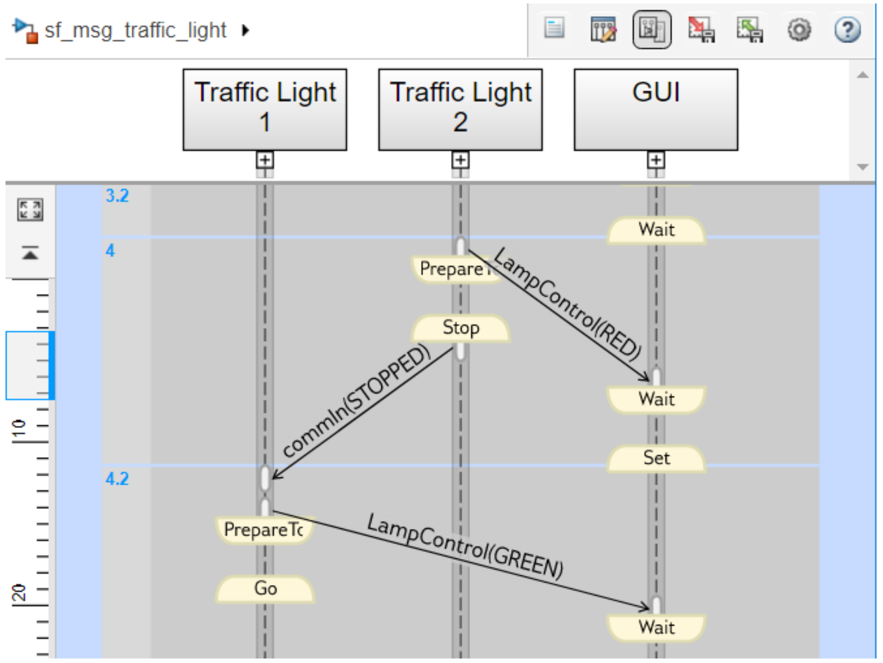
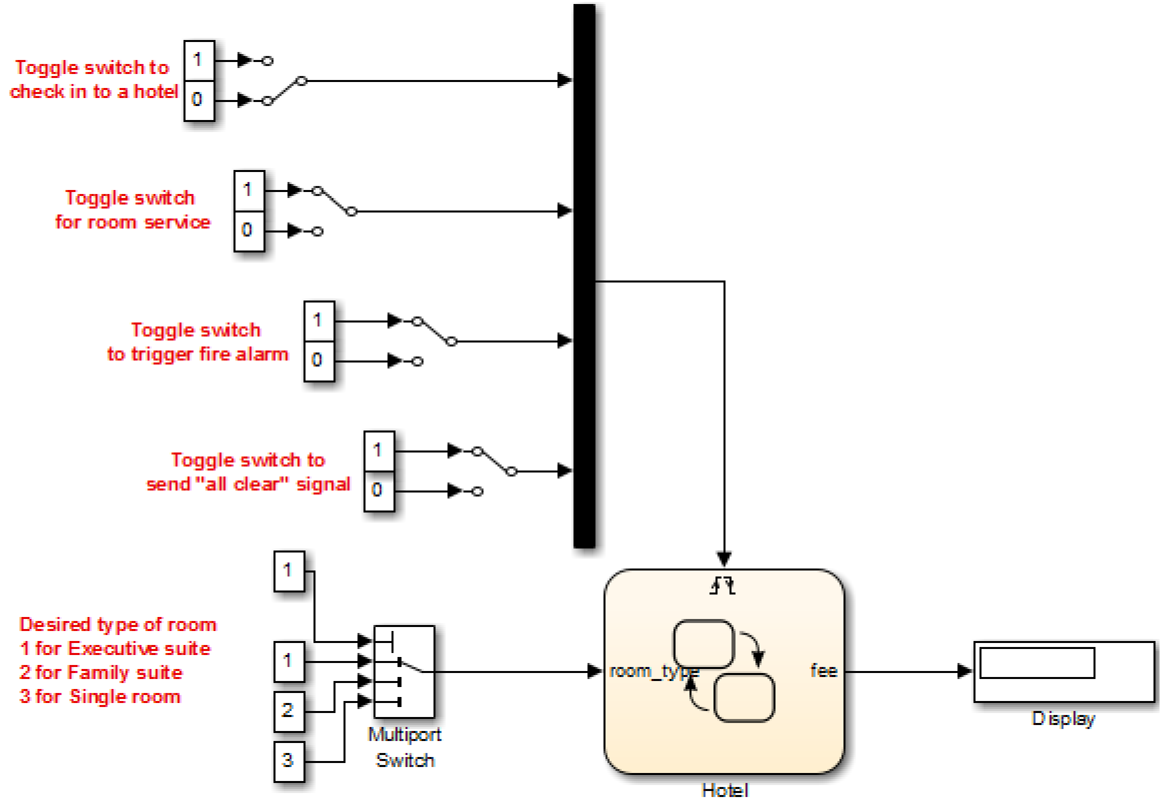
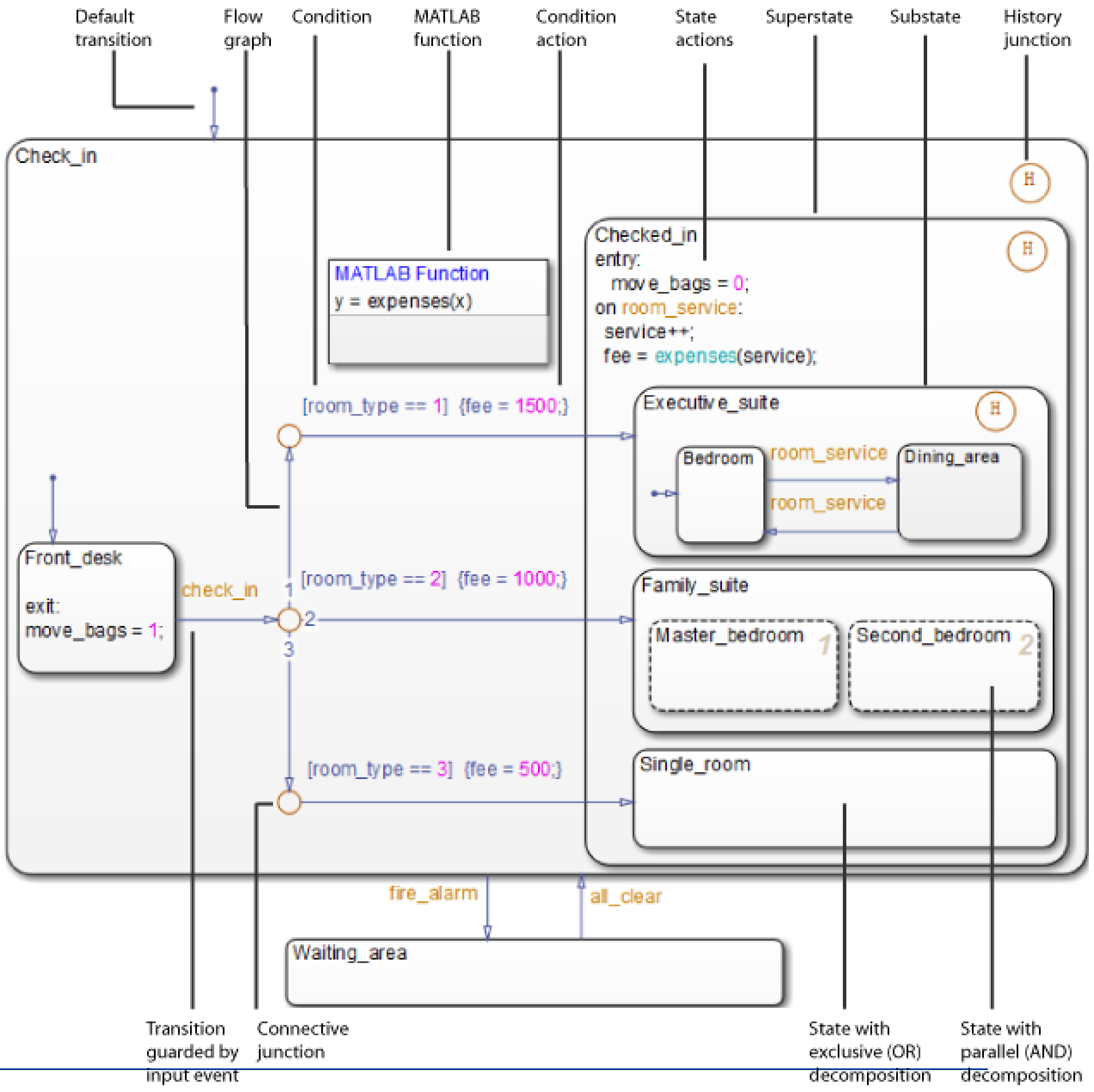


Example


Toggle switch to check in to a hotel
1
0
Toggle switch for room service
1
0
Toggle switch to trigger fire alarm
1
0
Toggle switch to send "all clear" signal
1
0
Desired type of room
1 for Executive suite
2 for Family suite
3 for Single room
1
1
2
3
Multiport Switch
room_type
fee
Hotel
Display


Default transition
Flow graph
Condition
MATLAB function
Condition action
State actions
Superstate
Substate
History junction
Check_in
H
MATLAB Function
y = expenses(x)
Checked_in
entry:
move_bags = 0;
on room_service:
service++;
fee = expenses(service);
H
[room_type == 1] {fee = 1500;}
Executive_suite
H
Bedroom
room_service
Dining_area
room_service
Front_desk
exit:
move_bags = 1;
check_in
1
2
3
[room_type == 2] {fee = 1000;}
Family_suite
Master_bedroom 1
Second_bedroom 2
[room_type == 3] {fee = 500;}
Single_room
fire_alarm
all_clear
Waiting_area
Transition guarded by input event
Connective junction
State with exclusive (OR) decomposition
State with parallel (AND) decomposition

Modeling Tips

- Use signals of the same data type for input events
- Use a default transition to mark the first state to become active among exclusive (OR) states
- Use condition actions instead of transition actions whenever possible
- Use explicit ordering to control the testing order of a group of outgoing transitions
- Use MATLAB functions for performing numerical computations in a chart