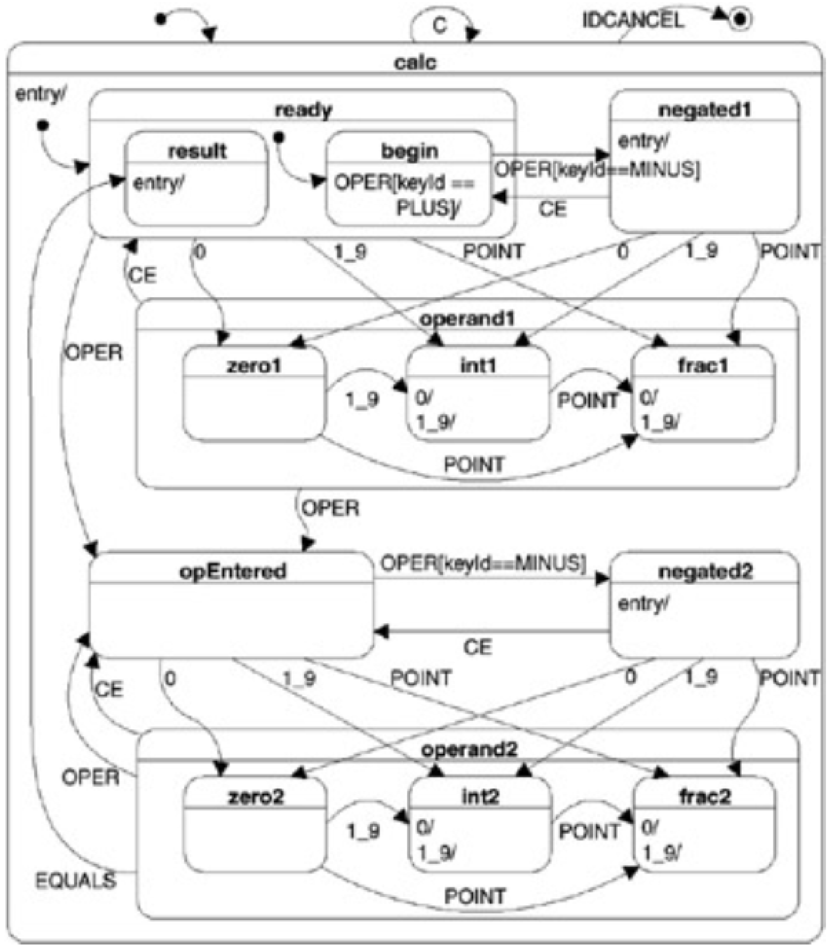
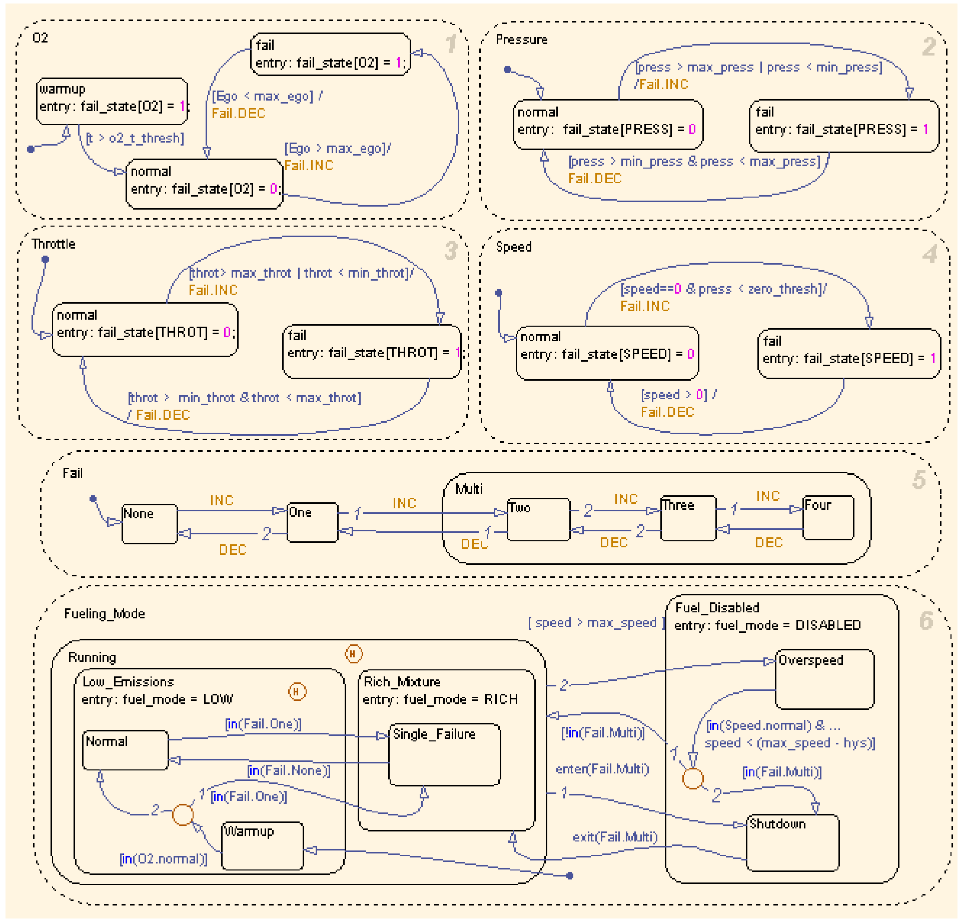
Statecharts (hierarchical FSMs)

Hierarchical FSMs (Statecharts)

Introduced by D Harel (1987)



UML notation


O2
warmup
entry: fail_state[O2] = 1;
fail
entry: fail_state[O2] = 1;
normal
entry: fail_state[O2] = 0;
[t > o2_t_thresh]
[Ego < max_ego] / Fail.DEC
[Ego > max_ego]/ Fail.INC
Pressure
normal
entry: fail_state[PRESS] = 0
fail
entry: fail_state[PRESS] = 1
[press > max_press | press < min_press] /Fail.INC
[press > min_press & press < max_press] Fail.DEC
Throttle
normal
entry: fail_state[THROT] = 0;
fail
entry: fail_state[THROT] = 1
[throt> max_throt | throt < min_throt]/ Fail.INC
[throt > min_throt & throt < max_throt] / Fail.DEC
Speed
normal
entry: fail_state[SPEED] = 0
fail
entry: fail_state[SPEED] = 1
[speed==0 & press < zero_thresh]/ Fail.INC
[speed > 0] / Fail.DEC
Fail
None
One
Multi
Two
Three
Four
INC
DEC
Fueling_Mode
Running
Low_Emissions
entry: fuel_mode = LOW
Normal
Warmup
Rich_Mixture
entry: fuel_mode = RICH
Single_Failure
[in(Fail.One)]
[in(Fail.None)]
[in(O2.normal)]
[speed > max_speed]
Fuel_Disabled
entry: fuel_mode = DISABLED
Overspeed
Shutdown
[!in(Fail.Multi)]
enter(Fail.Multi)
exit(Fail.Multi)
[in(Speed.normal) & ... speed < (max_speed - hys)]
[in(Fail.Multi)]

Stateflow notation

Hierarchical FSMs (Statecharts)

The FSM model presented until now can be extended by allowing

- Guards (conditions) and
- Actions on transitions

The original Statechart proposal added

- Hierarchy
- Concurrency
- Communication
- Transition joins
- History and deep history states

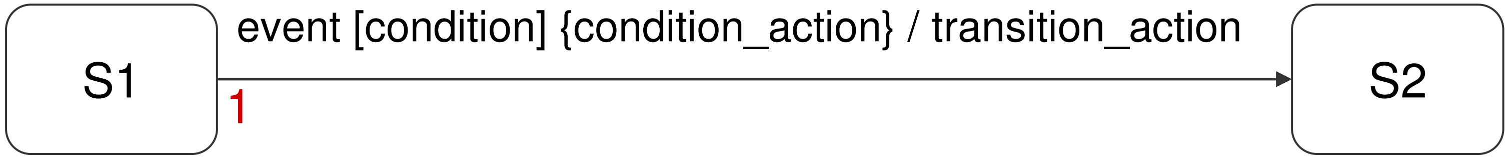
Completed with

- Entry,
- Exit,
- Do (while)

Actions on states

Transitions, conditions and actions (Stateflow)

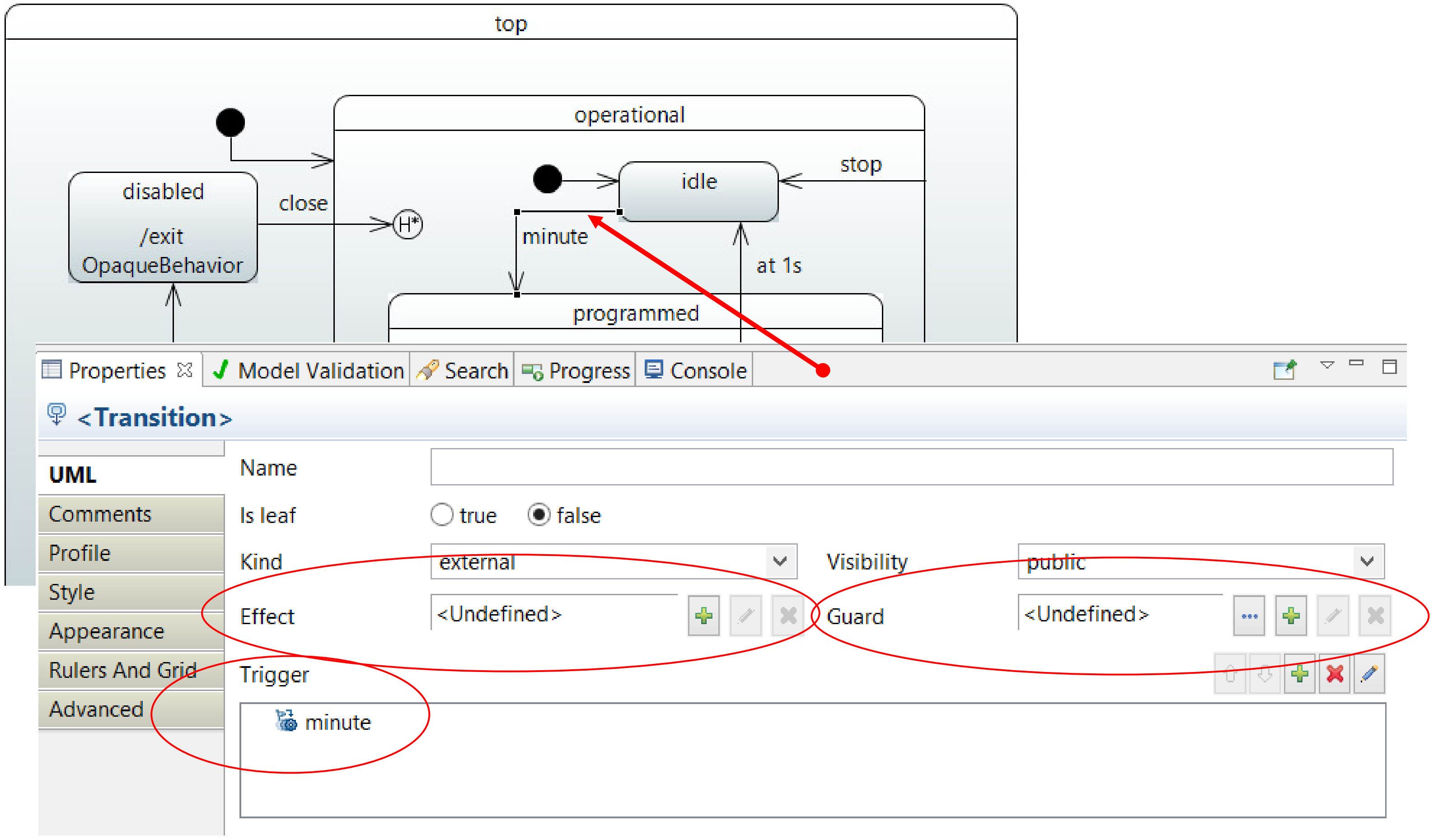
- The following example shows the general label format for a transition entering a state:



- When an event occurs (combination of events), the condition for the transition with a matching event ([condition]) is evaluated.
- If the condition condition evaluates to true, the condition action condition_action ({condition_action}) is executed.
- If the destination state is determined to be a valid destination, the transition is taken. State S1 is exited.
  - The difference between condition and transition actions is more clear when junctions are involved
- The transition action transition_action is executed when the transition is taken.
- State S2 is entered.

UML transitions

- UMl transitions are associated with a trigger event (or trigger operation), a guard (optional), an action (optional)



<Transition>

Name

Is leaf ( ) true [✓ false]

Kind: external

Visibility: public

Effect: <Undefined>

Guard: <Undefined>

Trigger

minute

Hierarchical FSMs (Statecharts)

Motivation for hierarchy: a complex system cannot be described naively in a flat, unstratified multitude of states, because of the very large number of such states.

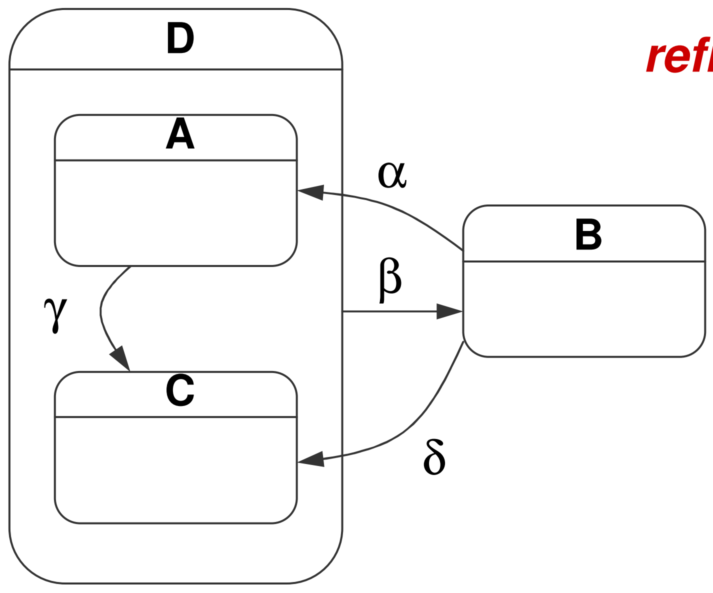
A state-based approach must be modular, hierarchical and well structured, without having to represent explicitly the combination of all states

Need to handle statements as

- “in all airborne states, when yellow handle is pulled, the seat will be ejected” (*cluster states into superstates*)
- “gearbox change of state is independent from braking system” (*independence or orthogonality*)
- “when selection button is pressed, enter selection mode” (*general transitions*)
- Display mode consists of time-display, date-display and stopwatch-display (*refinement of states*)

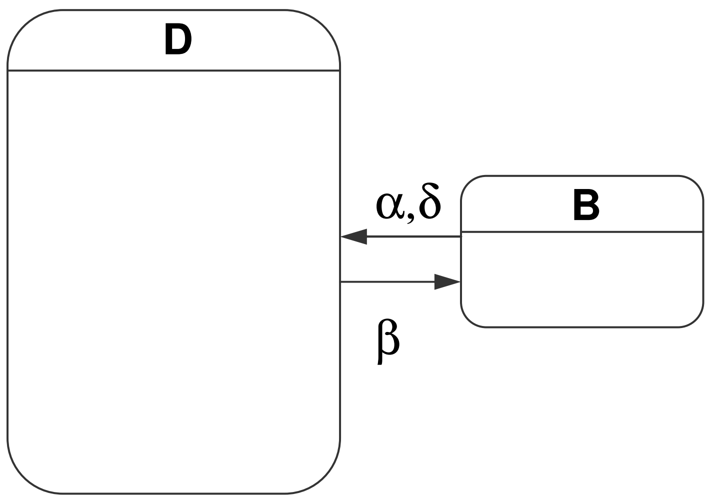
Hierarchical FSMs (Statecharts)

OR-clustering of states



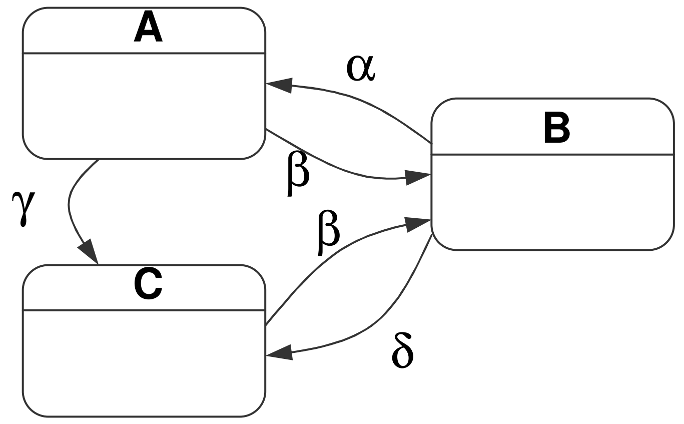
Allows abstraction

refines …



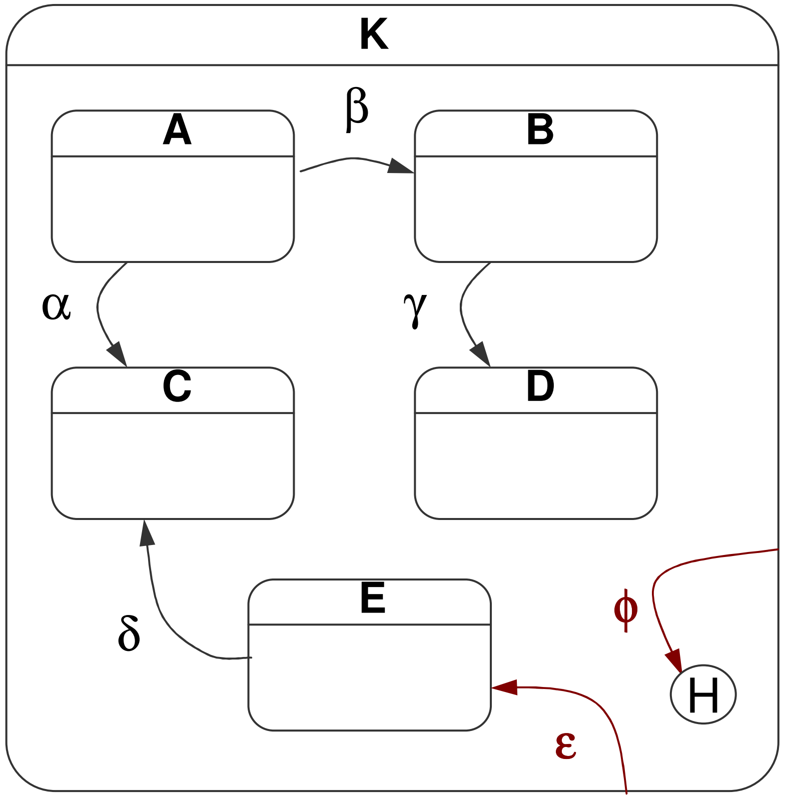
Same as …

(saves arrows)

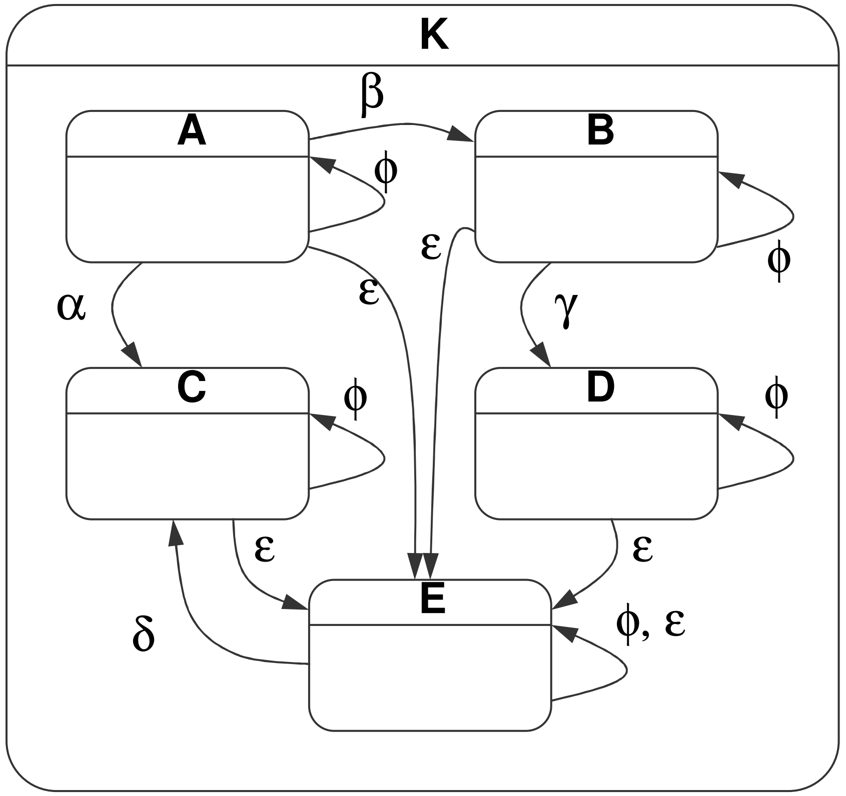


Hierarchical FSMs (Statecharts)

Transitions that apply to all the states of a superstate



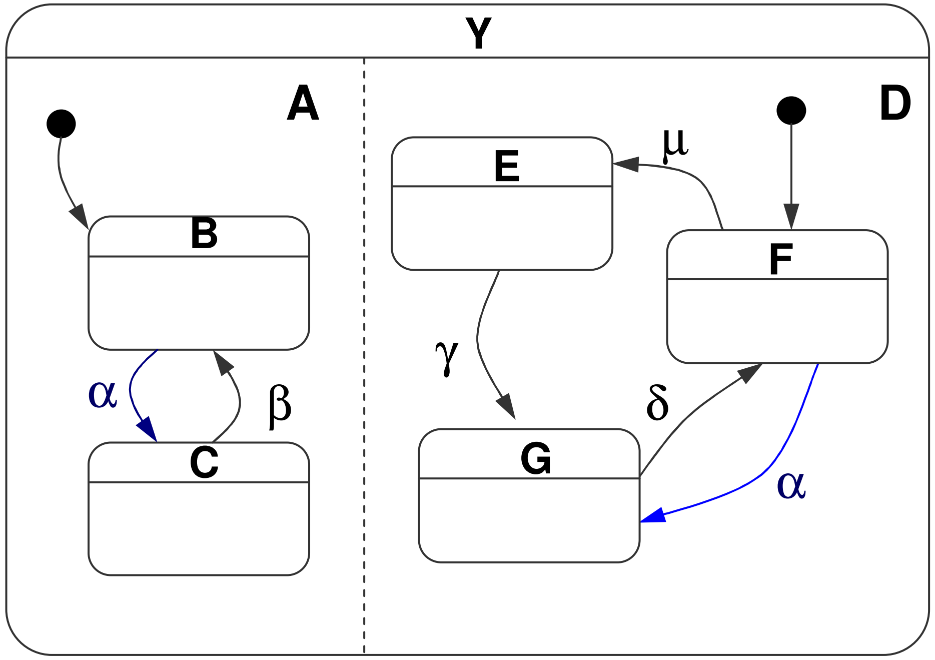
ε and ϕ apply to all states of K (A B C D E F)

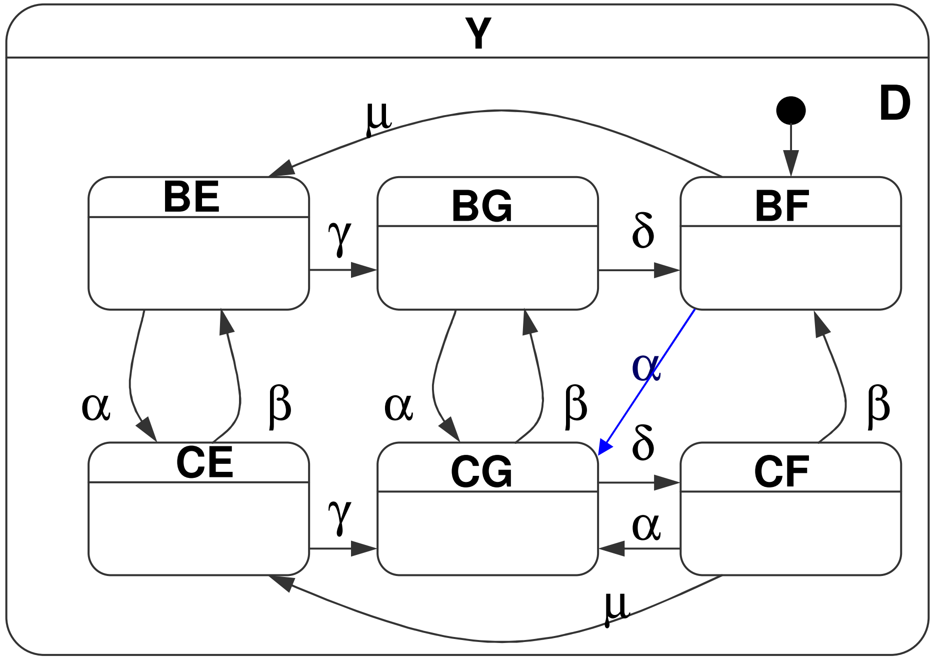


Same as …
(saves arrows)

Hierarchical FSMs (Statecharts)

AND-clustering of states





(UML notation)

The subsystem is explicitly defined as a number of FSM evolving in parallel

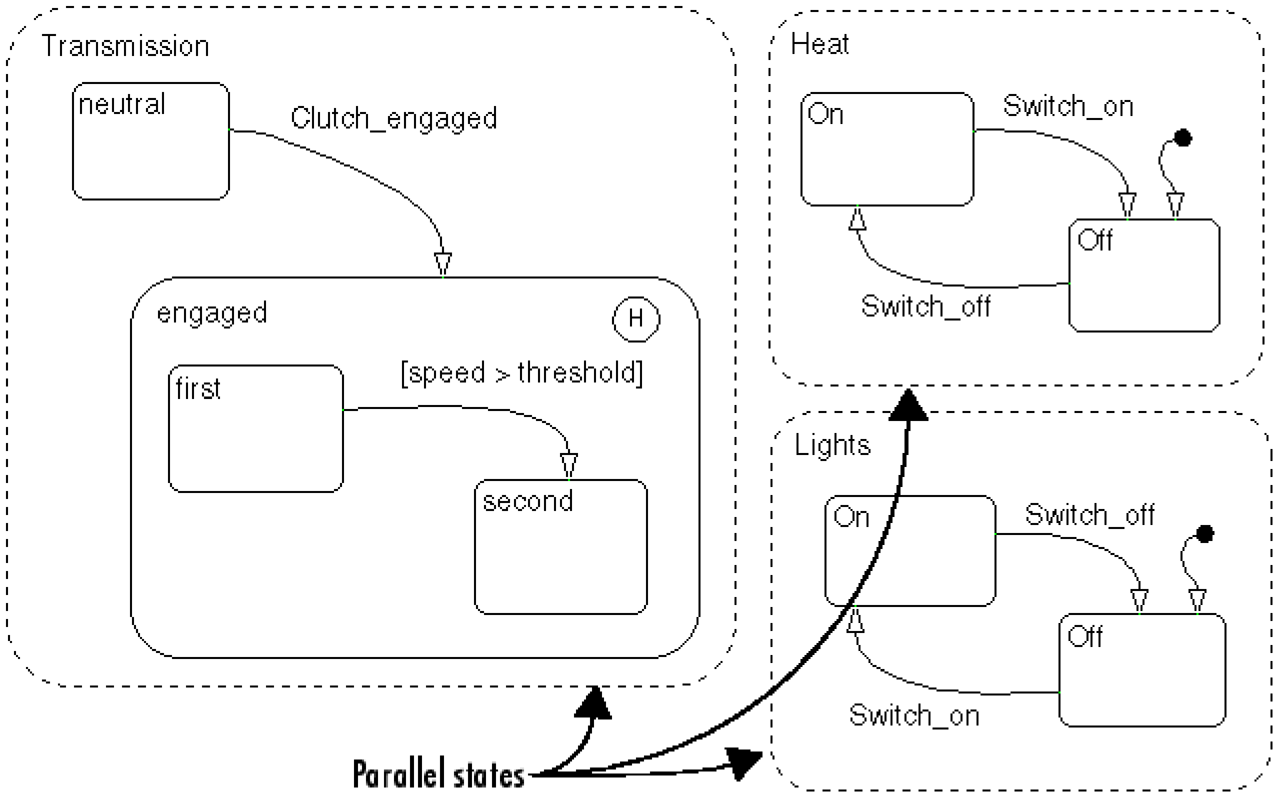
Same as …

There is a considerable reduction in the number of states and transitions.

α is taken synchronously!

Statecharts: AND (parallel)states

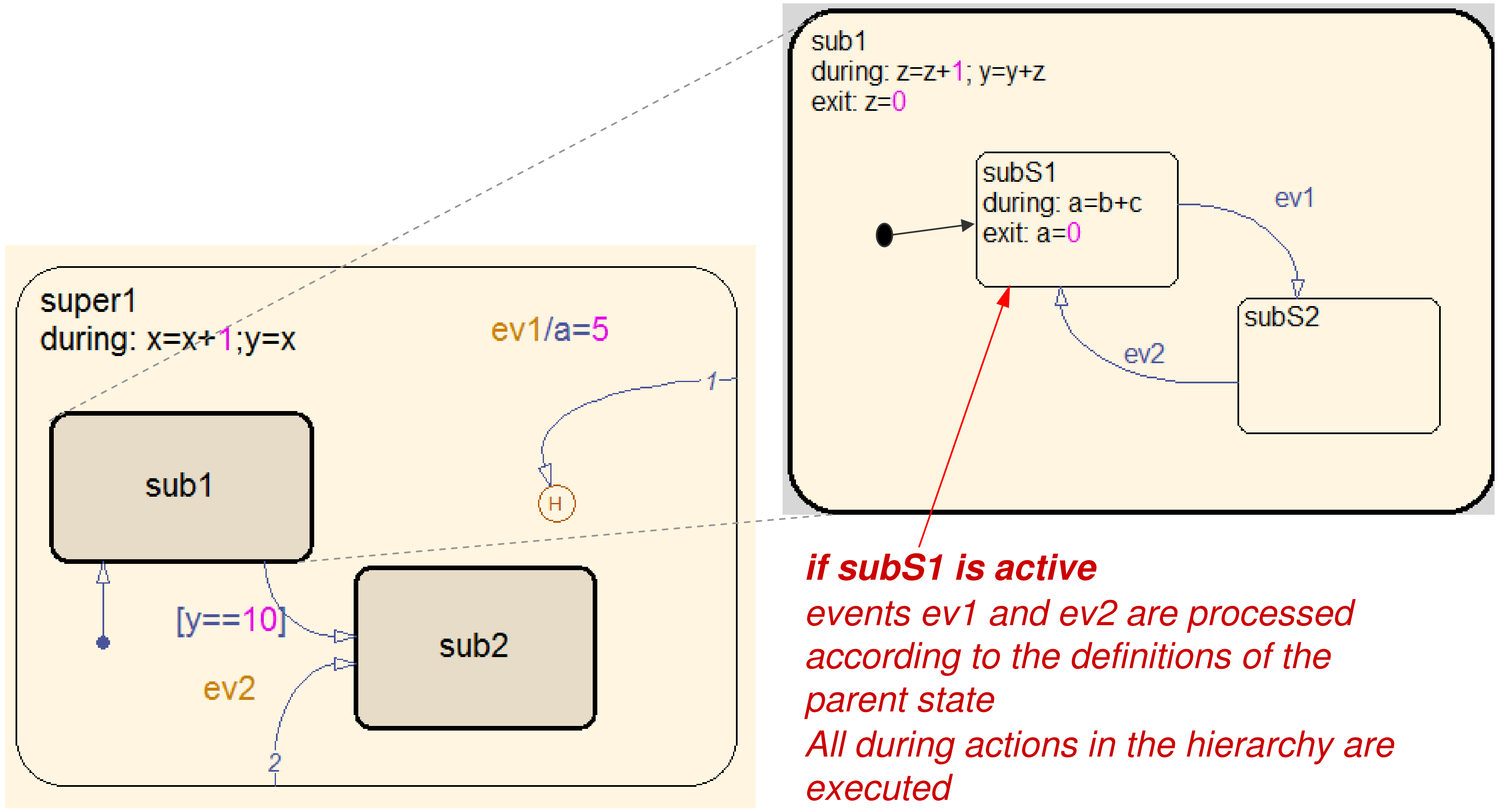
- Stateflow notation for AND states



Hierarchical FSMs (Statecharts)

Transition and action inheritance

Inner states inherit the transitions and actions of parent states



if subS1 is active

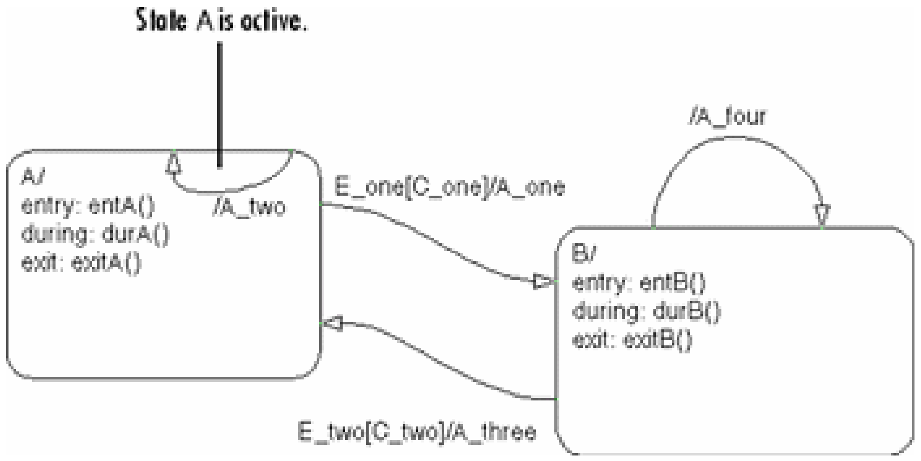
events ev1 and ev2 are processed according to the definitions of the parent state

All during actions in the hierarchy are executed

Inner and outer junctions

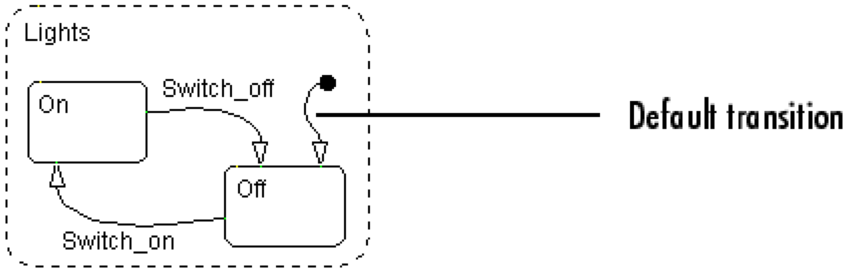
Difference between inner and outer transitions

- In inner transitions exit and entry statements are not executed
- In outer transitions, the state is exited and re-entered



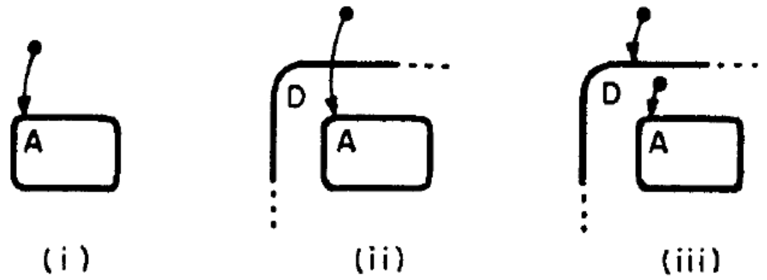
- UML does not have inner transitions

Default transition, history and deep history state



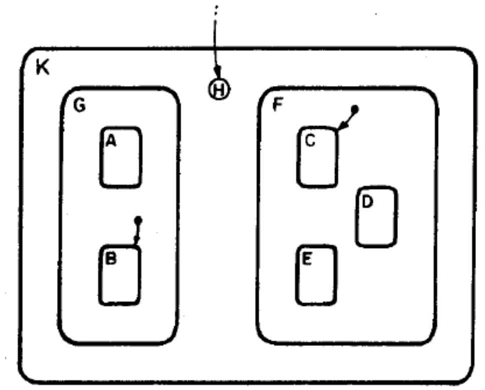
A default transition is taken when a chart (subchart) is entered first.

Extends the concept of initial state providing an initial transition

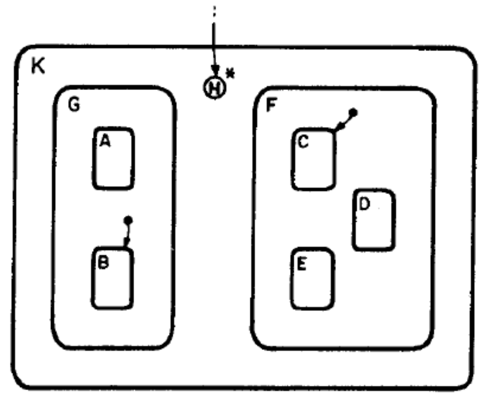


Several options are possible for subcharted states

History state (H): the last active state in the current subchart



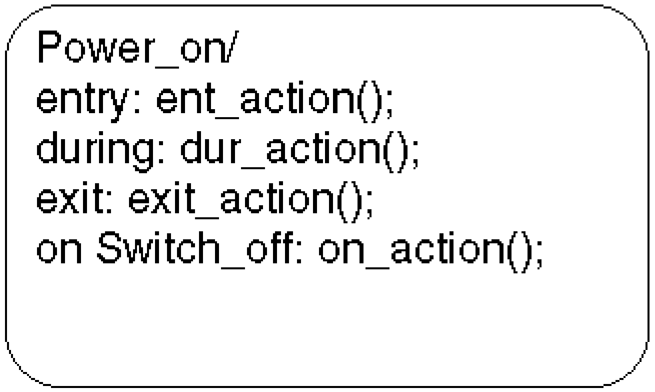
Deep history state (H*): the last active state in the current subchart and its subcharts (recursively)



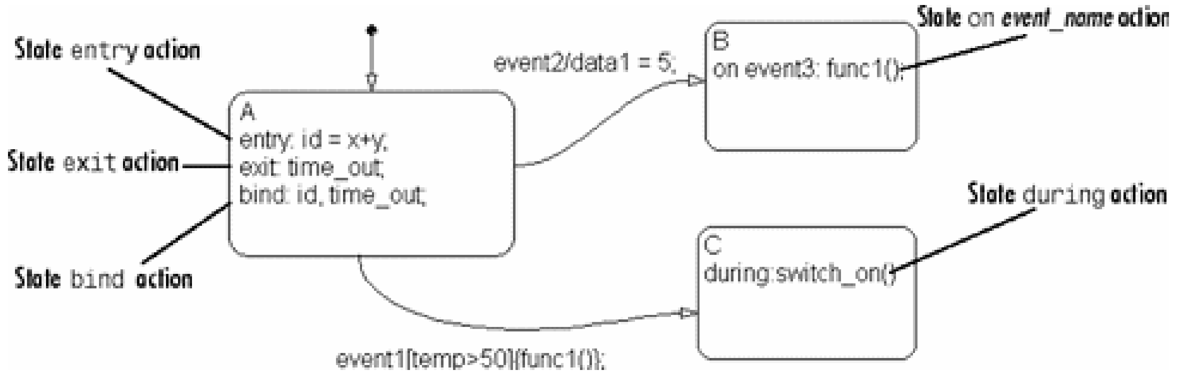
State actions

States can have different action types, which include entry, during, exit, bind, and, on event_name actions.
In stateflow, the actions for states are assigned using 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
```



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



State actions

Stateflow syntax

actions are preceded by the prefix or the short prefix, 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).

State actions

Entry Actions (entry: or en:)

Entry actions are executed for a state when the state is entered (becomes active).

Exit Actions (exit: or ex:)

Exit actions for a state are executed when the state is active and a transition out of the state is taken.

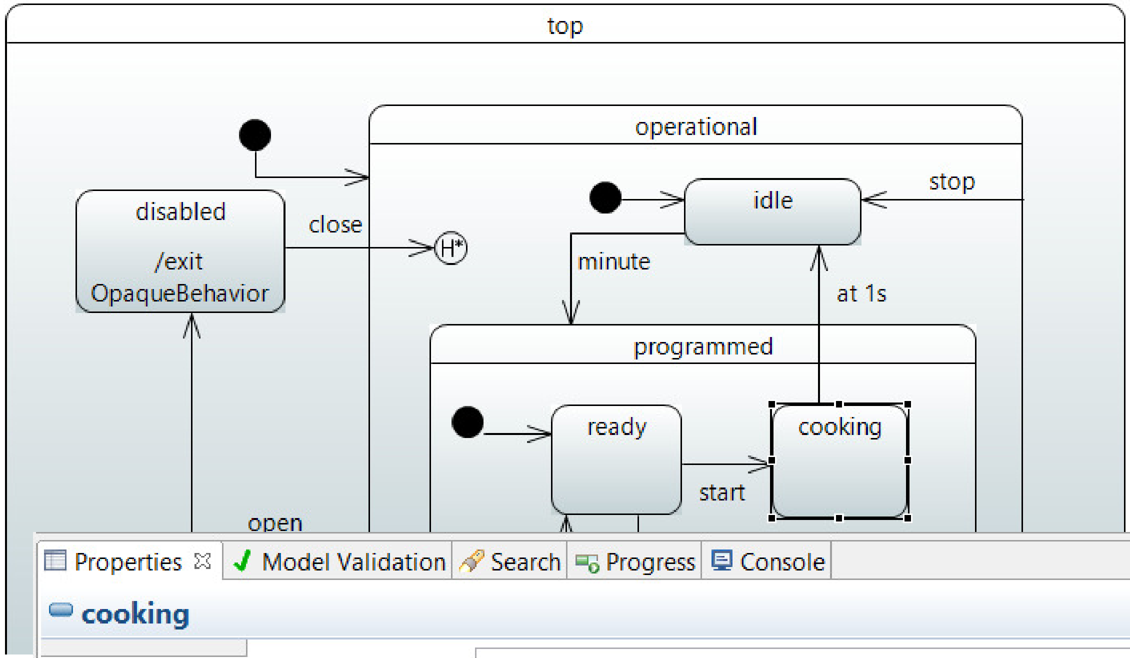
During Actions (during: or du:)

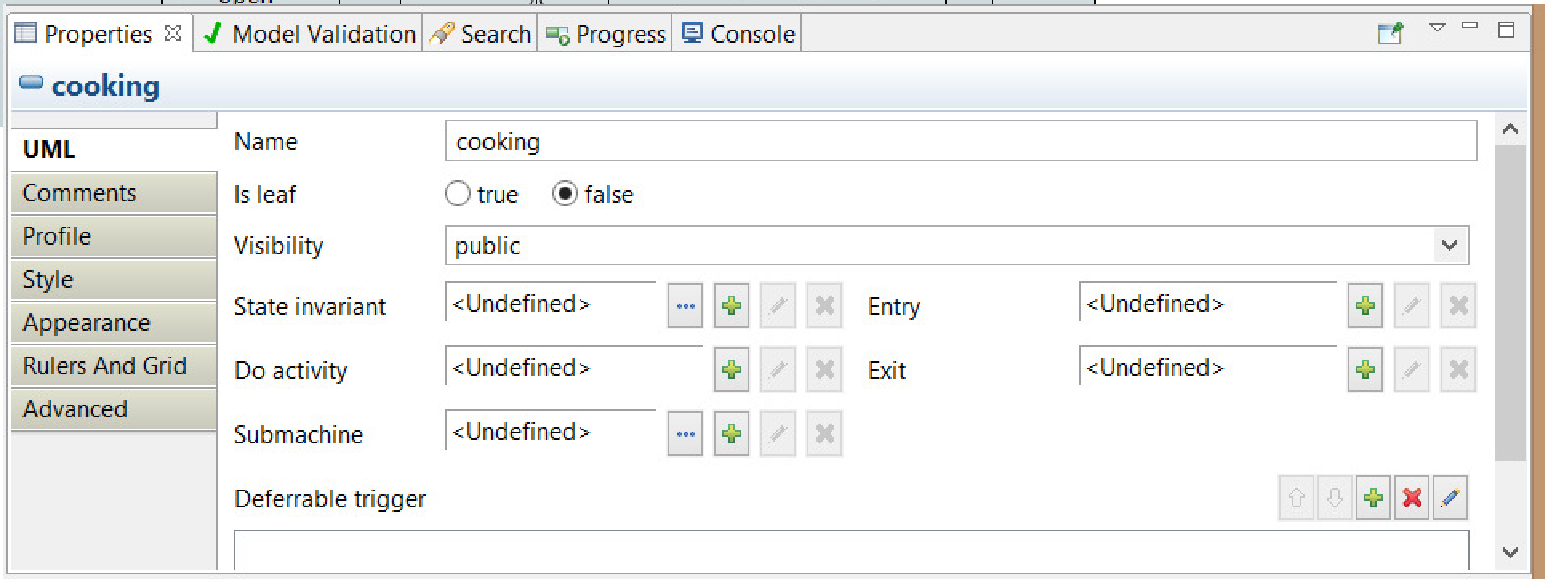
During actions are executed for a state when it is active and an event occurs and no valid transition to another state is available.

On Event_Name Actions (on event event_name:)

There can be multiple on event_name lines for different events. On event_name actions 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.

State actions in UML





cooking

UML
Comments
Profile
Style
Appearance
Rulers And Grid
Advanced

Name	cooking		
Is leaf	true [✓ false]		
Visibility	public		
State invariant	<Undefined>	Entry	<Undefined>
Do activity	<Undefined>	Exit	<Undefined>
Submachine	<Undefined>		
Deferrable trigger			

Entry Action

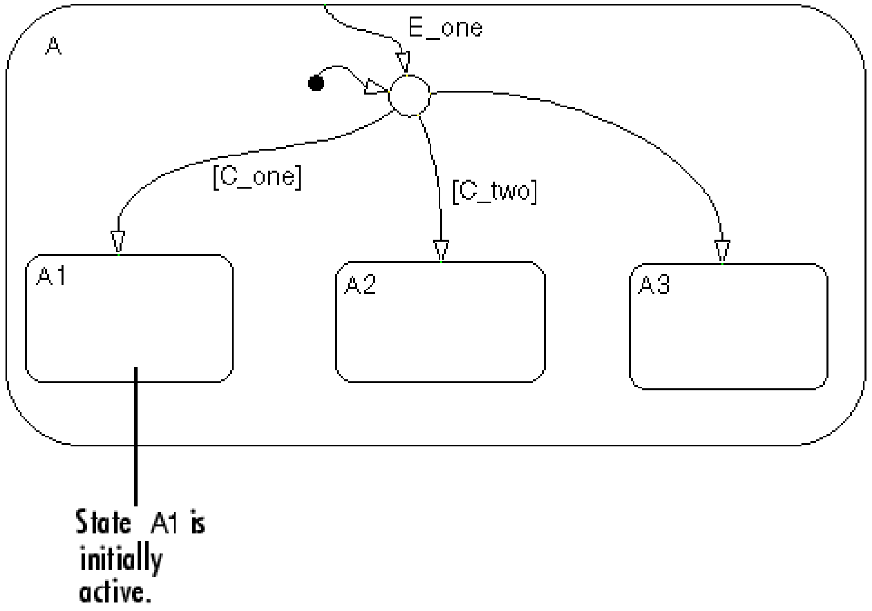
Exit Actions

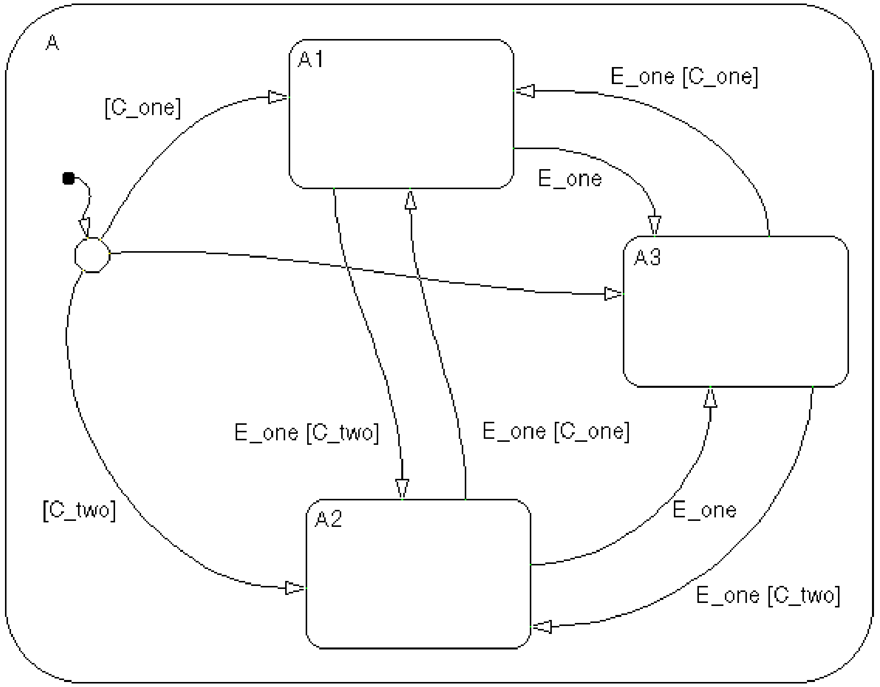
Do activity

State invariant

Transition junctions

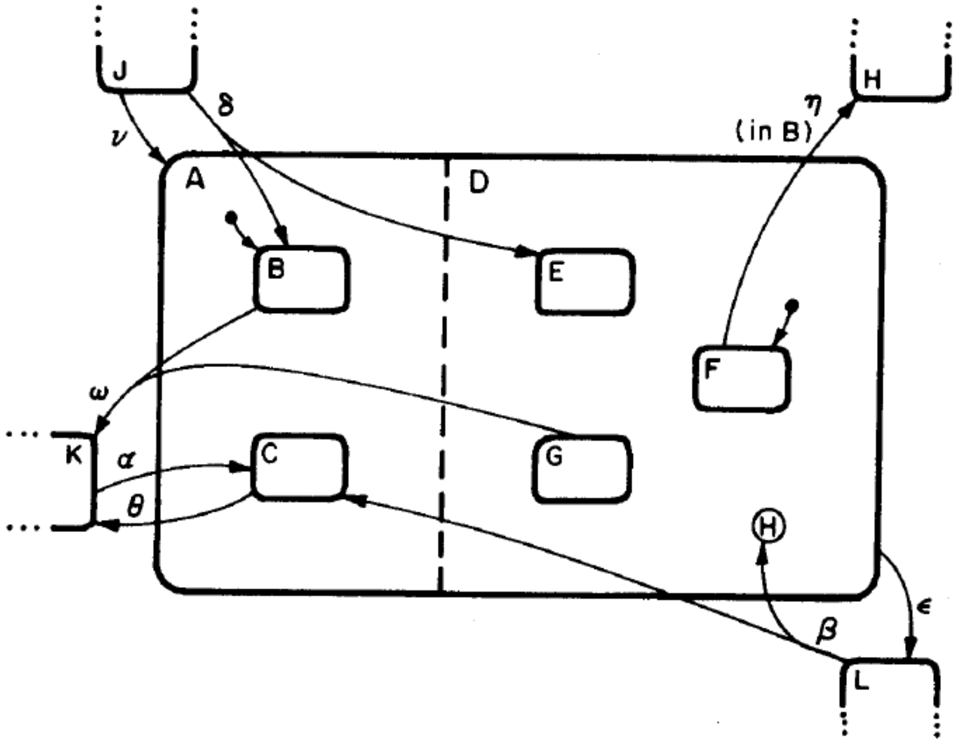
- Transition junctions are additional shortcuts that allow to group together conditions/actions that apply to multiple transitions

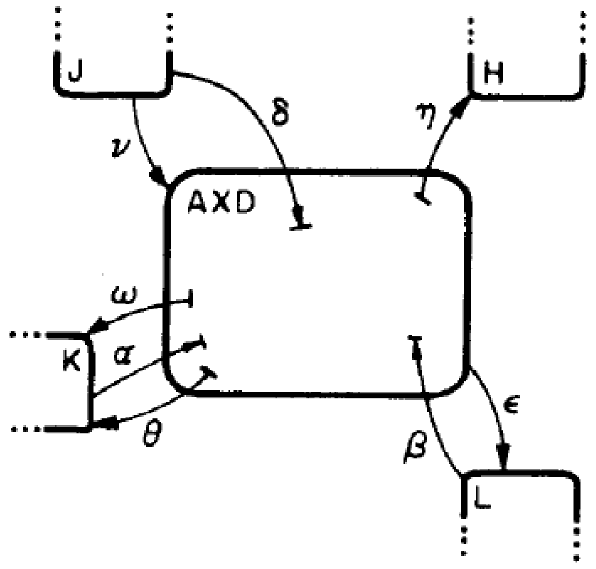




Connective junctions

- To/from AND states





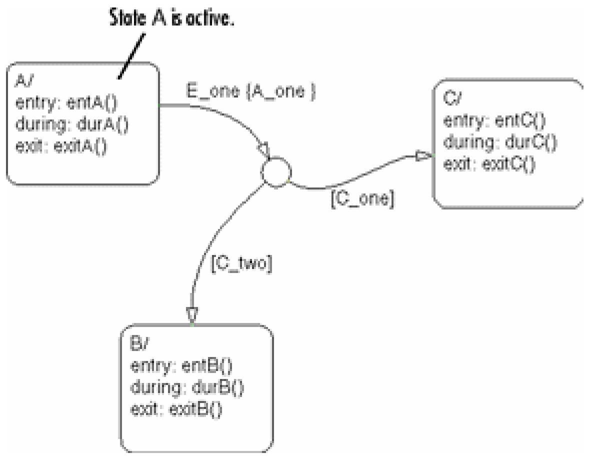
Connective junctions

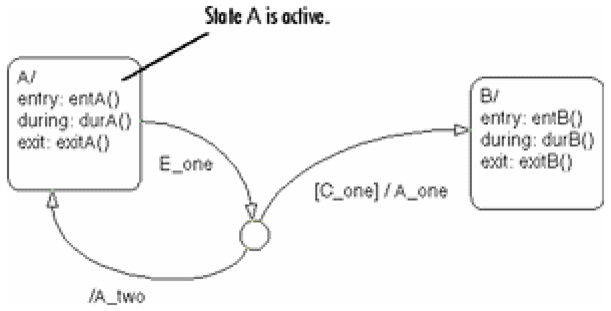
Other types:

From Mathworks' definition:

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

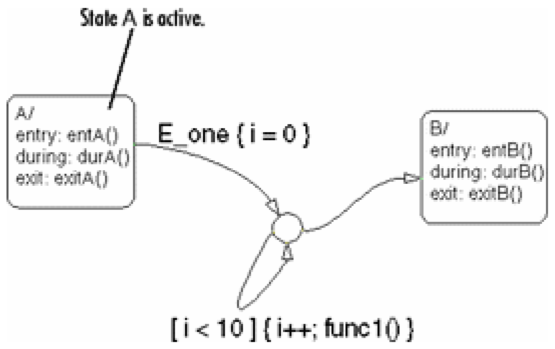


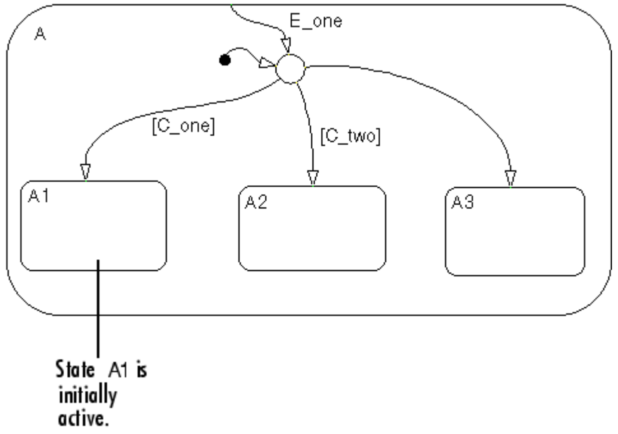


Connective junctions

Other types:

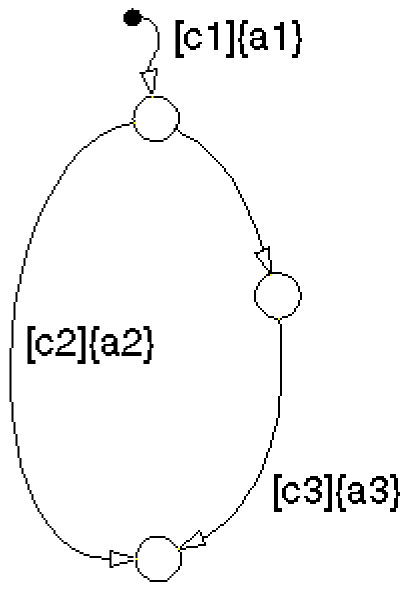
- …
- Variations of a for loop construct, by having a self-loop transition from the connective junction back to itself
- Transitions from a common source to multiple destinations
- Transitions from multiple sources to a common destination
- Transitions from a source to a destination based on common events





Connective junctions

- Connective junctions can be used to define a program dataflow



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

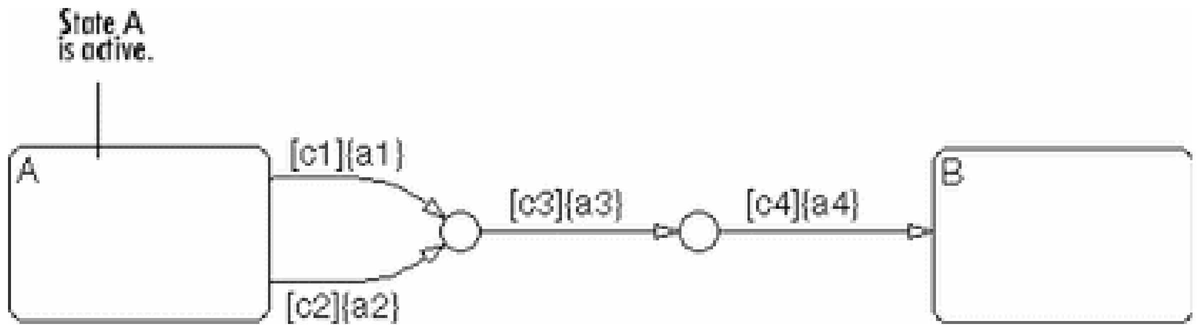
Backtracking on junctions

Transitions with junctions may force backtracking.

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

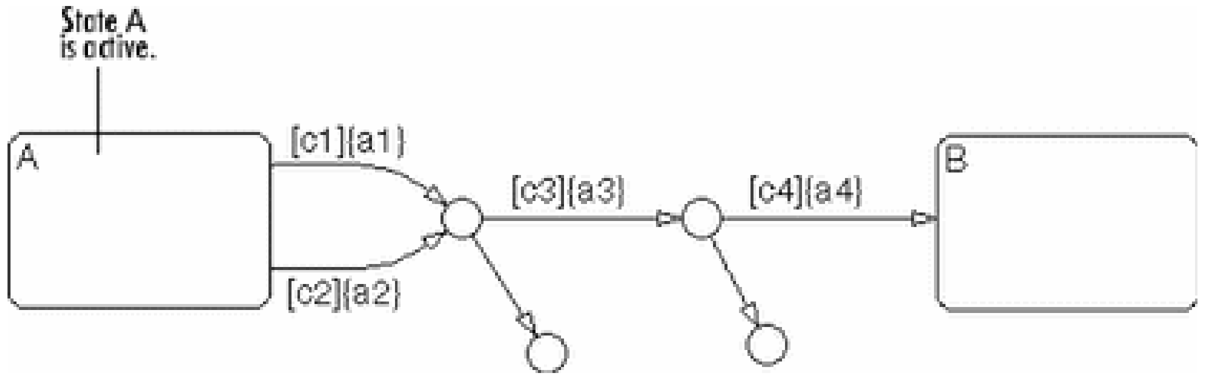
- Condition c1 is true, therefore action a1 is executed.
- Condition c3 is true, therefore action a3 is executed.
- Condition c4 is not true, therefore control flow is backtracked to state A.
- The Stateflow diagram root checks to see if there is another valid transition from state A. There is a valid transition segment marked with the condition c2 from state A to a connective junction.
- Condition c2 is true, therefore action a2 is executed.
- Condition c3 is true, therefore action a3 is executed.
- Condition c4 is not true, therefore control flow is backtracked to state A.

Both a1 and a2 are executed, a3 is executed twice.



Backtracking on junctions

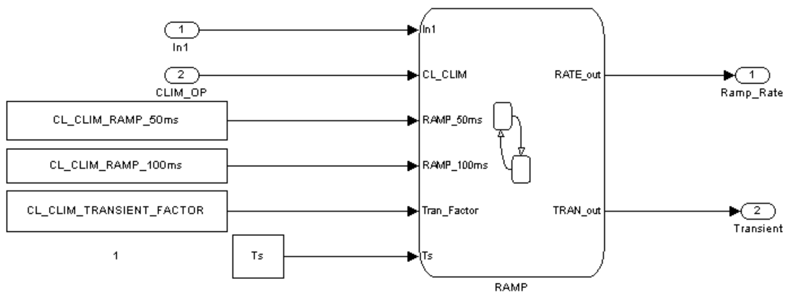
To resolve this problem, consider the following. The previous example is amended with two terminating junctions that allow flow to terminate if either c3 or c4 is not true. This leaves state A active without taking any unnecessary actions.

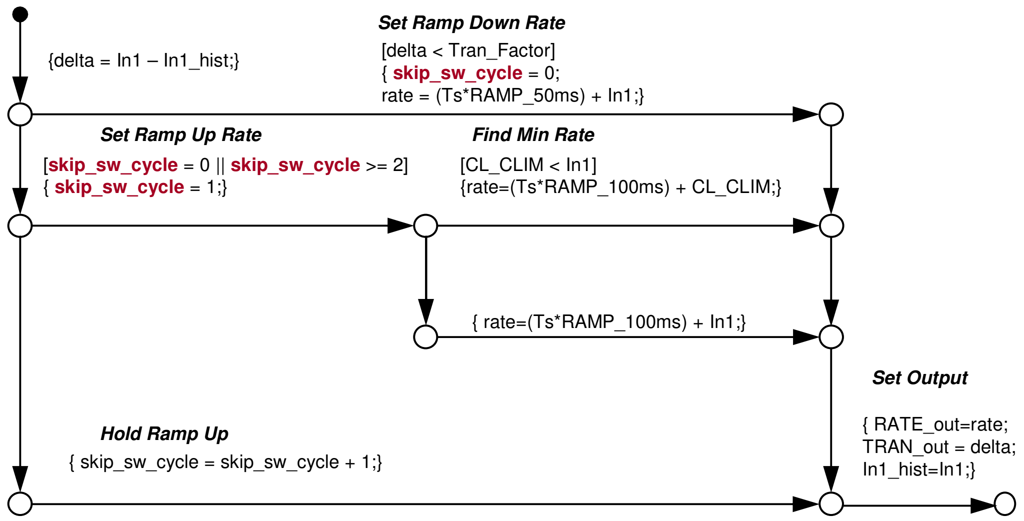


Transition junctions

Transitions with connective junctions and actions can be used to achieve the same expressive power of dataflows or standard programs (transition graphs).

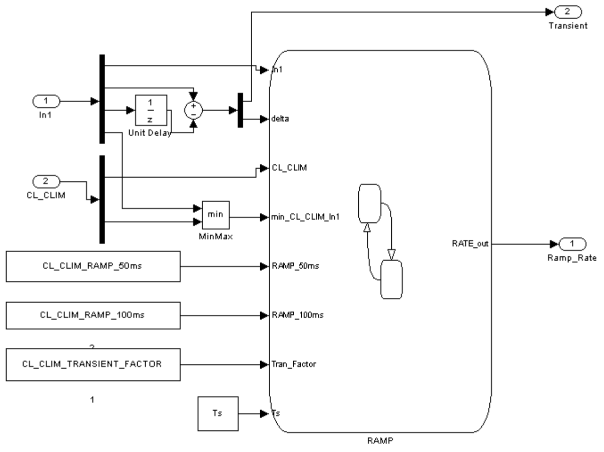
- This often occurs and it is not recommended (unless ***truly*** needed)

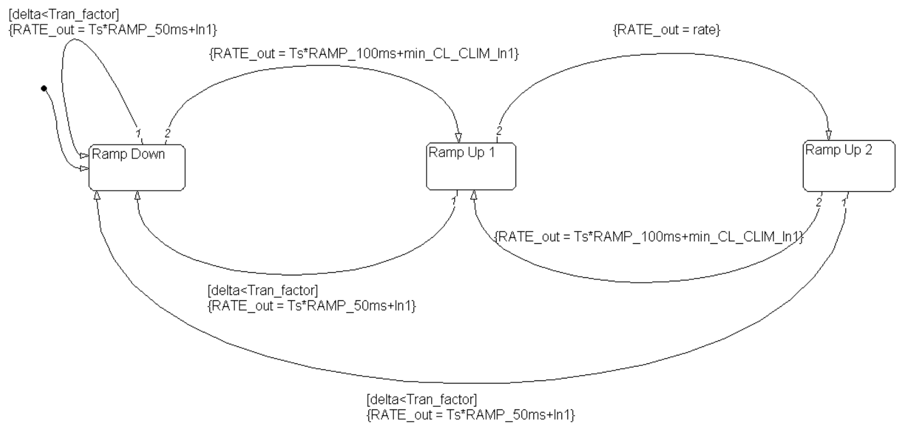




Stateflow models

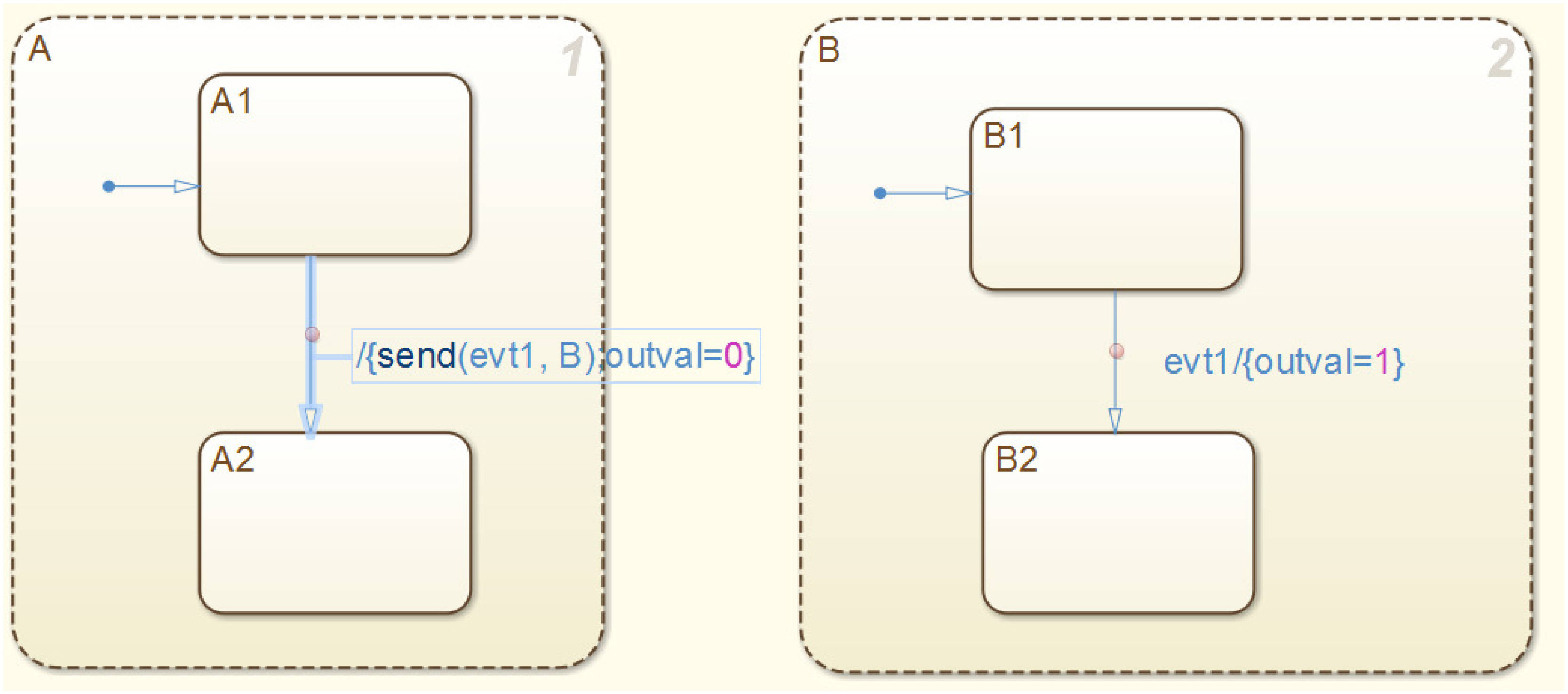
- Comment: not recommended for *many* reasons
  - Typically not a specification, but an algorithmic description
  - Hides the state view
  - Hides side effects
  - As difficult to debug and simulate as program!
  - Not necessary




[delta<Tran_factor]
{RATE_out = Ts*RAMP_50ms+In1}
{RATE_out = Ts*RAMP_100ms+min_CL_CLIM_In1}
{RATE_out = rate}
Ramp Down
Ramp Up 1
Ramp Up 2
1
2
2
1
2
1
{RATE_out = Ts*RAMP_100ms+min_CL_CLIM_In1}
[delta<Tran_factor]
{RATE_out = Ts*RAMP_50ms+In1}
[delta<Tran_factor]
{RATE_out = Ts*RAMP_50ms+In1}

Run to completion vs. interruptible

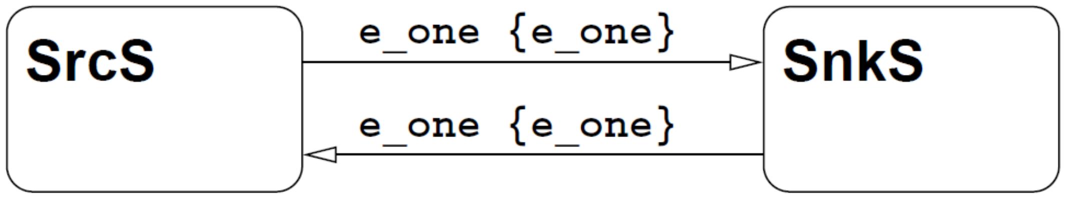
- Simulink does not have a rtc semantics (UML does)



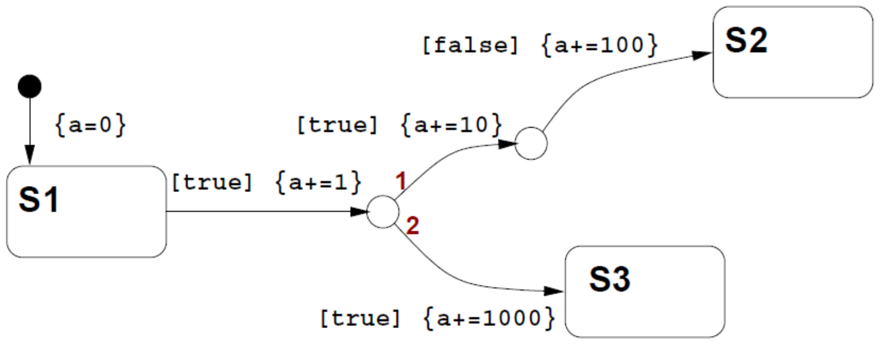
The end result for outval is 0

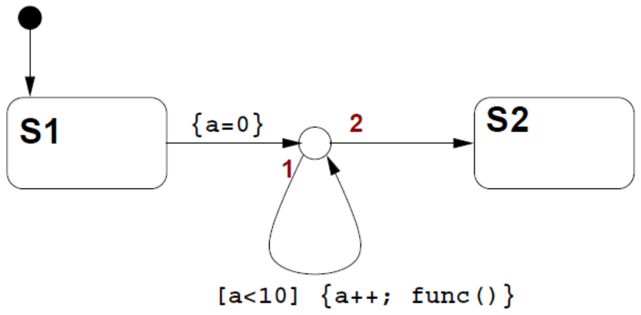
Stateflow semantics issues

- Possible infinite loop (recursion)



- Possible side effects





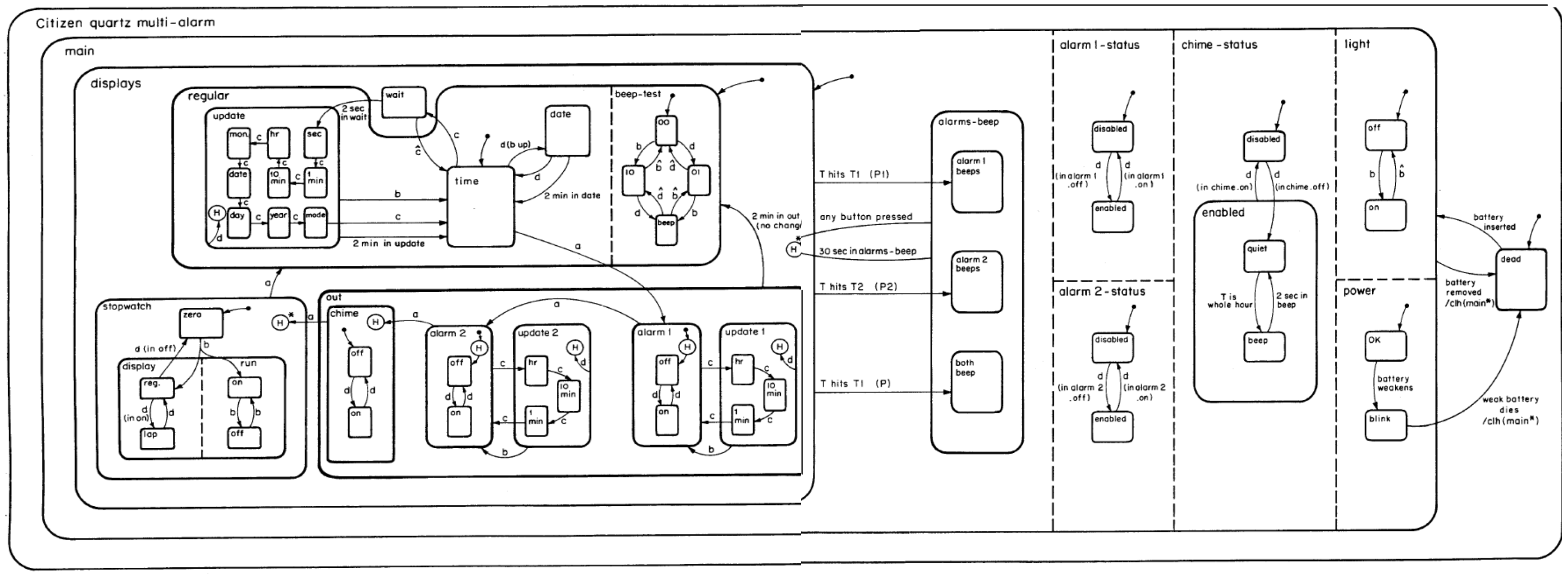
Stateflow – safety of models

- Absence of multi-segment loops when using junctions;
- Acyclicity of triggering and emitted events;
  - Avoid internal events?
- No assignment of values to variables in intermediate transition segments;
- Outgoing junction conditions form a cover;
- Outgoing junction conditions are disjoint;
- Assignment of different values to the same variable does not occur in concurrent states (confluence);
- The model is free of early return logic.

- For more, check the MAAB guidelines…

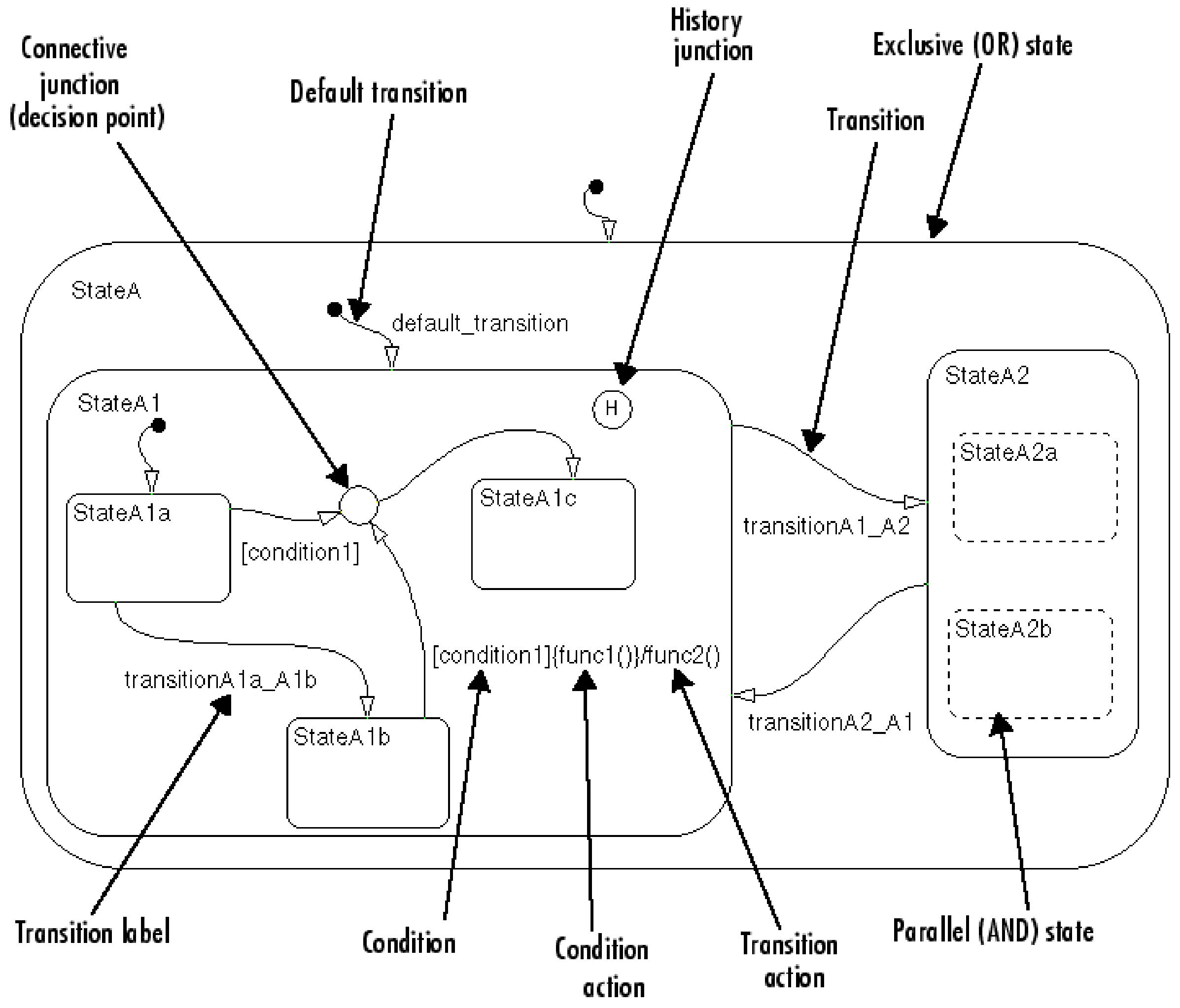
Statecharts

Harel's stopwatch

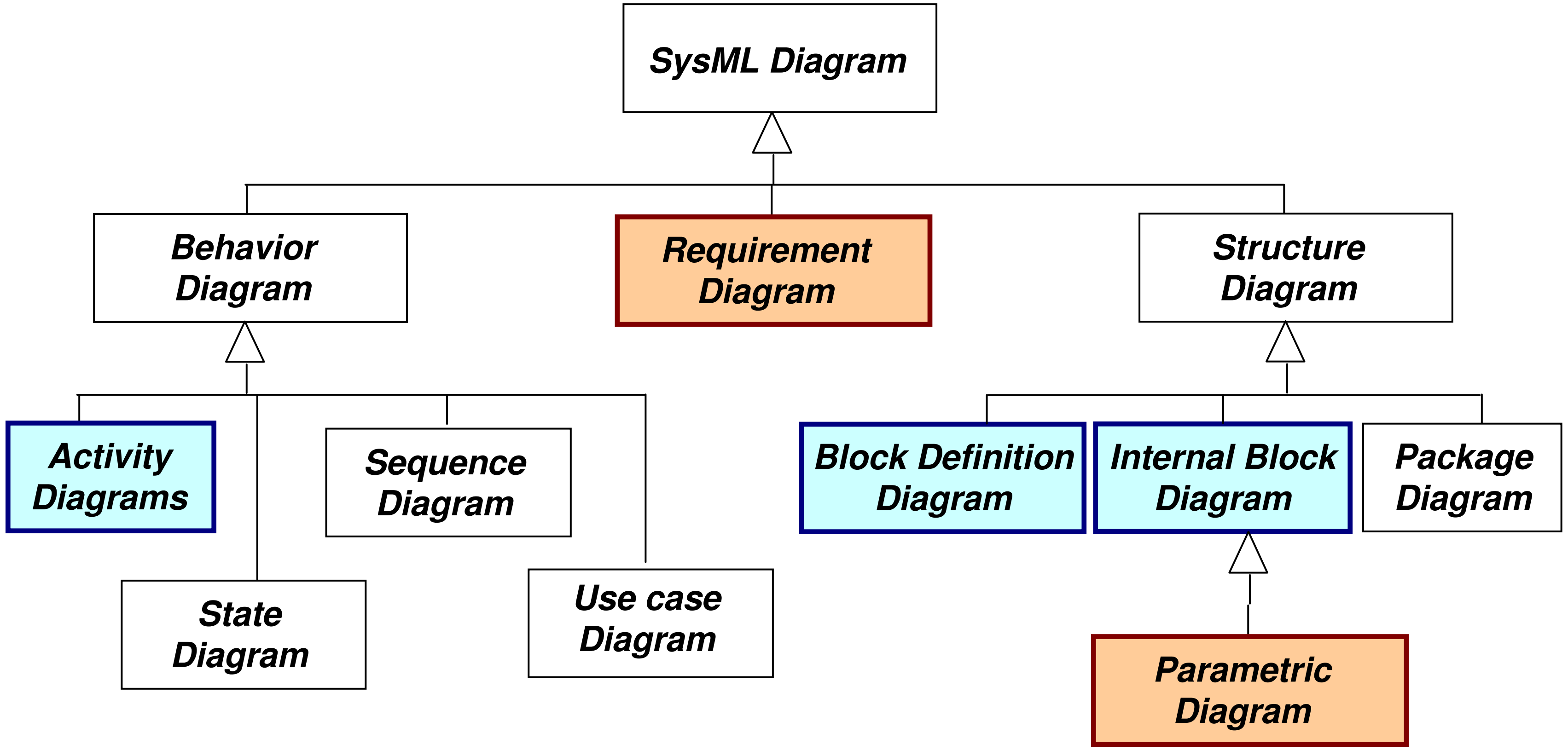


Stateflow

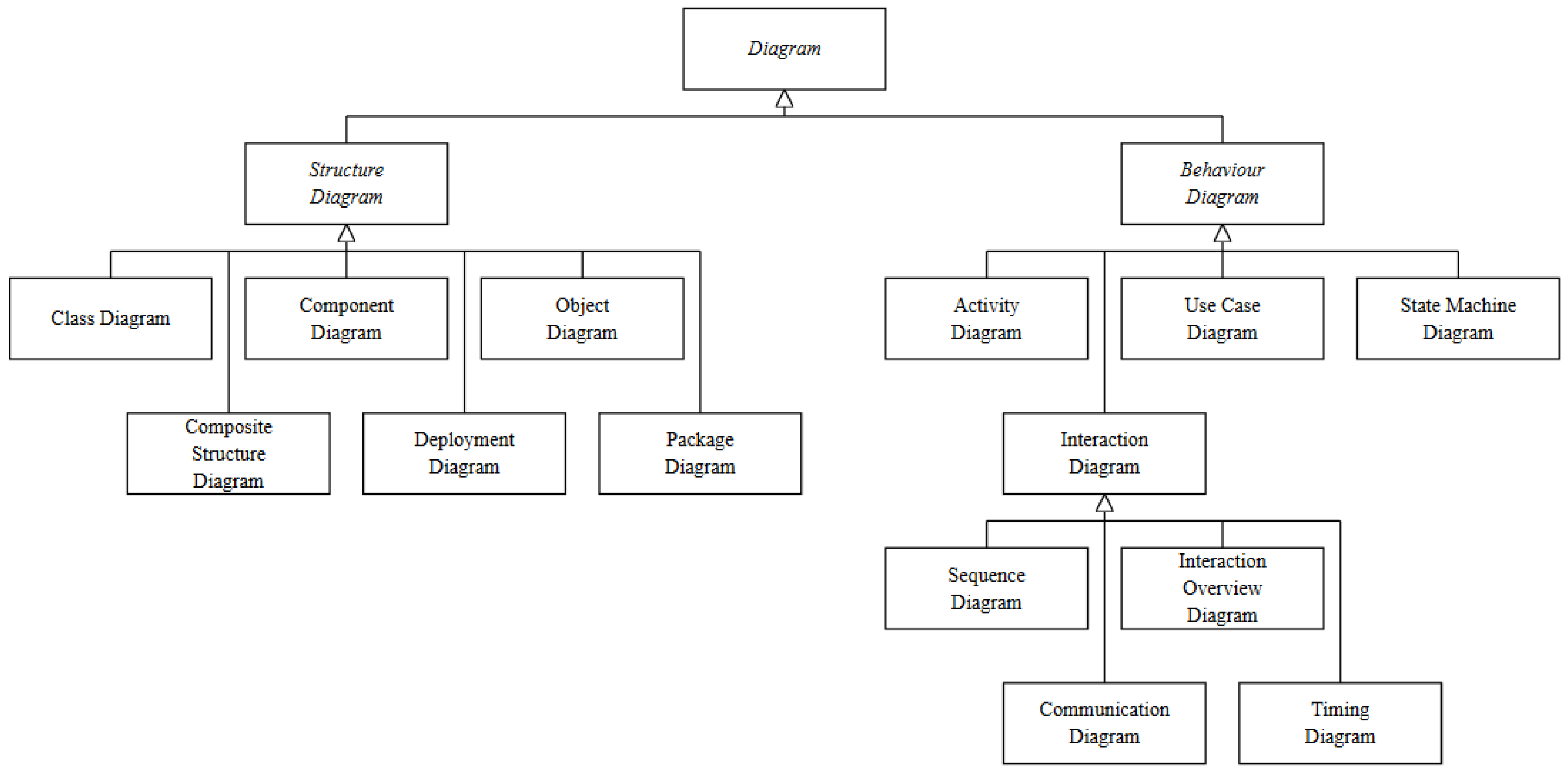
- a summary of the notation ….



SysML diagrams



UML diagrams

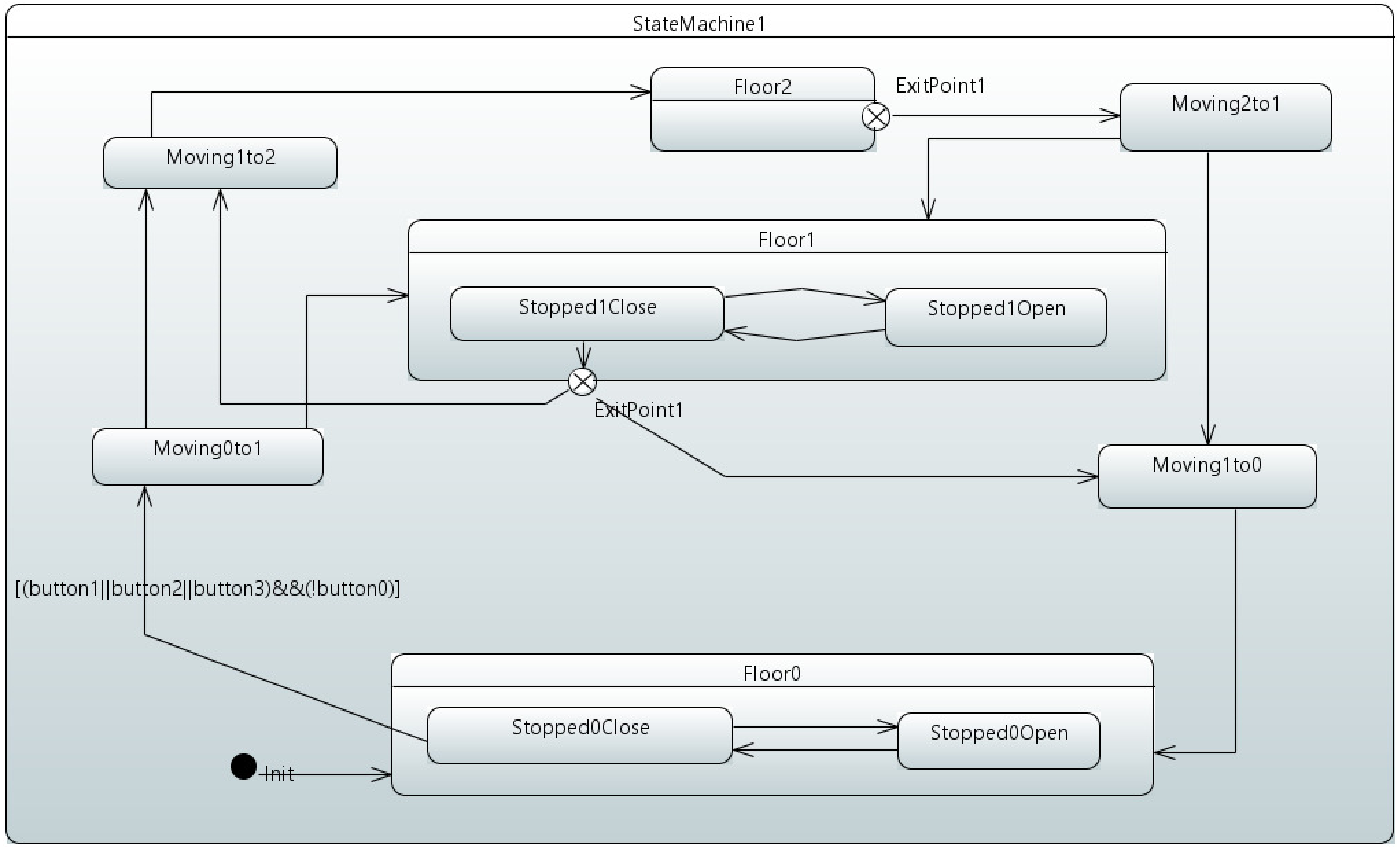


State Machine

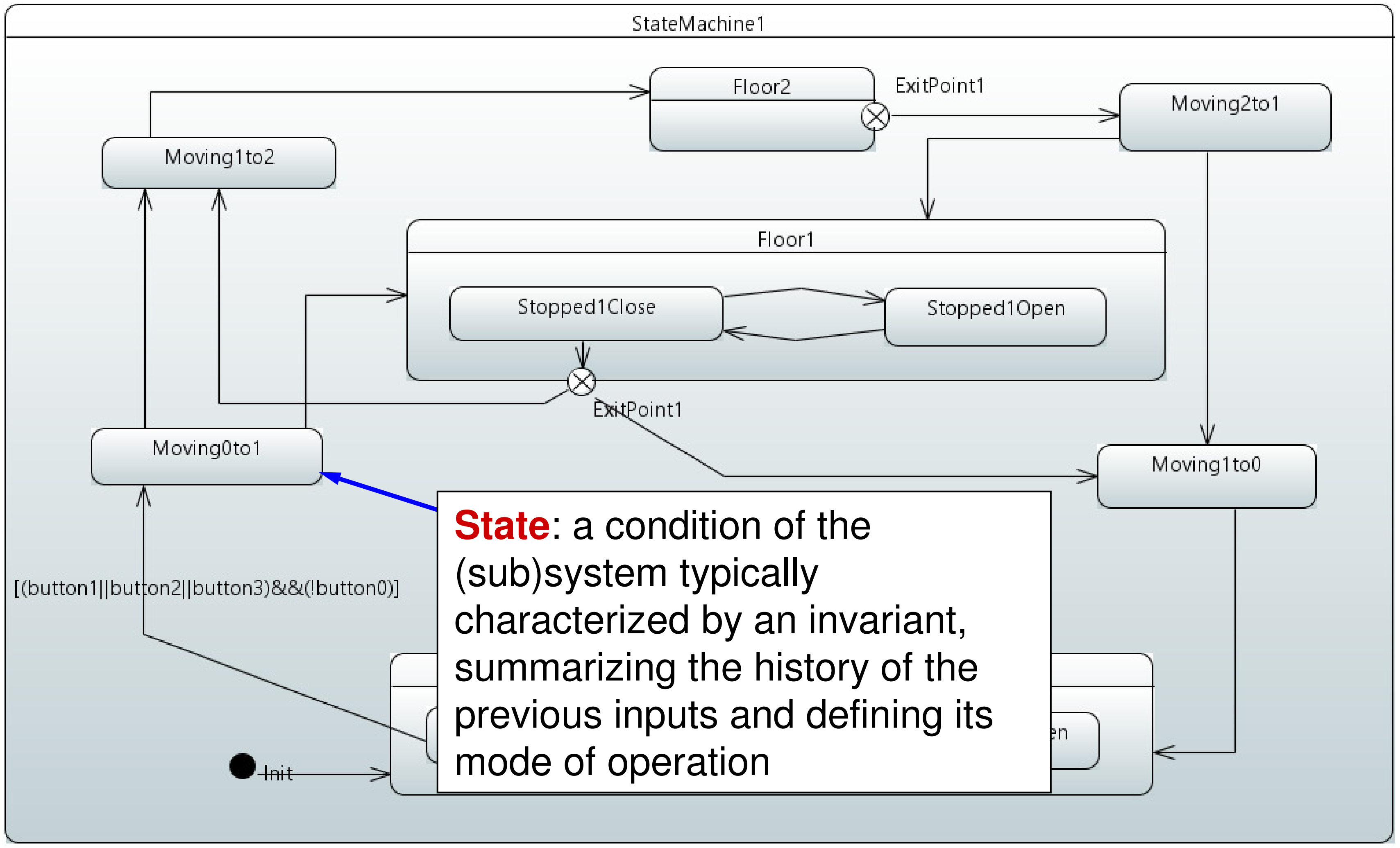
- Used to represent the life cycle of a block
- event-based behavior (generally asynchronous) Transition with trigger, guard, action
- State with entry, exit, and do-activity
- Can include nested sequential or concurrent states
- Can send/receive signals to communicate between blocks during state transitions, etc.

- Event types
  - Change event
  - Time event
  - Signal event

Elements of State Diagrams

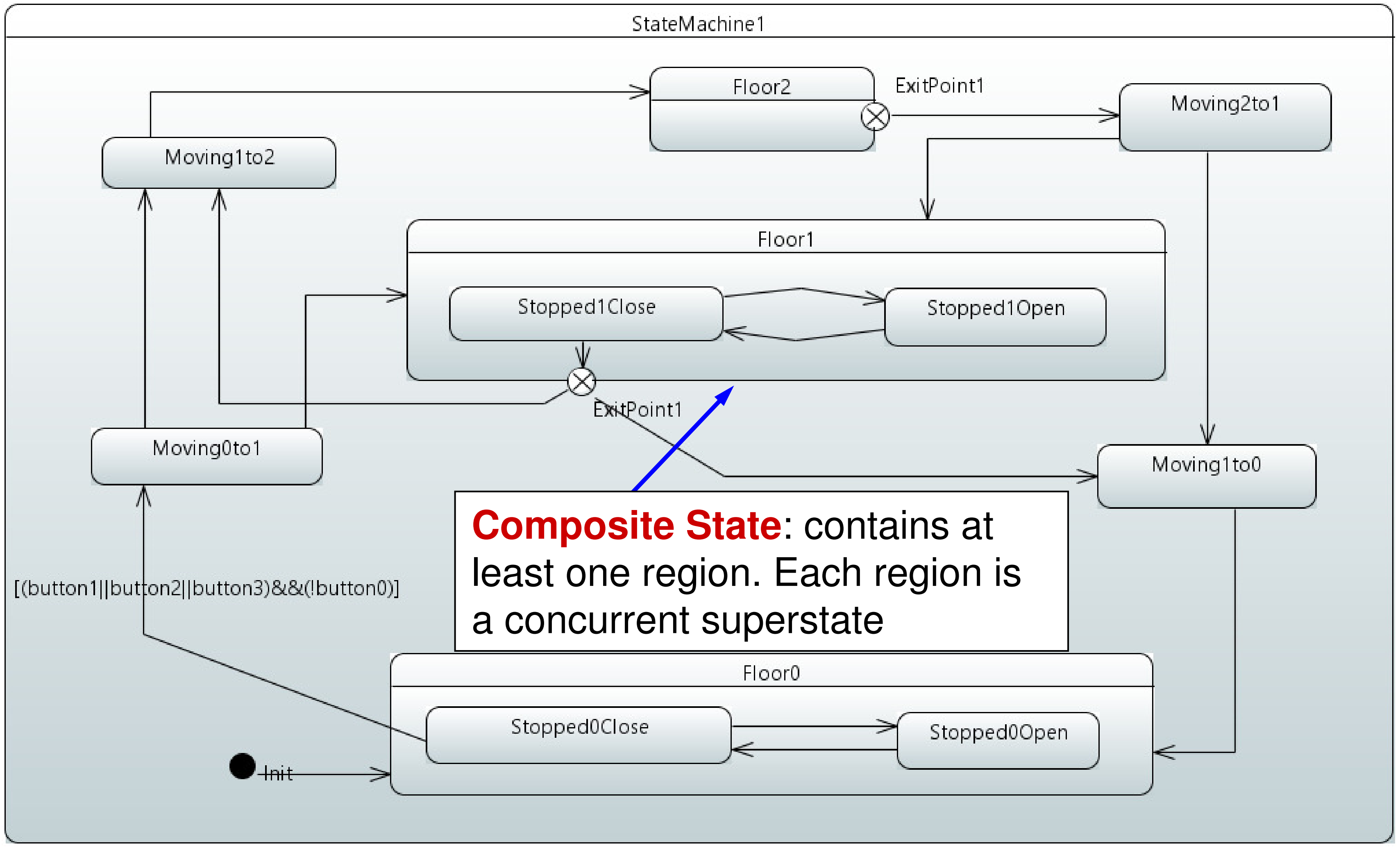


Elements of State Diagrams



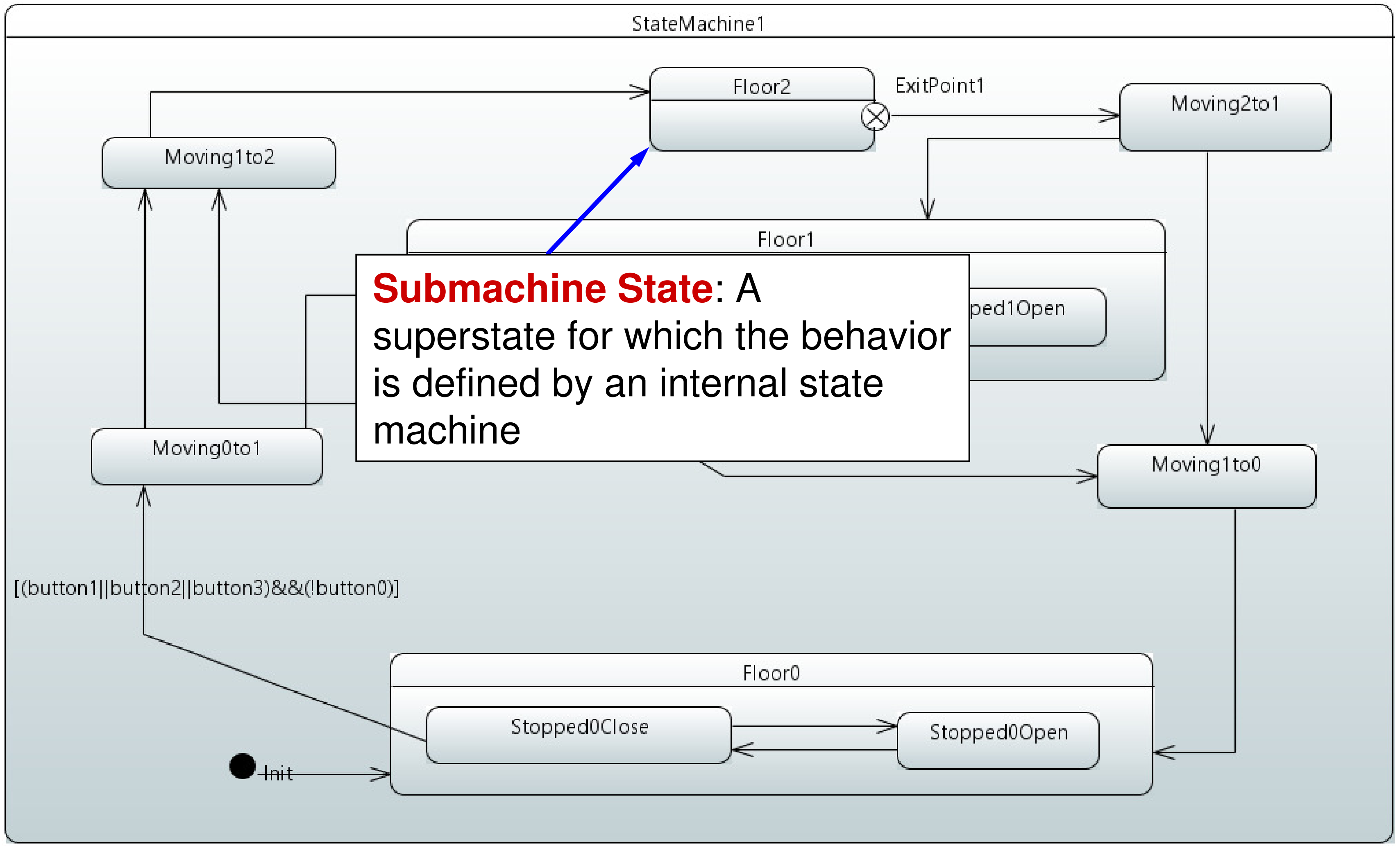
State: a condition of the (sub)system typically characterized by an invariant, summarizing the history of the previous inputs and defining its mode of operation

Elements of State Diagrams



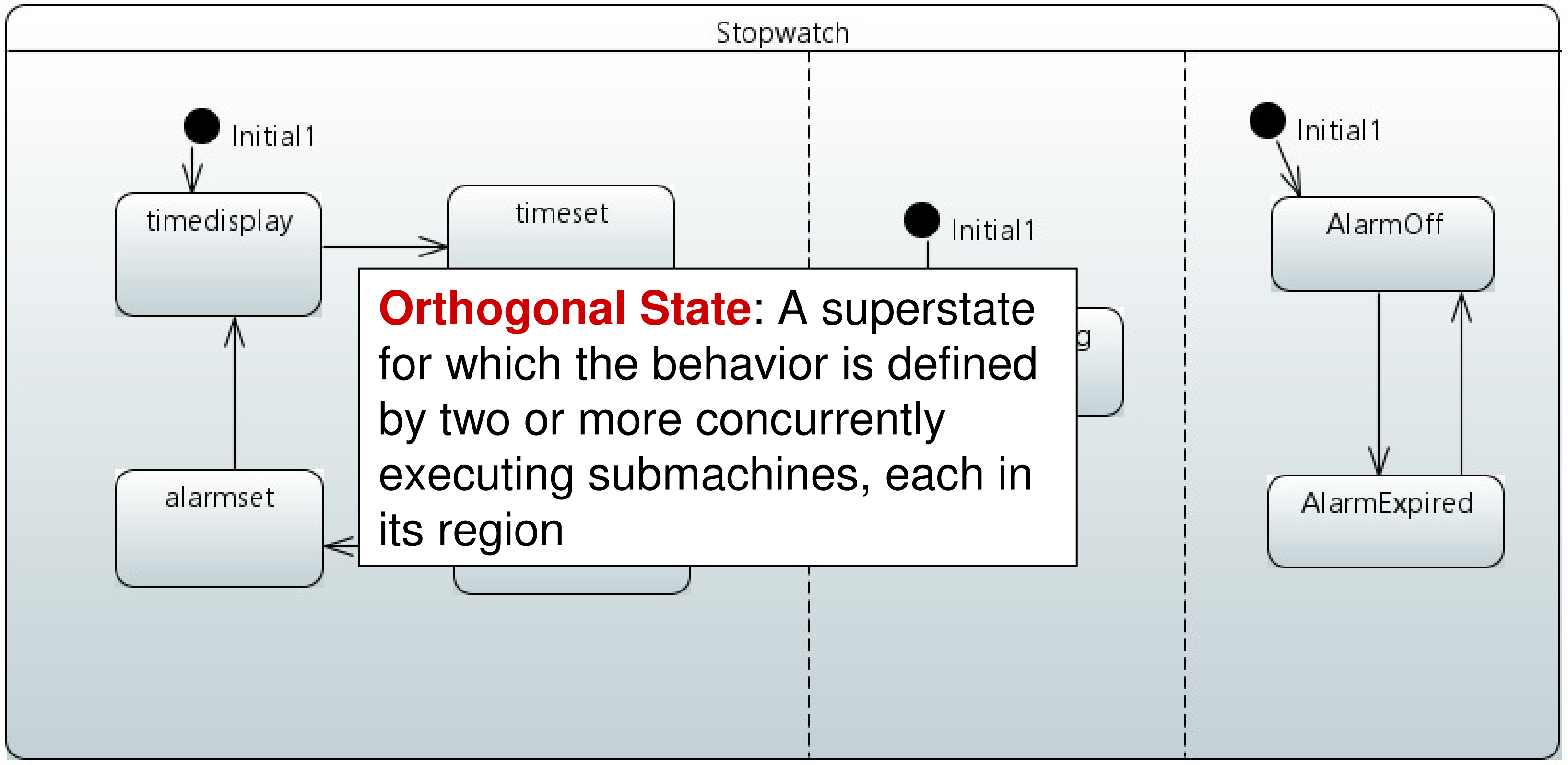
Composite State: contains at least one region. Each region is a concurrent superstate

Elements of State Diagrams



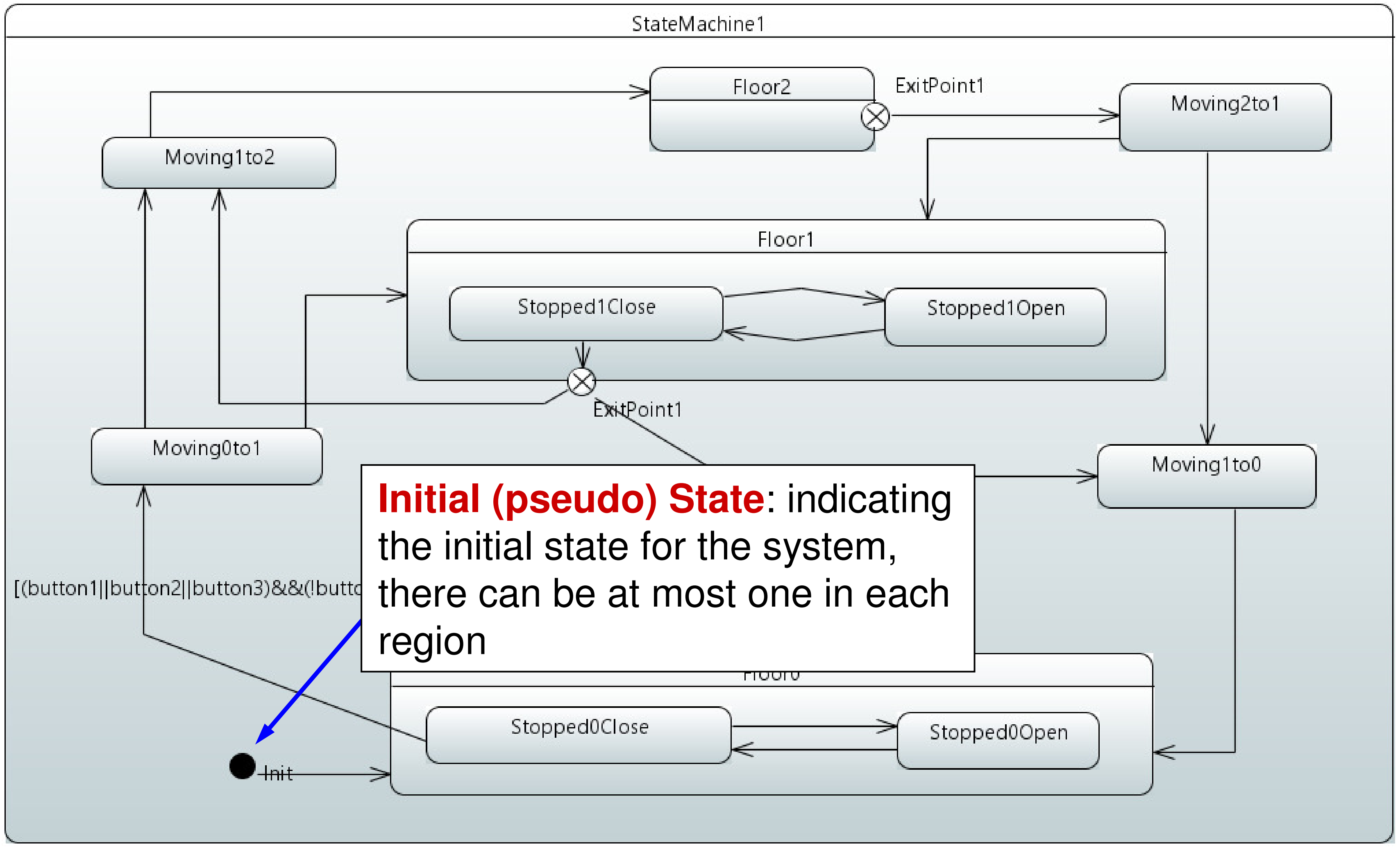
Submachine State: A superstate for which the behavior is defined by an internal state machine

Elements of State Diagrams



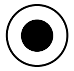
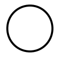
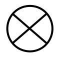
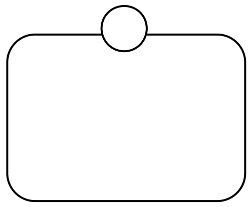
Orthogonal State: A superstate for which the behavior is defined by two or more concurrently executing submachines, each in its region

Elements of State Diagrams

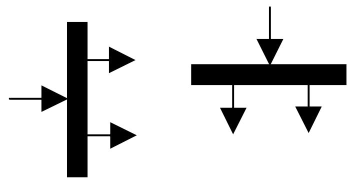


Initial (pseudo) State: indicating the initial state for the system, there can be at most one in each region

Elements of State Diagrams

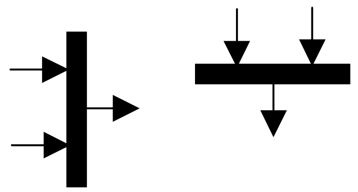
 **Final state**	A pseudo-state signifying either the leaving state for an object or the termination of the enclosing region
 **Entry point**	A reference for the target of a transition
 **Exit point**	A reference as the source of a transition
 **Connection point reference**	Used as a source or target of a transition. They represent entries into or exits out of the submachine machine referenced by the superstate.

Elements of State Diagrams



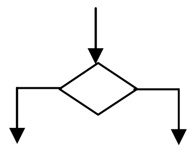
Fork

Splits an incoming transition into two or more transitions terminating on orthogonal target vertices



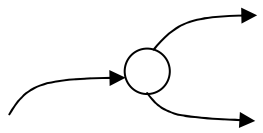
Join

Merge transitions emanating from source vertices in different orthogonal regions



Choice point

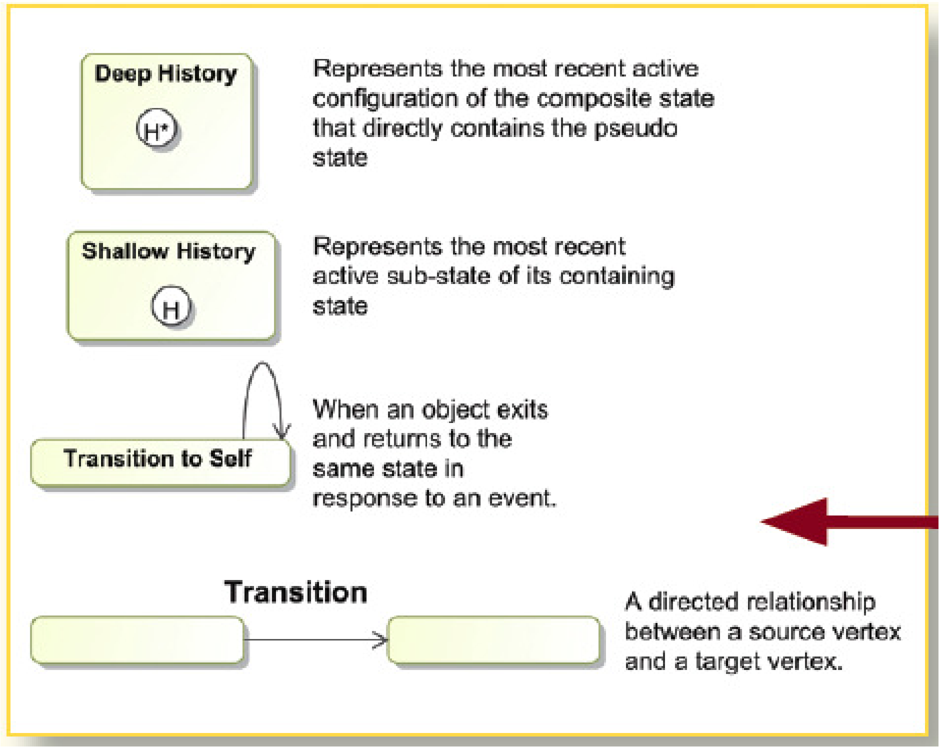
Split transition paths (OR decomposition)



Junction

Chain together multiple transitions

State diagram vs Protocol state diagram

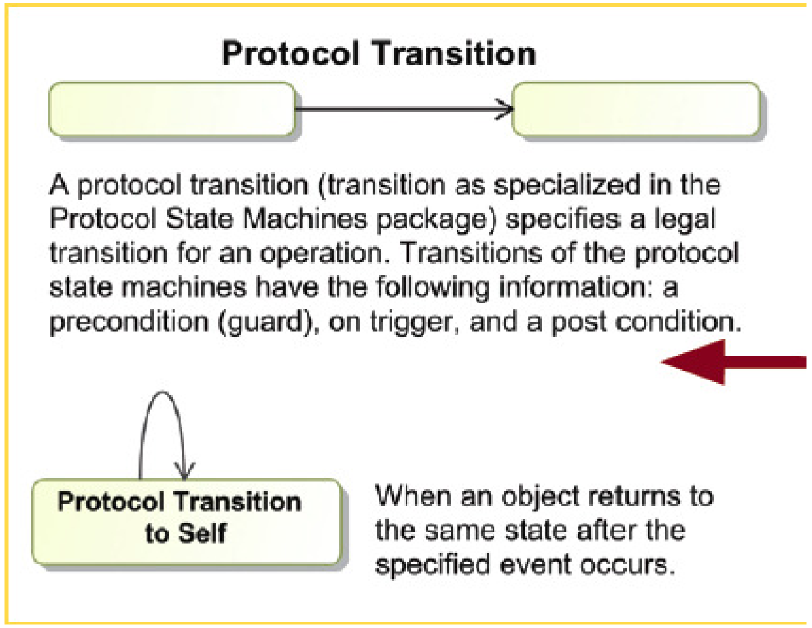


Represents the most recent active configuration of the composite state that directly contains the pseudo state

Represents the most recent active sub-state of its containing state

When an object exits and returns to the same state in response to an event.

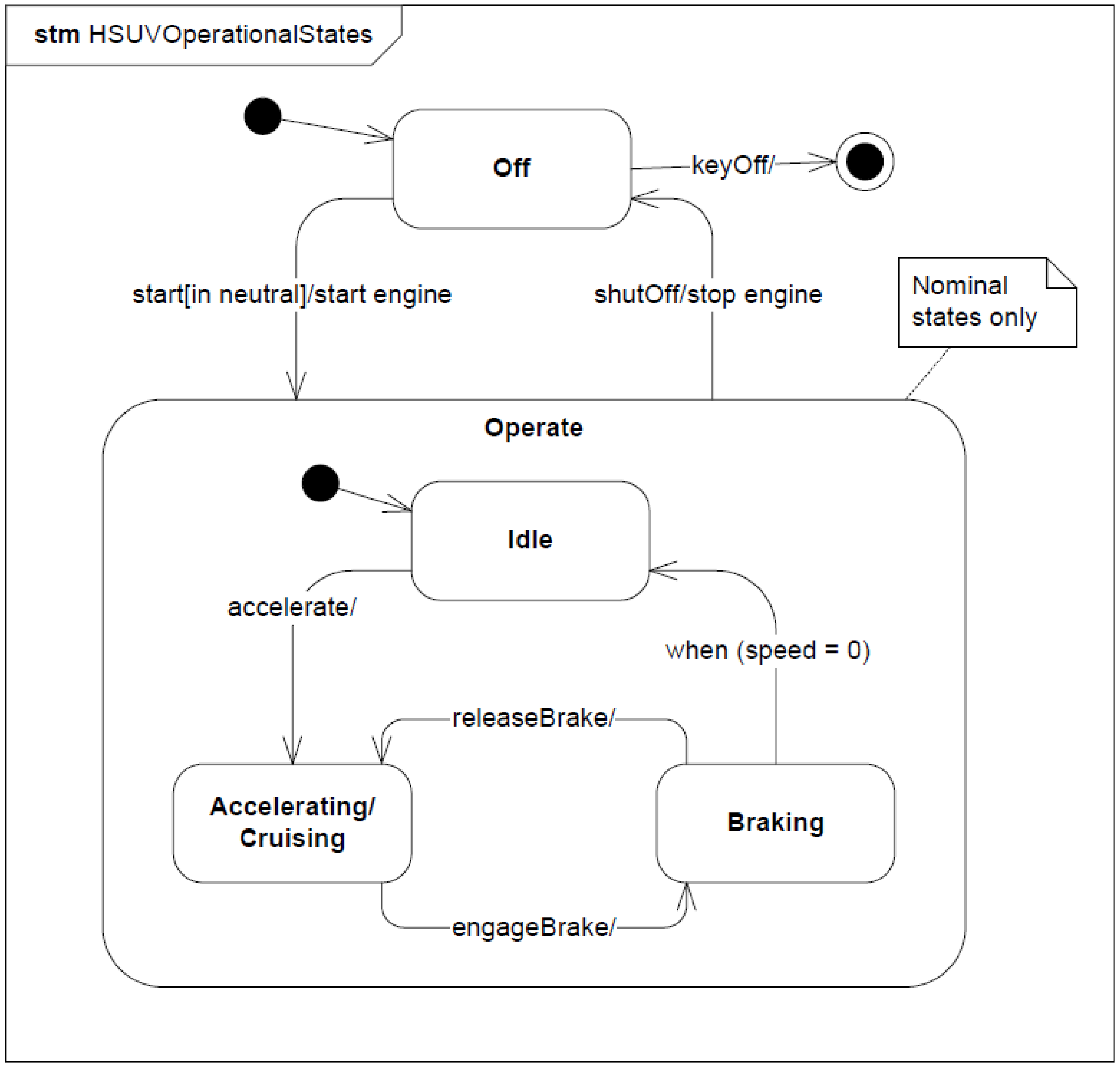
A directed relationship between a source vertex and a target vertex.



A protocol transition (transition as specialized in the Protocol State Machines package) specifies a legal transition for an operation. Transitions of the protocol state machines have the following information: a precondition (guard), on trigger, and a post condition.

When an object returns to the same state after the specified event occurs.

Example of state diagram


stm HSUVOperationalStates
Off
keyOff/
start[in neutral]/start engine
shutOff/stop engine
Nominal states only
Operate
Idle
accelerate/
when (speed = 0)
releaseBrake/
Accelerating/ Cruising
Braking
engageBrake/