Ch. 5.2: Part-A Advanced Behavioral Specification in UML

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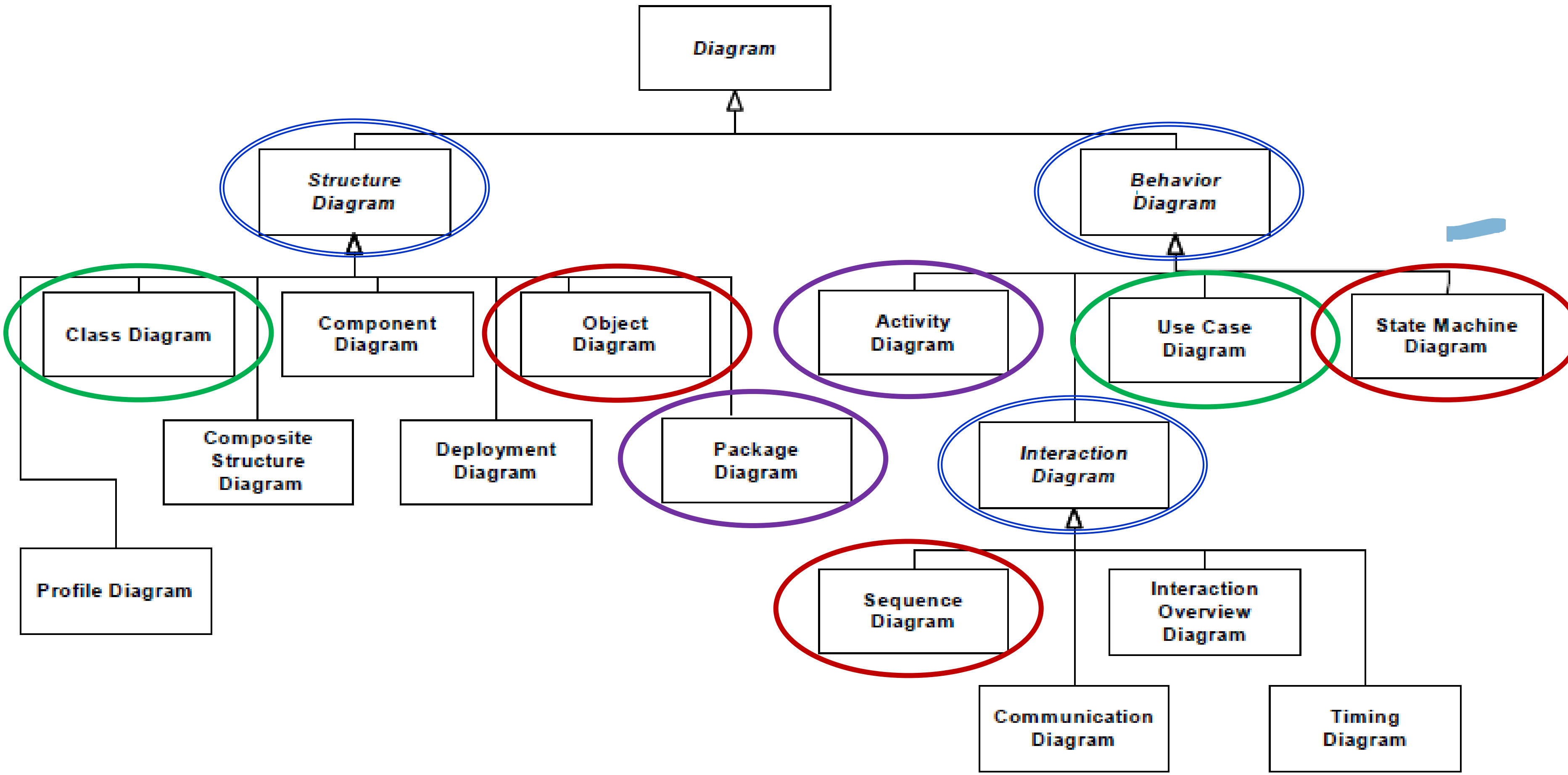
UML Languages



Element Abstract Syntax

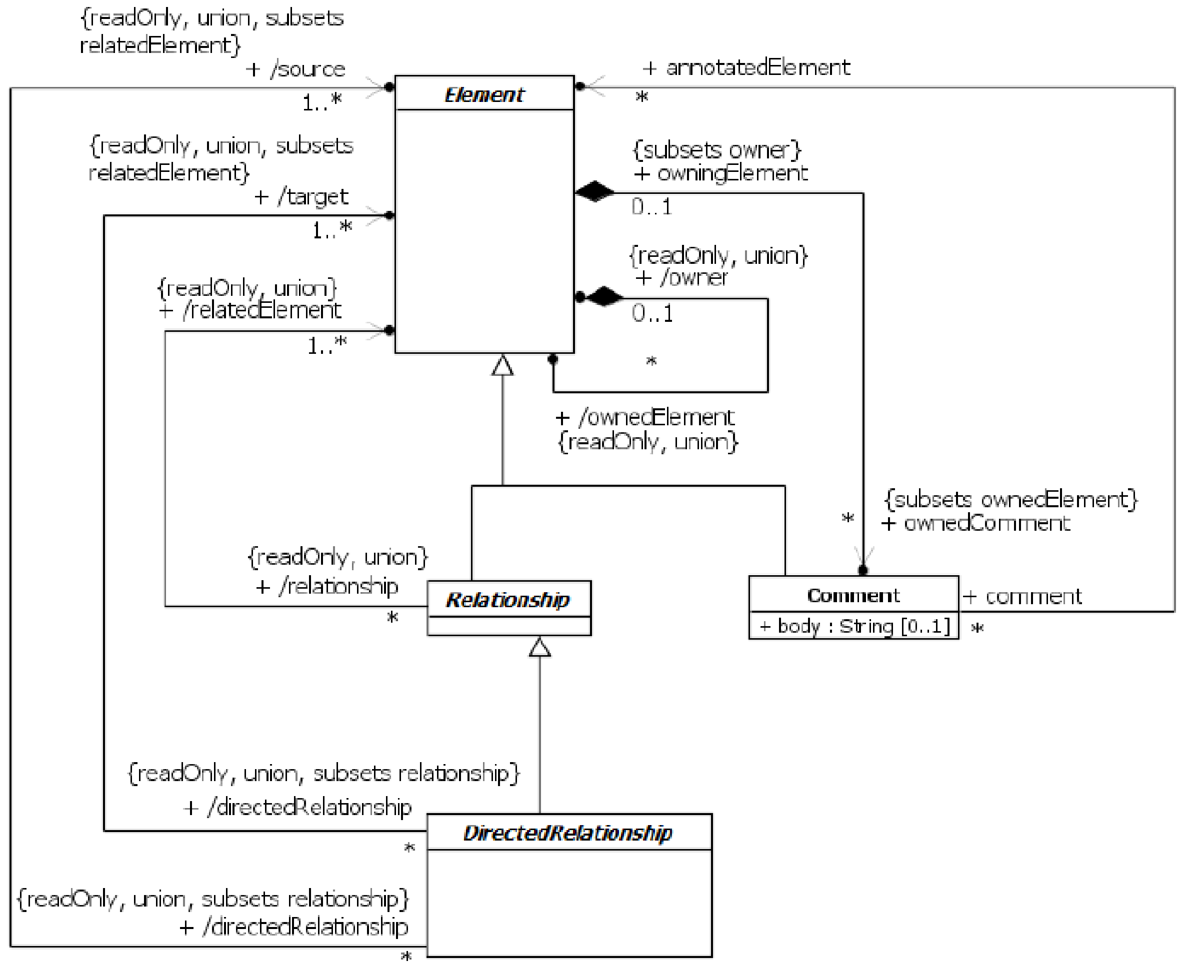
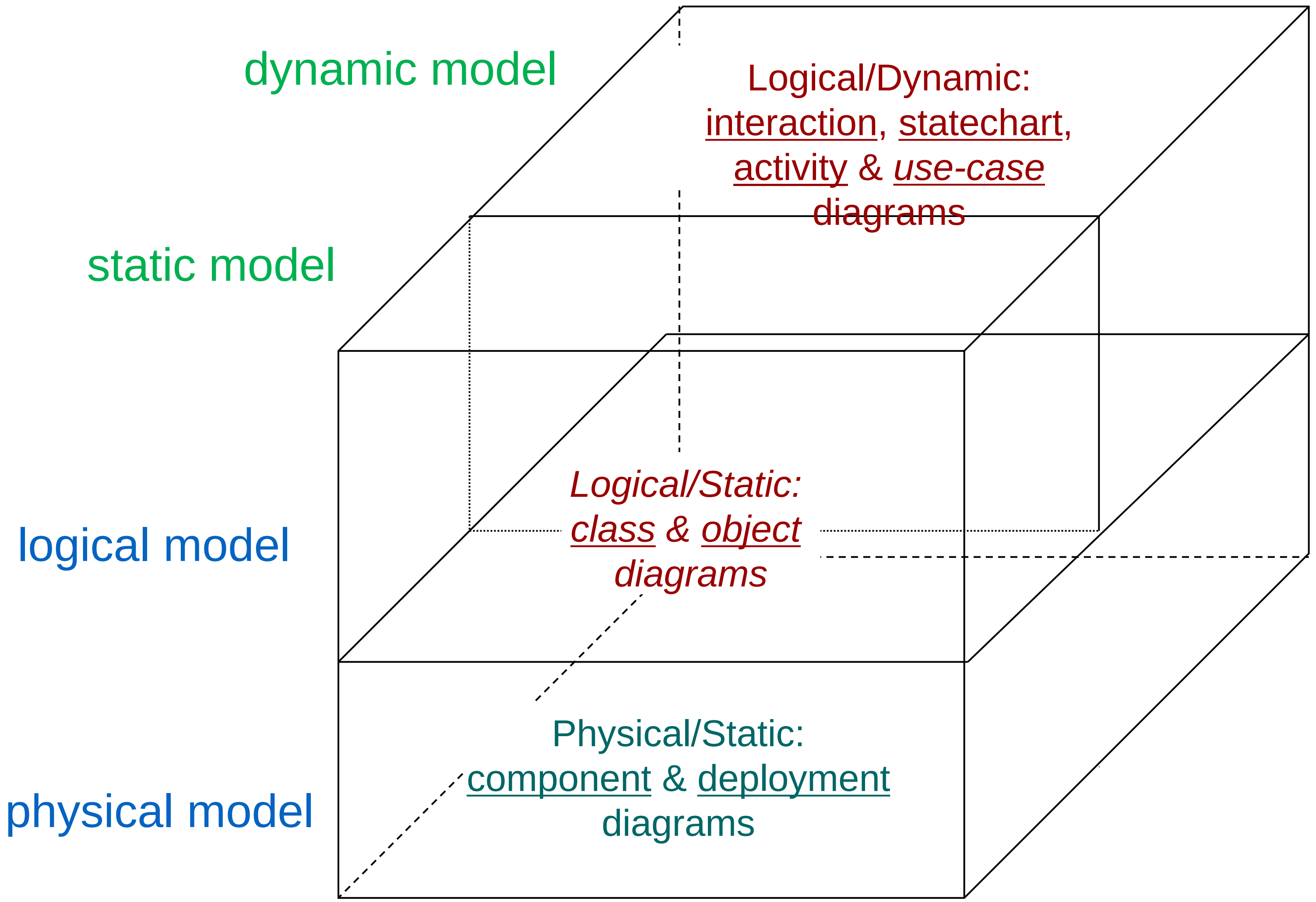
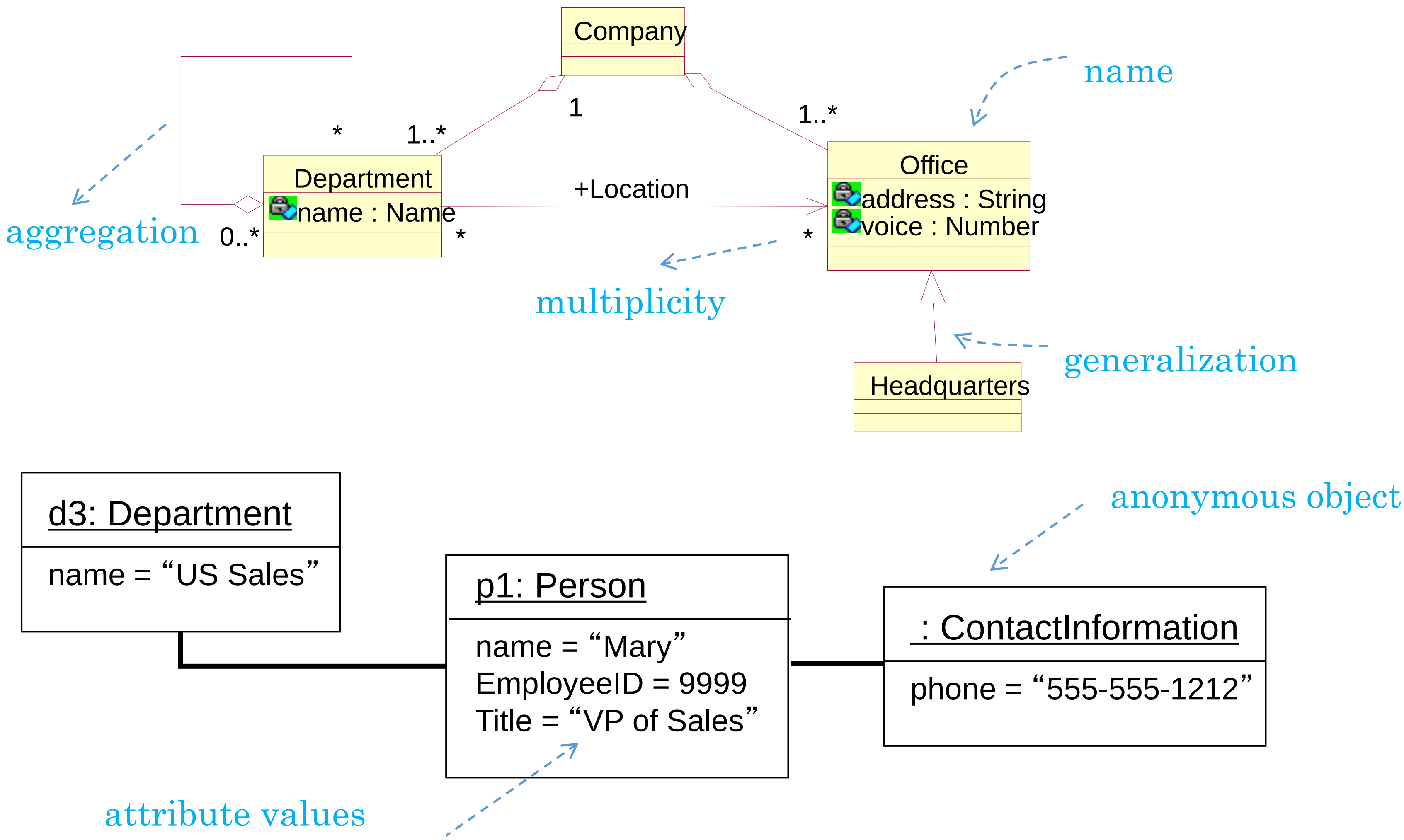


Figure 7.1 Root

Models and Views of Object-Oriented Development



Class and Object Snippet Diagrams



State Machines and Statechart Diagrams

State Machines and Statechart diagrams capture *dynamic* aspects of a software intensive system

- *Behavioral modeling*

Basic elements of a dynamic system can be represented with *states, events, transitions,* and *actions*. These model lifetime of an object in response to external and internal stimuli

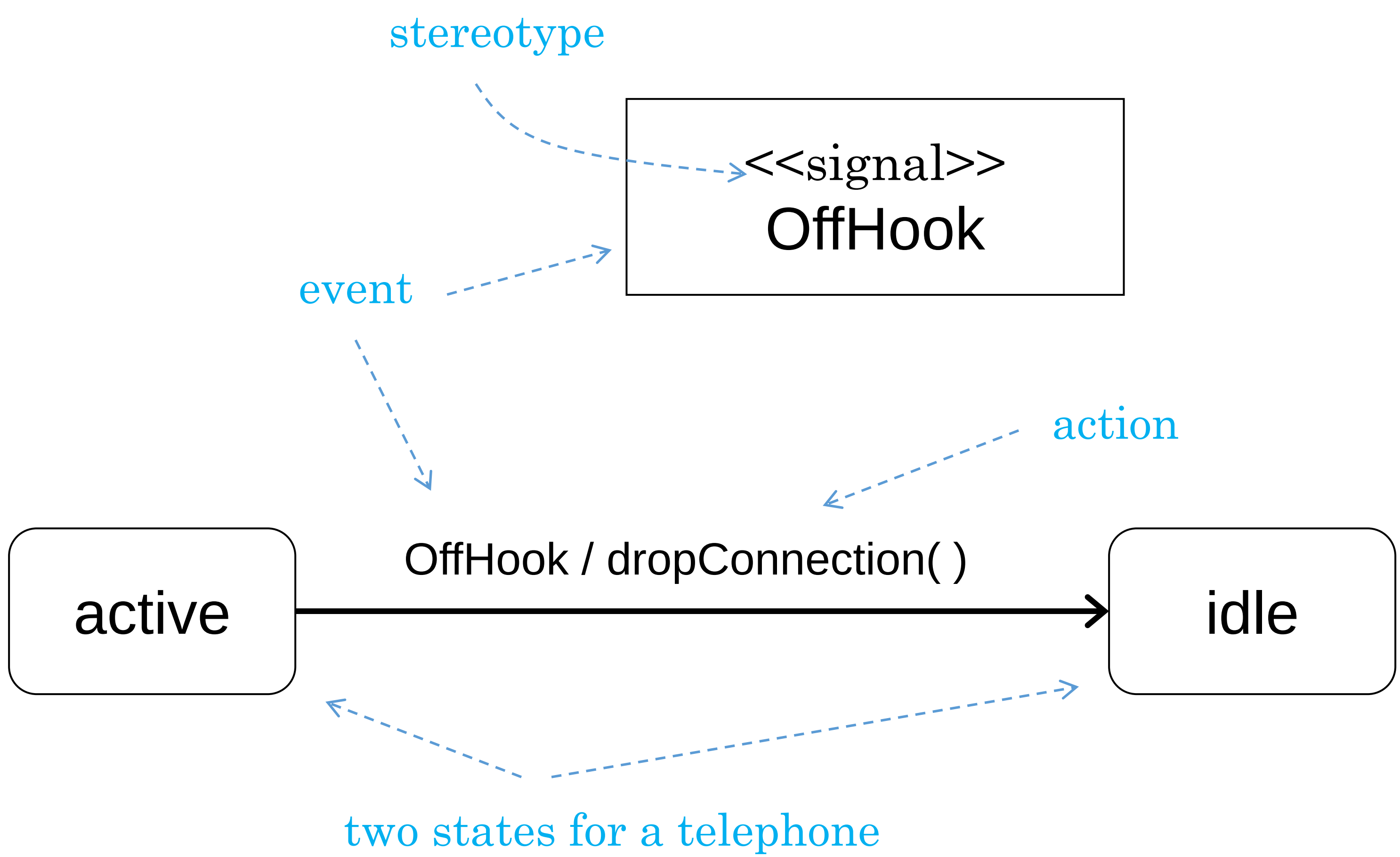
Events

Things that happen (e.g., OffHook) are modeled as events

- Event – is an occurrence of a stimulus that can trigger a state transition or invoke an operation
- Events are either external or internal
  - External: events that are created externally – events that pass between the system and its actors
    - pressing a car’s cruise control button
  - Internal: events that are created internally – events that pass among objects living inside the system
    - overflow of a buffer
- An event has a location in time and space

Events (cont.)

UML notation



Events (cont.)

There are four kinds of events:

- Signals
- Calls
- Change
- Time

- Signals, Time, and Change events are *asynchronous*
- Call events are generally *synchronous*

Signal Events

- **Signals: a signal represents a named object that can be dispatched by one object and received by another in an asynchronous manner**

- *Signals are similar to classes* – they may

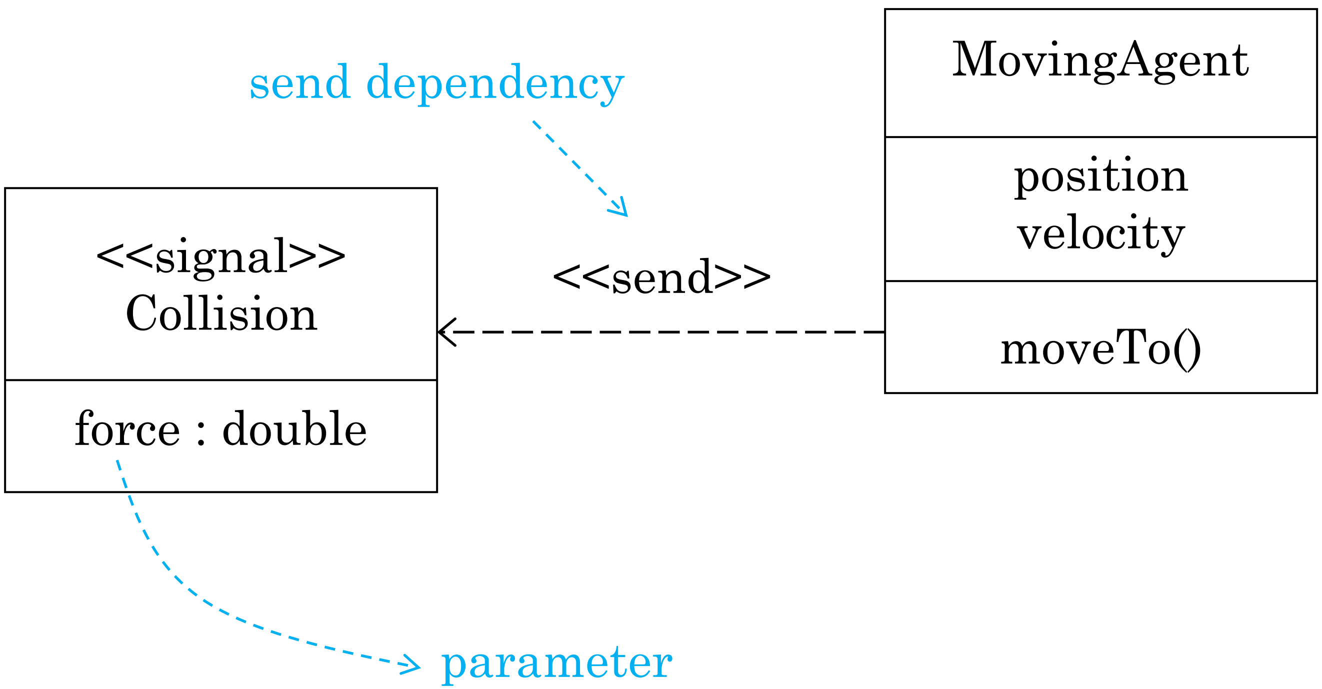
  - have attributes which serve as parameters – e.g., Collision(5.3)
  - have operations
  - have instances
  - participate in generalization relationships – e.g., HardwareFault is generalization of BatteryFault

- Exceptions are a common kind of internal signals

- Signals are sources of events for state transitions and interactions

Signal Events (cont.)

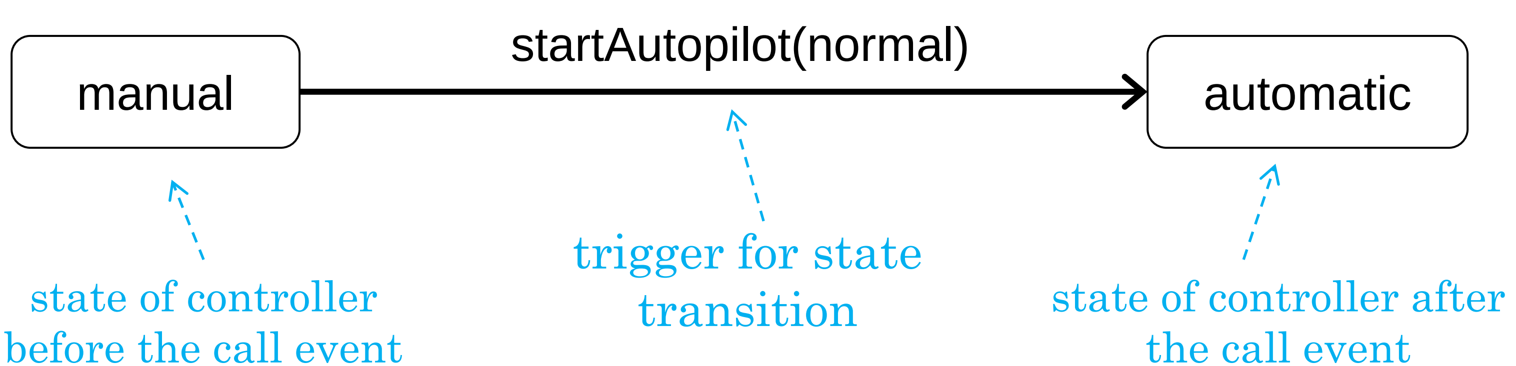
A class behavior can be specified in terms of the signals its operations can send



Call Events

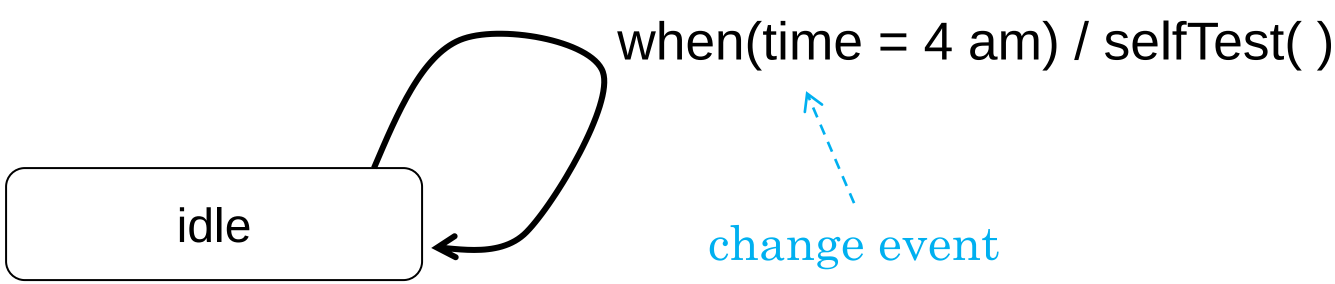
Call event: represents dispatch of an operation

- A call can trigger a state transition in a state machine
- A call is generally synchronous
  - An object (sender) invokes an operation of another object (receiver) which results in the receiver to take control
  - Upon completion of the operation by the receiver, the receiver transitions to a new state and control is returned to the sender



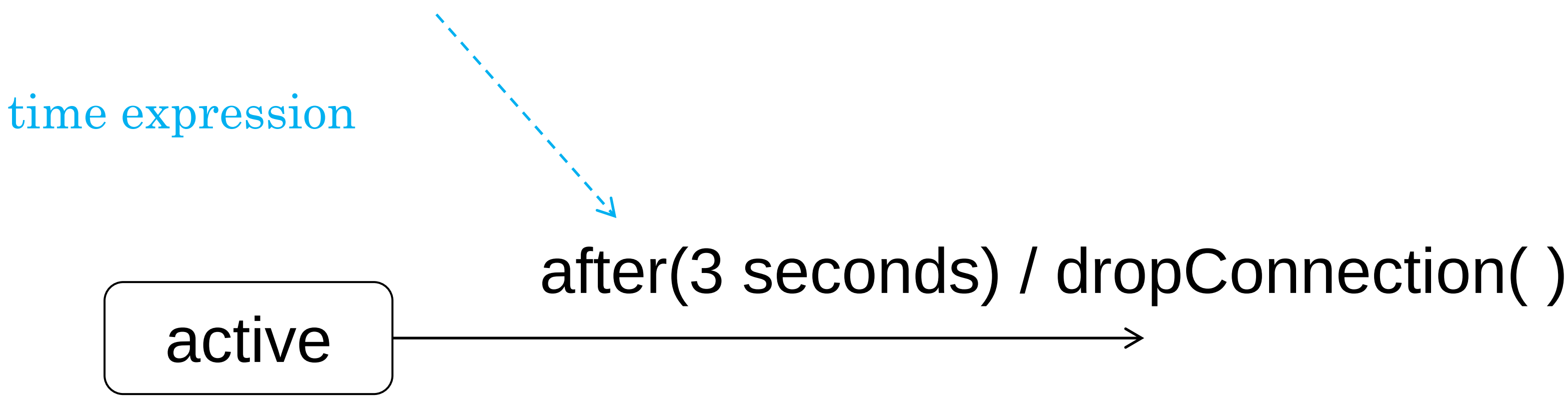
Change Events

- Change event: represents an occurrence of an event when a Boolean expression becomes true as a result of state change or the satisfaction of some condition
  - keyword ***when*** signifies the change event
  - a Boolean expression is used with the *when* keyword to invoke the change event
  - when(Boolean expression)/change event
  - change event ideally needs to be evaluated continuously, instead usually evaluation takes place at some discrete time points



Time Events

- Time event: represents the passage of time – i.e., expiration of a deadline
  - Keyword ***after*** signifies the time event
  - An expression which evaluates to some period of time is used with the *after* keyword to invoke the time event
  - after(expression)/time event



Signal and Call Events: Send and Receive

- **Signals**
  - Signals do not cause change of control from sender to receiver – sender continues along its flow of control after it dispatches a signal
  - Sender can send a signal as broadcast (any object which is listening can get the signal) or as multicast (all objects designated/targeted to receive the signal)

- **Calls**
  - Calls can be synchronous. There exists a rendezvous for the duration of the operation – i.e., the flow of control of the sender is in lock-step with the control of the receiver
  - Calls can be asynchronous. This is similar to signal events in that the sender and receiver are not bound together – the sender issues the call, but it does not wait for a response from the receiver for continuing with its next operation

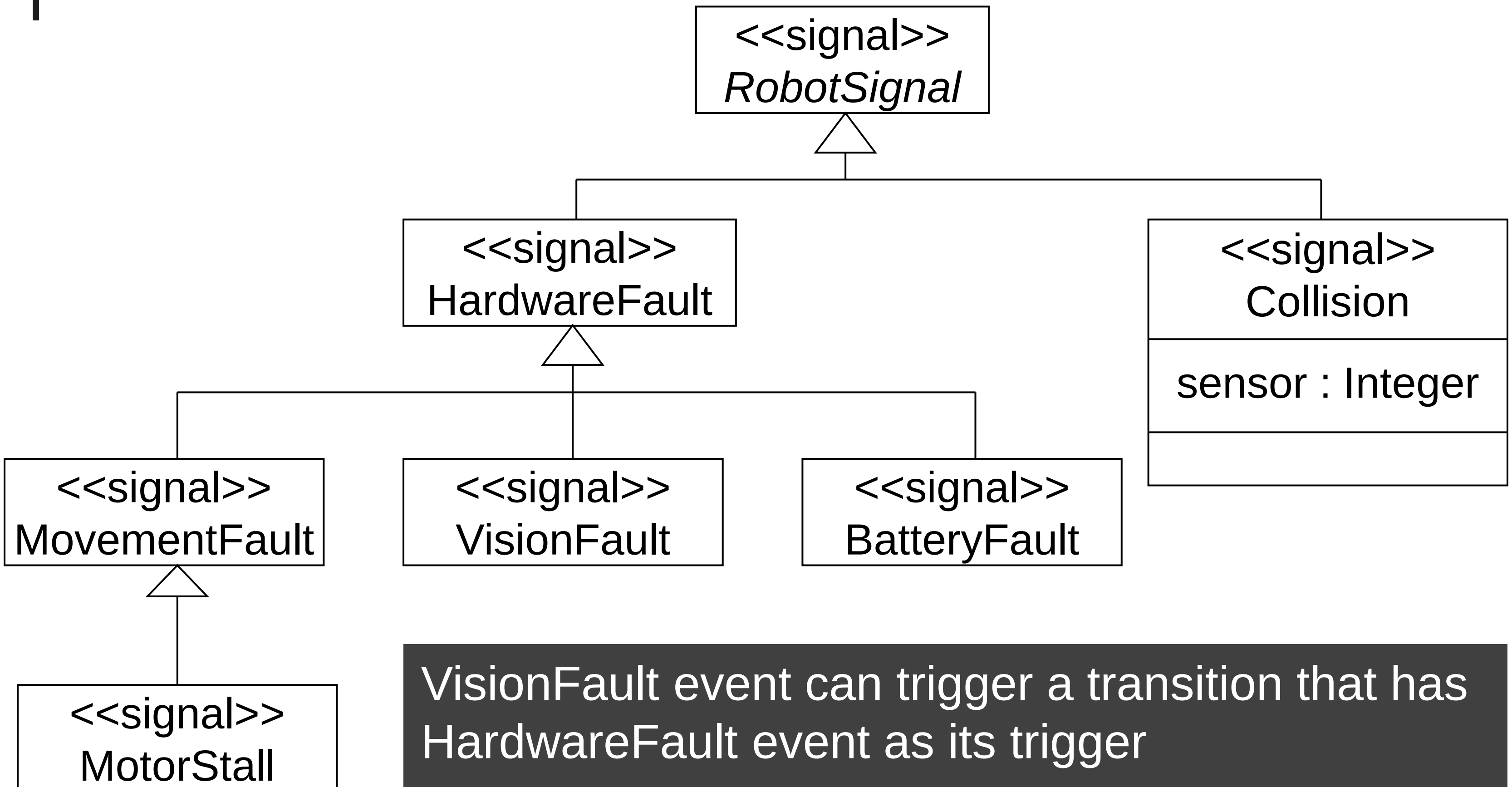
Modeling Signals

In event-driven systems signal events may have hierarchical relationship to one another.

Modeling Procedure

- Identify all different kinds of signal events to which one or more objects may respond
- Determine common kinds of signals and place them in **generalization/specialization** hierarchy. Use inheritance to elevate more general signals and to lower more specialized signals
- Determine where polymorphism (polymorphic event) can be effectively used in the state machines of the objects which can respond to the signals
- Revise signals hierarchy in view of state machines polymorphism

Modeling Signals: An Example



VisionFault event can trigger a transition that has HardwareFault event as its trigger

important for *software safety* analysis & design
(see Structured Analysis and Design chapter)

State Machines

- State machine is a behavior that specifies the sequence of states an object goes through during its lifetime

- A state machine represents an object's behavior in response to
  - **external stimulus** (e.g., an object's operation invoked by another object)
  - **internal changes** (e.g., state transition)
  - **passage of time**

State Machines (cont.)

A state machine models the dynamic behavior of an instance of a class, a (sub-) system, or a use-case

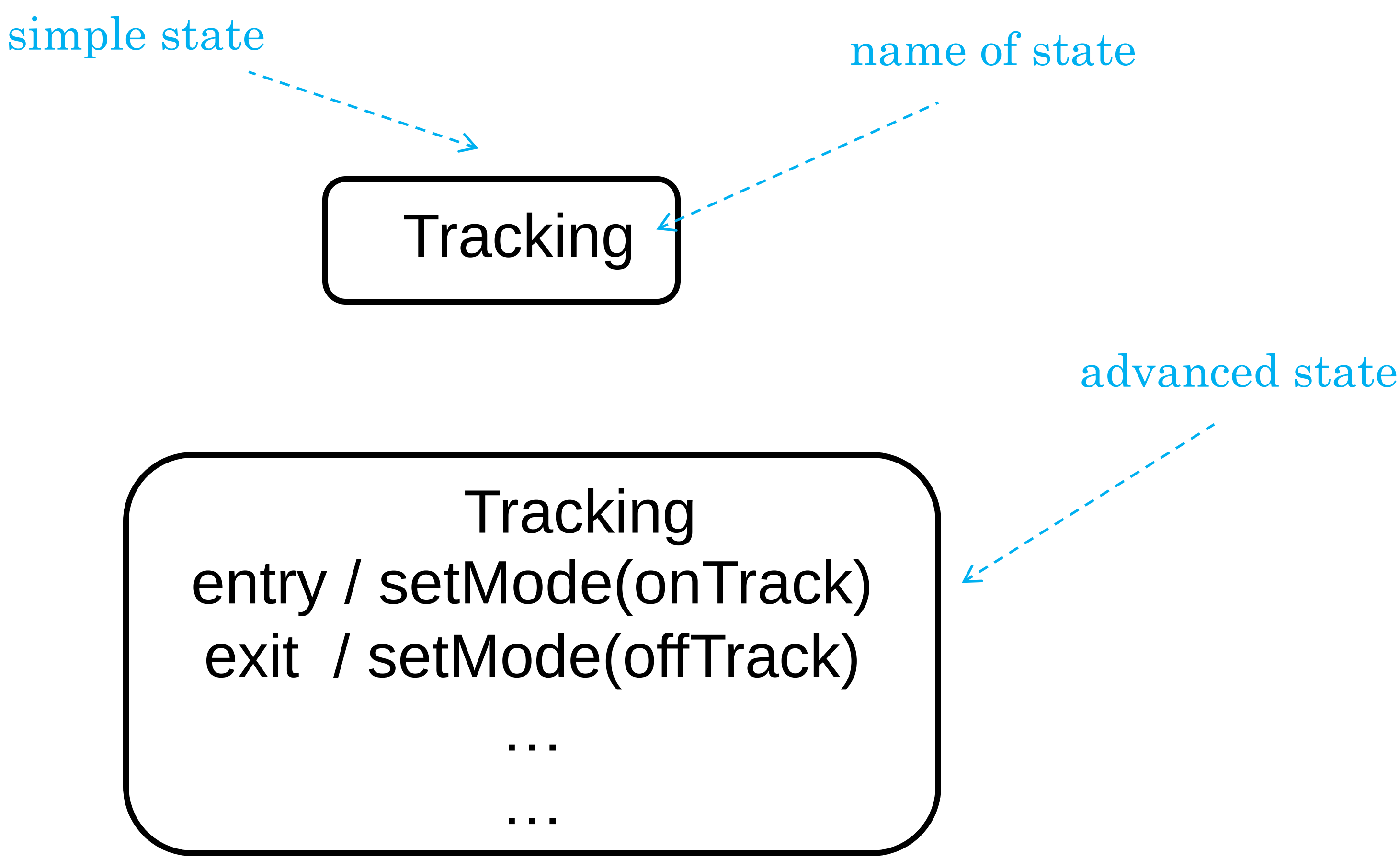
- **A state machine has**
  - set of states
  - set of events
  - sequence of state changes in response to received events (transitions)
  - responses due to received events (actions)
- **A state machine emphasizes**
  - lifetime of an object
  - potential states and transitions from one state to another
  - flow of control from activity to activity (Activity diagram)
- Well-structured state machines are simple, efficient, and adaptable.

State Machines Artifacts

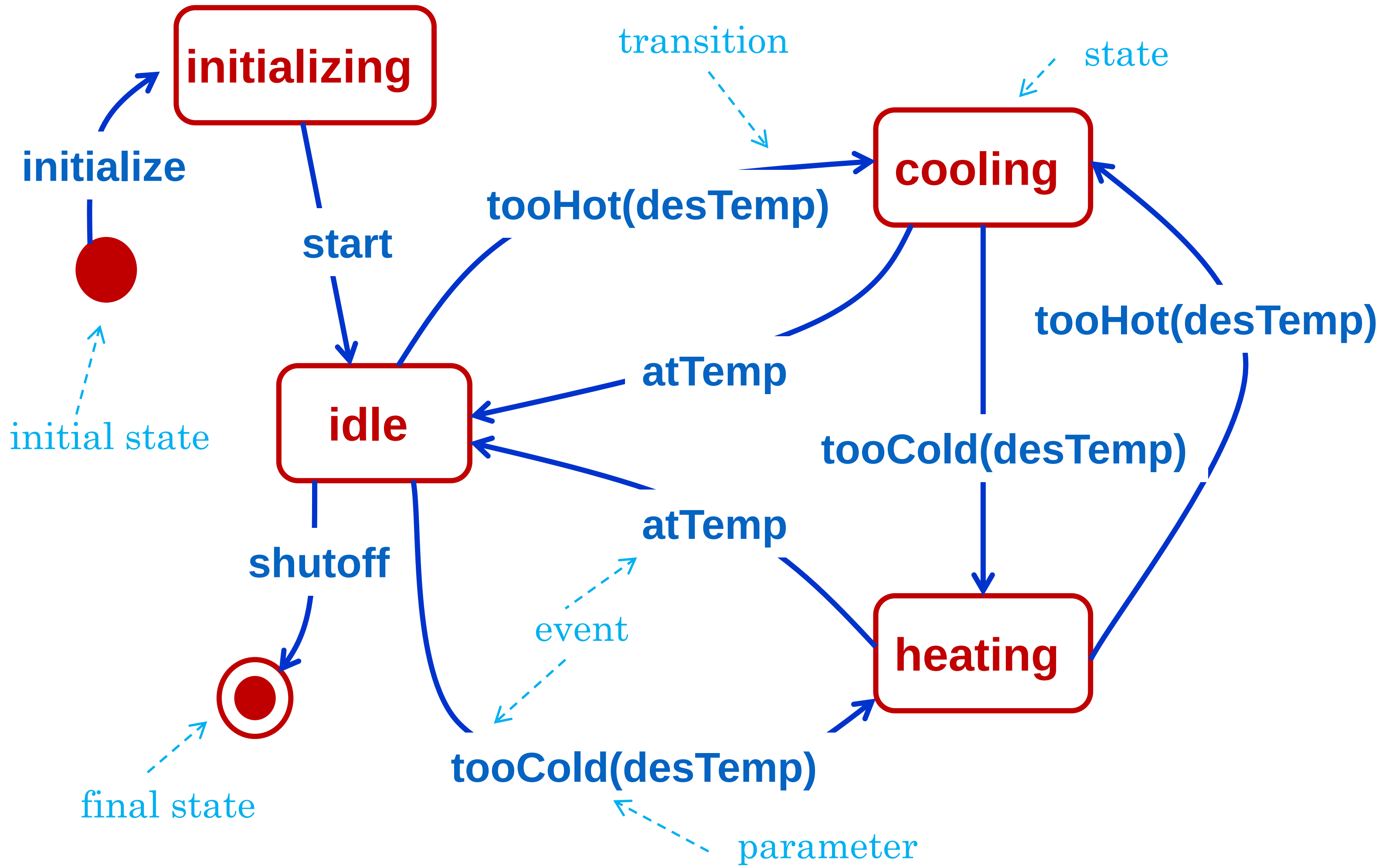
A state machine has of a collection of states and transitions

- **State** – a condition or situation in the lifetime of an object during which some condition is satisfied, some activity occurs, or waits
  - **name** – a textual string that is distinguishable from all other states of the object
  - **entry/exit actions** – actions executed upon entering/exiting a (simple, substate, or composite) state
  - **internal transitions** – transitions that do not cause state change
- State machine can have two special states – **initial & final**
- **Transition** – a relationship between two states indicating that an object in the first state will perform certain actions and enter the second state when a specified event occurs, and conditions are satisfied

Simple and Advanced States



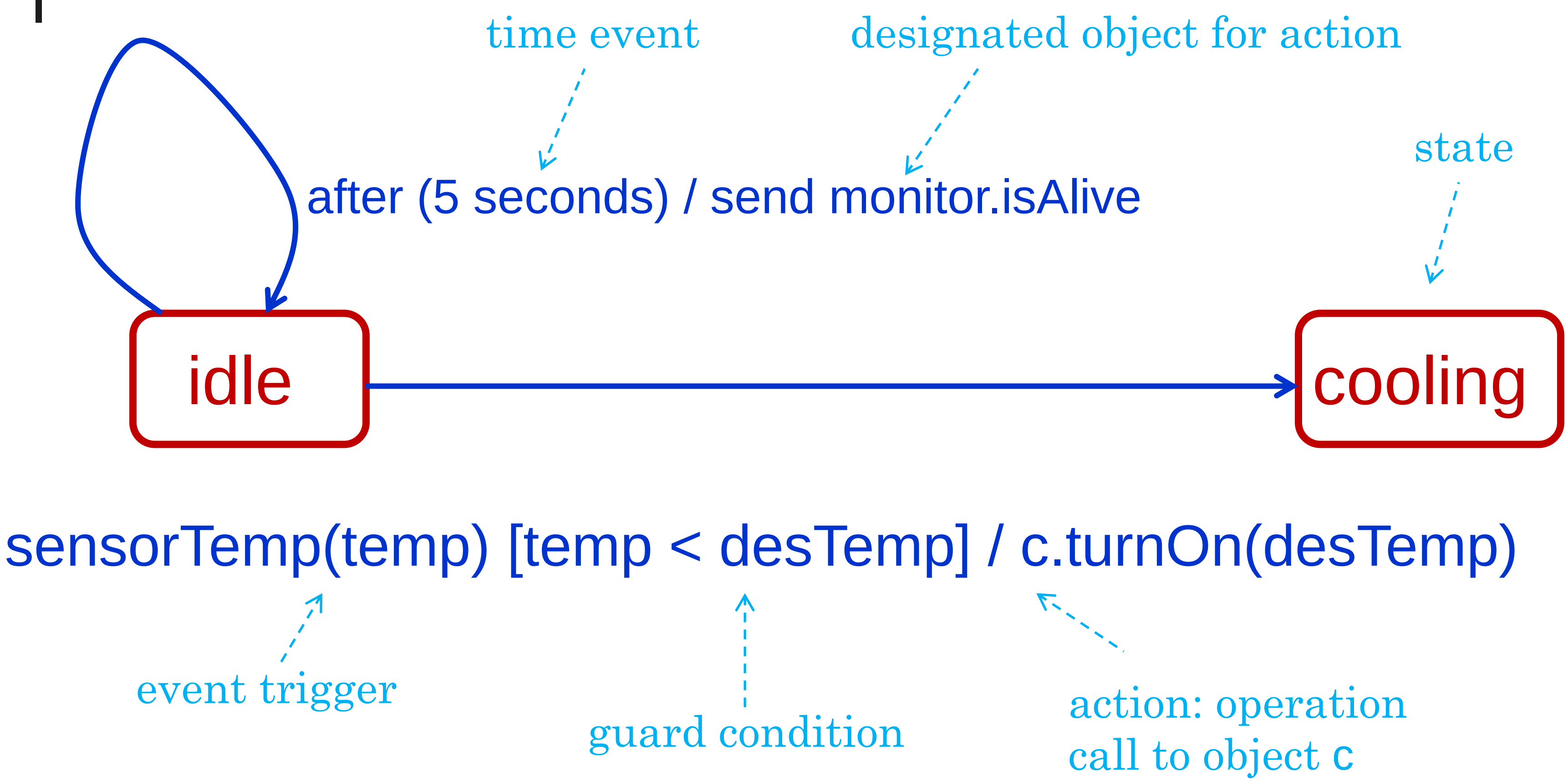
Thermostat State Machine Example



State Machines Artifacts (cont.)

- Transition – a relationship between two states specifying that an object in a state carries out some actions and enters into another state when an event occurs, and some specified condition is satisfied
  - A transition is said to **fire** when a change of state occurs – e.g., Cooler might transition from state "idle" to "active" when event tooHot(desTemp) occurs
- Prior to transition firing, the object is in **source state** and in the **target state** after the transition firing

Transitions



$\texttt{event-name}_{opt}(\texttt{parameter-list})_{opt}$ $[\texttt{guard-condition}]_{opt}$ $/$ $\texttt{action-list}_{opt}$

State Machines Artifacts (cont.)

- Transition has source and target states, trigger event and guard condition, and actions
- A transition which has the same source and target states is called self-transition
- A transition may have multiple sources – represents a join from multiple concurrent states)
- A transition may have multiple targets – represents a fork to multiple concurrent states
- An event that does not trigger a transition is lost or ignored
- Only one transition may fire (within one thread of control) in response to one event occurrence

Transition Artifacts (cont.)

Transition has

- **Source state** – state affected by the transition
- **Target state** – the state that becomes active after the completion of the transition (i.e., transition firing)
- **Event trigger** – the event whose reception triggers a state transition (transition becomes eligible to fire)
- **Guard condition** – a Boolean expression which is evaluated upon the reception of a trigger event; true evaluation results in event to be triggered and false evaluation results in the event to be lost unless another transition is triggered
  - Guard conditions for multiple transitions from a given source state need to be mutually exclusive – i.e., state transition is deterministic
- **Action** – an executable atomic computation; it can act on the object itself (direct) or act on other objects (indirect)

Event Trigger

- Receipt of an event trigger in the source state makes the transition eligible to fire provided its guard condition is satisfied if one is given
- **A transition can occur without a trigger** – called triggerless (or completion) transition is a transition that occurs upon the completion of some activity in the source state
- A signal or call may have parameters whose values are available to the transition
- **An event trigger can be polymorphic** – e.g., a transition whose trigger event is hardwareFault (parent signal) can also be triggered by visionFault (child signal)

Action

- **Action** – an executable atomic operation that results in a change in state, returns a value, or both
  - operation calls to the object that owns the state machine or any other visible object
  - creation and destruction of another object – note that stereotyped call events "created" and "destroyed" are distinct from the creation and destruction actions
  - sending a signal to an object (the keyword **send** is used as prefix to the signal name – visual cue)
  - atomic action – action must complete; *no event can interrupt the execution*

- **Activity** – a non-atomic execution within a state machine
  - an activity is associated with a given state
  - an activity is a sequence of actions – an event may interrupt it

Advanced State Machines

- Advanced features – advanced states and substates – support modeling complex behavior while reducing the number of states and transitions

- Use of idioms (e.g., dispatching the same action whenever a given state is entered) simplify specification of state machines

- UML advanced states and transitions enable multilayer state machines in a systematic fashion

  - **Entry action**
  - **Exit action**
  - **Internal transitions**
  - **Activities**
  - **Deferred events**

Other Artifacts of State Machines

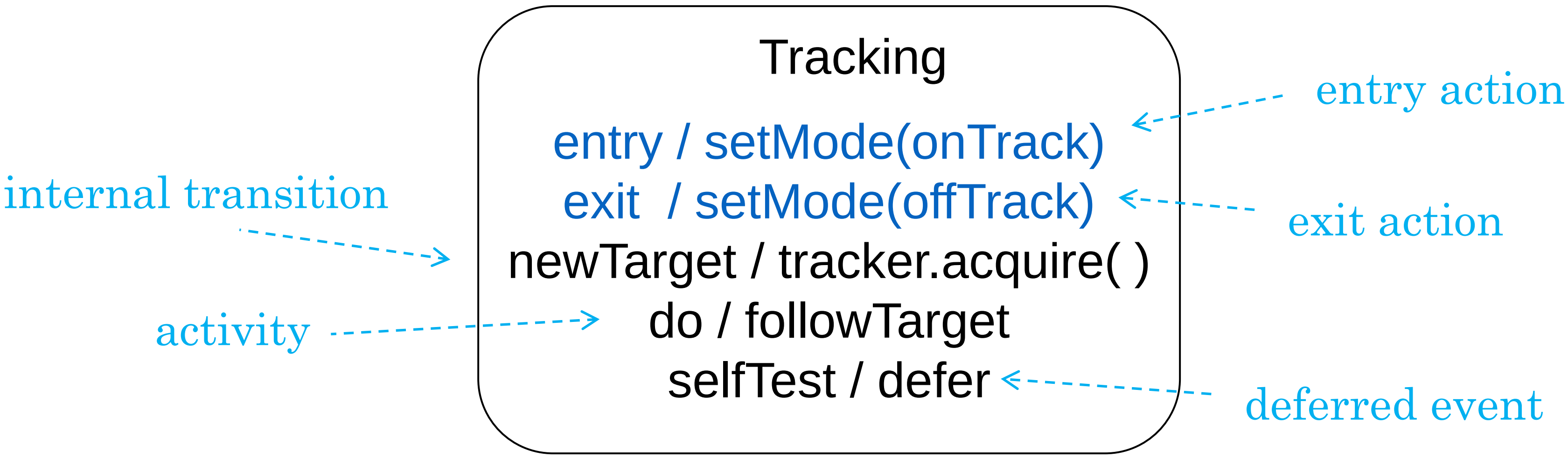
State machines can have sub-state machines

State has

- **name** – a textual string that is distinguishable from all other states of the object
- **entry/exit actions** – actions executed upon entering/exiting a (simple, substate, or composite) state
- **substates** – nested structure of state which may involve disjoint or concurrent substates
- **internal transitions** – transitions that do not cause state change
- **deferred events** – a list of events that are postponed/queued for handling in another state

Advanced State Example

Vehicle Guidance System



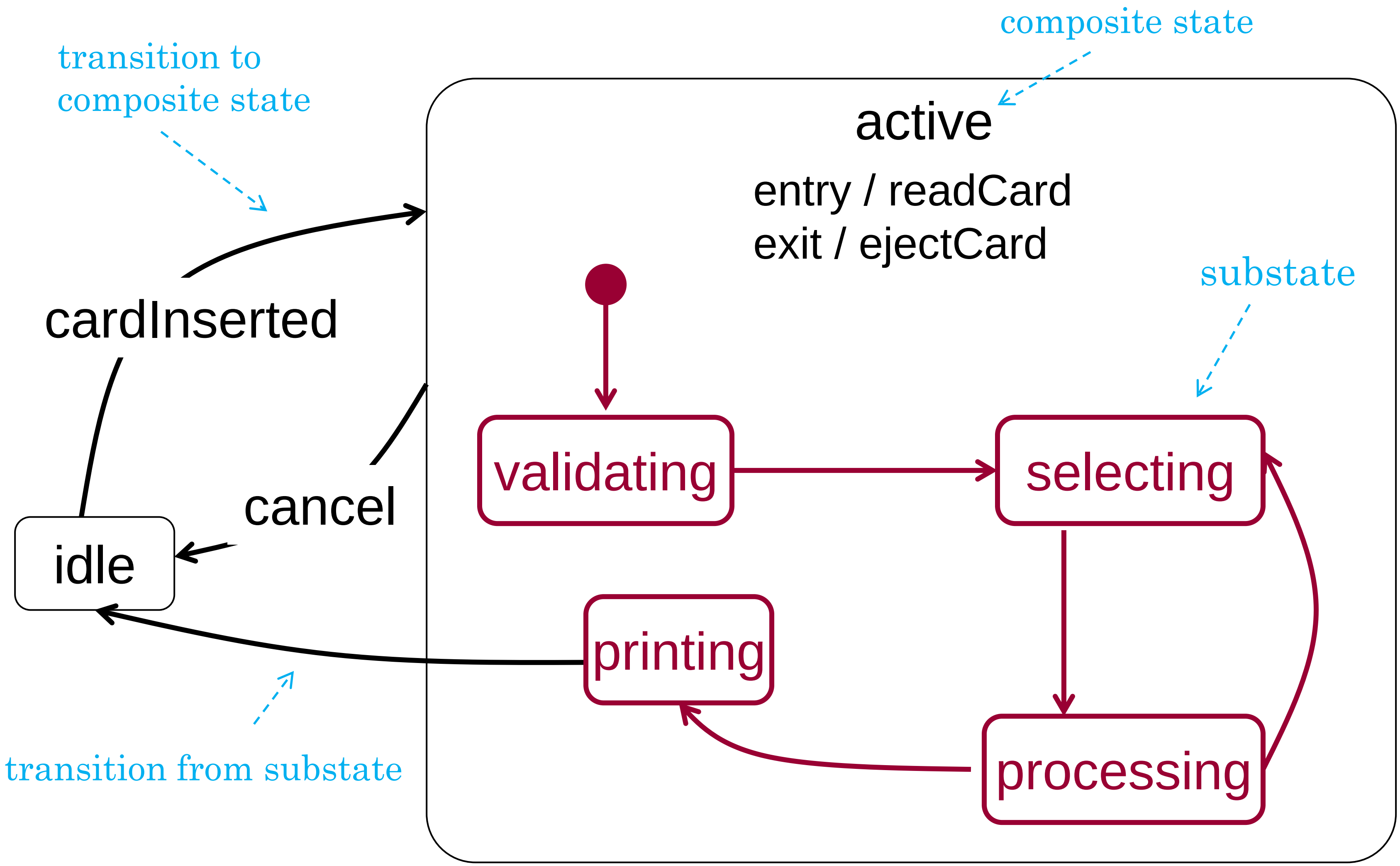
entry and exit actions: each action is dispatched for every state entry/exit regardless of which transition can lead into/out-of a state

internal transitions: these transitions do not cause a state transition as in a self-transition. Specifically, internal transition do not dispatch entry and exit actions

Composite State and Substates

- A composite state has substates or nested states; substates may be nested to any level
- A **composite state** has either
  - sequential states – a disjoint partitioning of a composite state
  - concurrent states – orthogonal partitioning of a composite state
- **Sequential substates**
  - Allows specifying one transition to be used for any number of the sequential substates – one transition is specified for the composite state instead of one transition for each of the sequential substates
- **Concurrent substates**
  - Allows specifying two or more state machines to execute concurrently in the context of an enclosing object

Composite State/Sequential Substates Example



Modeling State Machines

- Determine the context for the state machine of a class
  - collect the neighboring classes – includes parent classes and any class that is reachable by dependency or association
  - neighboring classes can be targets for actions or candidates for including in guard conditions
- Determine **initial** and **final** states; include **preconditions** and **postconditions** associated with initial and final states
- Determine the events object may be subjected to
  - some events may already be available in the object's interface
  - if events are not given in the object's interface, choose/specify neighboring objects which dispatch events to be consumed by the object

Modeling State Machines (cont.)

- Determine start and final states followed by determining the main (top-level) states the object can be in at a given time
  - Any of the main states may have substates
- Connect these states with appropriate transitions (e.g., a transition having a triggering event, a guard condition, and an action)
- Identify entry and exit actions and apply advanced states and transition idioms as applicable
- Expand any of the top-level state as necessary to its substates and all necessary transitions among them
- Verify that all events appearing in state machine match the object's events (signal, call, time, and change events)

Modeling State Machines (cont.)

- Verify that all events expected by the object's interface are accounted for in the state machine – some events may be intentionally ignored

- Verify that all actions in the state machine can be achieved given object's relationships, methods, and operations

- Trace through all possible sequences of state changes/transitions (either manually or by using tools) – verify expected sequences of events and their responses
  - account for any ***unreachable*** (or dead) state
  - eliminate ***superfluous* states** (reduce complexity!!!)

Attributes of a Well-Structured State Machine

- has a **well-defined context** – has access to all the objects visible to the enclosing object
- is **minimal and efficient** – it has minimum number of states and transitions
- states and transitions are **named appropriately** given the vocabulary of the system
- **substates are used as necessary** – for most systems one to two levels will handle complex behavior
- **concurrent substates are used sparingly**

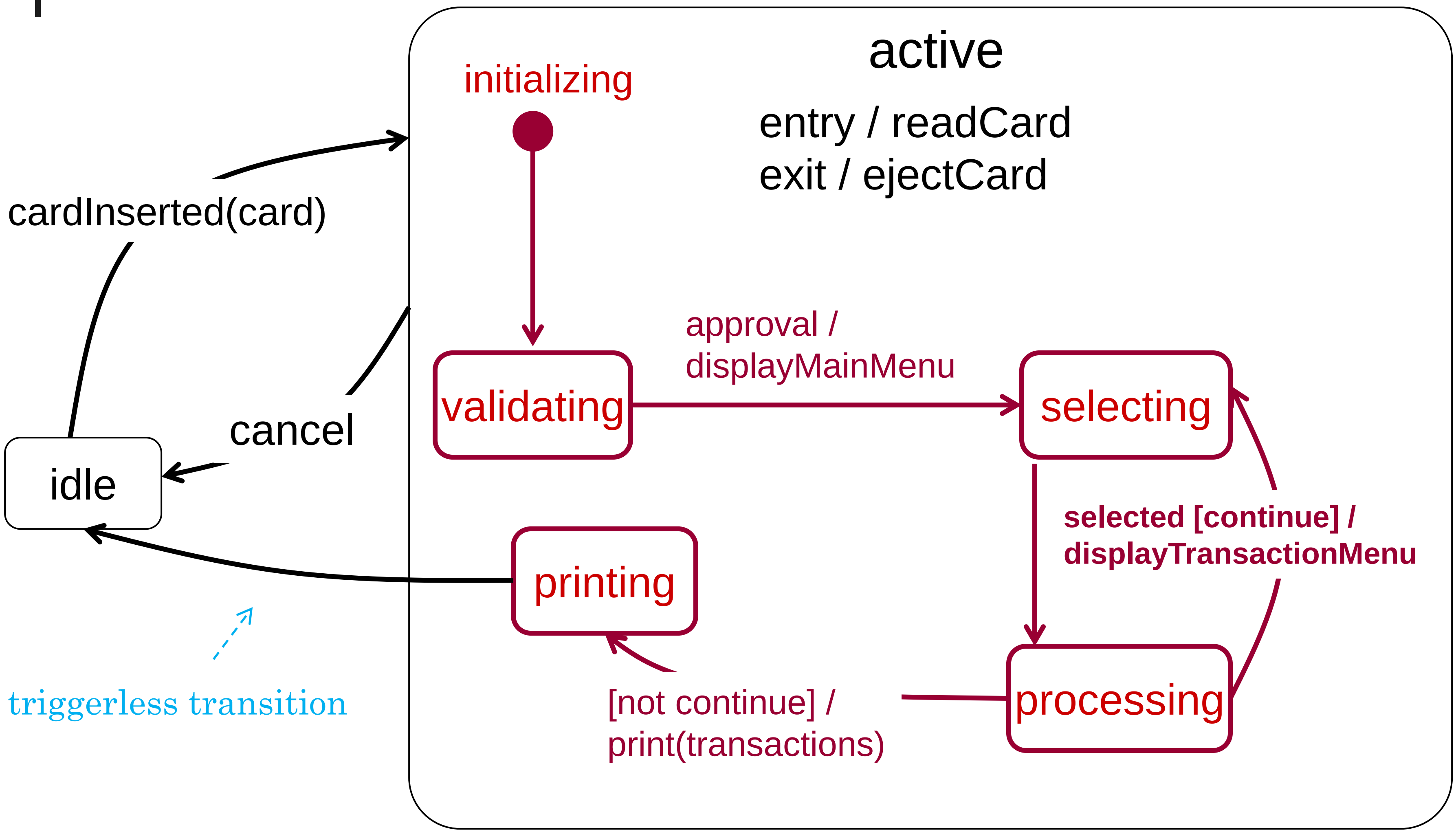
Statechart Diagram

- Statechart diagrams represent **dynamic aspects** (event-ordered behavior) of a system

- Statechart diagrams are especially important for **reactive objects / software**
  - a reactive object is one that its behavior is characterized primarily by its response to events dispatched from outside of its own context

- Statechart diagram shows **flow of control from state to state** – it specifies the <u>sequences of state changes</u> an object can experience during its <u>lifetime</u>

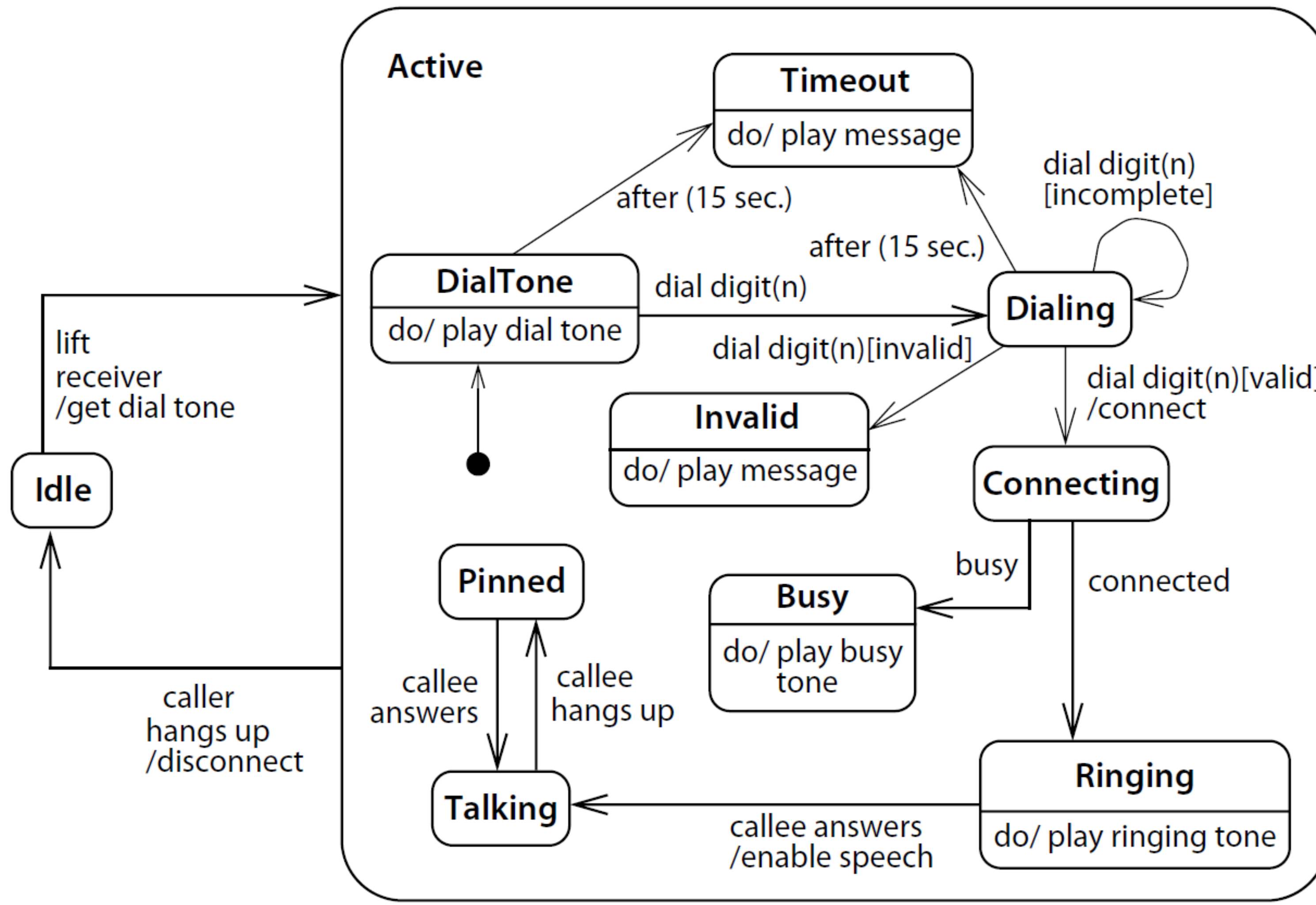
Statechart Diagram Example



References

- *Object-Oriented Analysis and Design with Applications, 3rd Edition, G. Booch, et. al. Addison Wesley, 2007*
- *OMG Unified Modeling Language Specification, http://www.omg.org/spec/, 2019*

Example State Machine



Source: The Unified Modeling Language Reference Manual, Page 439