Formal Specification of Software

UML State Machines

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UML State Machines

Important type of UML diagrams

For modelling behaviour

- **Lifecycle of objects**
- **Behaviour of operations**

History

- **Invented by D. Harel (State Charts)**
- **Made popular by J. Rumbaugh (OMT)**

Notions Related to State Machines

- State
- Transition
- Event
- Action, Activity
- Guards
- Sending messages
- Nesting
- Concurrency
- History states

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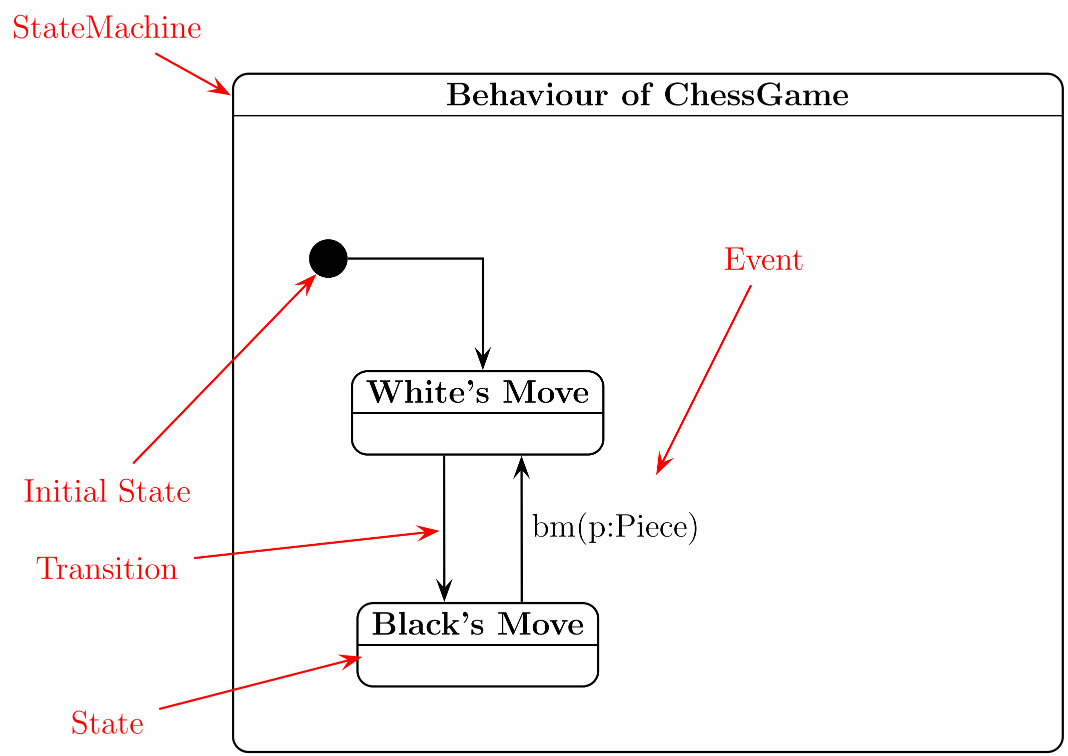

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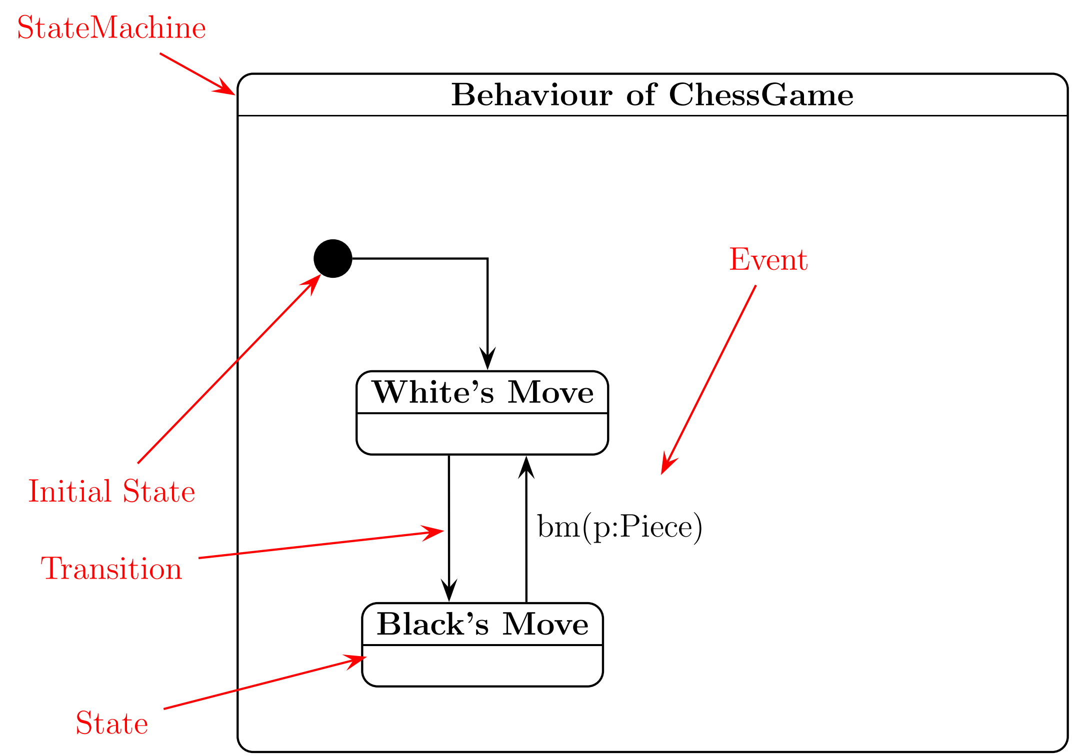

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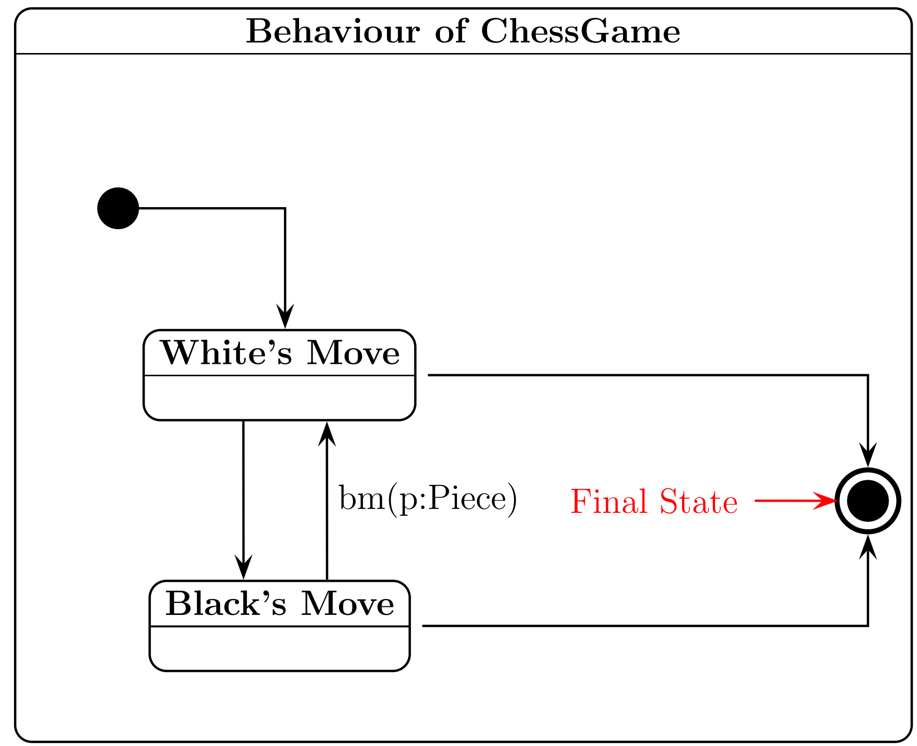

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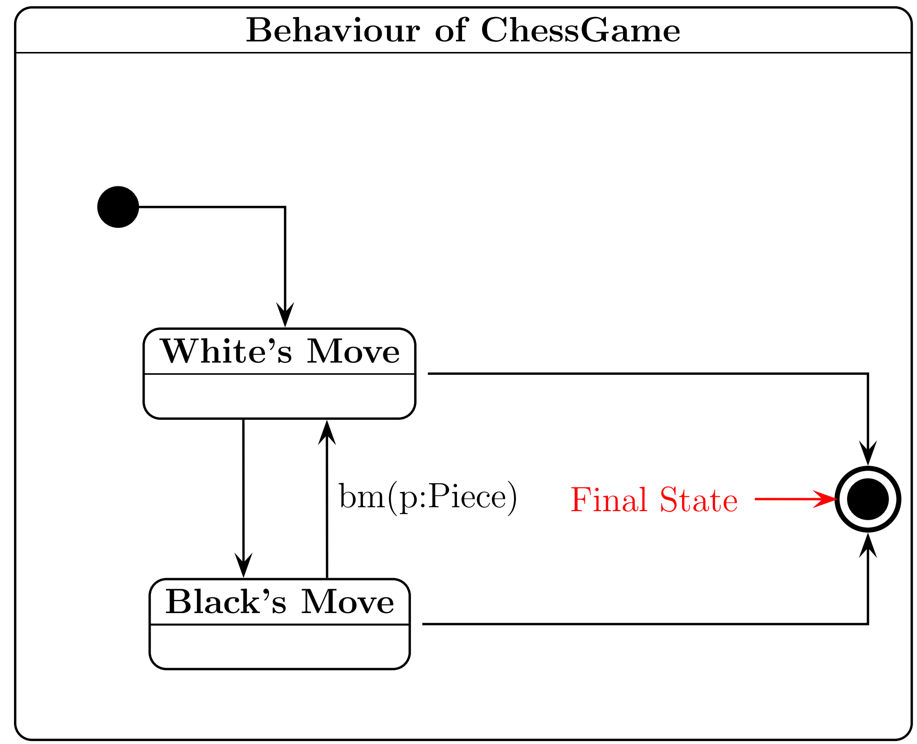

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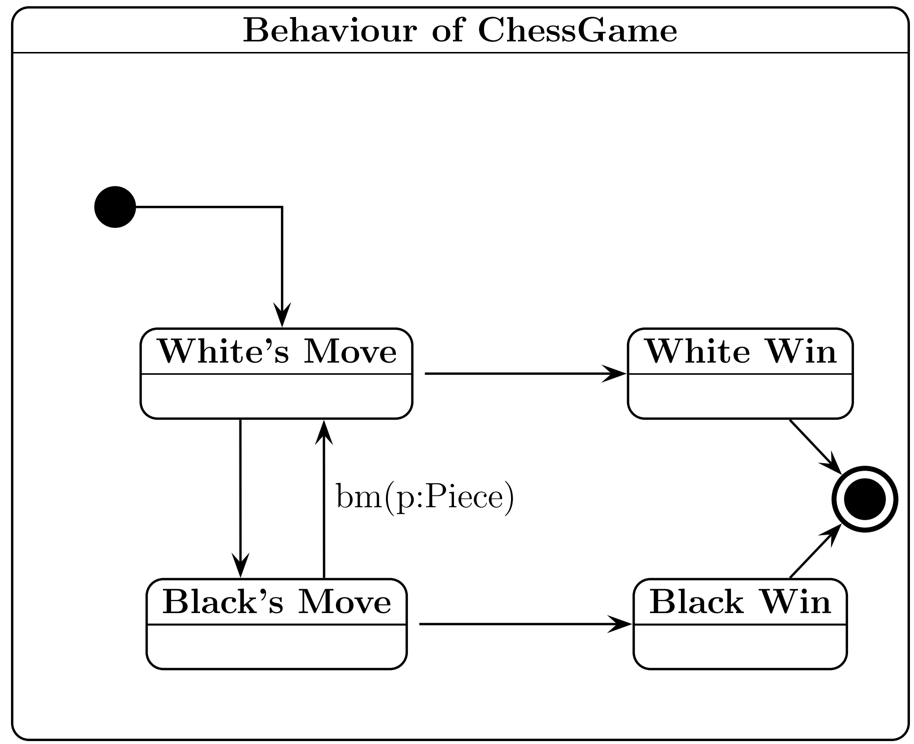

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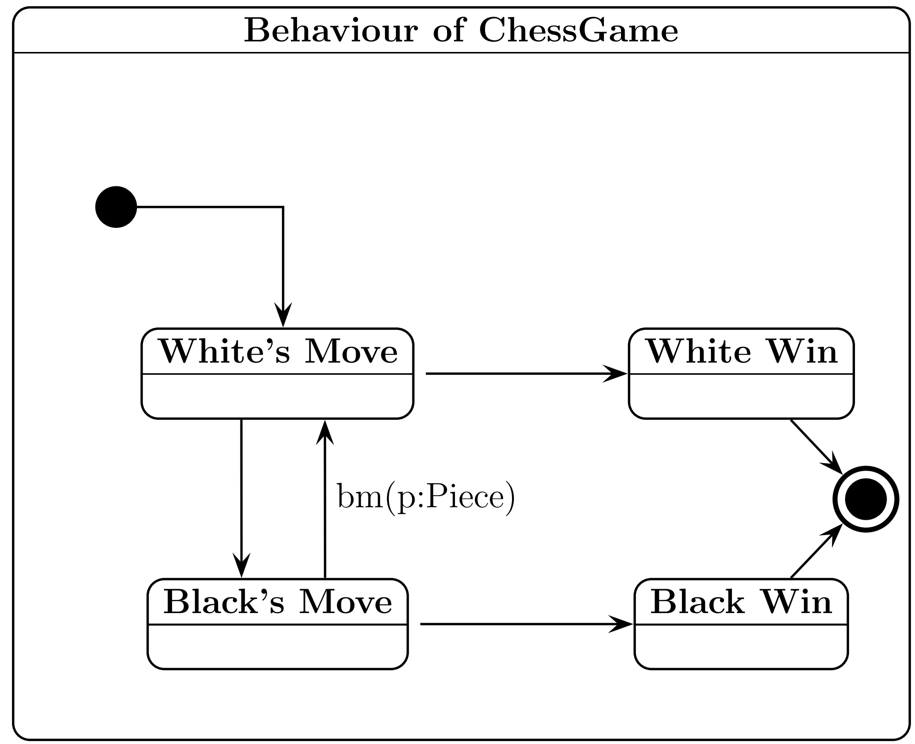

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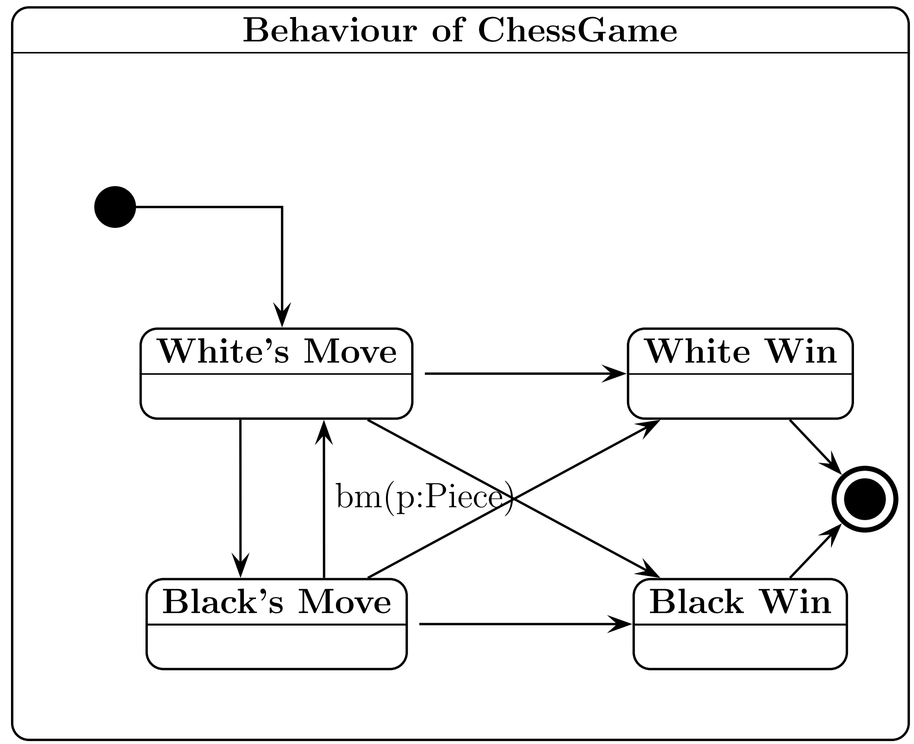

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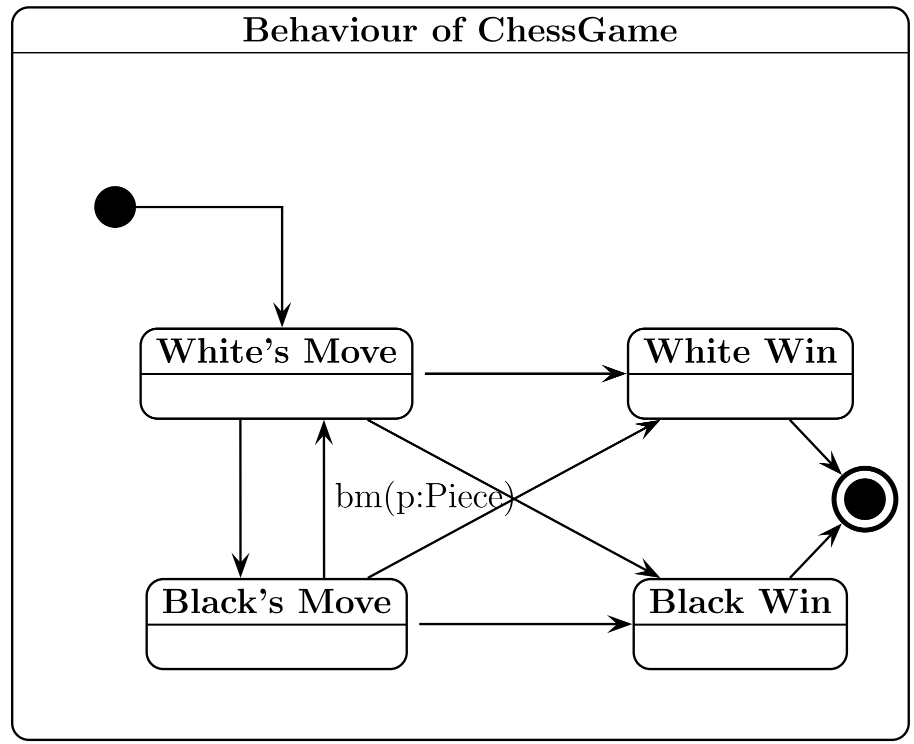

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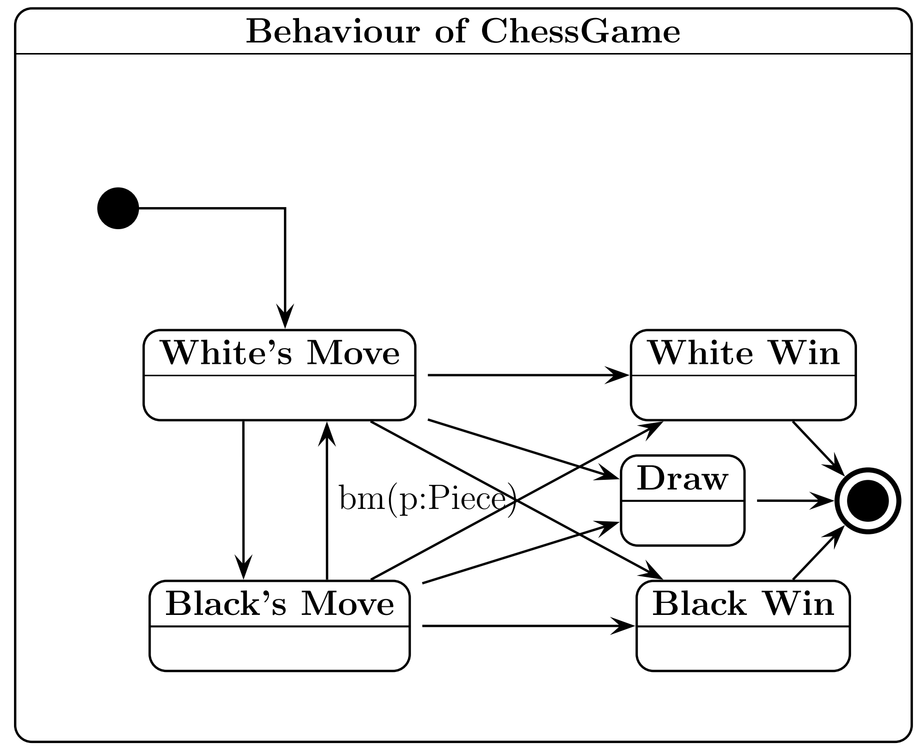

State Machines

State Machine

Labelled, finite graph (cycles possible)

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States

Nodes of the graph

Labelled with: name, do-, entry-, exit-action, ...

Initial and final states have special shapes

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Labelled, finite graph (cycles possible)

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Nodes of the graph

Labelled with: name, do-, entry-, exit-action, . . .

Initial and final states have special shapes

Transitions

Edges of the graph

Labelled with: event, guard, action, . . .

When to Use State Machines

Use State Machines . . .

- at an early stage of software development
- when behaviour of an object (lifecycle) or operation is not well understood yet

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Do NOT use State Machines ...

- when several objects are involved (interaction diagrams are better)

State

Abstract view

- the same response to the same stimuli
- the same active behaviour

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Abstract view

- the same response to the same stimuli
- the same active behaviour

Implementation view

- certain attributes have certain values

Event

Properties

- observable in the environment of the current object
- takes place at certain point in time (has no duration)
- has possibly parameters

Event

Properties

- observable in the environment of the current object
- takes place at certain point in time (has no duration)
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Role in diagram

- triggers a transition
- is “consumed” when transition is executed
- can be saved under certain circumstances

Types of Events

Signal event

An object that is dispatched (thrown) and received (caught)

Call event

Represents the dispatch of an operation

Time event

Represents the passage of a certain amount of time

Change event

Represents the fact that a Boolean expression is changed to true

The expression is checked continuously (polling)

Transition

Properties

- decribes change from one state to another state
- without duration when executed

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- decribes change from one state to another state
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Role in diagram

- triggering controlled by events, guards, state exit conditions
- execution can cause actions

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The customer must pass authentication before withdrawing money.

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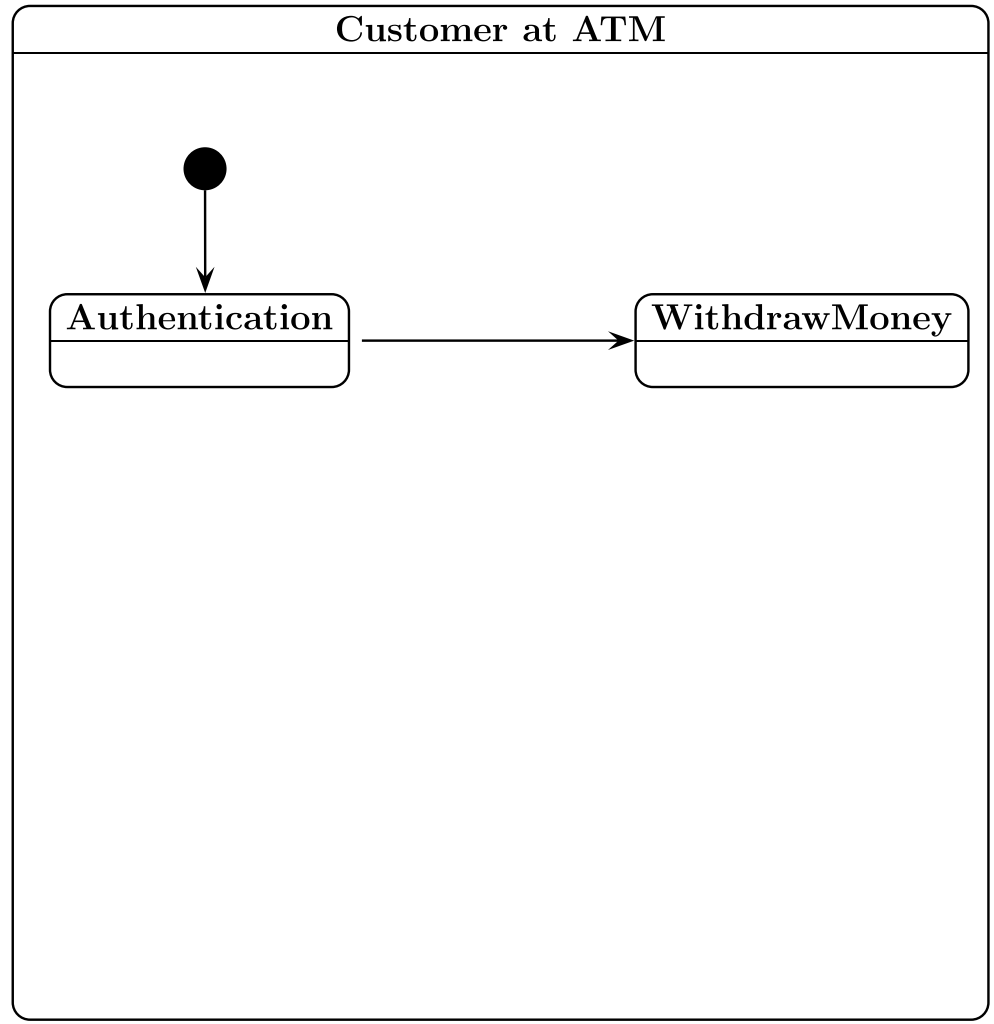

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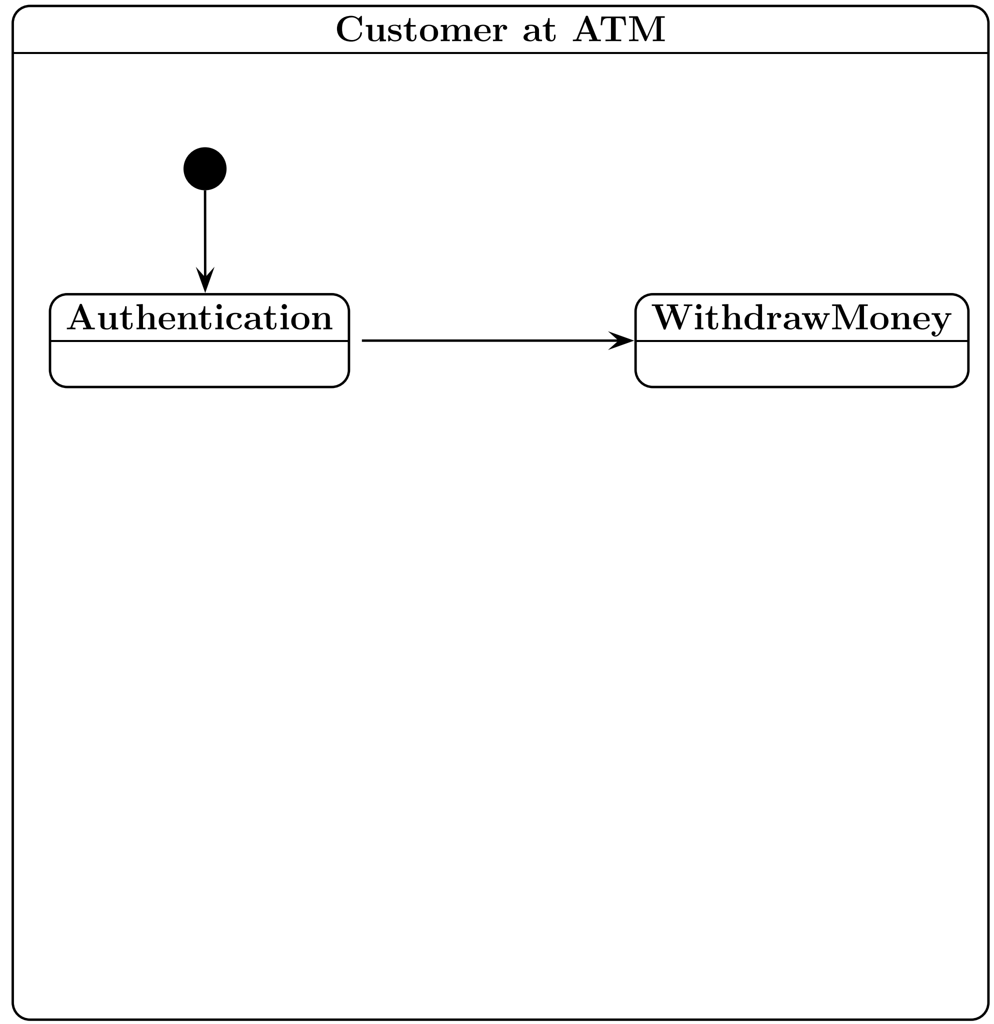

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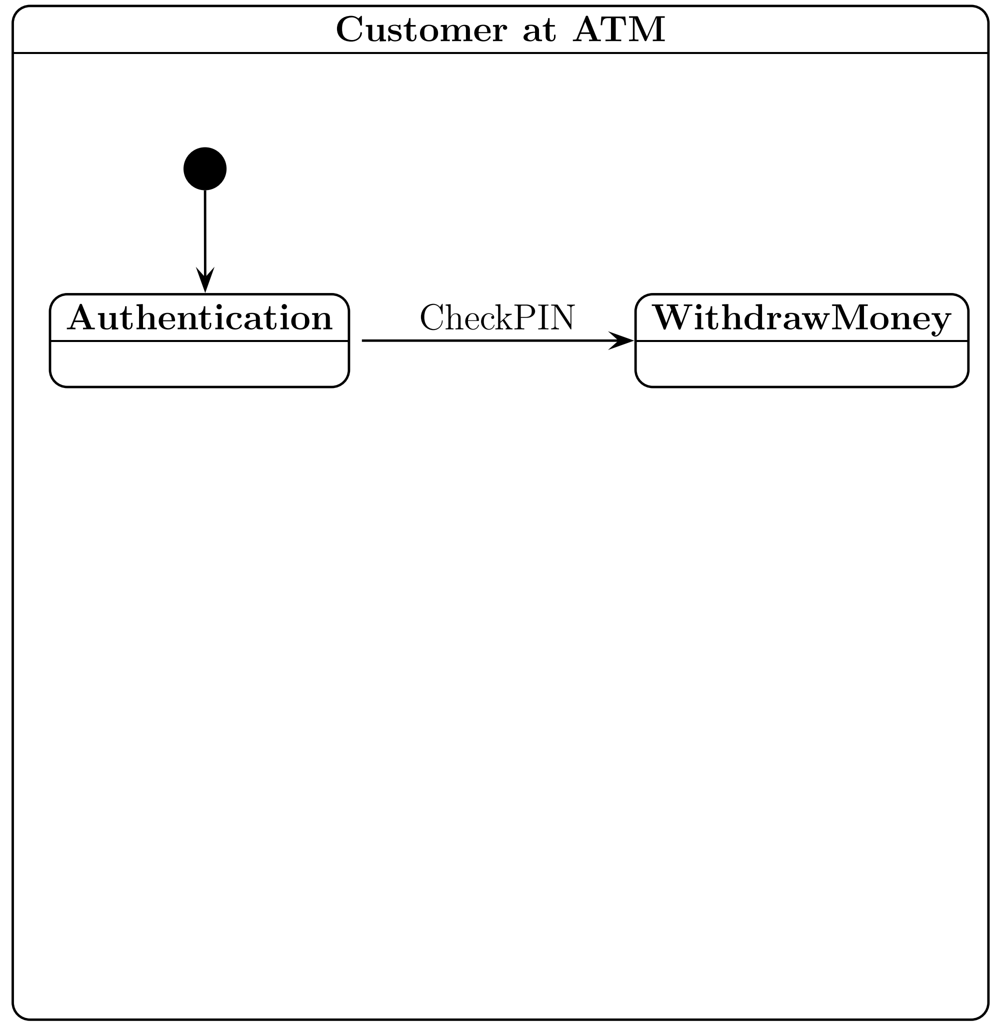

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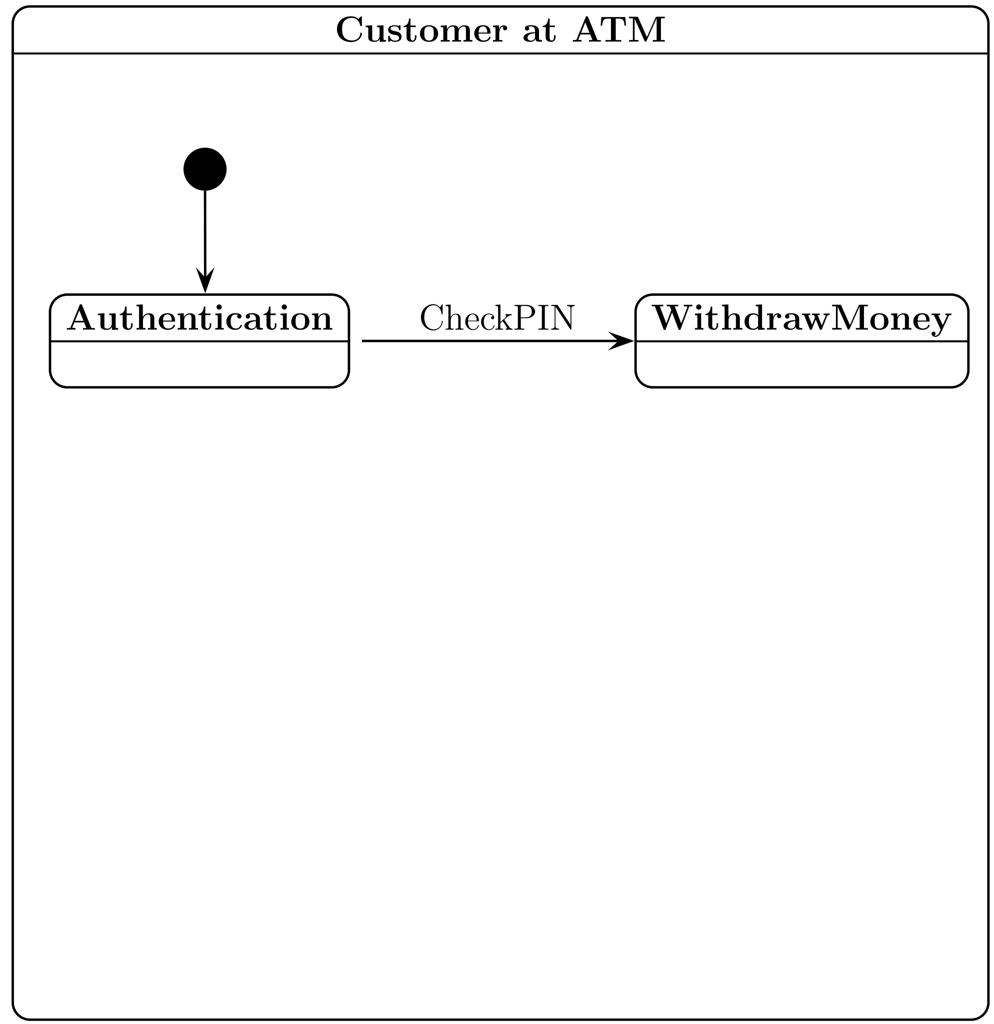
The customer must pass authentication before withdrawing money. Authentication is done by checking a PIN.

The PIN can be correct or not.



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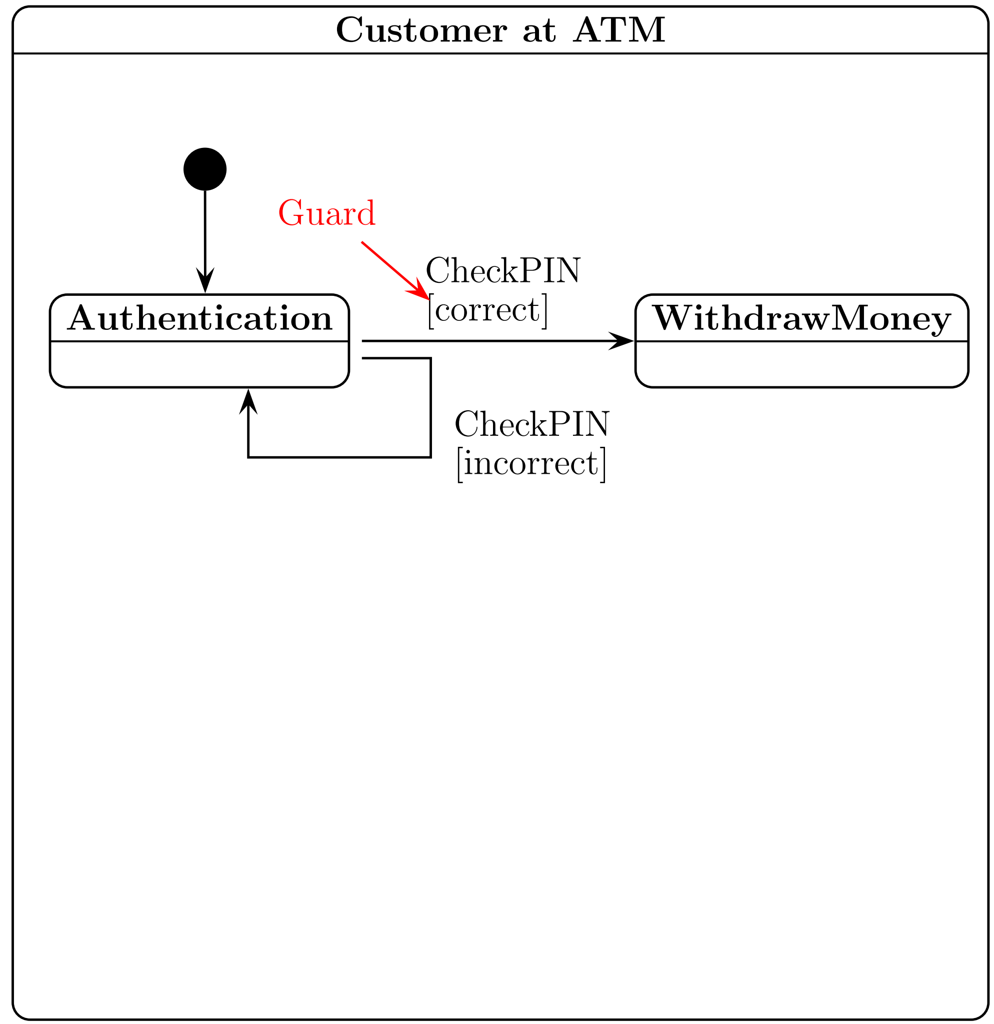

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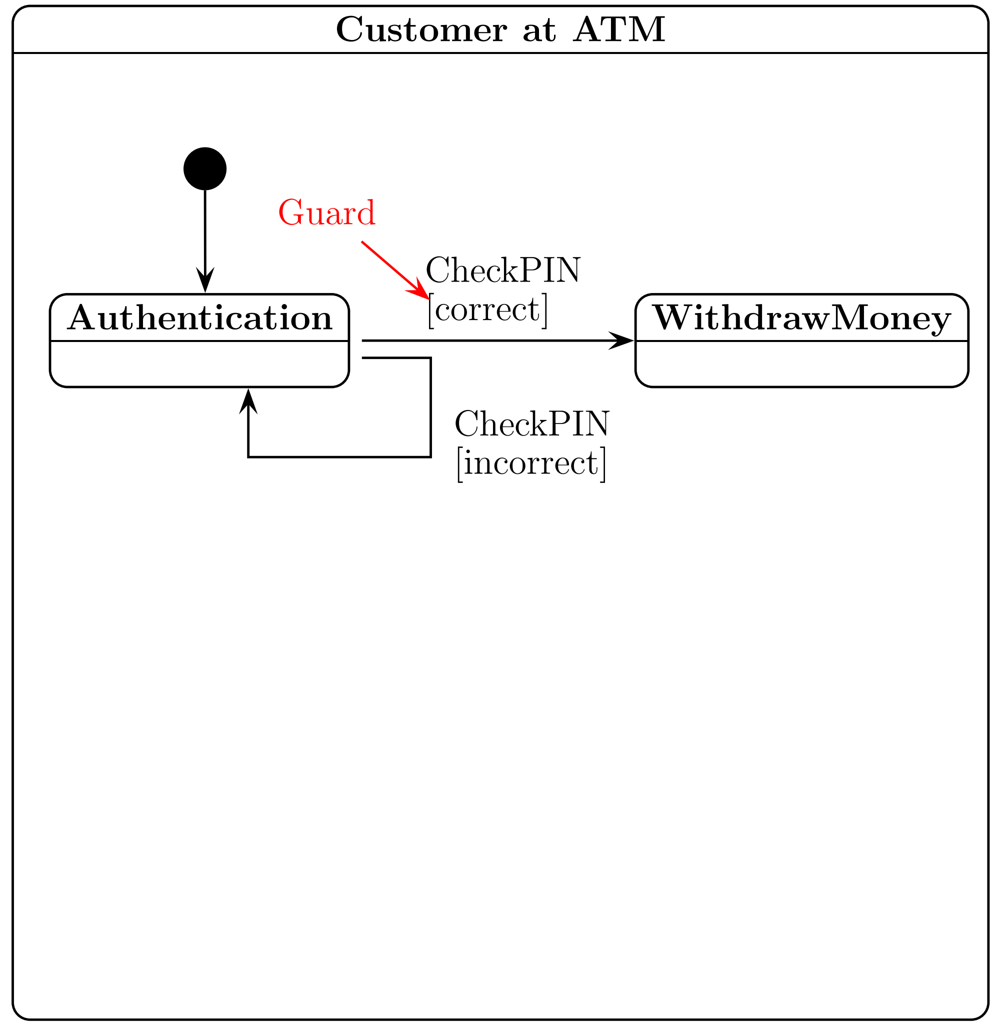

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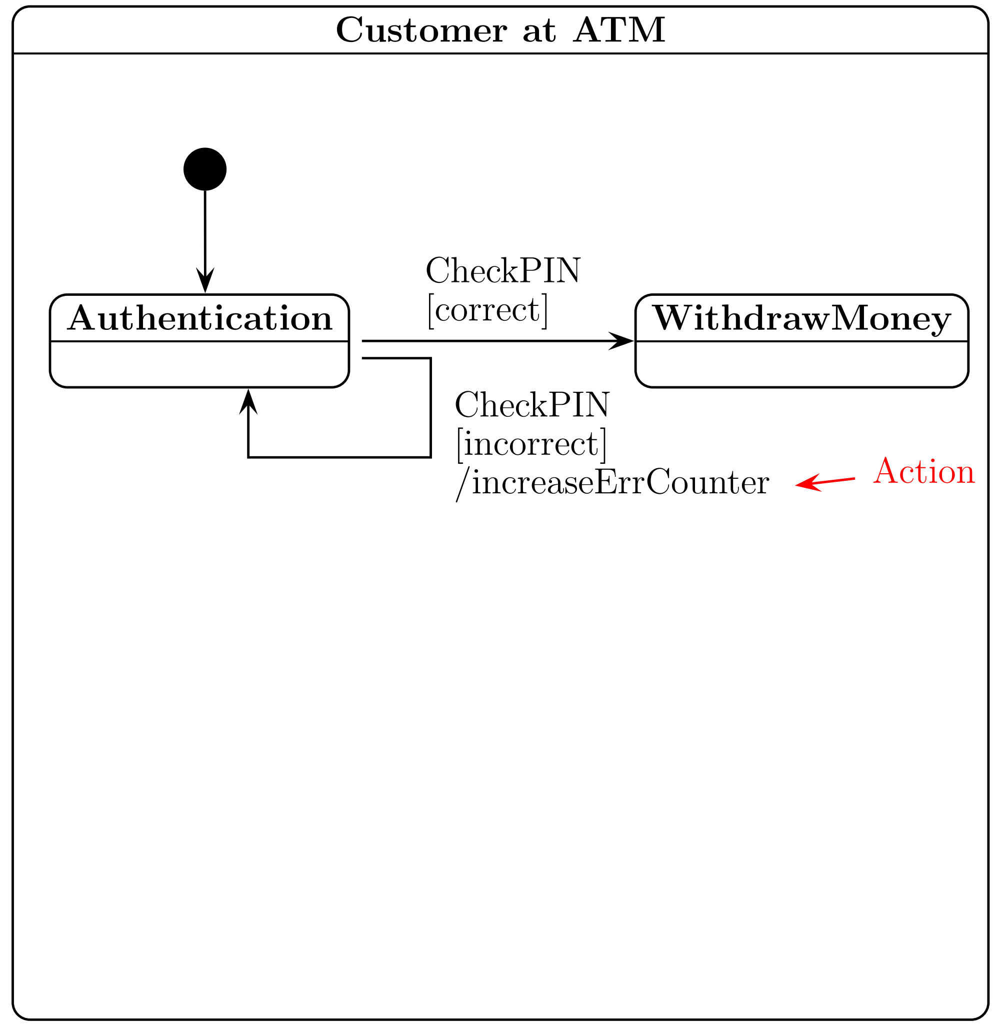

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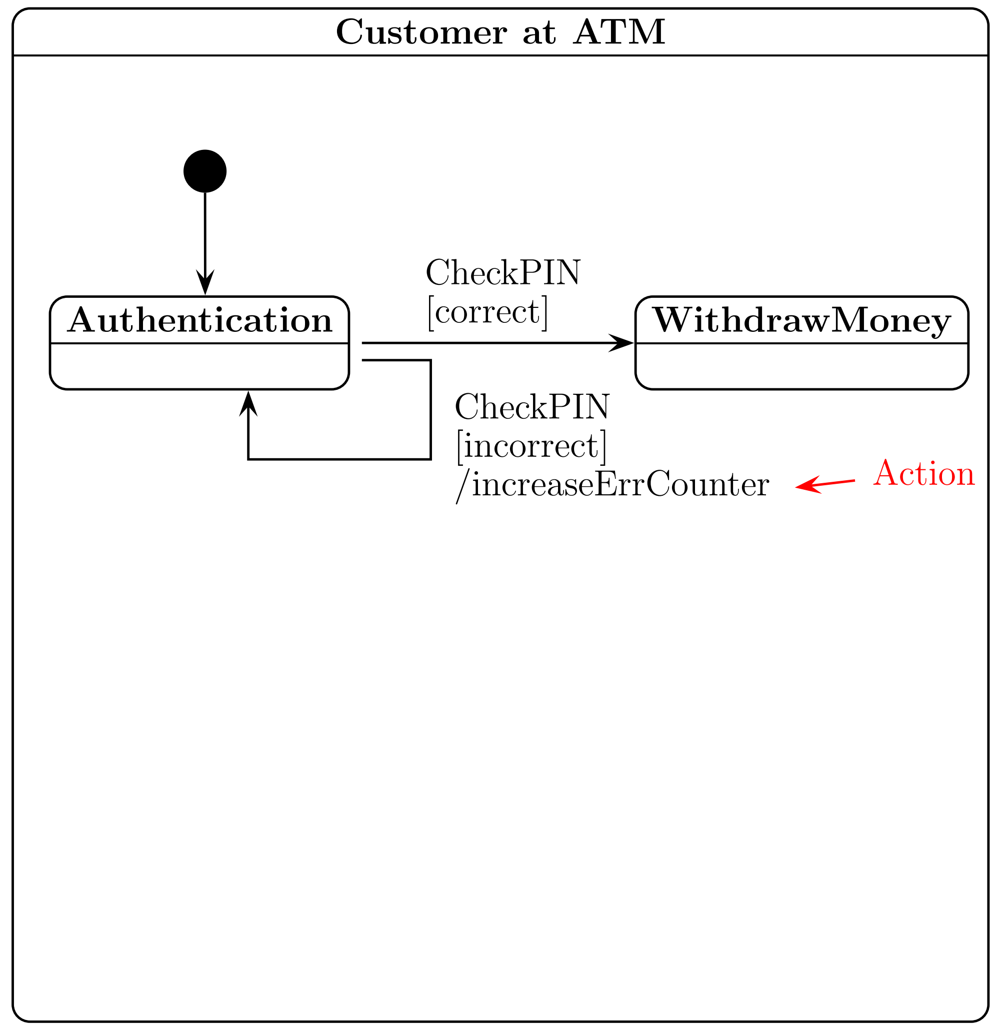

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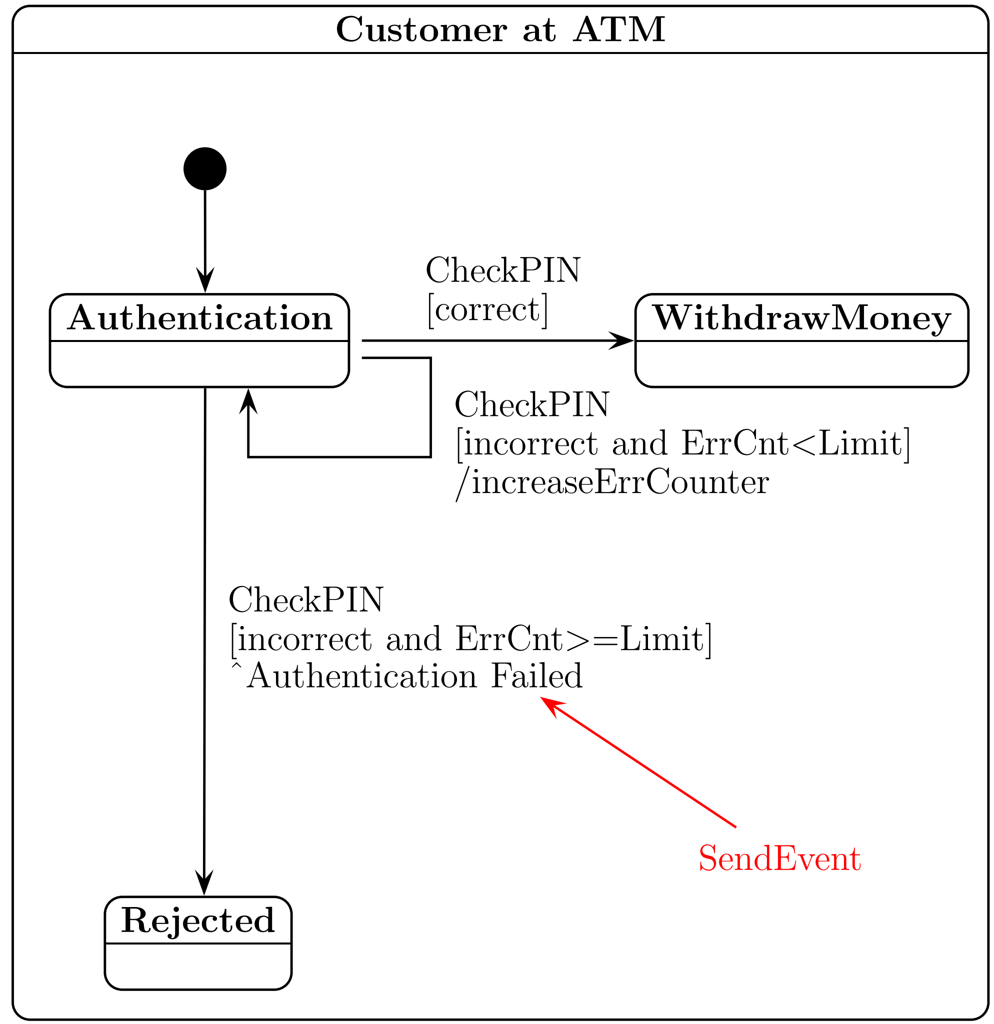


Internal Transitions

Notation

Written as

$$Event[Guard]/Action$$

within the state box

Example

Authentication
`reset/clearScreen`

Difference to self transition

Entry and exit actions are not dispatched

Entry and Exit Actions

Notation

Written as

$\texttt{entry}/\mathit{Action}$ **resp.**
$\texttt{exit}/\mathit{Action}$

within the state box

Semantics

Dispatched on entering resp. exiting the state

Activities

Notation

Written as

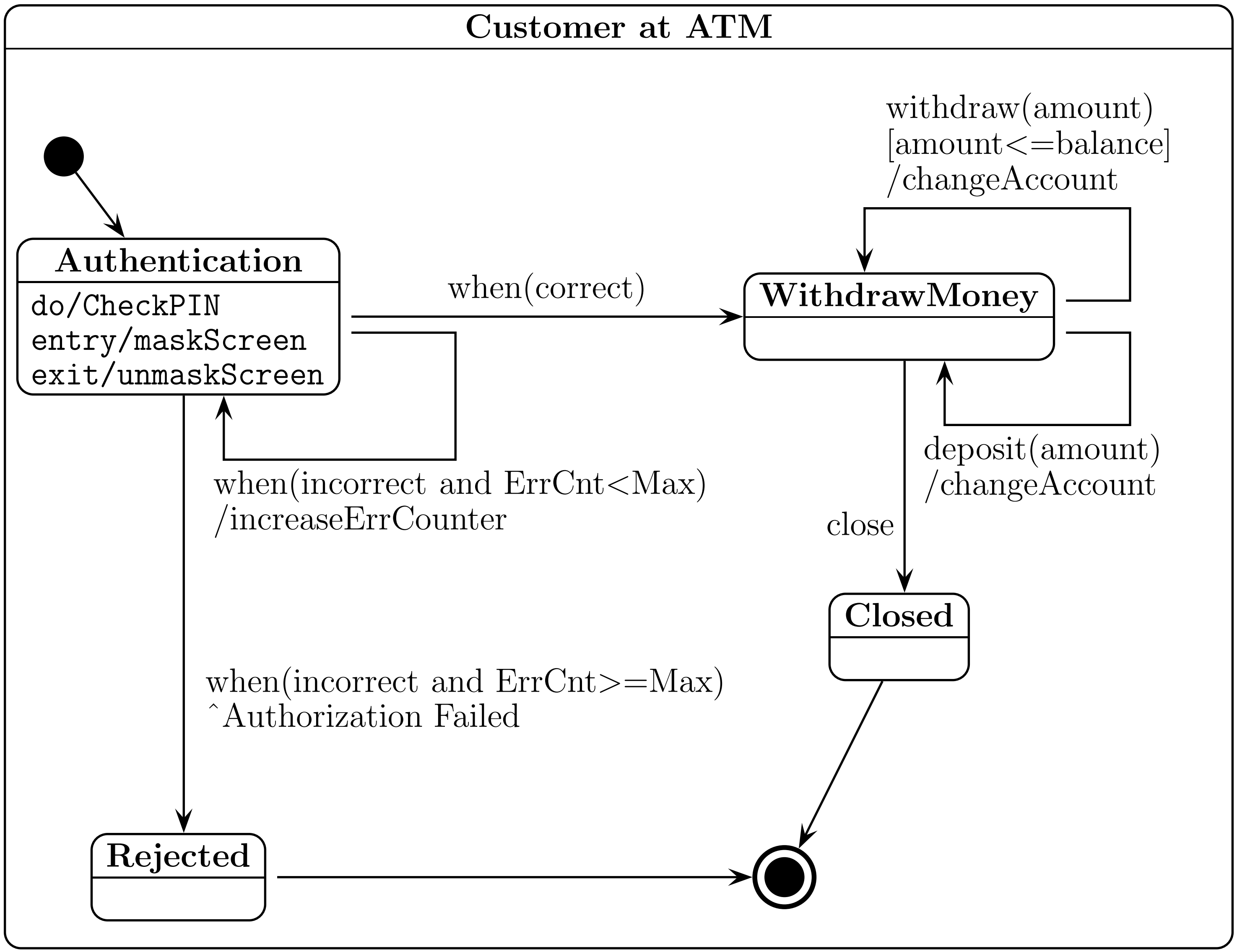
$$\mathrm{do}/\mathit{Action}$$

within the state box

Semantics

- **have duration**
- **can be finished by event for outgoing transitions**

Example: ATM (Alternative Formalisation)



Exercise

A student must complete the basic level before entering the advanced level.

After both levels, the student has to pass five examinations.

An examination can be retaken at most twice.
After the third failed attempt the student's registration is cancelled.

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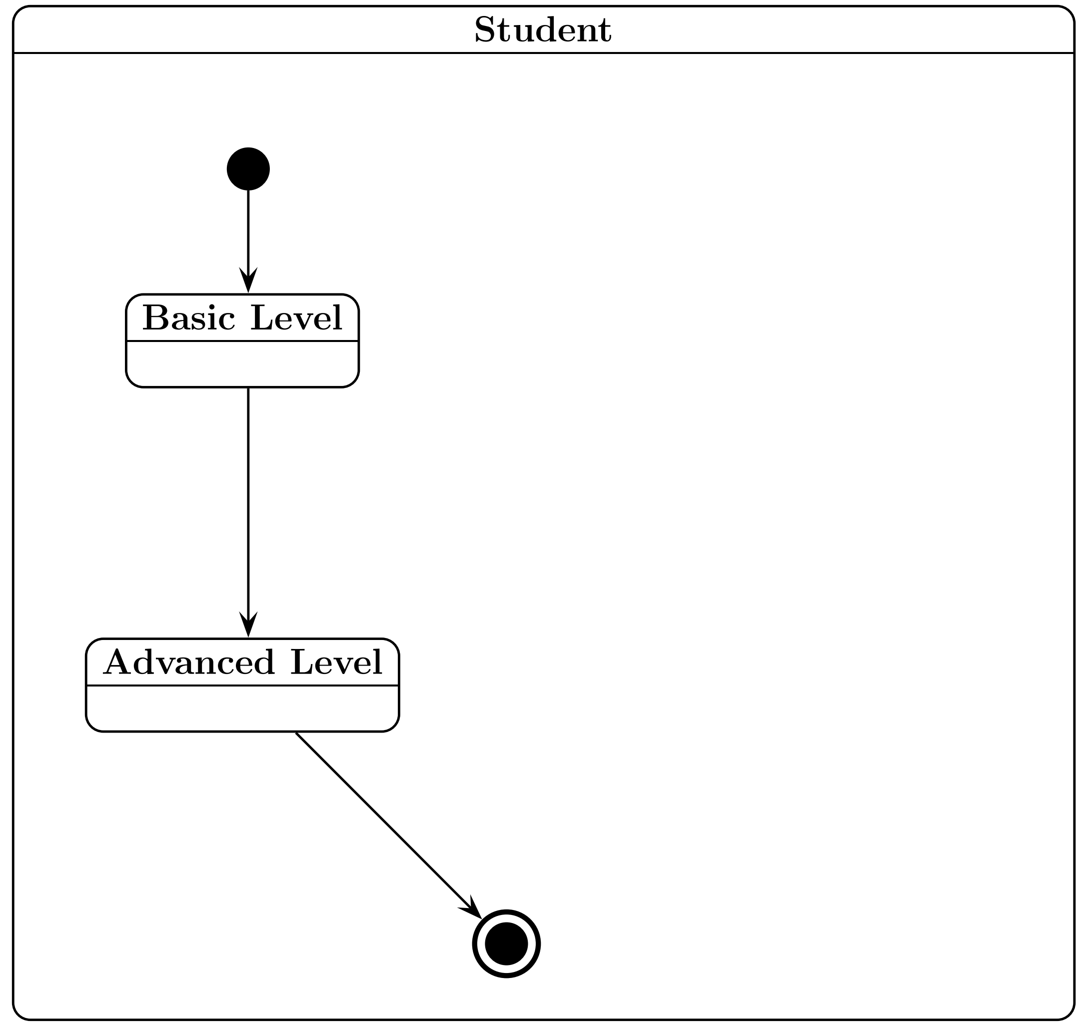

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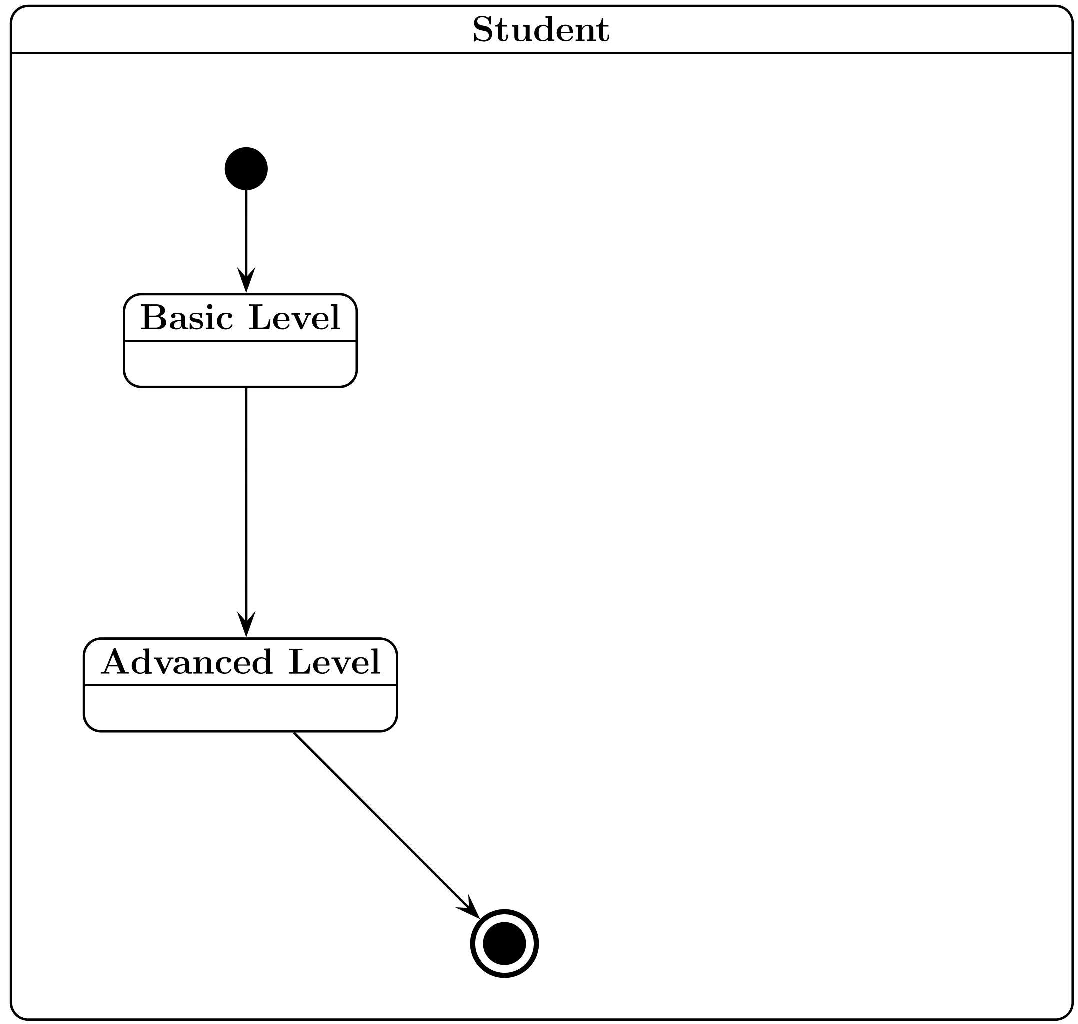

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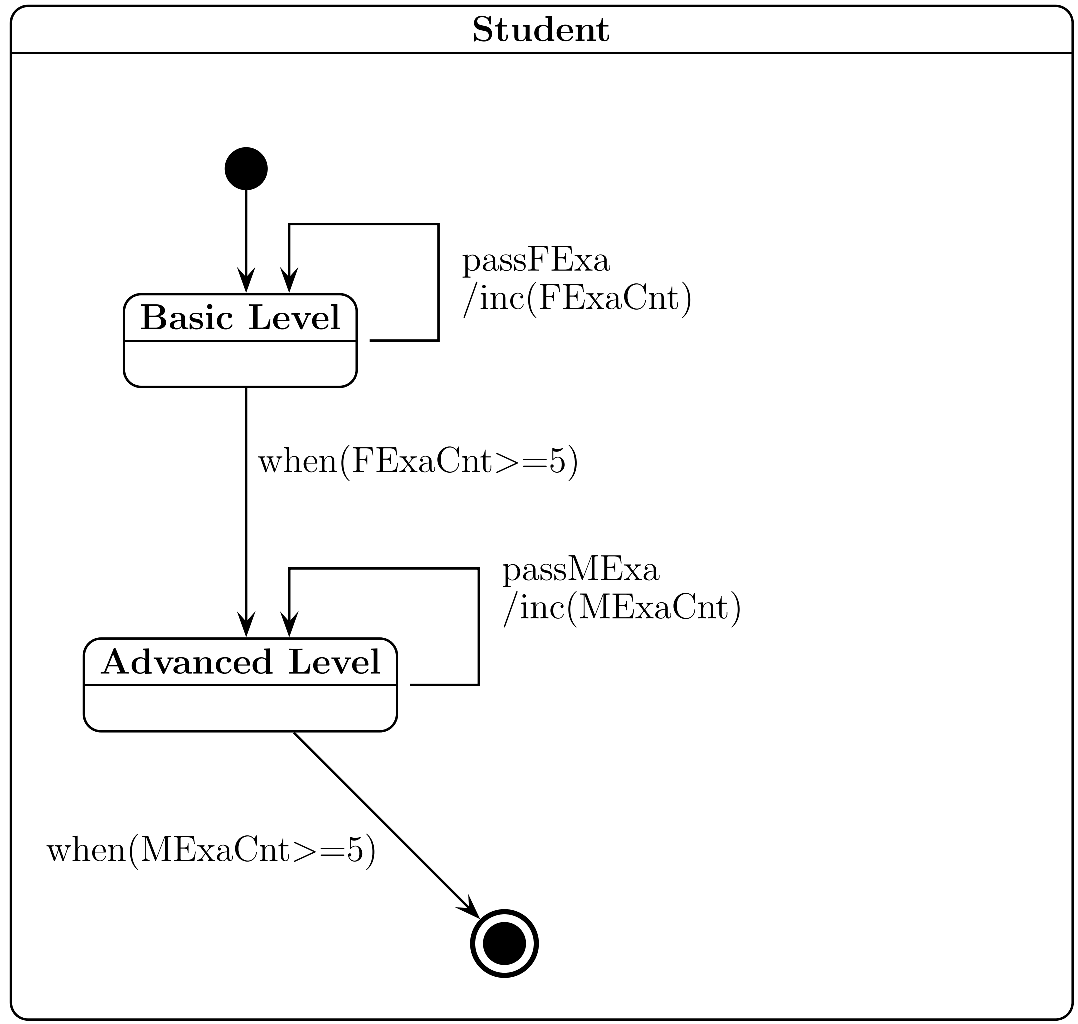

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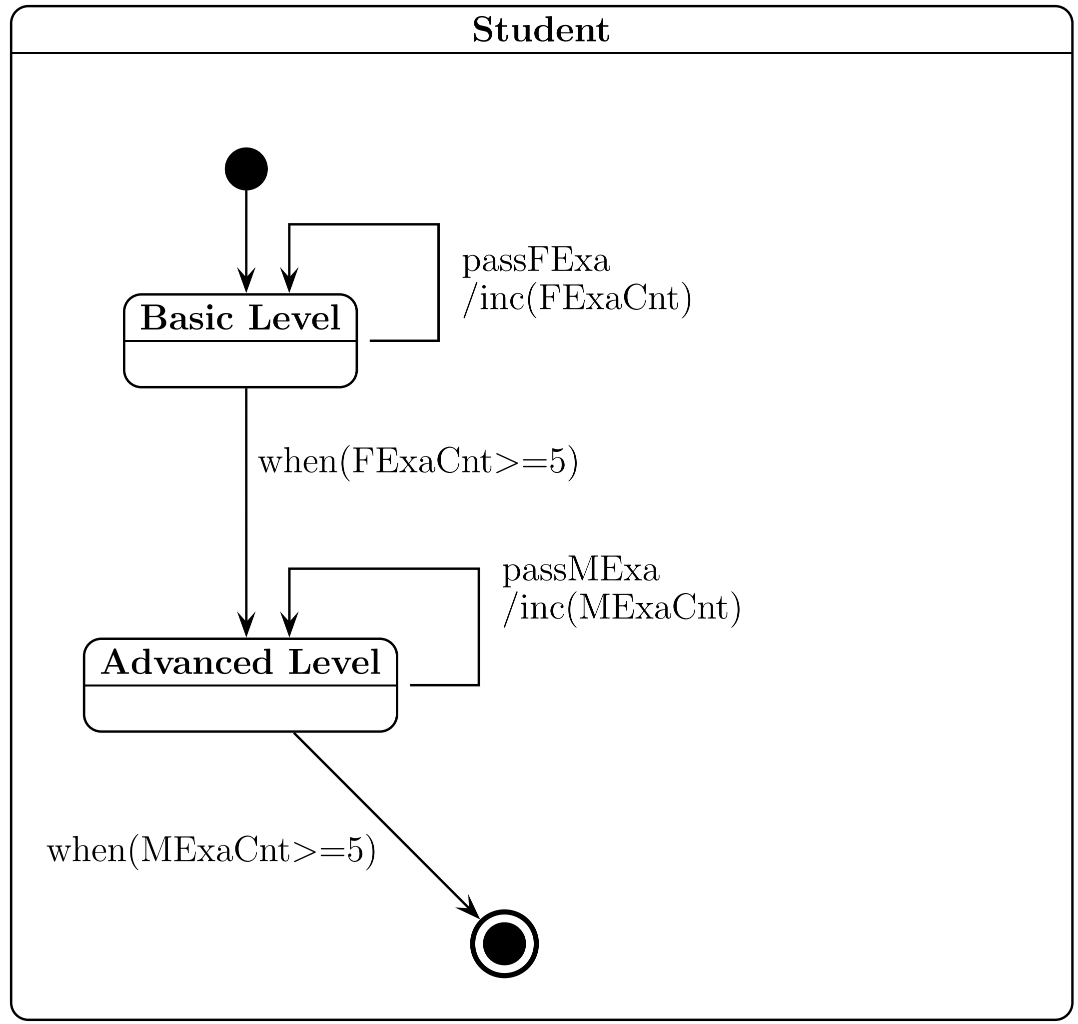

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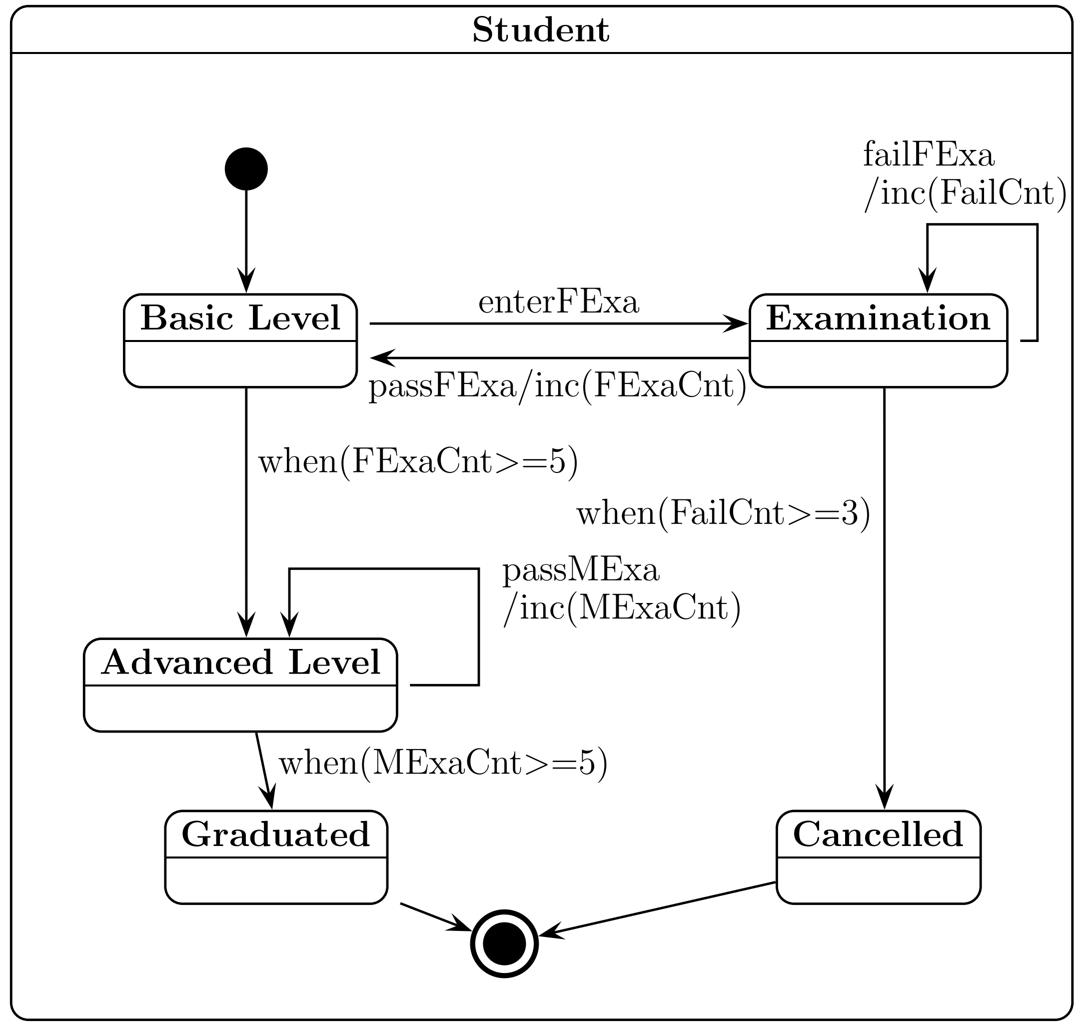


Criticism

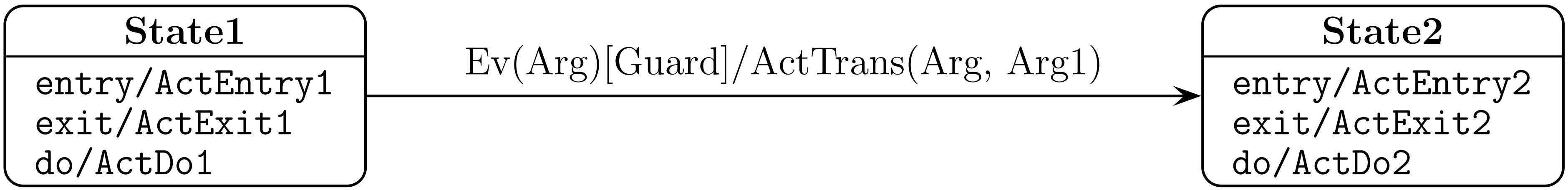
Not really a good model, because . . .

- **the student leaves the basic level to take an exam**
- **the student can cheat by repeating a passed exam**
- **the student cannot enter parallel exams**
- **the student has to complete each exam once tried**
- **the student cannot pass exams of the advanced level while in the basic level**

Advanced Constructs Can Help

- Deferred event
- Composite state
- Concurrent composite state
- Join state, Fork State
- Concurrent transition
- Junction state
- Sync state

Events: The Detailed View



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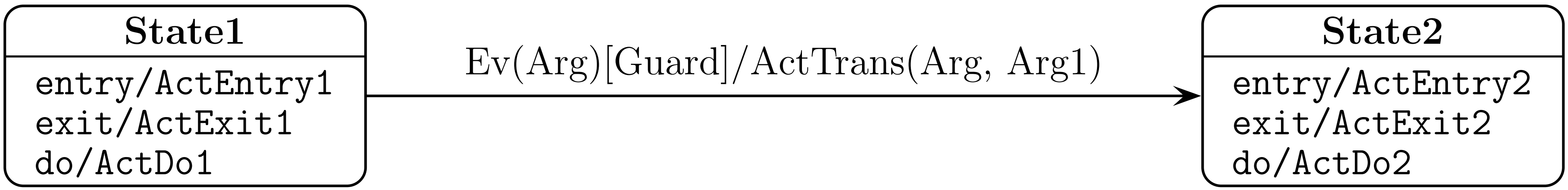

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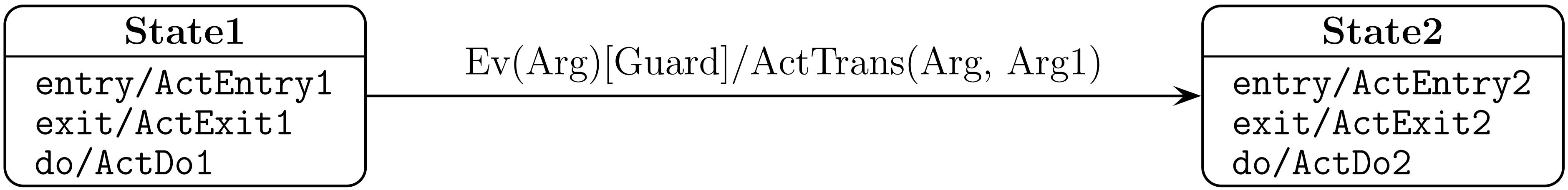

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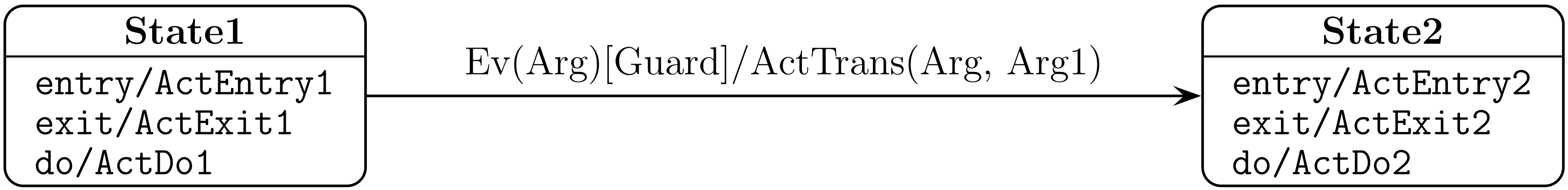

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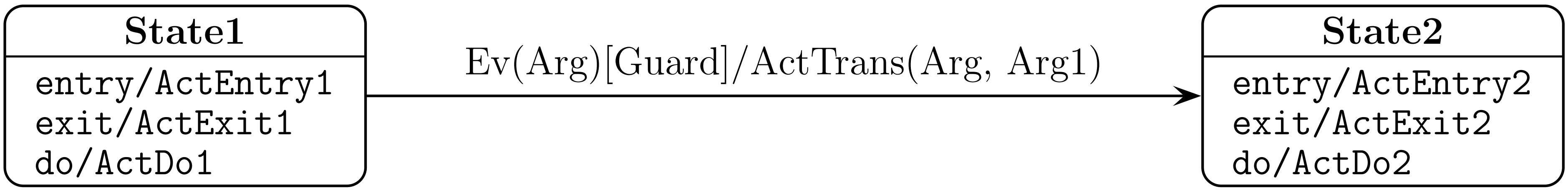

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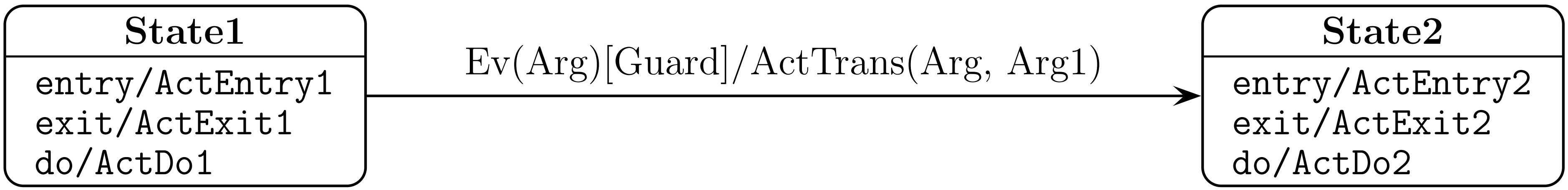

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5. **Event is consumed** Event is processed

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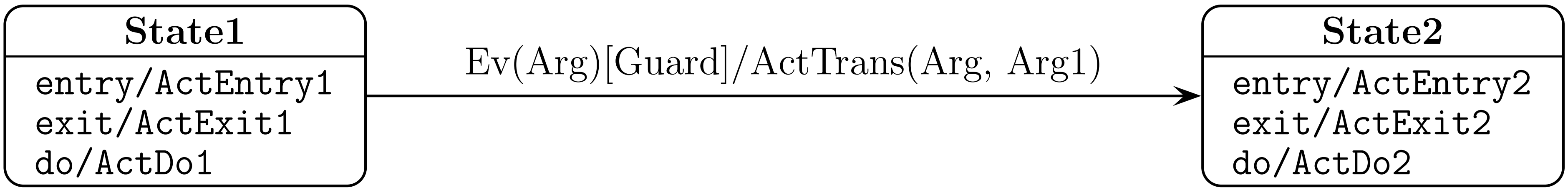

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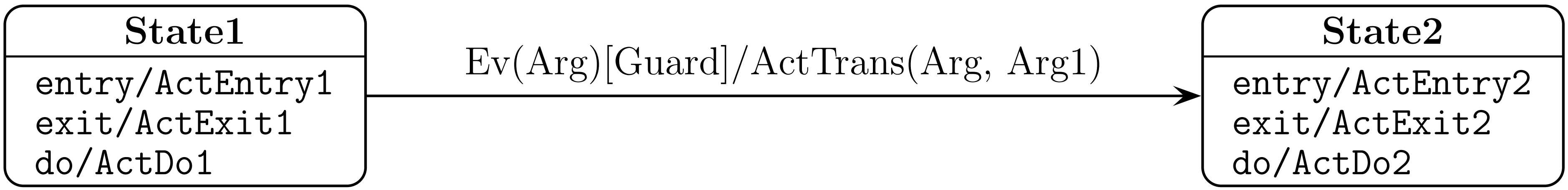

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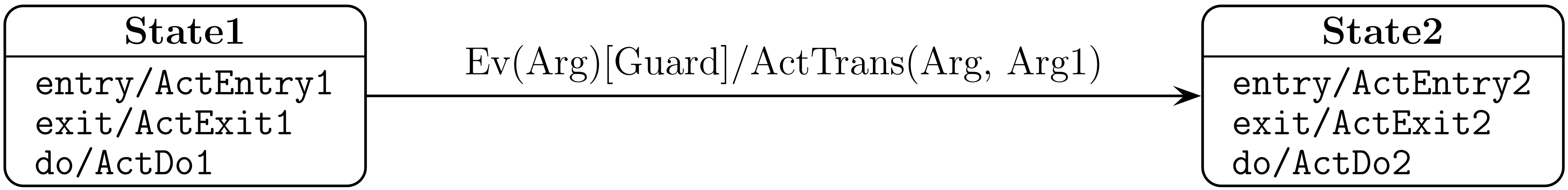

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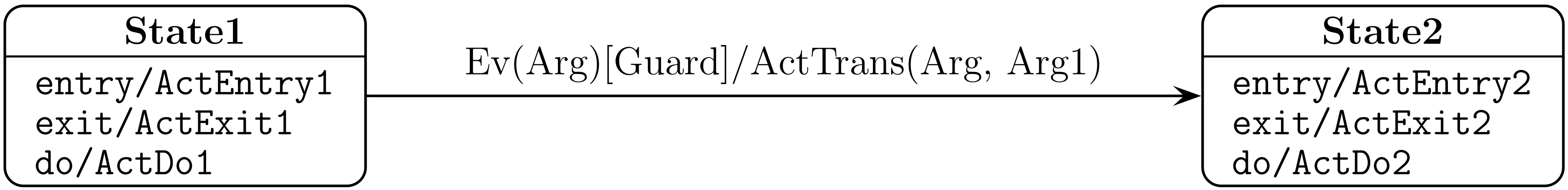

1. **check** `Guard` **– if** `false` **abort**

2. **abort** `ActDo1`

3. **execute** `ActExit1`

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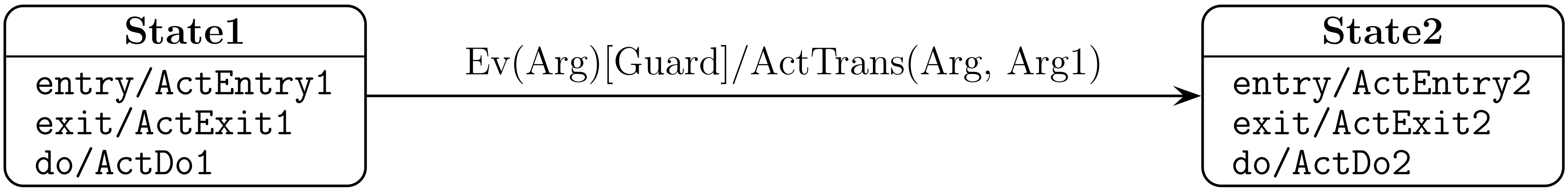

1. **check** `Guard` **– if** `false` **abort**
2. **abort** `ActDo1`
3. **execute** `ActExit1`
4. **execute** `ActTrans(Arg,Arg1)`
   (syncronous processing, i.e. wait until finished)

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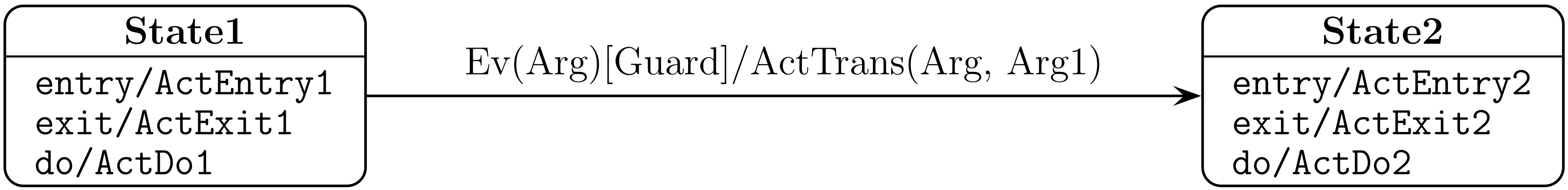

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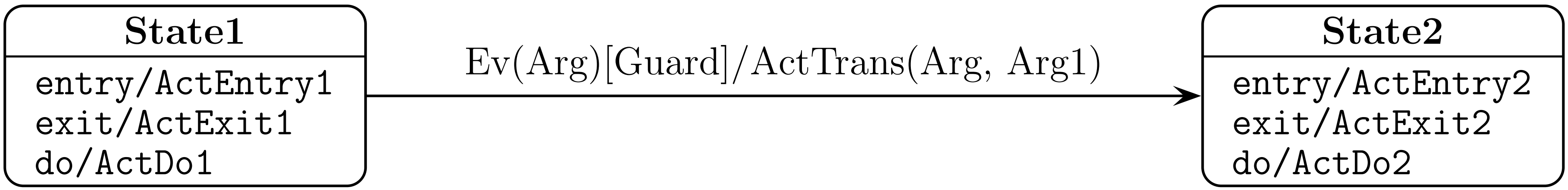

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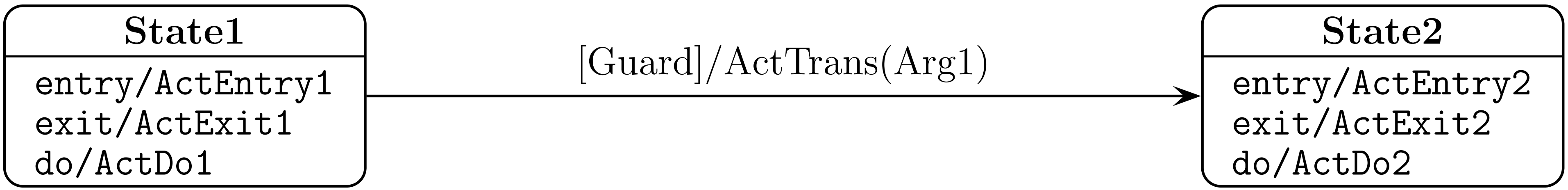

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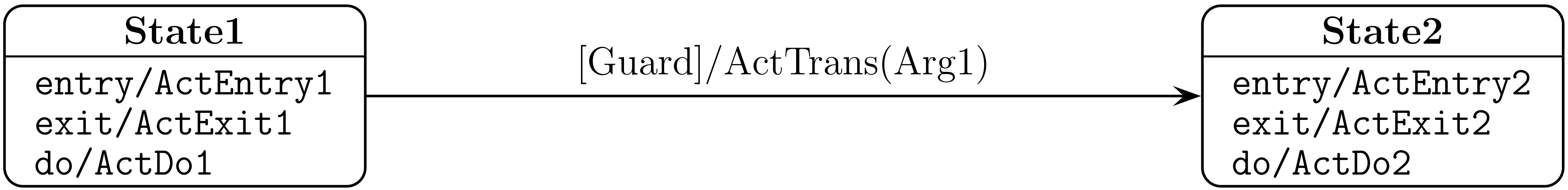

1. **wait until `ActDo1` finishes (raises *completion event*)**

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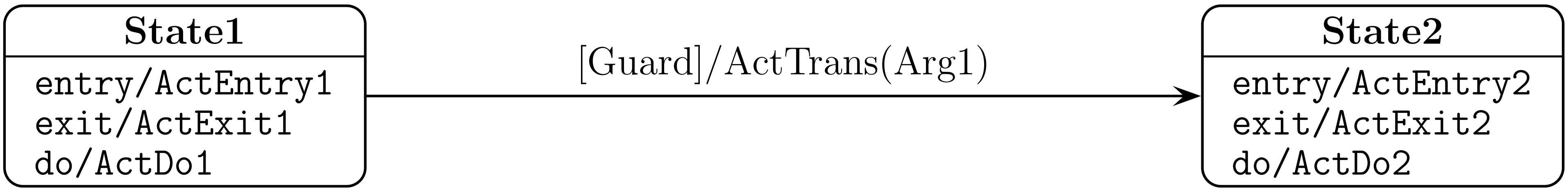

1. **wait until `ActDo1` finishes (raises *completion event*)**
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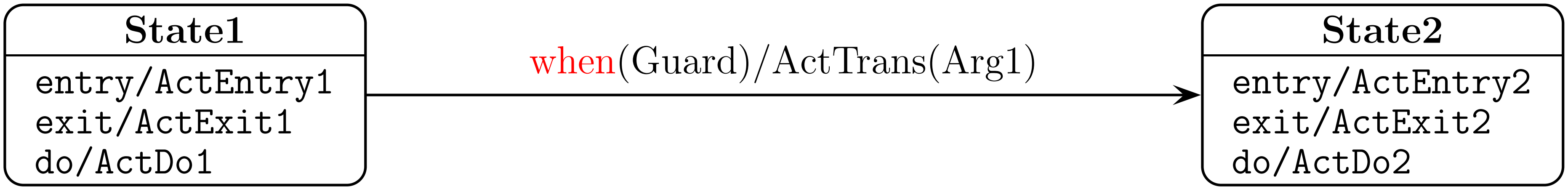
Event Processing: Change Event



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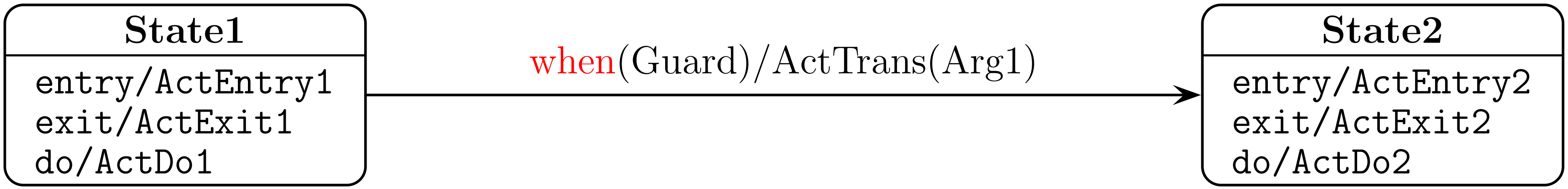

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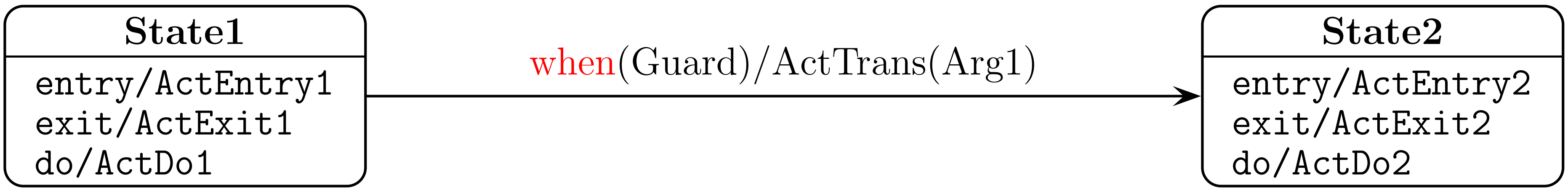

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5. **execute** `ActEntry2`
6. **execute** `ActDo2`

Completion Event vs. Change Event

Activity

Completion event: **after activity has** `ActDo1` **finished**

Change event: **activity** `ActDo1` **is aborted**

Completion Event vs. Change Event

Activity

Completion event: after activity has `ActDo1` finished

Change event: activity `ActDo1` is aborted

Guard

Completion event: guard checked only once (on completion of activity)

Change event: guard checked continuously

Event Processing: Deferred Events

Special action `defer`

```
Ev/defer
```

Puts event `Ev` in list of deferred events

Can only be used in a state (not to label a transition)

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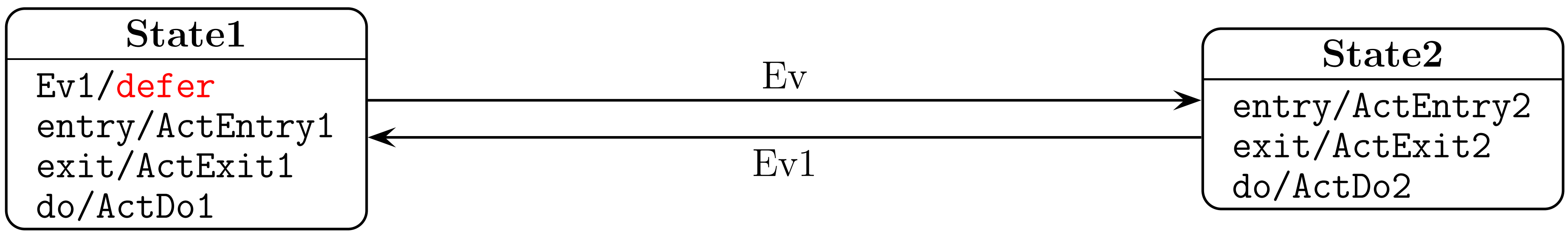
A deferred event is activated as soon as a state is entered where it is not deferred

Lost events

Events that are neither handled nor deferred in the current state are lost

Event Processing: Deferred Events – Example

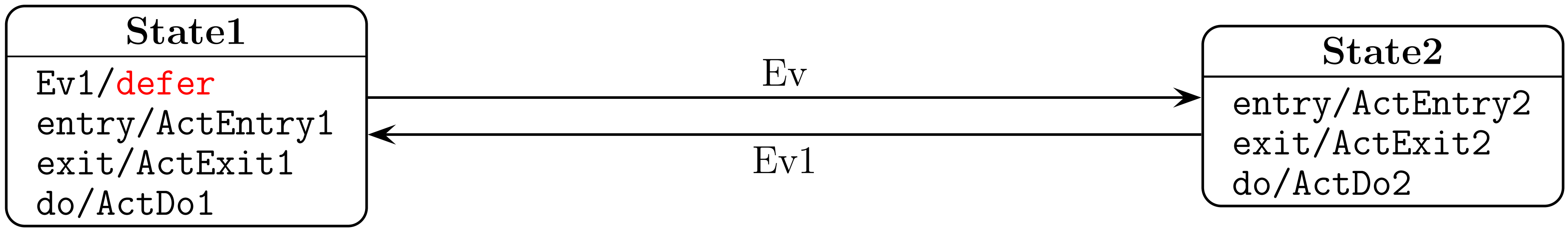


Scenario

`State1` **is current state**

`Ev1` **dispatched first,** `Ev` **dispatched afterwards**

Event Processing: Deferred Events – Example



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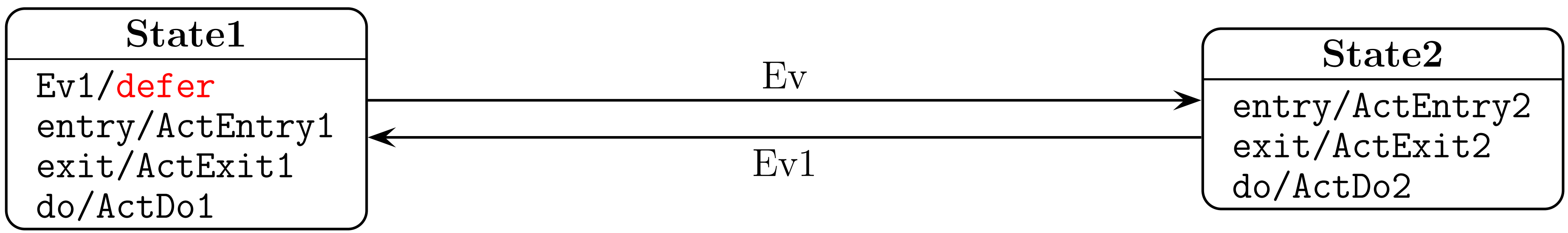

Scenario

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Then ...

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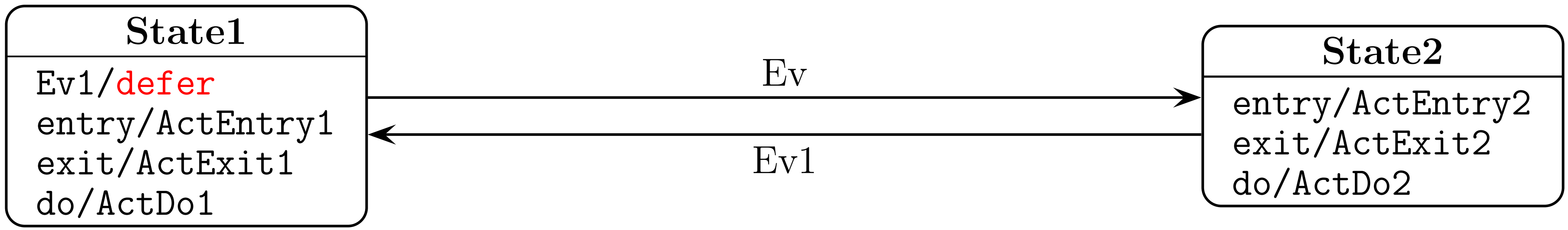

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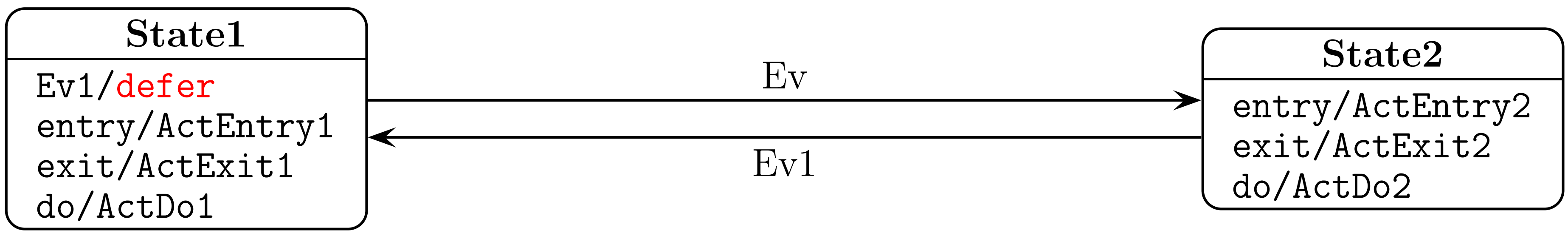

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Then . . .

1. **event** `Ev1` **is deferred**
2. **transition from** `State1` **to** `State2`**, consuming event** `Ev`
3. **event** `Ev1` **is re-activated**
4. **transition from** `State2` **to** `State1`**, consuming** `Ev1`

Composite States

Purpose

Allow to model complex behaviour

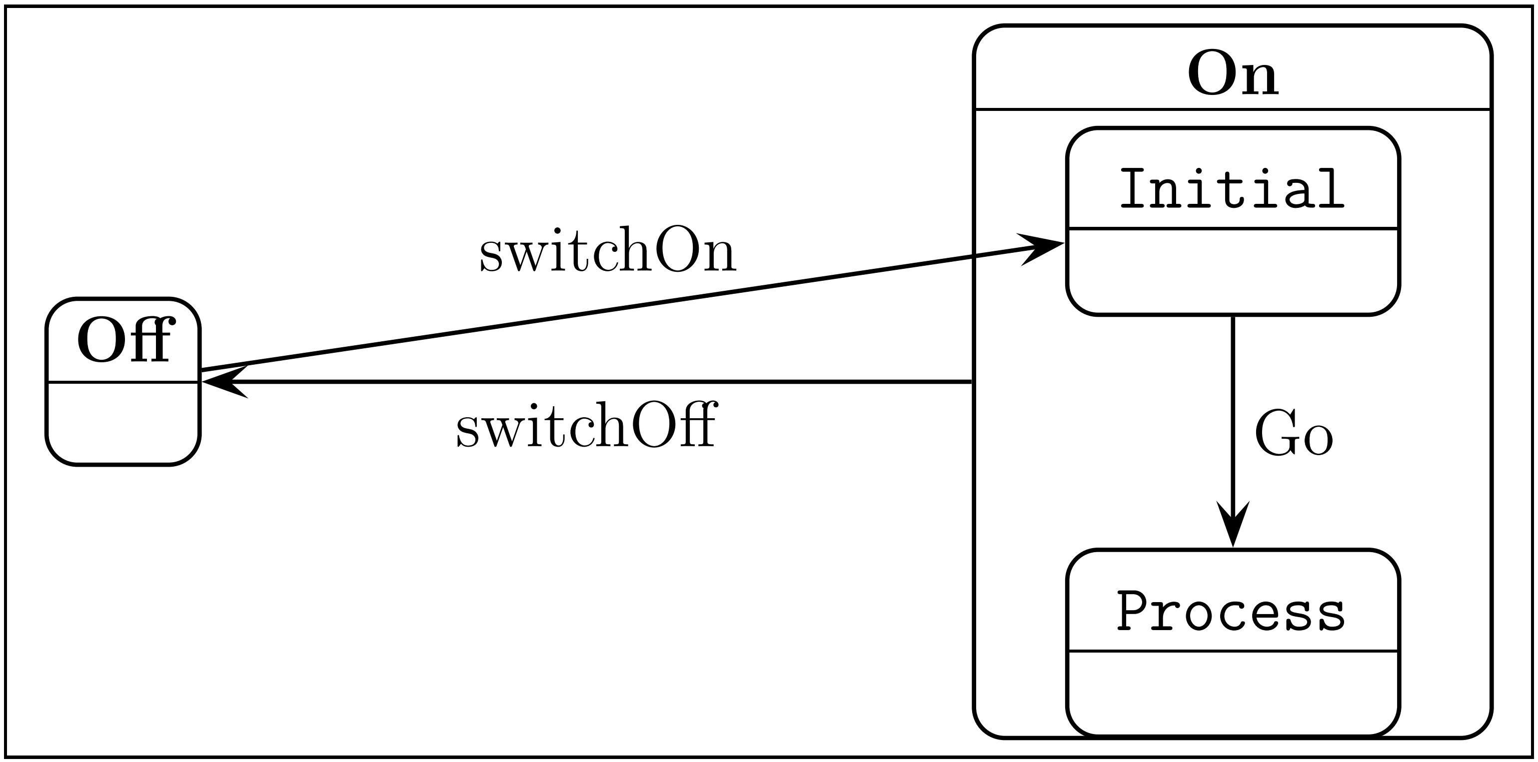
Idea

- Similar sub-states are grouped into a composite state (nesting hierarchy is a tree)
- Composite states can have transitions, entry/exit actions, `do` activities, . . . (transitions can connect states from different nesting levels)
- Sub-states “inherit” from the composite state

Note

State Machines are in fact composite states

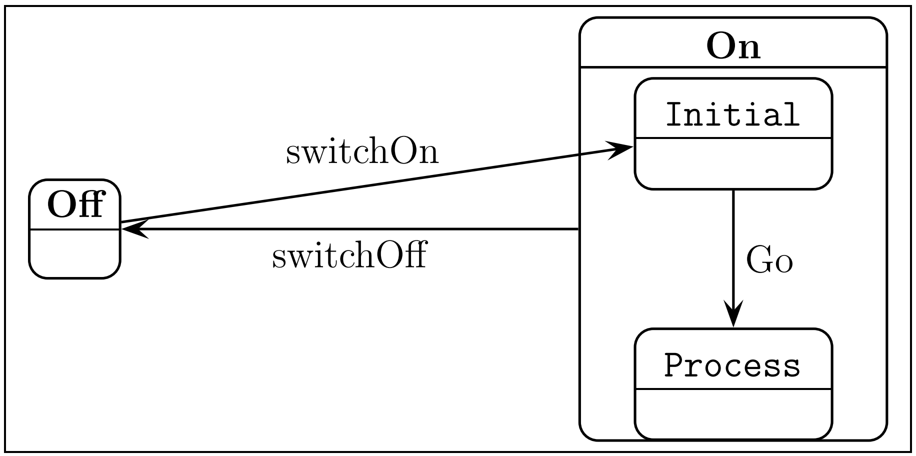
Composite States: Example



`Initial`, `Process` **are sub-states of** `On`

`Initial`, `Process` **“inherit” transition** `switchOff`

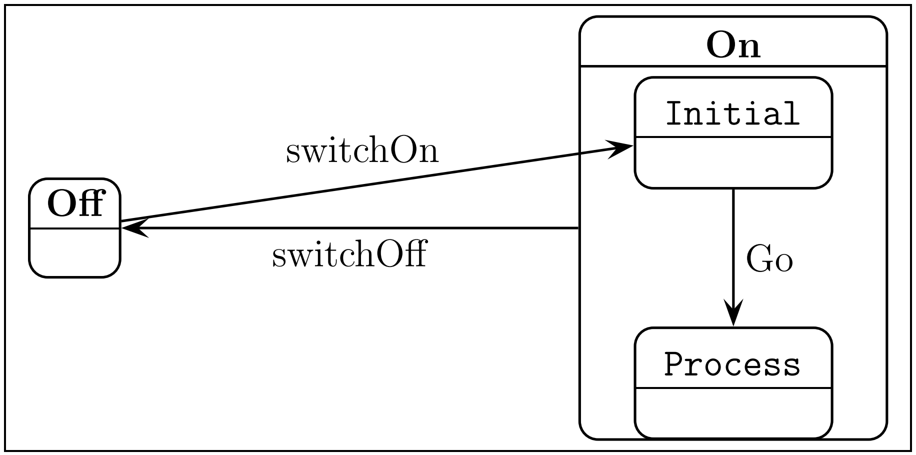
Composite States: Three Equivalent Models

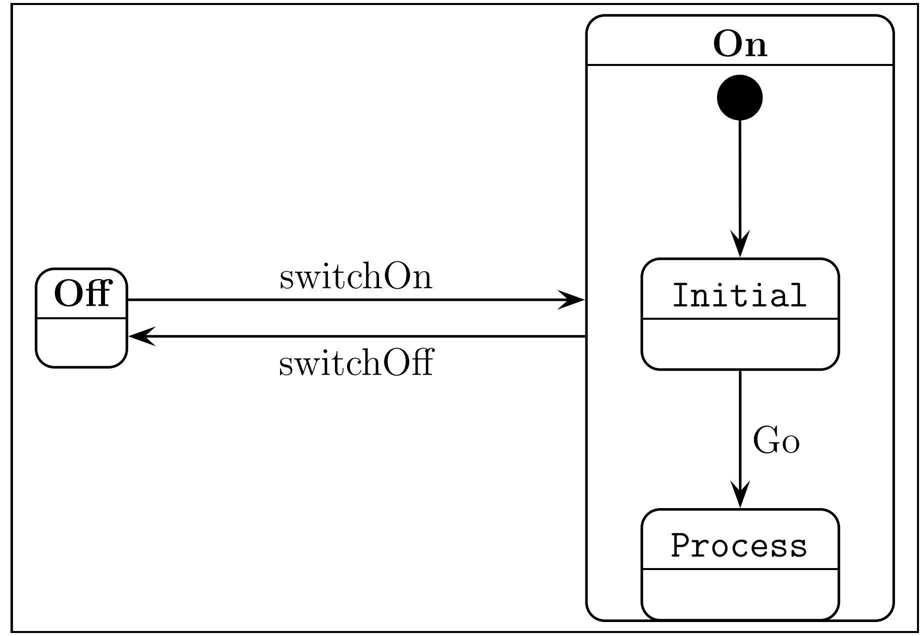


Note

These models are equivalent if entry/exit actions and do activities of `On` are ignored

Composite States: Three Equivalent Models





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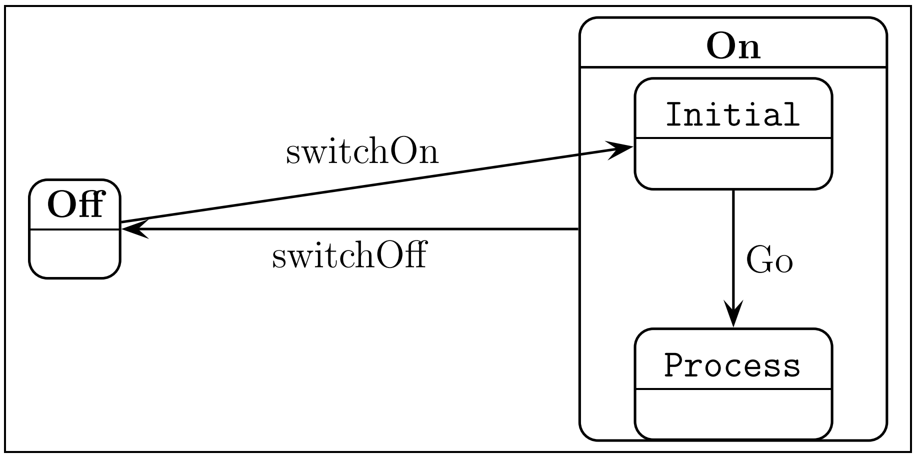
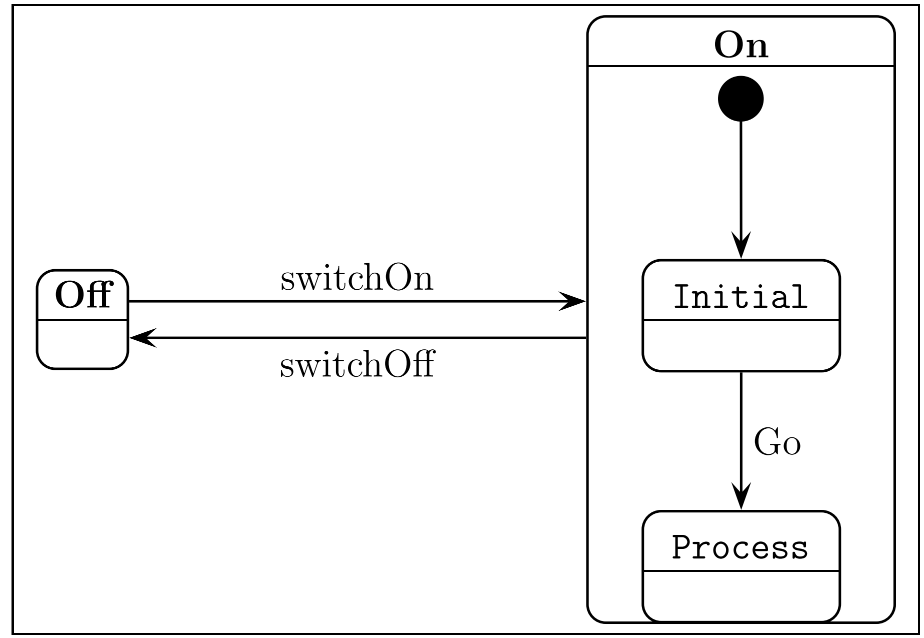
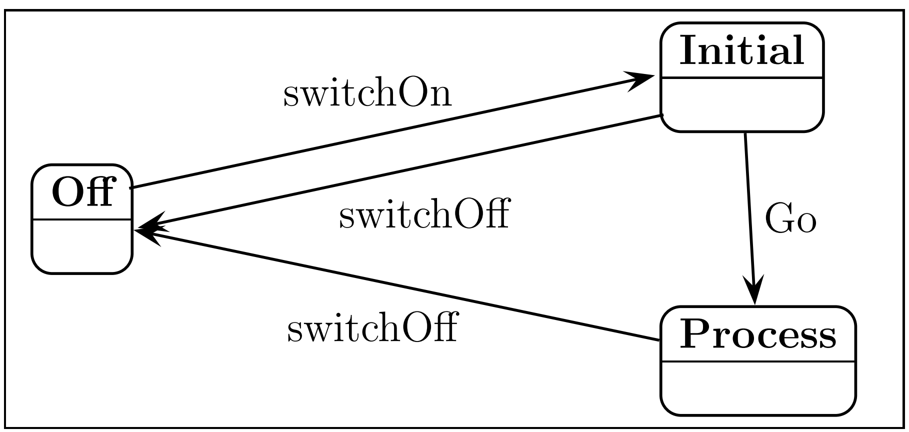
Composite States: Three Equivalent Models







Note

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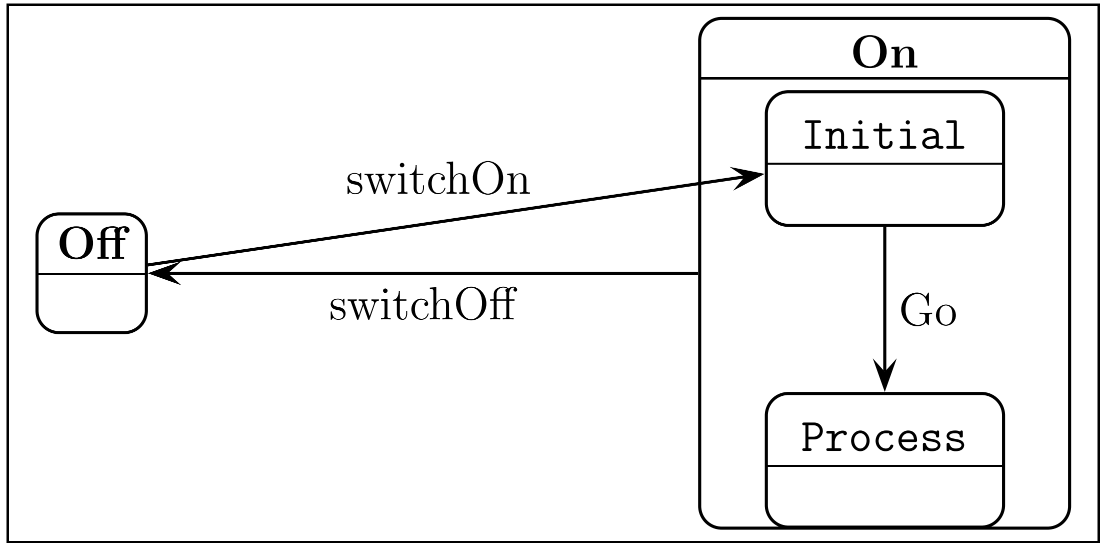
Composite States: Active States

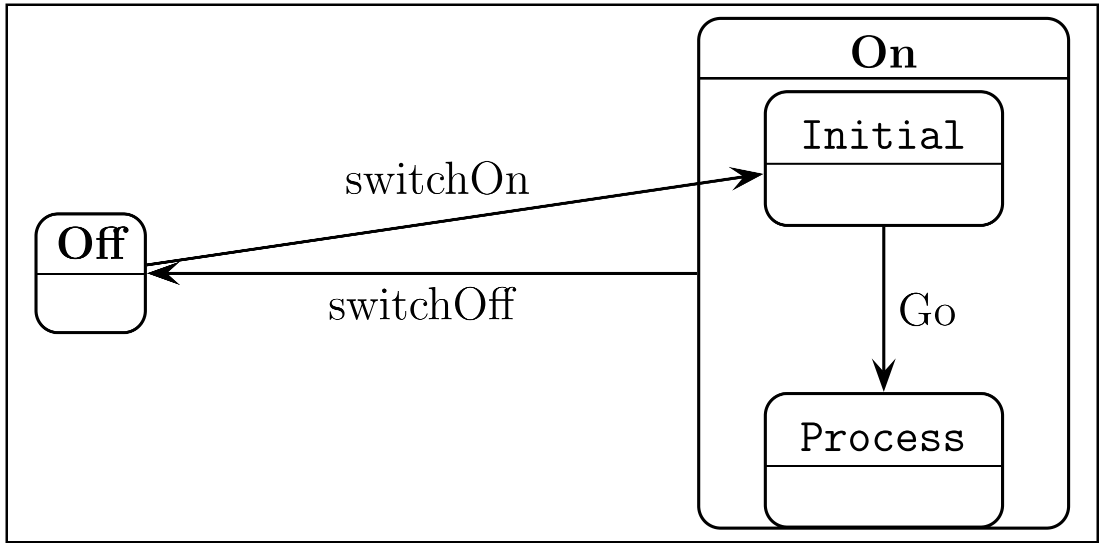


Active states

Sub-state and composite state can be active simultaneously

"Active state" now denotes a path
from a top-level state to a leaf node in the state hierarchy

Composite States: Rules for Entering States



Entering a composite state

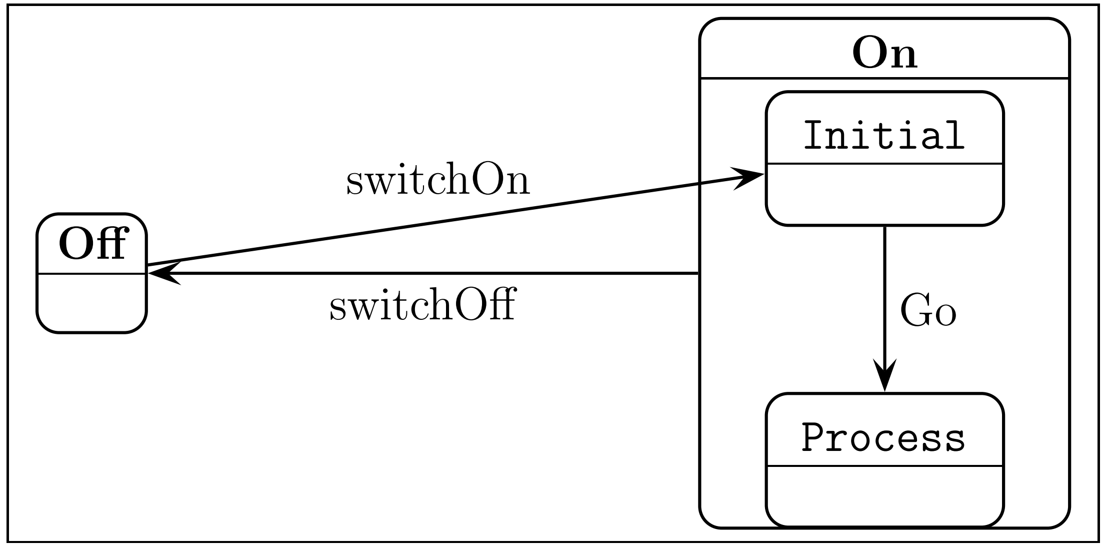
There must be an initial sub-state

Entering a sub-state

Both the composite state and sub-state are activated

Order of entry actions: top-down

Composite States: Rules for Exiting States



Exiting a composite state

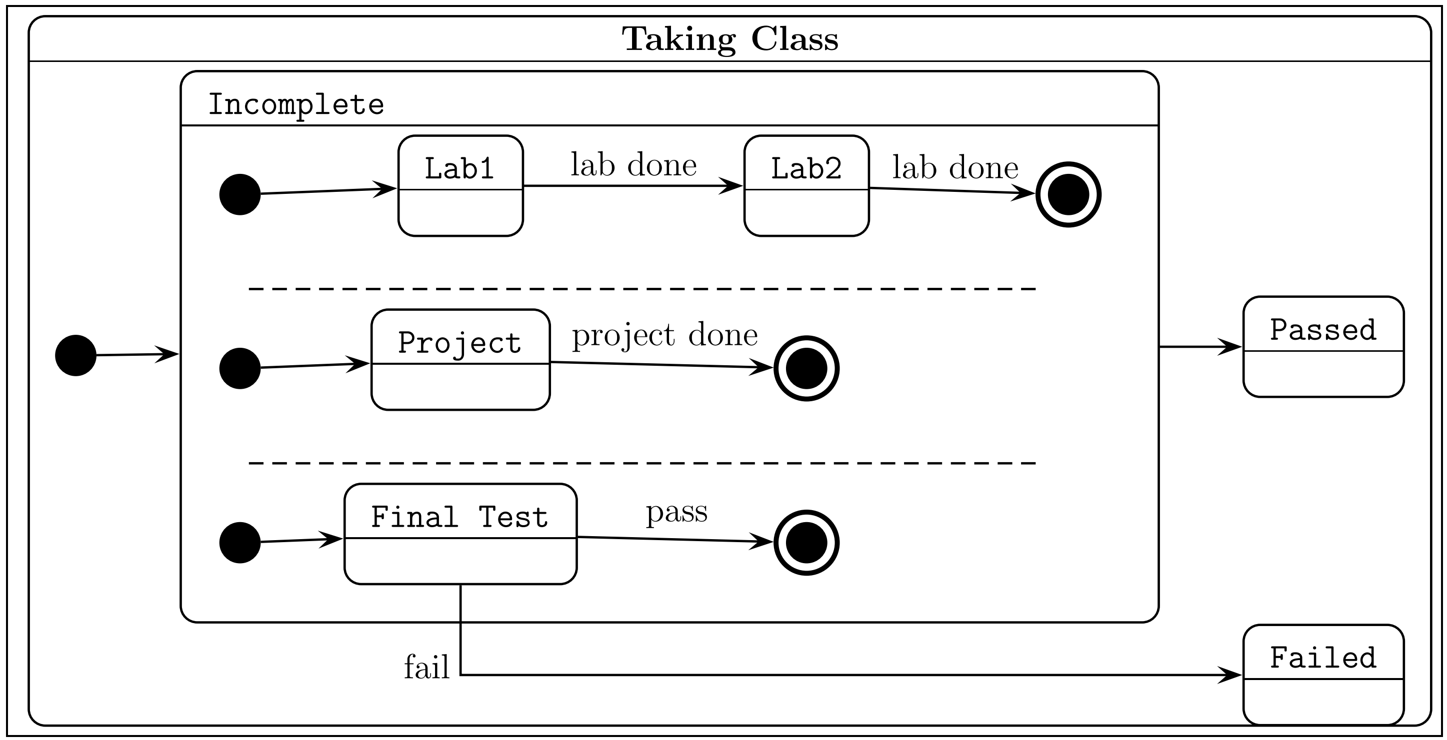
Exit active sub-state as well.

Exiting a sub-state

Order of exit actions: bottom-up

When final state becomes active sub-state, completion event is raised

Concurrent Composite States



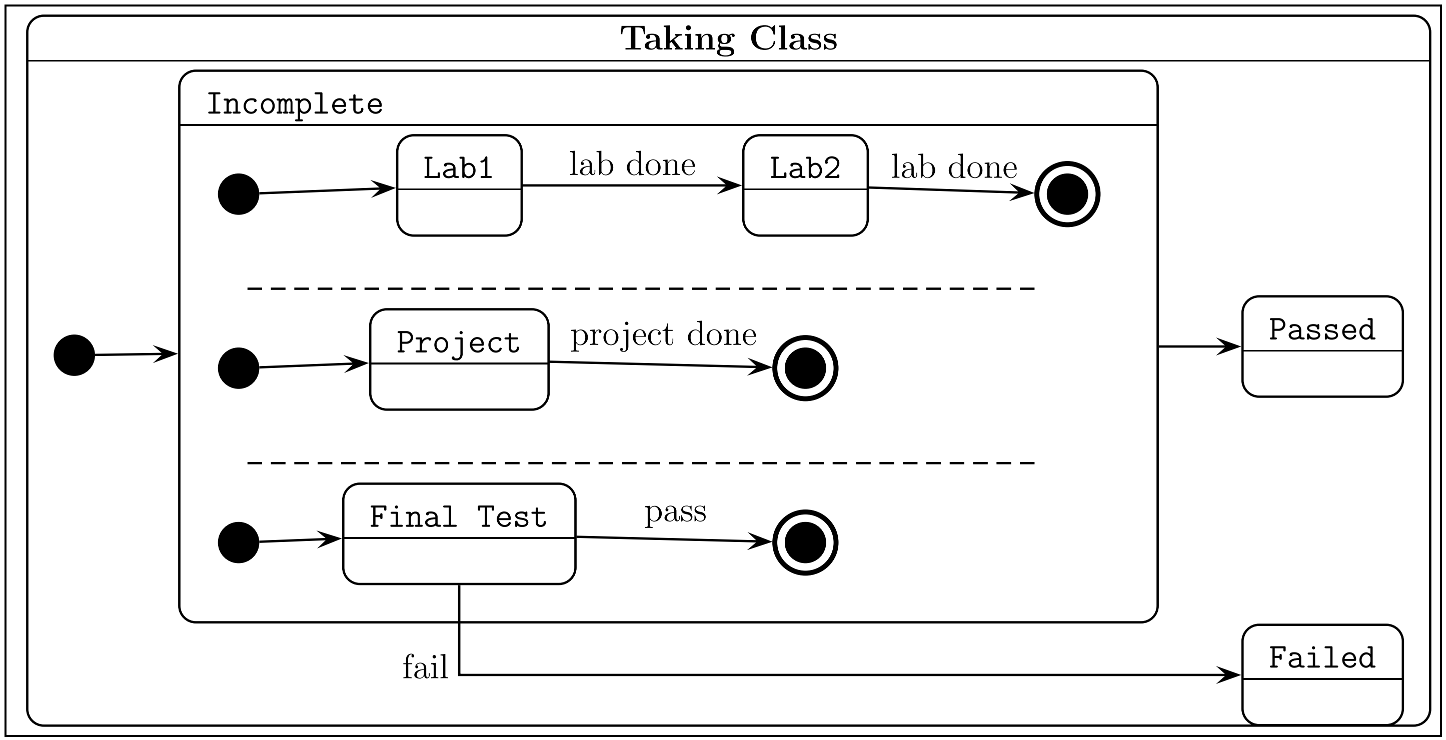
Regions

Concurrent parts of composite state

Are activated synchronously (when composite state is acitivated)

Separated by dashed lines

Concurrent Composite States

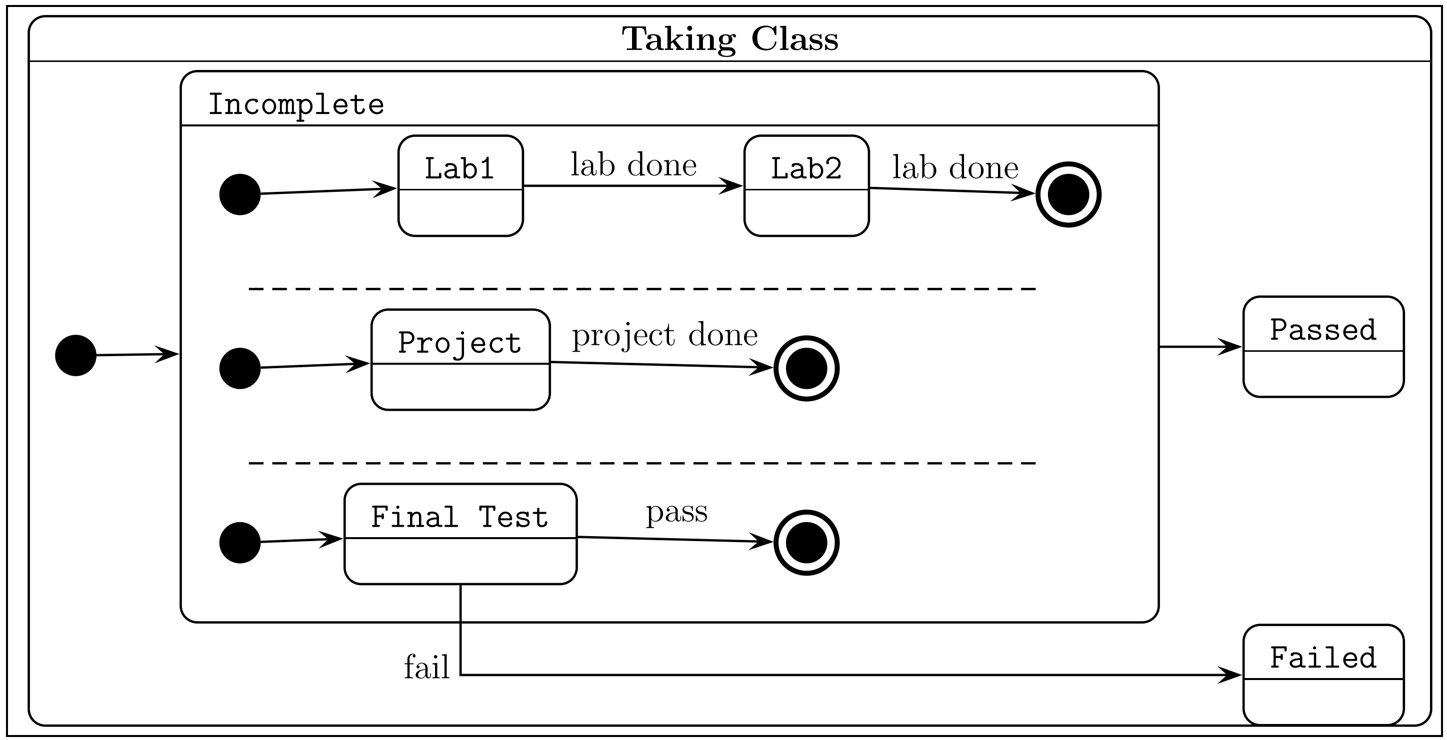


Active state

Also called *state configuration*

Now consists of ???

Concurrent Composite States

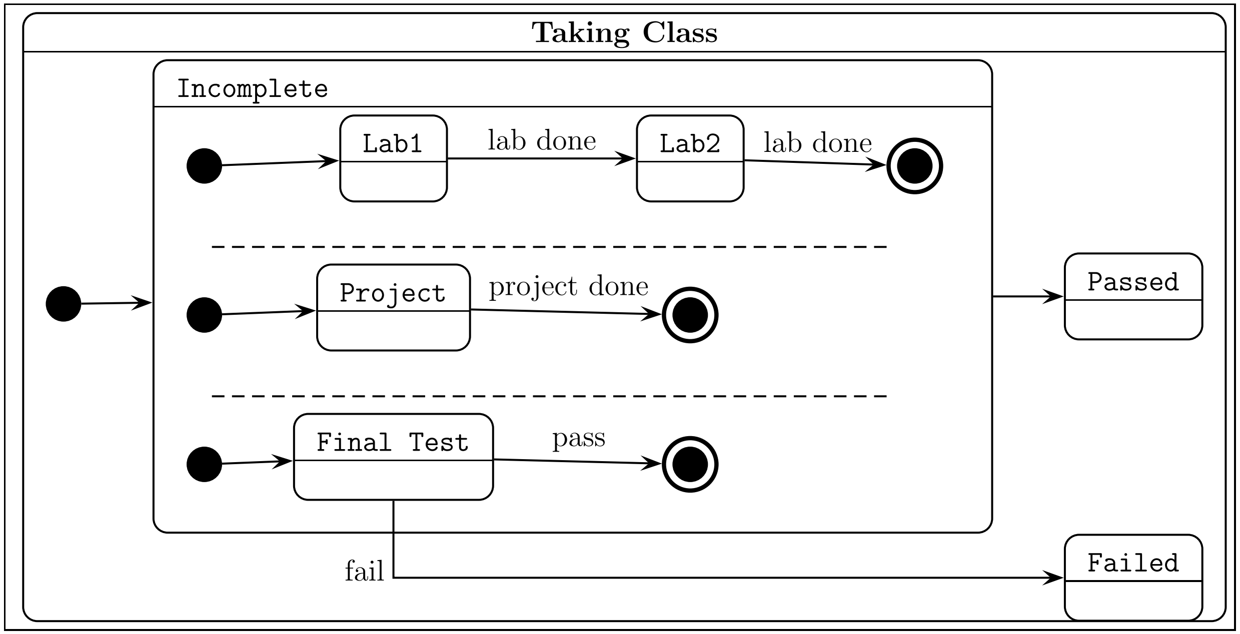


Active state

Also called *state configuration*

Now consists of a sub-tree of the state hierarchy

Concurrent Composite States: Rules for Entering



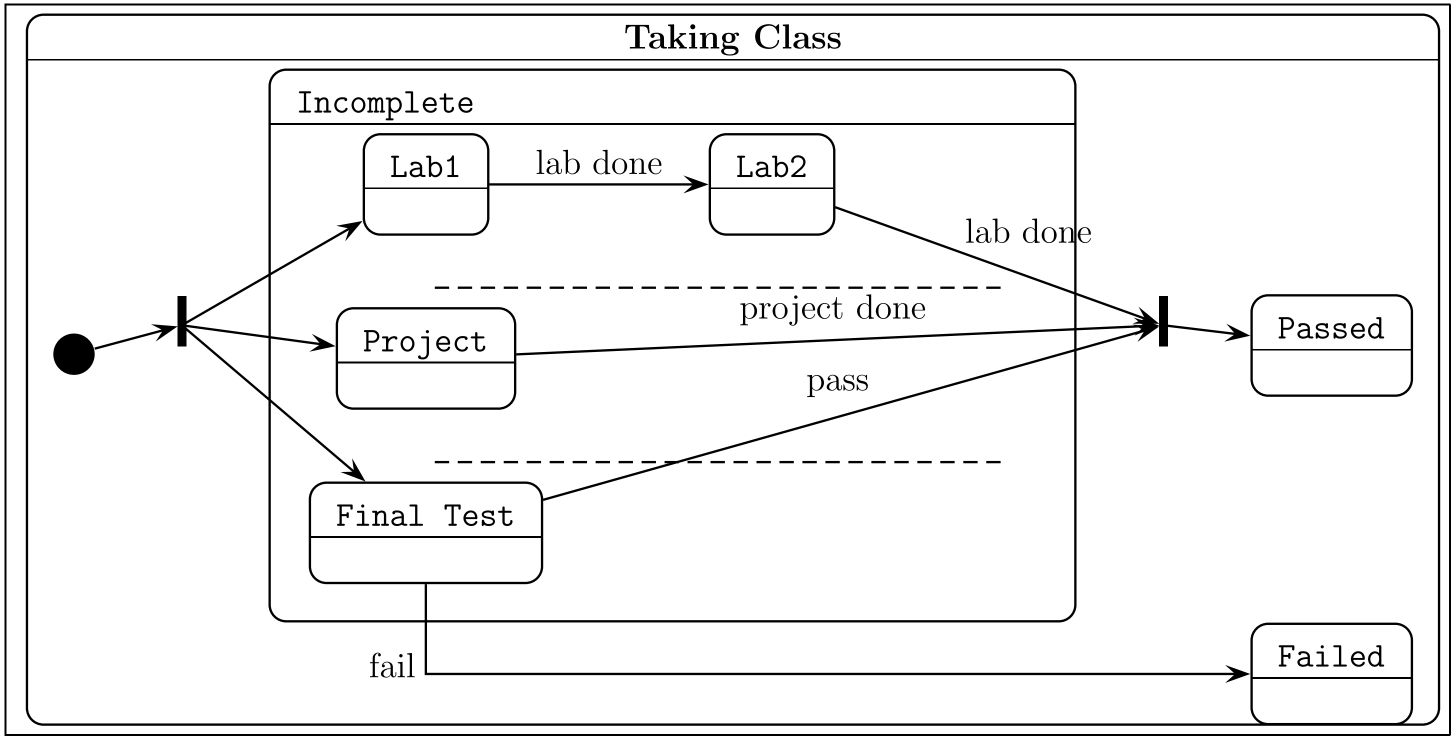
Entering a composite state

There must be an initial sub-state in each region

Entering a sub-state

There must be an initial sub-state in all other regions

Concurrent Transitions

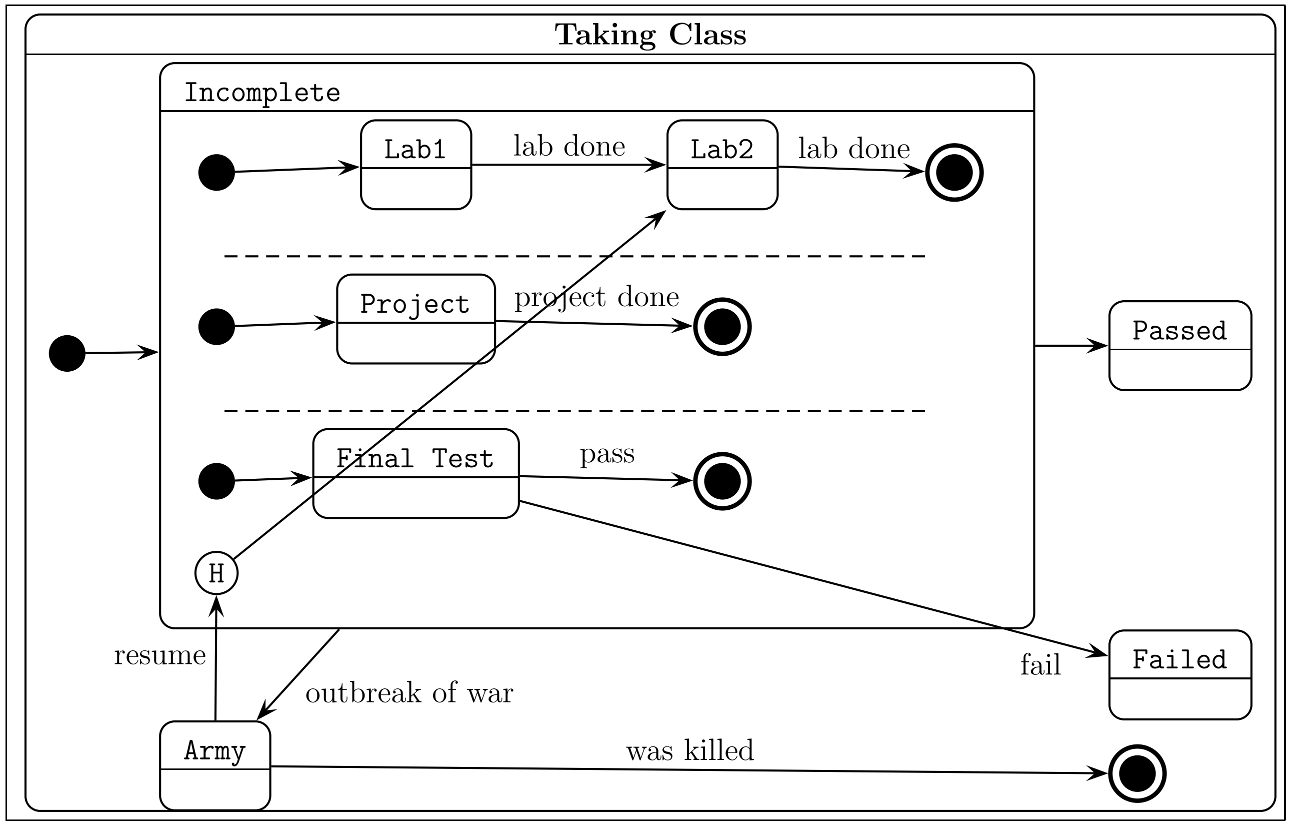


Concurrent transition

Alternative notation for entering concurrent composite state

Uses pseude-states “fork” and “join”

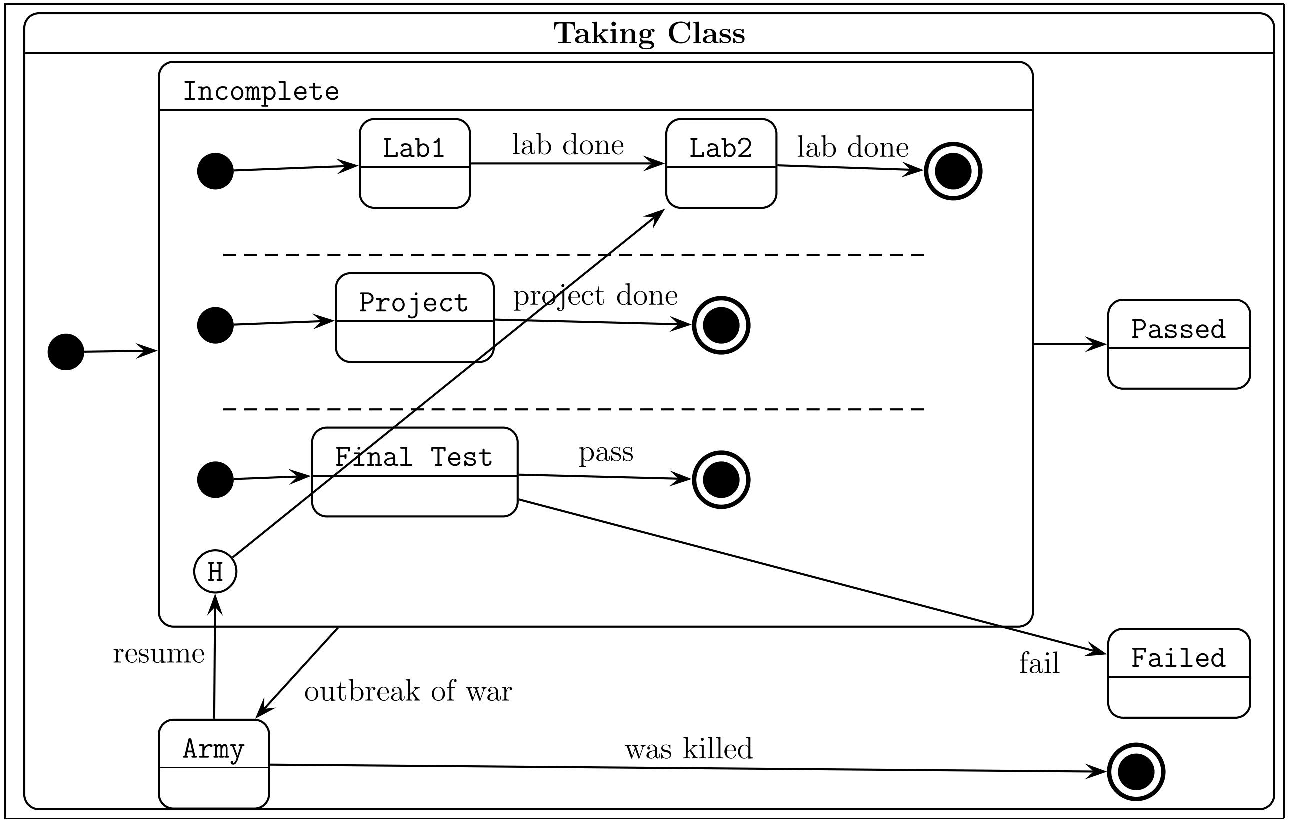
History States



When re-entering composite state, establishes the last active configuration

Outgoing transition indicates default active configuration

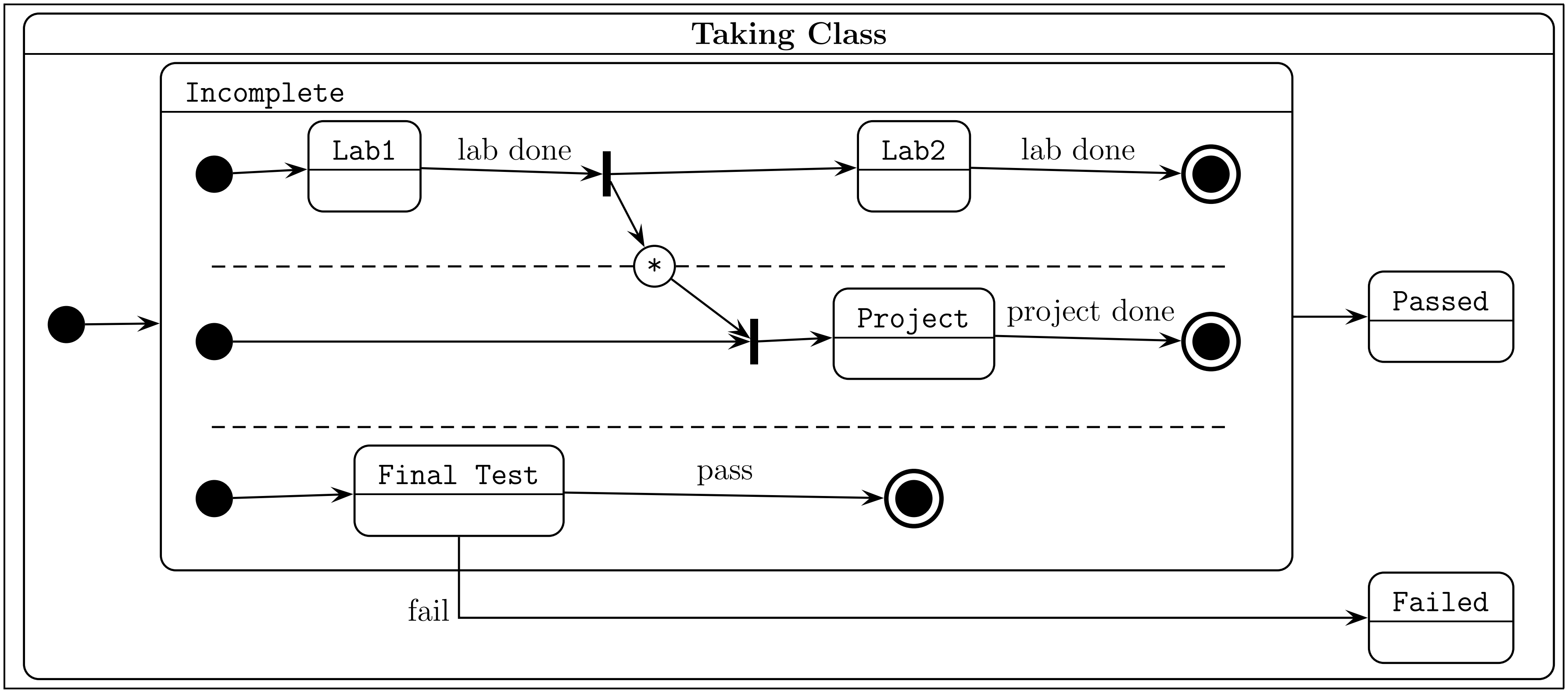
History States: Shallow vs. Deep



Shallow (H): **Records history only of composite state is belongs to**

Deep (H$*$): **Records history of sub-states as well**

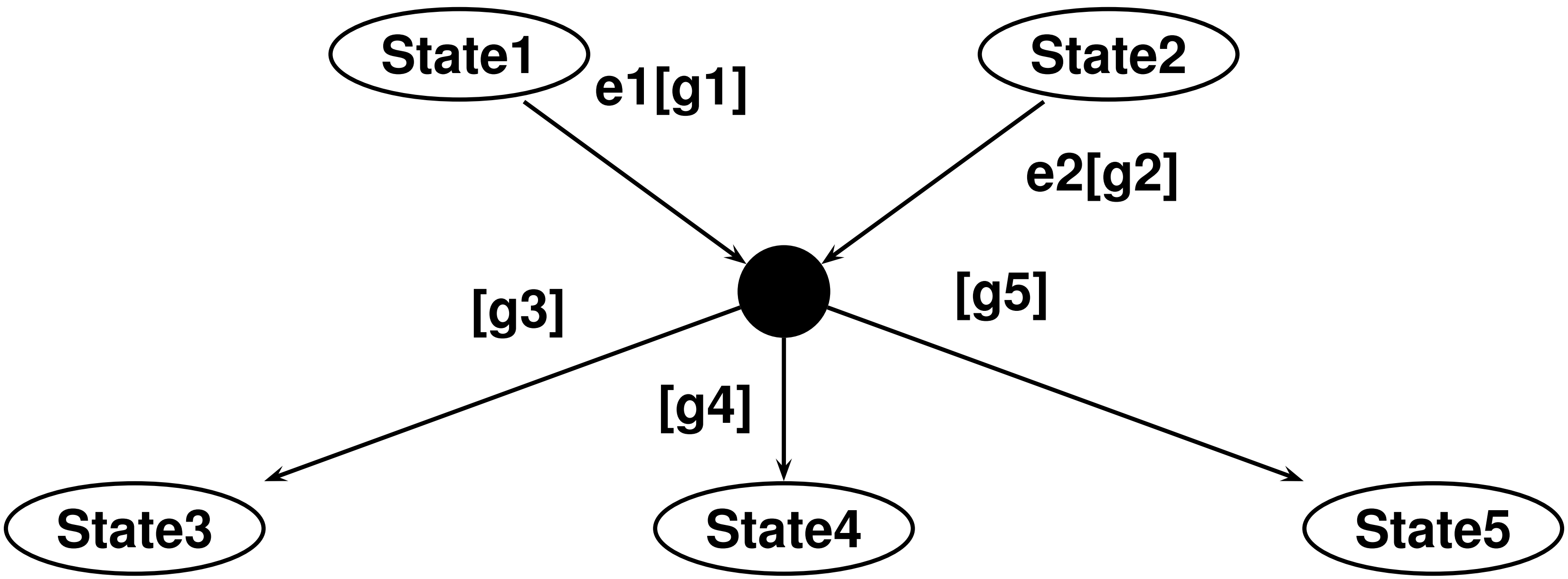
Synch States



Allow to synchronise regions

Used in combination with fork and join

Junction Points



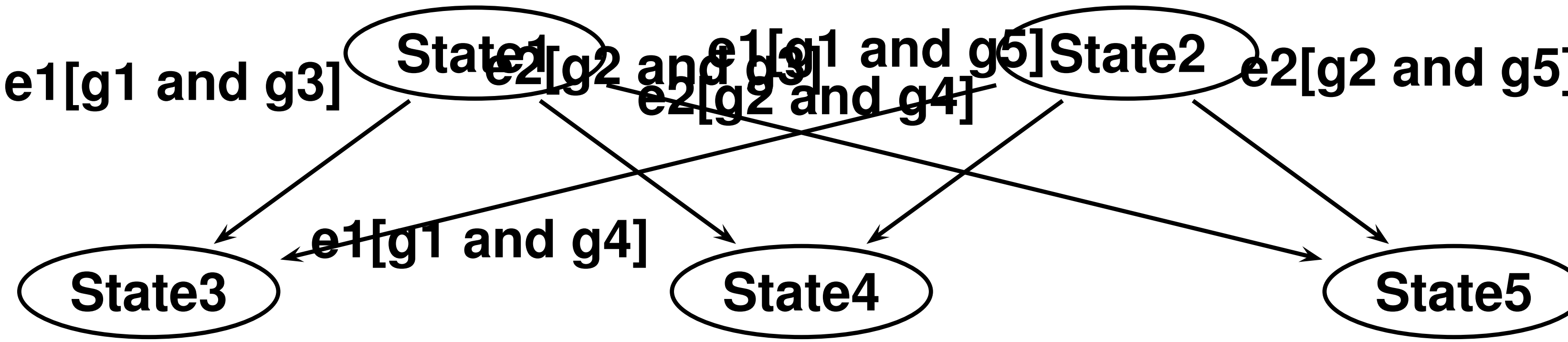
Purpose

Simplify notation, allow to “factor out” transitions

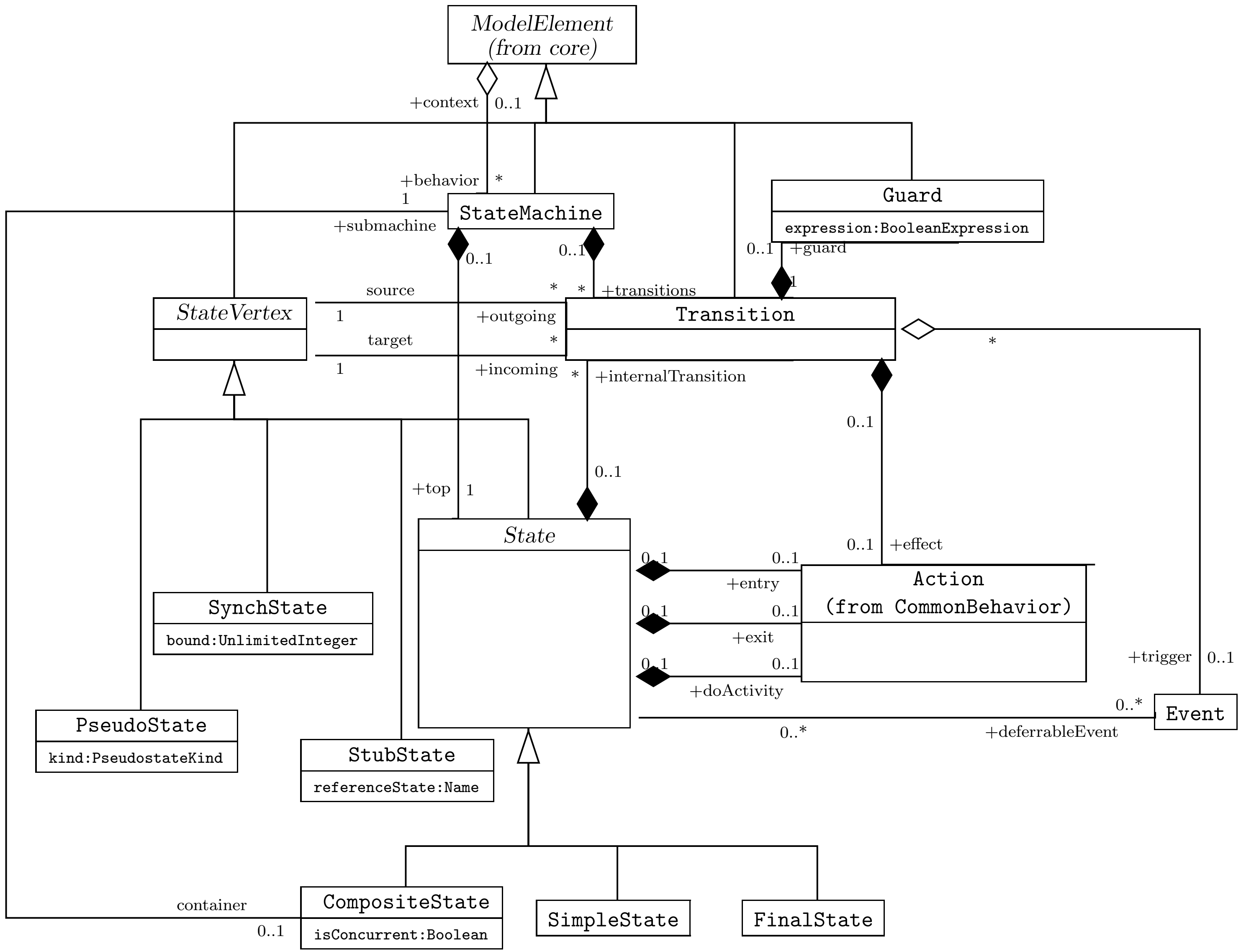
Different from fork/join

Junction Points

Example without junction point



Metamodel for State Machine



PseudoStateKind

- initial
- final
- deepHistory
- shallowHistory
- join
- fork
- junction

A Constraint of the Meta Model

Constraint on context of StateMachine

> **A state machine is aggregated within either a classifier or a behavioural feature (e.g. an operation)**

A Constraint of the Meta Model

Constraint on context of StateMachine

A state machine is aggregated within either a classifier or a behavioural feature (e.g. an operation)

context **StateMachine**

inv **self.context.notEmpty implies**

self.context.oclIsKindOf(BehavioralFeature) or

self.context.oclIsKindOf(Classifier))

Note

Nothing said about what happens if self.context.isEmpty